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Cover: Leaves and fruits of *Terminalia arjuna* in water colour artwork on cold pressed water colour paper by Bhama Sridharan.

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ARTICLE

Social structure and ecological correlates of Indian Blackbuck *Antilope cervicapra* (Linnaeus, 1758) (Mammalia: Artiodactyla: Bovidae) sociality at Point Calimere Wildlife Sanctuary, India

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Abstract: Indian Blackbuck's social system is fluid and composed of distinct groups. Information on age-sex association, temporal stability, and socio-ecological correlates are scarce. For establishing a baseline information on these, we studied the Blackbuck population at Point Calimere Wildlife Sanctuary, southern India, aimed at understanding the (i) social structure, (ii) association patterns, temporal stability and (iii) socio-ecological correlates related to predation, season, and anthropogenic covariates. Focal herds were observed following scan sampling during 2017–2019. Female herds and territorial pseudo-harems spread tightly, while mixed herds were spread in different degrees. Bachelor herds were loose or scattered with small herds. Dyadic associations of female herds were stronger and more stable than mixed-sex herds and pseudo-harems, but males were in flux. Both grasslands and habitat openness were associated with higher levels of female sociality, indicating their importance in foraging, sociality, and predator vigilance, to which proliferating invasive *Prosopis juliflora* poses a detrimental effect. The presense of sympatric invasive species and lower level of anthropogenic activity was another significant covariate that influenced resource choice grouping, fission-fusion, and ultimately association dynamics. To help answer broader questions about the blackbuck's sociality, and its socio-ecological environment that drive its association patterns, we present here some baseline data on the species from a coastal forest. We suggest control of invasive species and more detailed societal studies to arrive at conservation and management clues through understanding evolutionary and ecological basis of sociability of the antelope species.

Keywords: Association, conservation, covariates, dyadic, herds, fission-fusion, invasive species, predation, temporal stability.

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Author contributions: The study was conceived and designed by NB. SA, SS, and SG all worked on the project in the field. SA performed analyses and led the writing. NB supervised the research; he also reviewed the manuscript's final version.

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SERB INDIA

INTRODUCTION

The ecology, behaviour, and population dynamics of a species can be better understood by looking at the society in which it exists (Whitehead 1997). A society is suggested to be composed of three interrelated components: (1) the social organization, (2) the mating system, and (3) the social structure, referring interactions and relationships among dyads of society (Kappeler & van Schaik 2002). Herds are fundamental to ungulate social structure. Social groups range from short-term associations (foraging groups) to long-term socially cohesive units (communal rearing groups) (Parrish et al. 1997; Krause et al. 2002). Social group variation may reflect a trade-off between fitness benefits and costs of decision to joining or leaving groups. These benefits and costs can be influenced by socio-ecological conditions and shared behavioural strategies, which cause variation in sociality. It may also be a response to predation (Hamilton 1971) and social foraging (Rieucau & Giraldeau 2011). Intrinsically, social groups may stratify based on age, relatedness, and sex (Pérez-Barbería et al. 2005).

Group membership in social mammals, which undergo frequent changes due to high fission-fusion dynamics, remains poorly understood (Couzin 2006; Smith et al. 2015; Ruczyński & Bartoń 2020). According to research on vertebrate sociality, factors like age (Michelena et al. 2008), relatedness (Wolf et al. 2011), sex (Pérez-Barbería et al. 2005), and predator pressure (Hamilton 1964, 1971) are key socio-ecological determinants that influence the strength and stability of an association (Janson 1986). The dynamic nature of fission-fusion societies provides an ideal framework for testing socioecological theory, which identifies ecological factors that drive variation in social behaviour. These can provide key insights into large-scale evolutionary processes. Temporal-spatial fluidity is thought to confer reproductive or survival benefits, allowing individuals to exploit their environment and reduce intraspecific competition (Webber & Vander Wal 2018). When groups are fluid, as in fusion-fission species (Kummer 1971), the mechanisms of association are not well understood. However, recent studies have shown their social structure is non-random and highly structured (Lusseau et al. 2003; Croft et al. 2005). When comparing the biological benefits and costs of group living in various habitats, the benefit-to-cost ratio may be greater in open habitats (e.g., grasslands) than in closed woody habitats (Fryxell et al. 2014)

Social structure related studies are rare on Indian antelopes, e.g., Four-horned Antelope (Baskaran et al. 2011; Meghwal et al. 2018); Blue Bull or Nilgai, and Chinkara (Bagchi et al. 2008; Dookia & Jakher 2013; Akbari et al. 2015). Earlier studies on Blackbuck sociality go in-depth on behavioral ecology, territoriality or lek mating system, e.g., the cost and benefits, and environmental factors influencing them (Mungall 1978; Isvaran & Jhala 2000; Isvaran 2003, 2005, 2007). Little is known about their social structure being shaped by age-sex association and temporal stability or determinants of the same. This gap offers an opportunity to examine social associations among herds in the antelope.

This foundational understanding is useful for predicting the persistence of Blackbuck societies, which is a crucial aspect of population biology (Leuchtenberger & Mouro 2008). Because it affects both gene flow and the spatial distribution pattern of the species, it can be used in conservation efforts (Whitehead 1997). Additionally, various limiting factors associated with antelope sociality in the study area would get revealed, allowing for subsequent recommendations to be made to neutralize or minimize their effects.

We studied the population of Blackbuck at Point Calimere Wildlife Sanctuary (PCWS), southern India, aimed at (i) establishing baseline information on social herd composition, size and spreading degree of the species; (ii) determining the patterns of association and temporal stability among and within age-sex classes of the social units; and (iii) investigate if habitat, predation, and anthropogenic factors influence the patterns of association in female dyads (where a dyad is a pair of individuals).

It is hoped that the recommendations made on the basis of the present study are also applicable to blackbuck populations elsewhere with similar conditions or other species with similar sociality. Besides, the new insights into animal societies and socio-ecological pressures, could in turn shed better light on the ecological and evolutionary mechanisms and the need for long-terms studies to comprehend them.

Study area

Point Calimere Wildlife Sanctuary is in Tamil Nadu (Figure 1) at the juncture of the Bay of Bengal and Palk Strait. Situated between 10.27° N, 79.83° E and 10.33° N, 79.84° E at a low elevation zone (4–9 m). The area extends over about 26.5 km^2. The reserve, established in 1967 has been noted as a Blackbuck area in scientific records since 1800s (Jerdon 1874). It receives an average of 1,366 mm of rain a year, and summer temperatures peak at 37^{o}C and dip to 21^{o}C. Daily humidity can be as low as 68% and as high as 82%. Humidity can reach 90% on foggy winter mornings (Jan–Feb) (using climatic data

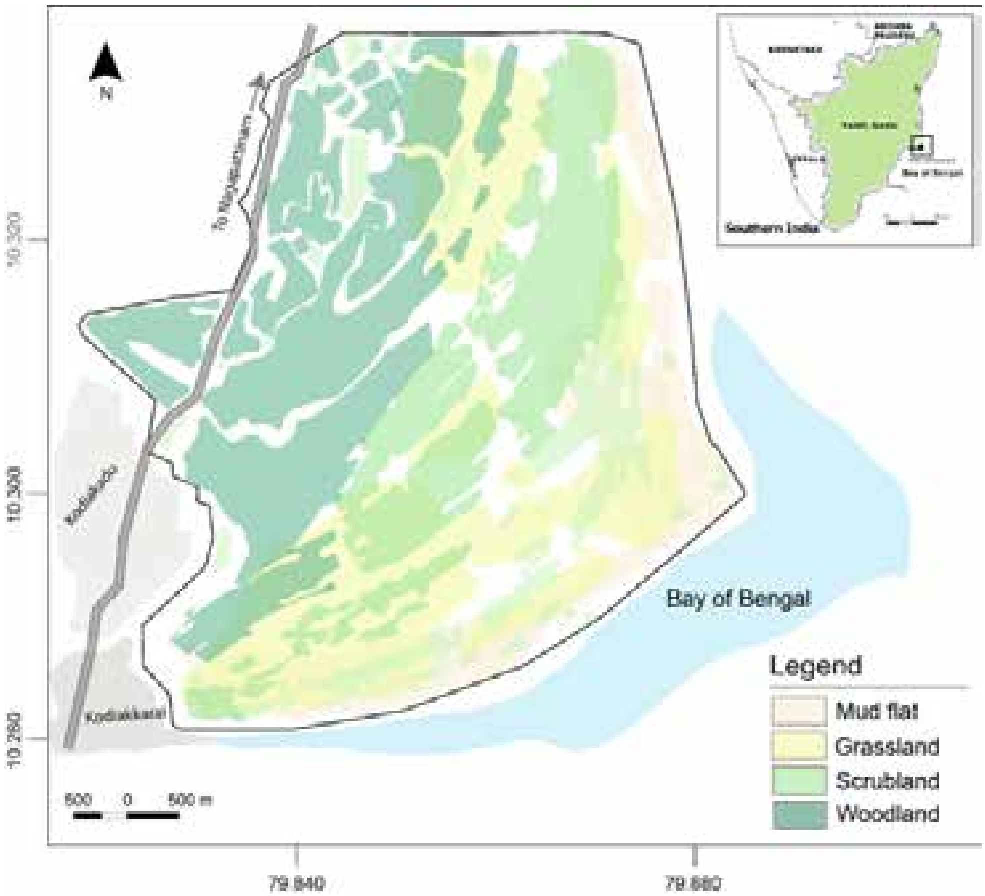

Figure 1. Study area (Point Calimere Wildlife Sanctuary).

from Kodikkarai Light house 2 km apart). This area lacks a perennial water supply, but rains replenish natural and man-made water sources.

The sanctuary's core is tropical dry evergreen, but Blackbuck avoid its thick wood and graze near natural and man-made water holes. The grassland habitat of PCWS includes mainland sea beach grassland and salt marsh grassland, home to Blackbuck and the feral horse. *Prosopis juliflora* is the only invasive woody plant in the sanctuary. It was introduced in the late 1960s and is reported as harmful to native flora and fauna (Ali 2005; Baskaran et al. 2019). The feral Horse *Equus caballus* and the Chital *Axis axis* are both introduced mammals in the sanctuary and the former is considered invasive, sympatric with the Blackbuck (Krishnan 1971; Baskaran et al. 2016). Villagers are allowed to graze their domestic cattle and goats. Cattles in foraging groups as large as 50 individuals and a mean group size of eight individuals were observed during the sampling and the large groups are thought to disrupt the Blackbucks' social activity. There are also reports that feral/stray dogs threaten the Blackbucks in the sanctuary. Due to its coastal location, the sanctuary has the most human activity in the region, including fishing, firewood collection, and tourist visits (Arandhara et al. 2021).

Study species

The Indian Blackbuck *Antilope cervicapra* is endemic to the Indian subcontinent, historical numbers approximated four million and the species inhabited wherever conditions were favorable (Jerdon 1874; Groves 1972). Presently, they are classified as 'Least Concern' on the IUCN Red List and are protected under Schedule I Category in Indian Wildlife (Protection) Act (1972). The species inhabit in scrub and grassland, and may also penetrate more open parts of predominantly deciduous forests (Prater & Barruel 1971). It is known to be a social species living in with fission-fusion dynamics (Isvaran 2007). The species is territorial, and males are known to exhibit characteristic lek mating strategy. Their social herds are composed of female herds of different age groups, mixed age-sex herds, bachelor herds and pseudo-harem herds that are tended by territorial males.

METHODS

Defining Social groups and Sampling

Herds were defined as the collection of individuals within a 50 m radius who were engaging in the same or similar behavioural activities (Clutton-Brock & Isvaran 2007; Isvaran 2007). Herds were separated by an average of 350 m in space, and within each herd, individuals were categorized according to their age-sex structure. The distance between two herds or from the observer and the angle between the herds were measured by using rangefinder. A trigonometric cosine calculation was done to arrive at the distance between the two herds, which was then averaged. For each herd, the average distance between members was measured, and herd size was calculated using total counts, a method recommended for open-area socially aggregating species (Sutherland 1996; Jethva & Jhala 2004; Isvaran 2007).

The herds were classified into: female-herd, mixed-herd, territorial pseudo-harem, and bachelor-herd (based on Mungall 1978; Jhala 1991). These were then categorized according to their spreading degree. In a 'tight herd', separation between herd members was greater than one body length and less than five body lengths, and a mean neighbor distance was <5 m. In a 'loose herd' the separation was greater than five body lengths apart with <10 m mean neighbor distance. In 'scattered groups' the individuals were spread apart by >10 m and <50 m distance.

Group size

When estimating grouping tendencies, studies on animal sociality suggest that the typical group size, i.e., the group size in which an animal participates on average, is a more useful measure than the mean group size (Leuthold 1979; Clutton-Brock et al. 1982; Jarman 1982). Group size was measured as typical group size experienced by individuals (based on Jarman 1974; see Reiczigel et al. 2008).

Typical group size = $(\Sigma N_g(i)^2) / (\Sigma N_g(i))$, where N_g is the size of each group.

Scan sampling

After three–four weeks of habituating the animals to the presence of observers during December 2017–January 2018, data were obtained by scanning a focal herd for 30 minutes at a distance of 50–150 m, ensuring non-interference with natural behaviours (Altmann 1974). Herds were recognized according to the number of individuals with similar age-sex classes and socializing at proximate locations. One herd observed in the morning from approximately 0600 h to 1200 h, was observed in the afternoon from 1330 h to 1830 h the alternate day and vice versa. During a scan progressing in one direction, behavioural records on an individual and its proximate conspecific, i.e., the nearest neighbor, were recorded, including other variables, mentioned in later section.

In total, 34 focal herds were observed, covering 816 hours of observation (n = 136 days) during January 2018 to June 2019. Data were collected through Animal Observer app (Caillaud 2012) on an Apple® iPad-5th gen (customized for behavioural observations for the Blackbuck). The collected data in the form of sftp (Secure File Transfer Protocol) was exported to a computer and converted in to SocProg (Whitehead 1999) usable format using the animal observer toolbox in R program (R Core team 2019).

Association analysis

Associations were defined based on "gambit of the group" approach, that assumes clustered animals in a herd are in association (Whitehead & Dufault 1999). Physical interactions are difficult to observe in antelopes like Blackbuck and their relatives because they are not "contact animals" but rather "distance animals," maintaining a certain "proximate distance" between each other except during mating, nursing fawns, and males fighting (Hediger 1941; Walther et al. 1983). In such taxa, relationships suggested to be expressed through associations rather than interactions (Whitehead 1999). Further, we considered abstractions of relationships among pairs of individuals to age-sex classes of individual, due to inability to discriminate visually all individuals from a herd reliably during different field days as (i) the animals were unmarked, (ii) there is a chance that an individual can move to a different herd (Perry 1996; Whitehead 2009). To determine patterns of association, age-sex categories were considered when engaged in proximate activities (forming a dyad) within a herd (Owen et al. 2002; Rogers et al. 2004; Möller et al. 2006).

Association data were converted to a binary matrix (0: non-association; 1: association) between two individuals' age sex classes. Simple ratio association index (SRI) was used as the association metric for dyads among age-sex classes of Blackbuck (Cairns & Schwager 1987; Ginsberg & Young 1992). This index was chosen for its accuracy, as it does not double count or average sightings, and is best for small data sets (Ginsberg & Young 1992). The SRI metric is defined as the proportion of time two individuals (or dyad) spent in association (ranges from 0–1) (Cairns & Schwager 1987; Ginsbergand & Young 1992), calculated as,

$$SRI = X/(X+Y_{AB}+Y_A+Y_B)$$

where X is the number of observations during which individual A and B were observed together, Y_{AB} is the number of observation periods during which A and B were observed separate, Y_A is the number of observation periods during which only A was observed, and Y_B the number of observations in which only B was observed. Days were used to define the sampling period, and 30 minute scan sampling for a herd was used to define associations. The simple ratio association matrix was computed to test whether there were statistically significant associations within and among the classes by using a Mantel t-test. The calculation of the association index (AI) and subsequent analyses were carried out in SOCPROG 2.4 (Whitehead 2009) run in the MATLAB computing environment.

Test for preferred and avoided associations

Preferred or avoided associations between sampling periods were examined using permutation tests (Manly 1995; Bejder et al. 1998). This permutation technique was used as significance test for relationship between associations that occur more frequently against the null hypotheses that animals associate randomly or expected by chance (Manly 1995; Bejder et al. 1998). Associations were permuted at 10,000 permutations (at the 0.05 significance level), based on comparisons between observed and random associations. 1:0 matrix was subjected at 1,000 flips, while keeping the herd size and the number of times an individual was seen constant, until the p-value is stabilized within sampling intervals, this is reported to remove possible demographic effects (Whitehead 1999; Whitehead 2008a,b). The observed number of animals was also tested against group size as expected by random association, which was determined using the same permutation method as described above. Preferred associations are identified as animals that were regularly seen in groups (>0.975 of the population) or avoided (<0.025 of the population) than expected by random association.

Temporal stability of association

To address temporal stability of associations of age-sex classes at population and herd level, standardized lagged association rates (SLAR) was used, this metric estimates the probability that two currently associated individuals or age sex will continue to associate after a specified time lag (τ). SLAR estimates were compared to the standardized null association rates (SNAR) to determine whether preferred associations were stable in the population over time. SNAR represents the values associated with SLAR, if animals are randomly associated (Whitehead 2008).

For species where individuals cannot be identified in groups, standardizing the lagged and null association rates is recommended to account for variation in individual and associates within sampling periods (Whitehead 1995; 2008). The temporal association patterns (SLAR) shown by the herds were then fitted into four default social stability models. Interpreted as (i) constant companions (CC): individuals stay acquainted throughout the study period; (ii) casual acquaintances (CA): individuals associate for time, disassociate, and may reassociate; (iii) constant companions and casual acquaintances (CC + CA): the lagged association rate falls but stabilizes above the null association rate. A situation in which units have a permanent core membership but there are also "floaters" who move between units; iv) two levels of casual acquaintances (2CA). This represents the short-term movement of strongly associated individuals among social groups, and the long-term disassociation of these bonds because of movement between social units, shifts in preferred companions, mortality, emigration, or a combination of these. The quasi likelihood Akaike Information Criterion (QAIC) was computed in SocPROG to determine which of these models best fit the data (Whitehead 2007).

Ecological correlates

While scan sampling a herd, apart from noting dyadic associations, ecological variables such as habitat type: grassland, open-scrub; habitat openness: >0.2/<0.2 km^2; sympatric species: feral-horse and cattle (presence/absence); predators: jackal and domestic dogs (presence/absence); anthropogenic-activity (presence/absence); and season (dry-season/wet-season) were noted down. Association index was calculated for each dyad under either category of the ecological variables stratified at population levels. Manly & Bejder permutation significance test was run to arrive at the preferred associations between a covariate category (e.g. habitat type: grassland or open scrub) for within female sex class. To test which covariates significantly influenced associations, we carried out a multiple regression quadratic assignment procedure (MRQAP) test using the "double- semi-partialing" technique for each covariate (predictor variable) and calculated standardized partial correlation coefficients (Whitehead & James 2015), this procedure builds on the Mantel test to examine for a relationship between a dependent matrix and an independent matrix while controlling for multiple independent matrices, all of which are dyadic variables (Dekker et al. 2007).

Further, to understand the effects of multiple covariates on dyadic associations, we run a GLMM using a set of six a priori models based on biology of Blackbuck (Table 9). Each dyad was considered a random effect while the covariates (habitat type, habitat openness, sympatric species, predator, anthropogenic activity, and season) were considered fixed. Models were fit using 'lme4' (Bates et al. 2016) and 'MuMIn' (Barton 2015) packages in R-program. We also constructed the null model (with the intercept only) and used information-theoretic approach for model selection following Burnham & Anderson (2002). Δ (Delta) Akaike information criteria (corrected for small sample size, AICc) values were computed to give the difference in AICc scores between the best model and other models. Model weights (Akaike-weight, Wi) were computed to identify comparative explanatory power of models.

RESULTS

Group composition

The survey yielded 31 herds, each herd varying between 6–38 individuals, totaling 516 individuals, in which 331 females (196 adults, 135 subadults), 95 males (39 adults, 56 subadults) and 90 fawns were observed (Table 1). Most herds were composed by female adults, subadults and fawns, whereas the bachelor herd comprised of few male adults and subadults only. Female herd and territorial pseudo-harem were observed predominantly in the tight spreading degree, with lower mean neighbor distance. Bachelor herd were either loose or in scattered aggregation with the smallest group size, individuals apart at the highest distance between individuals (Table 1). No bachelor herd were found in tightly aggregated groups, while no female-herd and pseudo-harem tend to be in scattered dispersion except when disturbed but, reunited when disturbance ceased. Significant difference was observed in the group size between the Bachelor-herd vs. the following herds: Female-herd (Man Whitney-U = 23, p = 0.025); Mixed-herd (U = 76, p = 0.013); Territorial Pseudo-harem (U = 57, p = 0.032).

Patterns of association

Variation in the association indices was observed within and between the age-sex classes with the highest association values (mean and maximum) usually within the same female age class, this is due to the high-level female-female associations (Table 2), exhibiting female's preferred associates within her cohort group and fawns especially in herds with females age sex. Males of the either age class associated less often with females of the either age and fawns had no or little associations with males. In bachelor herds, there is evidence of adult males associated with other adult males indicated that they are maximum associate of the same age-class. Similarly, subadult males were maximum associates with other subadult males.

For the community levels (herds), within age sex class associations were higher, based on Mantel test, the mean association indices varied significantly between and within age-sex class of Blackbuck, in case of overall population level: t = 8.84, p = 0.001; female herd: t = 2.918; p = 0.0035 and Mixed herd: t = 2.918; p = 0.0035. No significant difference was observed in case of the bachelor and pseudo-harem herds (Mean and max level of associations for each herd given in S-table 1–4).

Preferred and avoided associations

Analysis of the association patterns using permutation tests confirmed that the standard deviation of mean association index for the observed data was significantly higher than the randomly permuted data in the following age-sex classes, adult female-adult female (overall population: p <0.01; female herd: p <0.01; pseudo harem: p = 0.05); adult female-subadult female

Table 1. Summary of group (herd) age-sex composition, neighbor distance and spreading degree of Blackbuck herds.

Herd (no. of herds)	Typical group size	Adults		Subadults		Fawn	Mean neighbor distance (m)	No. of herds with spreading degree		
		M	F	M	F			Tight	Loose	Scattered
Population level (31)	16.3 ± 2.37	39	196	56	135	90	10.65 ± 2.12	13	14	4
Female-herd (9)	18.6 ± 3.47	-	75	-	56	37	7.1 ± 1.57	5	4	-
Mixed-herd (7)	22.1 ± 3.46	5	63	25	36	26	11.6 ± 2.11	2	3	2
Territorial Pseudo-harem (9)	15.5 ± 2.06	9	58	4	43	27	6.7 ± 0.98	6	3	-
Bachelor-herd (6)	9.2 ± 1.06	30	-	22	-	-	97.2 ± 14.59	-	4	2

Table 2. Mean and max level of associations within and between age sex classes for overall population.

Classed by Age-sex	AF	SAF	FA	AM	SAM
Mean (SD)					
AF	0.19 (0.11)	0.12 (0.08)	0.08 (0.07)	0.01 (0.01)	0.01 (0.01)
SAF	0.12 (0.08)	0.05 (0.04)	0.05 (0.05)	0.01 (0.01)	0.01 (0.01)
FA	0.08 (0.07)	0.05 (0.05)	0.03 (0.03)	0.01 (0.01)	0.01 (0.01)
AM	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.09 (0.05)	0.05 (0.01)
SAM	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.05 (0.01)	0.06 (0.05)
Within associations	0.16 (0.14)				
Between associations	0.06 (0.04)				
Max (SD)					
AF	0.49 (0.27)	0.35 (0.19)	0.24 (0.19)	0.11 (0.10)	0.03 (0.01)
SAF	0.35 (0.19)	0.21 (0.14)	0.18 (0.15)	0.03 (0.02)	0.04 (0.04)
FA	0.24 (0.19)	0.16 (0.15)	0.08 (0.08)	0.03 (0.01)	0.02 (0.02)
AM	0.11 (0.10)	0.03 (0.02)	0.03 (0.01)	0.18 (0.11)	0.08 (0.06)
SAM	0.03 (0.01)	0.04 (0.04)	0.02 (0.02)	0.08 (0.06)	0.15 (0.11)
Within associations	0.42 (0.33)				
Between associations	0.37 (0.19)				
Mantel test	**t = 8.849 (p = 0.001)**				
Matrix correlation	**0.255**				

AF—Adult-female | SAF—Subadult female | FA—Fawn | AM—Adult male | SAM—Subadult male. Values represent mean of simple ratio index, larger value indicated higher level of association.

(overall population: p = 0.02; female herd: p = 0.08); adult female-fawn (overall population: p = 0.01; female herd: p = 0.01; mixed herd = 0.03); subadult female-fawn (overall population: p <0.01; female herds: p = 0.01). Thus, the null hypothesis of no long-term preferred associations could be rejected showing evidence for long-term preferential association among adult and subadult females, but not among females and males (Table 3; S-table 5–8).

At overall population, 49 dyads associated significantly more or less than expected at random over the total duration of the study, out the total, 35 and 14 dyads exhibited preferred and avoided associations respectively, female-female dyads had the most number (21) showing preferred associations and male-male dyads showed the most (five) number of significant avoidances. Similarly, at herd levels: (female herd = preferred: 35, avoided: 12; mixed-herd = preferred: three, avoided: one; pseudo-harem = preferred: 15; avoided: three; bachelor-herd = preferred: 0; avoided: 0). Bachelor-herd indicated that males were at random association (Table 4).

Temporal stability of association

Lagged association rates computed for female-female associations for overall population and female herd were best described by constant companion + casual acquaintances model (CC + CA), in case of mixed herd and pseudo harem, they were modelled as two levels of casual acquaintances (2CA). For all the herds with female age class and at overall population level, female-all associations were formed as constant companion + casual acquaintances model (CC + CA). Male -male and male- all associations exhibited casual acquaintances model at overall population and other herd types except bachelor herd modelled by two levels of casual acquaintances (2CA) (Table 5; Figure 2).

Ecological correlates of Blackbuck sociality

Permutation tests used to examine the influence of covariates on the association between the female sex classes. Significantly higher SD of the observed associations compared to random indicated preferred and avoided associations among these individuals under the influence of grassland habitat type (p = 0.003); more open habitat openness (p = 0.001); absence of feral-horses (p = 0.004); and the absence of anthropogenic activity (p = 0.034). Further, MRQAP tests revealed a similar significant correlation of associations with grassland habitat (r = 0.66; p = 0.001), more open habitat

Table 3. Tests for preferred association for overall population.

Age sex class	Mean association		SD of association		p-value (SD)
	Observed	Random	Observed	Random	
All individuals	0.07	0.07	0.14	0.14	p-value= <0.01
AF-AF	0.19	0.19	0.21	0.2	p-value= <0.01
AF-AM	0.01	0.02	0.05	0.08	0.97
AF-SAF	0.12	0.12	0.15	0.15	0.02
AF-SAM	0.01	0	0.03	0.03	0.95
AF-FA	0.08	0.08	0.15	0.14	0.01
AM-SAF	0.01	0	0.03	0.04	0.99
AM-FA	0.01	0	0.04	0.04	0.91
AM-SAM	0.25	0	0.17	0.17	0.9
SAM-SAF	0.01	0	0.03	0.03	0.83
SAM-FA	0.01	0	0.02	0.02	1
SAF-FA	0.05	0.05	0.09	0.09	p-value= <0.01
AM-AM	0.32	0	0.26	0.27	0.9

If the standard deviation of the mean association indices for the observed data was significantly higher than the random data, then the null hypothesis that there is no preferential association is rejected.

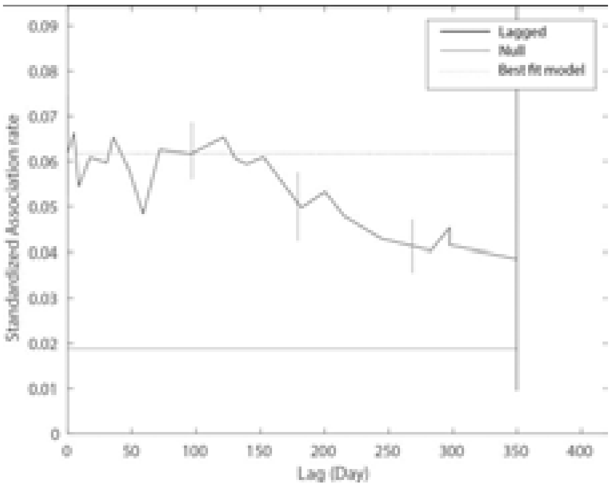

Figure 2. Standardized Lagged Association Rate for individuals recorded for female-female herd. The best-fit model: Casual Acquaintances + Constant Companions (CA + CC) [0.06+0.02-0.065τ], null association rate is included for reference.

openness (r = 0.87; p = 0.001), absence of feral-horses (r = 0.89; p = 0.001), absence of cattle (r = 0.34; p = 0.041), and anthropogenic activity (r = 0.56; p = 0.051) (Table 6).

The best model (model 4) explaining variation in dyadic association included the interaction effects of habitat type * habitat openness + sympatric species * anthropogenic activity + predator * sympatric species. This model accounted for 57% of the AICc weight and indicated a significant relationship between the association strength and the explanatory predictors (The a priori models given in Table 7).

The effect of habitat type [grassland], interaction between habitat type * habitat openness, and anthropogenic [absence] shows positive significance in explaining the association strength. While, habitat type [dry-evergreen], predator [presence], sympatric species [presence], and interaction between sympatric species * anthropogenic activity shows a negative trend (Table 8a,b,c).

DISCUSSION

To help answer broader questions about antelope sociality and the theoretical link between ecological covariates that drive association patterns, we present here some baseline data on the social structure of Blackbuck from a coastal forest. Here we first describe the summaries related to group composition, neighbor distance and spreading degree; then explore the social associations among the age-sex classes of different herd types, know their temporal stability of associations and determine the ecological correlates of sociality.

Group composition

Blackbuck group sizes varied greatly within the study population. Of the 31 herds surveyed, the typical group size ranged around 16.3 individuals at the population level, which is consistent with previous findings in the study area (Jhala & Isvaran 2016). For the most part,

Table 4. Number of dyads associating significantly different from random for the herds studied.

Herd	Preferred associations (p >0.975)	Avoided associations (p <0.025)
Overall population	**35**	**14**
Female-female	21	4
Female-fawn	7	1
Female-male	1	1
Male-male	6	5
Male-fawn	0	3
Female-herd	**35**	**12**
Female-female	27	8
Female-fawn	8	4
Mixed-herd	**3**	**1**
Female-female	2	0
Female-fawn	1	0
Female-male	0	0
Male-male	0	1
Male-fawn	0	0
Territorial pseudo-harem	**15**	**3**
Female-female	8	1
Female-fawn	4	2
Female-male	1	0
Male-male	2	0
Male-fawn	0	0
Bachelor-herd	**0**	**0**
Male-male	0	0

Table 5. Models of temporal stability of Blackbuck herds.

Herd	Model	Best fit	ΔQAIC
Overall population			
Female-female	CC+CA	$0.06+0.02^{-0.065\tau}$	0
Female-all	CC+CA	$0.04+0.02^{-0.065\tau}$	0
Male-male	CA	$0.04^{-0.0002\tau}$	2
Male-all	2CA	$0.03^{-0.24\tau}+0.05^{-0.0002\tau}$	0
Female-herd			
Female-female	CC+CA	$0.05+0.07^{-0.52\tau}$	0
Female-all	CC+CA	$0.04+0.06^{-0.53\tau}$	1
Mixed-herd			
Female-female	2CA	$0.12^{-0.59\tau}+0.06^{-0.001\tau}$	2
Female-all	CC+CA	$0.05+0.18^{-1.11\tau}$	0
Male-male	CA	$0.62^{-0.03\tau}$	0
Male-all	CA	$0.96^{-0.07\tau}$	0
Pseudo-harem			
Female-female	2CA	$0.68^{-0.64\tau}+0.45^{-0.001\tau}$	0
Female-all	CC+CA	$0.56+0.28^{-0.36\tau}$	1
Male-male	CA	$0.51^{-0.0001\tau}$	2
Male-all	CA	$0.05^{-0.0006\tau}$	2
Bachelor-herd			
Male-male	2CA	$-0.03^{-1.2178\tau}+0.08^{-0.0008\tau}$	1

Interpreted as (i) constant companions (CC)—individuals stay acquainted throughout the study period | (ii) casual acquaintances (CA)—individuals associate for some time, disassociate, and may reassociate | (iii) constant companions and casual acquaintances (CC+CA).

larger herds were found in the sanctuary's southeastern portion, generally around the larger grassland extent, where the species can gain a higher level of social and foraging opportunities. Smaller herds were found in patchy grassland interspersed between dry evergreen trees and shrubs throughout the sampling period. Female herds and territorial pseudo-harems were primarily found in a degree of tight spreading, with female herds ranging up to 31 m in mean neighbor distance. While pseudo-harems were even compact at up to 26 m. This can be viewed in light of the habitat availability in which the herds are dispersed and social activity they experience.

Despite maintaining individual distances, the majority of female herds are dispersed closely in open grasslands, scattered through a network of patchy trees and shrubs. Individuals closely clustered together reap social benefits, as explained by cohesion, which is dependent on the motivation of individuals to remain together while maintaining inter-individual distance (Hediger 1955; McBride 1963). Further, greater attraction between individuals of the same sex would make single-sex herds more cohesive and less prone to split than mixed-sex herds whatever the level of activity within the herds (Michelena et al. 2008).

In pseudo-harems, females temporarily stay with a territorial male, their size might be expected to be as the same as that of pure female groups. In a territory, when a herd enters such a territorial mosaic, each buck tries to herd females in his territory, and he cuts out a section of the big herd, the tight spreading is mainly due to the male that ensures the females are within the territory by exhausting himself in an outburst of herding and chasing actions, it is considered to assist with group cohesiveness (Mungall 1978).

Mixed herds were found in all three of the spreading degrees. Fewer herds exhibited tight clustering, while some herds had individuals as far apart as 40 m from one another. In vast expanses of the grassland habitat, wider extent available space facilitated the individuals with the option of spreading out more while still having neighbors (Couzin & Krause 2003).

Table 6. Female preferred or random associations at different covariate categories.

Age sex class	Female-all others					
	Mean assoc.		SD assoc.		p	MRQAP r (p)
	Obs.	Rand.	Obs.	Rand.		
habitat type						
grassland	0.222	0.221	0.375	0.37	0.003	0.66 (<0.001)
open scrub	0.171	0.174	0.219	0.221	0.583	0.48 (0.07)
habitat openness						
less	0.195	0.195	0.23	0.231	0.784	0.19(0.64)
more	0.276	0.275	0.294	0.291	0.001	0.87(<0.001)
feral-horse						
Presence	0.1	0.1	0.138	0.14	0.181	0.11 (0.41)
Absence	0.152	0.151	0.177	0.175	0.004	0.89 (<0.001)
cattle						
Presence	0.194	0.197	0.242	0.242	0.33	0.28(0.054)
Absence	0.169	0.166	0.217	0.217	0.06	0.34(0.041)
predators						
Presence	0.08	0.08	0.117	0.118	0.67	0.27(0.67)
Absence	0.359	0.352	0.416	0.417	0.17	0.39(0.3)
anthropogenic-activity						
Presence	0.261	0.266	0.27	0.271	0.45	0.43(0.086)
Absence	0.364	0.361	0.389	0.388	0.034	0.56(0.051)
season						
dry-season	0.195	0.198	0.204	0.204	0.58	0.37(0.07)
wet-season	0.258	0.254	0.295	291	0.003	0.67(0.061)

Mixed herds have been reported to show an ever-changing mix of individuals. There are “casual herds of variable size and composition forming, breaking up, and reforming at frequent intervals”, characteristic of “fission-fusion” society (Conradt & Roper 2005).

Bachelor herd was either loose or in scattered aggregation with the smallest group size, separated at the greatest distance of over 40 m. No bachelor herds were found in tightly aggregated groups, and no female herds or pseudo-harems were found in scattered dispersion except when disturbed but regrouped when the disturbance ceased. Formation of herds are very unstable, However, dyadic relationships among age sex classes were stable. When females interact, they usually avoid contact (Walther et al. 1983).

Table 7. Details of 6 “a priori” models to explain Blackbuck female association strengths.

Covariate-model ID	1	2	3	4	5	6
Habitat type	x		x		x	x
habitat openness	x	x	x		x	
Sympatric species	x		x			x
Predator	x	x	x			x
Anthropogenic activity	x		x		x	
Season	x	x	x	x		x
Habitat type * habitat openness			x	x		
Sympatric species * anthropogenic activity			x	x	x	
Predator * sympatric species			x	x	x	

Female associations

Although female herds are unstable associations, the strength of associations between members of the female sex was greater than that of associations among members of different sexes, indicating that female Blackbucks exhibit sex-based homophily, in which individuals preferentially group with conspecifics of the same sex (Hirsch et al. 2012; Brambilla et al. 2022).

This is consistent with previous findings that adult female-female spatial associations are generally stronger than male-male and female-male spatial associations in different age classes (Carter et al. 2013; Mejía-Salazar 2017). Females who share a home range are said to be more likely to be in the same herd as females who don't. Females may form herd based on their current physiological state, such as those who are nearing the end of their pregnancies or those who are nursing young. Female social bonds may improve reproductive success (Wittemyer et al. 2005). As a result of these social bonds, individuals have easier access to food (Silk 2007), experience less harassment (Cameron et al. 2009), and have lower levels of glucocorticoids (Cameron et al. 2009; Silk et al. 2012). In Blackbucks, the females leave the herd to give birth, and the calf lies out before rejoining the herd for varied amounts of time before rejoining (Mungall 1991). Calves may create crests in the herd, and females of similar age and sub-adults are known to form close bonds. Adult females' spatial associations are expected to strengthen as a result of these actions (Walther et al. 1983).

Male associations

In this study, the strength of associations among males were weak as compared to females. A territorial male endeavor to exclude all other territorial males and attempts to herd all females that enter his territory, where he has exclusive mating rights. He may allow bachelor herds to enter his territory, but when females are present, he will typically drive them away. In a few species, they may be kept entirely outside the territory (Walther et al. 1983).

Non-territorial adult and sub-adult males form bachelor herds. Territorial males often keep sub-adult males from mingling with the herd's females, but bachelor males are often allowed entry into the territories. Individuals in bachelor herds are free to join, but because their home ranges coincide, the herds often see each other again (Mungall 1978).

Temporal stability

Using the LAR, we were able to measure for the first time in the blackbuck species the stability of relationships between and within certain age-sex classes. For all the herds with female age class and at overall population level, female-female and female-all associations were formed as constant companion + casual acquaintances model (CC + CA). They were more likely to associate with casual acquaintances who disassociated and re-associated over time, which is typical of the fission-fusion society they lived in. But there are some associations that remain constant over time. There is strong evidence from previous studies that females are more likely to associate with each other based on their reproductive status and previous social familiarity (Herzing & Brunnick 1997). Primates have shown that female reproductive success depends on the successful raising of young, and females will use social relationships to achieve their reproductive goals (Sterck et al. 1997). Benefits to female grouping may be ecological in nature, such as increased predator

Table 8a. GLMM models used to characterize relationship between dyadic association and covariates.

Model ID	logLik	AICc	ΔAICc	Weight
Model 4	**-383.04**	**773.984**	**0**	**0.57456**
Model 3	**-383.8**	**776.416**	**1.9608**	**0.15808**
Model 1	-385.32	778.62	4.6208	0.02736
Model 6	-389.88	786.828	12.8364	0.00076

Table 8b. GLMM output showing significant covariates (fixed effect) and dyads (random effect) affecting association of female Blackbuck at PCWS.

Predictors	Estimates	CI	p
(Intercept)	**1.51**	**1.46 – 1.55**	**0.003**
Habitat type [Grassland]	0.06	0.01 – 0.23	**0.002**
Habitat type [Dry-evergreen]	-0.09	-0.13 – -0.05	**0.005**
Habitat type*habitat openness	0.03	0.02 – 0.18	**0.054**
Predator [Presence]	-0.45	-0.33 – -0.19	**<0.001**
Sympatric species [Presence]	-0.18	-0.29 – -0.16	**<0.001**
Anthropogenic [High]	-0.02	-0.08 – -0.05	**0.046**
Predator*Sympatric species	0.03	0.01 – 0.14	0.12
Sympatric species*Anthropogenic activity	-0.07	-0.16 – 0.04	**0.033**
Random Effects			
σ^2	265		
τ_{00} Dyad	<0.01		
N	1432		
Observations	11154		
Marginal R^2	0.652		

σ^2 = represents the mean random effect variance of the model | τ_{00} = the random intercept variance, or between subject variance | N = number of observations.

Table 8c. GLMM output showing influence of random effect covariate (dyads) contributing towards association.

Covariate	Term	Variance	SD
Dyad	(Intercept)	0.83	0.66
Residual		7.9	4.58

protection and food distribution (Sterck et al. 1997), or social, including calf care and social learning (Miles & Herzing 2003; Bender et al. 2008; Gibson & Mann 2008). Results indicate that familiarity and reproduction are strong influences in female sociality. Adaptive value of sociality is described for female Bottlenose Dolphins in a unique approach by Frère et al. (2010), showing that sociality influences the fitness trait in a wild population, consistent with the results of many social analyses (like this study) that show strong associations between females. Thus, genetic and social effects on fitness are intertwined, both important in determining female success (Frère et al. 2010). Although mixed-sex herds and pseudo-harems were structured similarly to female herds, they were weaker and less stable over time than the female herds.

Male-male and male-all associations exhibited the casual acquaintances model in the overall population as well as in other male-present herds, according to the findings. There were two levels of casual acquaintances (2CA) in most bachelor herds, indicating that they were in a state of constant flux on a daily basis. There are likely more factors shaping the temporal association patterns between individuals and classes. More precise data on the age of individuals will help to make such definitions more precise.

Ecological correlates

Significant correlations were found in dyadic associations between the covariates sampled, as revealed by per MRQAP test and GLMM. According to this finding, females have different social options depending on how their society is structured in relation to the covariates, elaborated below:

Influence of habitat and predation

We obtain non-random associations at grassland habitat as shown by higher SD of observations, a significant MRQAP correlation and positive relationship between association strength of dyads. This pattern of association is supported by "resource, habitat and predation hypothesis" (Crook 1965; Jarman 1974; Clutton-Brock 1989; Davies 1991) which suggests that female grouping is related to resource available habitats and occur where competition for high-quality food is low, food availability is patchy, and presence predation risk either favors larger herds or does not influence group size. Males comprise a negligible proportion of the herds, so female-to-female associations are shaped primarily by their presence.

Another disturbance in PCWS is due to proliferation of *Prosopis juliflora*, which has been seen growing exponentially changing the grassland into thickets (Arandhara et al. 2021), it is difficult for social species like the Blackbuck that lives in large herds to socialize or flee at early detection of a predator in a habitat with impenetrable bushes. These transitions may lead to spatially clumped resource distributions and, consequently, disturb the species societies. In PCWS, *Prosopis* has been reported to show detrimental effect on Blackbuck (Ali 2005; Arandhara et al. 2021) and elsewhere in India (Ranjitsinh 1989).

Predators are reported to influence social dynamics, according to the "predation pressure hypothesis," female home range and herding are influenced by predation pressure and that Blackbuck form larger herds in PCWS, where there are no large predators other than jackals (Baskaran 2016, 2019). In our GLMM results we obtain a negative influence. Although predation was considered as a factor in this study, there were no large predators in the area except for jackal and the feral dog, which mostly pose a threat to neonate and young fawns. Feral dogs, which prey on Blackbucks, are reported to carry diseases that affect the wild ungulate population (Butler et al. 2004; Ali 2005; Jyoti & Rai 2021). According to our observations, jackals in open grasslands of PCWS maintain 200 m (mean) and beyond from the herds of Blackbucks. This pattern is also supported by the results as there is no significant random association when predators appear, when Blackbucks socialize.

Influence of sympatric invasives

Management of feral-horse at point Calimere has been a subject of recommendation for several years (Ali 2005; Baskaran et al. 2016, 2020; Arandhara et al. 2020). This study shows random association with negative effect of female Blackbuck dyads when sympatric feral-horse, coexist in proximity over time and space. Further, the result shows a similar pattern of significant dyadic preference in the absence of cattle herds. Even in open habitats, Blackbucks were observed to be distributed away from cattle herds with a minimum distance of about 150 m. It is essential for Blackbucks to restrict their movements to areas near water sources during the dry season, as a result of decreased water content in forage; whereby the restriction of movement due to presence of cattle might also add further constrain in limiting the food and water. Furthermore, because grass biomass is estimated to be higher near fresh water sources, cattle presence may pose a displacing threat to Blackbuck societies, which is a specialist grazer. There are reports that feral-horses, which are larger and more aggressive than other medium sized antelopes, influence Blackbuck's foraging habits by keeping the latter away from the primary food source (Arandhara et al. 2020). Further, studies have attributed low female associations with high feeding competition and feral-horse out-competes native ungulates for water (Miller 1983; Ostermann-Kelm et al. 2008; Perry et al. 2015; Gooch et al. 2017); overlaps in diet and spatiotemporally with the blackbuck (Baskaran et al. 2016). This finding provided corroborating evidence that feral-horses and cattle impose negative effect on social integrity of the blackbuck species at Point Calimere.

Influence of anthropogenic activity

Animals observed in and around anthropogenic areas at PCWS show nonrandom sociality, also exhibited by a significant MRQAP test and negative relationship between dyadic association. Increasing levels of anthropogenic activities are evident in the beaches adjacent to the study area, in the form of fishing, boating, and other shore activities, these activities have minimal disturbance to the wildlife. Inside the sanctuary, the species frequently come across tourist vehicles and recreational visitors, Blackbuck being a diurnal species, the visitors time (0900–1700 h) coincides with peak activity hours of Blackbuck, influencing the grouping, fission-fusion, and association dynamics of the Blackbuck herds. Anthropogenic concentrations of food can alter mammals' foraging behaviour (Ali 2005; Baskaran et al. 2019) and deliberate provisioning can cause change in animals' social interactions (Wrangham 1974).

Influence of season

Even though the results of MRQAP and GLMM do not show significance in season determining association strength, permutation test results show a non-random female association during the wet season. Mating season for blackbuck at PCWS lasts from mid-August through late October, as females enter estrus coinciding before the onset of early downpours and predictably increase in foraging resources for the next months. During this cyclic peak adult males being more aggressive tend harems in their territories, we were able to identify 30% (during September–October) territorial pseudo-harems and 23% non-territorial 'floaters' seeking opportunity to tend female herds by increased frequency of fights for dominance, as reported earlier studies (Mungall 1978; Walther et al. 1983). Non-random associations are evident in this wet season as females become cohesive, when in pseudo-harem herds. Weaker association strengths are likely caused by frequent chasing when females flee and young adults reported to severely harass females during the lek breeding (Anderson & Wallmo 1984; Prothero 2002; Isvaran 2003), these situations incline a female herd towards seeking older adult males' attention in order to keep harassing males away.

As expected in environments with well-defined seasonality as in PCWS, fawning peak correlates with growth of grasses, low in fiber, high in nutrients and significantly high biomass (Sathishkumar et al. 2023). Once fawns are born during the onset of dry season, mothers remain isolated with their offspring, away from other individuals, the peak of lactation coincides with the peak of food availability. Isolation lasts till (May–June) when mothers and fawns join larger herds.

CONCLUSION AND RECOMMENDATIONS

Among Blackbuck group units, the female herds and territorial pseudo-harems spread tightly, while the bachelor herds were loose or scattered with small groups. Female-herd based dyadic associations were stronger and more stable than mixed-sex herds and pseudo-harems, but males were in flux. Ecological correlates viz. grasslands and habitat openness were associated with higher levels of female sociality, indicating their importance in foraging, sociality, and predator vigilance, which is negatively affected by rapidly growing alien invasive *Prosopis juliflora*. Therefore, management of grasslands is essential to avoid invasion of alien woody plant. Invasion of *Prosopis*, which is modifying the natural habitats, suggests for management intervention on priority. One of the other significant covariates that threaten Blackbuck societies, especially in allocating feeding resources while socializing, is the presence of feral-horses and cattle. Invasive herbivores are predicted to outcompete natives, so they should be controlled. The feral-horse in the sanctuary, which competes with the native Blackbuck for resources and poses a serious threat, drives the Blackbuck away from suitable habitats. Thus, it is essential to humanely control the population of feral horses as the native population of Blackbuck is already showing a declining trend. To better manage a polygamous social species, it is important to understand its social preferences and their effects on females' lifetime reproductive success. Future research should examine the ecological costs and benefits of female social relationships, kin selection, male competition, behaviour-specific associations, covariate-specific association, and socio-spatial variation of populations.

This would help assess social organisation in this taxon and provide management clues by better understanding the evolutionary and ecological basis for antelope conservation and management.

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S-Table 1. Mean (a) and max (b) level of associations within and between age sex classes for female herds.

Classed by Age-sex	**AF**	**SAF**	**FA**
Mean			
AF	0.21 (0.11)	0.13 (0.08)	0.05 (0.05)
SAF	0.13 (0.06)	0.03 (0.03)	0.03 (0.03)
FA	0.05 (0.05)	0.03 (0.03)	0.00 (0.00)
Within associations	0.10 (0.12)		
Between associations	0.08 (0.06)		
Max			
AF	0.55 (0.28)	0.60 (0.22)	0.38 (0.22)
SAF	0.67 (0.18)	0.94 (0.14)	0.15 (0.15)
FA	0.21 (0.17)	0.19 (0.16)	0.00 (0.00)
Within associations	0.28 (0.30)		
Between associations	0.37 (0.22)		
Mantel test	t = 2.918; p = 0.0035		
Matrix correlation	0.1051		

S-Table 2. Mean (a) and max (b) level of associations within and between age sex classes for Bachelor herds.

Classed by Age-sex	**AM**	**SAM**
Mean		
AM	0.43 (0.09)	0.38 (0.16)
SAM	0.38 (0.12)	0.55 (0.09)
Within associations	0.48 (0.11)	
Between associations	0.38 (0.14)	
Max		
AM	0.88 (0.17)	0.60 (0.22)
SAM	0.67 (0.18)	0.94 (0.14)
Within associations	0.90 (0.16)	
Between associations	0.63 (0.20)	
Mantel test	t = 1.645; p = 0.100	
Matrix correlation	0.1609	

S-Table 3. Mean (a) and max (b) level of associations within and between age sex classes for Mixed herds.

Classed by Age-sex	**AF**	**SAF**	**FA**	**SAM**
Mean				
AF	0.41 (0.11)	0.32 (0.11)	0.32 (0.07)	0.05 (0.05)
SAF	0.32 (0.08)	0.26 (0.05)	0.22 (0.05)	0.03 (0.04)
FA	0.32 (0.07)	0.22 (0.06)	0.22 (0.03)	0.03 (0.05)
SAM	0.05 (0.06)	0.03 (0.05)	0.03 (0.05)	0.00 (0.00)
Within associations	0.30 (0.14)			
Between associations	0.25 (0.09)			
Max				
AF	0.69 (0.22)	0.58 (0.20)	0.59 (0.20)	0.09 (0.09)
SAF	0.65 (0.16)	0.52 (0.18)	0.40 (0.11)	0.06 (0.08)
FA	0.64 (0.16)	0.41 (0.14)	0.34 (0.06)	0.07 (0.09)
SAM	0.14 (0.11)	0.09 (0.13)	0.09 (0.13)	0.06 (0.08)
Within associations	0.52 (0.27)			
Between associations	0.60 (0.22)			
Mantel test	t = 3.268; p = 0.0011			
Matrix correlation	0.2269			

S-Table 4. Mean (a) and max (b) level of associations within and between age sex classes for Territorial pseudo-harem herds.

Classed by Age-sex	AF	SAF	FA	AM	SAM
Mean					
AF	0.25 (0.09)	0.21 (0.14)	0.21 (0.17)	0.39 (0.00)	0.09 (0.10)
SAF	0.21 (0.07)	0.24 (0.05)	0.18 (0.07)	0.33 (0.00)	0.19 (0.09)
FA	0.21 (0.11)	0.18 (0.10)	0.12 (0.07)	0.36 (0.00)	0.07 (0.06)
AM	0.39 (0.00)	0.33 (0.00)	0.36 (0.00)	0.09 (0.10)	0.25 (0.00)
SAM	0.09 (0.01)	0.19 (0.03)	0.07 (0.02)	0.25 (0.00)	0.67 (0.00)
Within associations	0.25 (0.15)				
Between associations	0.19 (0.11)				
Max					
AF	0.68 (0.21)	0.38 (0.25)	0.40 (0.31)	0.85 (0.00)	0.30 (0.00)
SAF	0.50 (0.18)	0.43 (0.11)	0.34 (0.11)	0.65 (0.00)	0.22 (0.10)
FA	0.55 (0.28)	0.36 (0.12)	0.20 (0.13)	0.75 (0.00)	0.08 (0.09)
AM	0.85 (0.00)	0.65 (0.00)	0.75 (0.00)	0.36 (0.12)	0.30 (0.00)
SAM	0.28 (0.04)	0.35 (0.07)	0.16 (0.08)	0.30 (0.00)	0.67 (0.00)
Within associations	0.52 (0.25)				
Between associations	0.50 (0.25)				
Mantel test	t = 1.687; p = 0.0915				
Matrix correlation	0.1105				

S-Table 5. Tests for preferred association for female herd.

Age sex class	Mean association		SD of association		p-value (SD)
	Observed	Random	Observed	Random	
All individuals	0.09	0.09	0.15	0.13	0.00
AF-AF	0.19	0.19	0.21	0.20	0.00
AF-SAF	0.13	0.13	0.15	0.14	0.08
AF-FA	0.05	0.05	0.09	0.09	0.01
SAF-FA	0.03	0.03	0.08	0.06	0.01

S-Table 7. Tests for preferred association for mixed herd.

Age sex class	Mean association		SD of association		p-value (SD)
	Observed	Random	Observed	Random	
All individuals	0.27	0.27	0.21	0.21	0.84
AF-AF	0.41	0.41	0.21	0.22	0.92
AF-SAF	0.32	0.32	0.21	0.21	0.64
AF-SAM	0.05	0.00	0.08	0.00	1.00
AF-FA	0.32	0.32	0.19	0.18	0.31
SAM-SAF	0.03	0.00	0.06	0.00	1.00
SAM-FA	0.03	0.00	0.07	0.00	1.00
SAF-FA	0.22	0.22	0.13	0.15	0.95

S-Table 6. Tests for preferred association for bachelor herd.

Age sex class	Mean association		SD of association		p-value (SD)
	Observed	Random	Observed	Random	
All individuals	0.42	0.42	0.28	0.28	0.83
AM-AM	0.43	0.00	0.29	0.00	0.91
AM-SAM	0.38	0.00	0.26	0.00	0.99

S-Table 8. Tests for preferred association for pseudo harem herd.

Age sex class	Mean association		SD of association		p-value (SD)
	Observed	Random	Observed	Random	
All individuals	0.20	0.20	0.21	0.20	0.07
AF-AF	0.25	0.24	0.25	0.23	0.05
AF-AM	0.39	0.00	0.33	0.00	1.00
AF-SAF	0.21	0.21	0.19	0.19	0.81
AF-SAM	0.09	0.00	0.10	0.00	1.00
AF-FA	0.21	0.22	0.24	0.25	0.39
AM-SAF	0.33	0.00	0.22	0.00	1.00
AM-FA	0.36	0.00	0.29	0.00	1.00
AM-SAM	0.25	0.00	0.07	0.00	1.00
SAM-SAF	0.17	0.18	0.10	0.09	0.05
SAM-FA	0.07	0.07	0.05	0.05	0.05
SAF-FA	0.18	0.18	0.14	0.14	0.16
SAM-SAM	0.67	0.00	0.33	0.00	1.00

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ARTICLE

Diversity and distribution of birds in the Bharathapuzha River Basin, Kerala, India

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Abstract: Bharathapuzha River is the second largest, west-flowing river in Kerala, Western Ghats. This river is exposed to high levels of anthropogenic and natural pressures. This study attempts to understand the diversity and distribution of birds in this river basin. The observations were made from October 2017 to July 2019 in 70*1 km^2 grids distributed in three strata (i.e., upper, middle, and lower reaches). A total of 262 bird species were recorded from the river basin. The diversity and richness of birds were found high in the upper reaches of the river and the species abundance was found more in the lower reaches. Due to the high turnover of migratory species, the rank abundance model for upper and lower reaches showed a high degree of dominance while middle reaches showed a relatively even distribution of abundances. Deforestation, sand mining, and water pollution were found to be the major threats in the river basin. Hence the results show the importance of the protection and rejuvenation of the ecosystems associated with the river for the conservation of avian diversity in the region.

Keywords: Bird community, ecological indicators, ecological zones, migrant birds, Nila river, rank abundance models, resident birds, riverine biodiversity, riverine birds, Western Ghats.

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Author contributions: ARPN—study design, field surveys, data analysis and preparation of manuscript, PP—study design, review, preparation of manuscript, ADV—data analysis, preparation of manuscript.

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INTRODUCTION

Rivers are considered an important ecological entity that supports rich biodiversity. The water flow, geography, interaction between the terrestrial and aquatic ecosystems, and the dynamic nature make the rivers one of Earth's most complex biophysical systems (Naiman et al. 1993). Though the rivers harbour rich biodiversity, they are also prone to many natural and anthropogenic challenges. Therefore, understanding the biological communities of the river system is essential for its management and conservation prioritization. The diverse habitats on the river corridors support many birds (Stevens et al. 1977; Stauffer & Best 1980; Knopf 1985). Since birds are considered as ecological indicators, habitat quality can be assessed through long-term avifauna monitoring. Understanding the bird communities and habitat association of different species (including migratory species) in different seasons is important for planning conservation strategies (Rice et al. 1980; Naiman et al. 1993; Gergel et al. 2002).

Kerala is one of the important places for avian research. The high level of habitat heterogeneity and its mosaic nature supports a wide range of birds (Neelakantan 1969, 1970, 1981, 1982; Neelakantan & Sureshkumar 1980; Neelakantan et al. 1980; Ali & Ripley 1983; Pramod 1995). The wetlands in Kerala enhance avian diversity by hosting migratory birds, hence many of the larger wetlands in Kerala were announced as Ramsar sites (Jayson 2002; Nameer 2005)

Bharathapuzha River (10.416–11.25 N and 75.833–76.916 E) in Kerala is known for its cultural and ecological significance. This river is considered as the cradle of civilization in Kerala. The major portion of the Bharathapuzha River flows through a human-dominated and agricultural landscape. The diverse habitat in the fluvial channel of the river supports great bird diversity. Many researchers have attempted to document the bird diversity in the river basin (Namassivayam & Venugopal 1989; Namassivayam et al. 1989; Kurup 1991; Uthaman & Namassivayam 1991; Neelakantan et al. 1993; Pramod 1995; Kurup 1996; Bijukumar 2006; Arif et al. 2010). However, the information available about the bird diversity of this river basin is sporadic.

In this investigation, we considered the river basin as a single ecological entity. We employed a ridge-to-reef approach to document the bird diversity from headwaters, main tributaries, mainstream and estuary. This study aims to establish baseline information about the avifauna of the Bharathapuzha River Basin and as a potential survey design for other river basins.

MATERIALS AND METHOD

Study area

The river Bharathapuzha originates from the southern part of the Palakkad Gap, in the Anamalai hills in the state of Tamil Nadu. It flows through the Palakkad gap covering Pollachi in Tamil Nadu; Palakkad, Thrissur, and Malappuram districts in Kerala and debouches into the Arabian Sea at Ponnani on the Malabar coast. The total length of the river is 250 km, of which 209 km flows through Kerala and 41 km through Tamil Nadu (Figure 1). The total extent of the river drainage basin is 6,186 km^2 between an elevation gradient of 2,461–0 m with an annual discharge of 3.94 km^3 water. The study divided the river drainage basin into three different ecological zones based on the stream orders as per Strahler (1957). Streams of order one to three were denoted as upper reaches (Image 1), order four to five as middle reaches (Image 2) and sixth-order streams were denoted as lower reaches (Image 3) (Abel et al. 2008).

The major tributaries of the river are Chiturpuzha, Gayathripuzha, Kunthipuzha, and Kalpathipuzha. All these tributaries originate from the northern and southern tips of the Palakkad Gap, which are the permanent and important water sources for the river. There are 11 dams constructed on this river for drinking water supply and irrigation to serve millions of people in the region.

Study design

The hydrology layer for the river basin was extracted using ASTER GDEM V2 and stream orders were established using the Strahler (1957) method. Field surveys were conducted along 453 km stretches at these ecological zones (Figure 1). These stretches were divided into 70 grid cells of 1 X 1 km. These selected locations were sampled from October 2017 to July 2019 in three replications which include two migratory (November–March) and one non-migratory season (April–October). In each cell bird observations were made for a 15 min period using point count with the fixed-width method (Reynolds et al. 1980). A total of 840 point counts were conducted in the sampling area. Over-flying birds, bird detections >50 m, and uncertain bird identifications were truncated from the data to improve the robustness of the study. Direct and indirect signs of birds were observed at 0600–1100 h and 1530–1900 h in each location. Direct observations were made using binoculars and spotting scopes. Bird identification was done using field guides (Ali & Ripley 1983; Ali 1999; Grimmett et al. 1999; Kazmierczak 2000) and photographs. The bird checklist was prepared using Praveen et al. (2020).

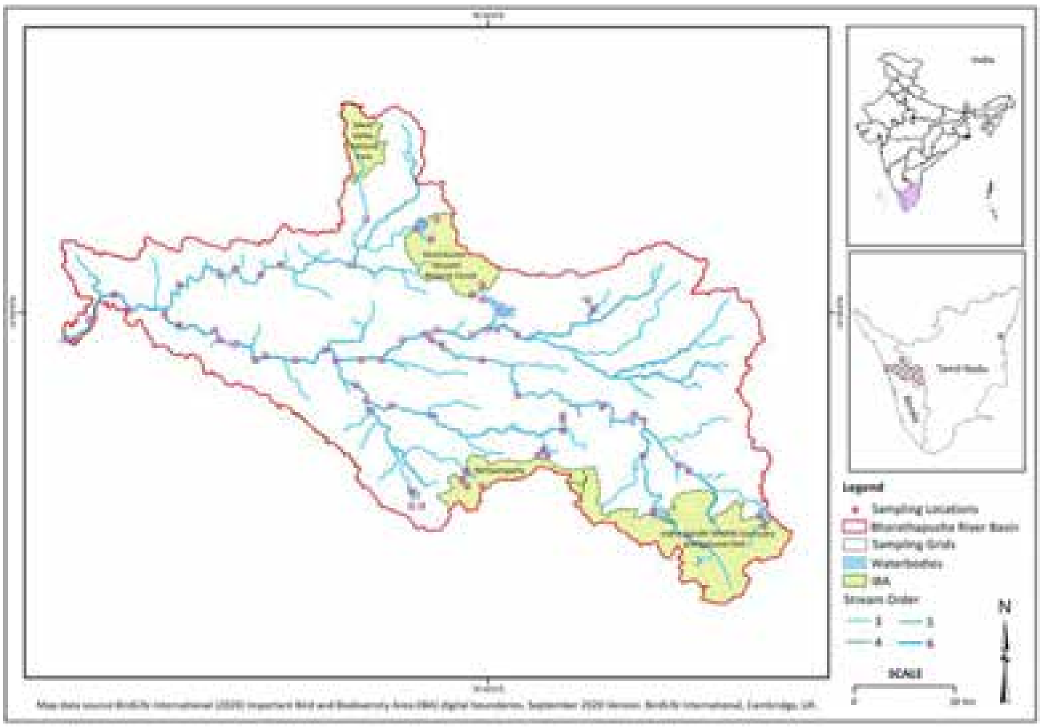

Figure 1. Location map of Bharathapuzha River Basin showing streams and sampling locations.

Image 1. Habitat in the upper reaches of Bharathapuzha River Basin. © P.N. Anoop Raj.

Image 2. Habitat in the middle reaches of Bharathapuzha River Basin. © P.N. Anoop Raj.

Opportunistic bird observations, i.e., the birds observed in the study areas after the predesigned observation period were recorded as ad libitum. The time of observation, date and number of individuals sighted, and habitat were noted.

Data analysis: Bird abundance data was arranged in the species vs sites contingency table. Absolute species richness for each region was tabulated. To check sampling adequacy, species richness was also estimated using Chao 1 ™index. To compare diversity, dominance and evenness Shannon-Weiner (H') and Simpson index were estimated (Magurran 1988). Relative abundance for all species was calculated in each ecological zone (Sutherland et al. 2004) using the formula.

$$RAi = \left(\frac{Ni}{\mathrm{p}}\right) \mathrm{x}100$$

Where RA = relative abundance of species i, Ni = Abundance of species i in ecological zone, P = Population of all species in river basin.

Relative abundance was calculated with the whole population of birds in the river basin to make it comparable

Image 3. Habitat in the lower reaches of Bharathapuzha River Basin. © P.N. Anoop Raj.

between ecological zones. The relative frequency of occurrence (RF) of birds in grids was used to understand the commonality/rarity of birds in each ecological zone. Hence the birds with RF more than 50% are considered as common, 20% to 50% as less common and >20% as rare.

To understand the migratory species of birds, bird species observed were classified into three categories such as resident, local migrant or long-distance migrant (SoIB 2023). To assess species distribution patterns, rank abundance distribution patterns were examined. All statistical analyses were performed using R statistical language V4.3.0 with R Studio IDE for R V2023.03.01. Diversity indices and rank abundance distributions were estimated using 'vegan': Community Ecology Package 2.6-4 (Oksanen et al. 2013).

RESULTS

Diversity

The bird observations were conducted from 0ctober 2017 to July 2019. A total of 262 species of birds were recorded belonging to 20 orders and 71 families (Table 1). Out of 262 bird species recorded in the study area 235 species of birds were recorded while employing the bird survey method; 27 bird species were observed in the opportunistic observations. Ecological zone-wise sampling efforts, bird species observed and the number of individual birds sighted are shown in Table 2. A total of 36,811 individuals were recorded from the river basin in migratory (n = 27,242) and non-migratory (n = 9,569) seasons during the survey. Passeriformes were the most dominant group in the river basin (42%) followed by Charadriiformes (13%), Falconiformes (8%), and Ciconiformes (6%). Passerine birds were the most dominant group (N = 146) followed by waders (N = 33), raptors (N = 20), and shorebirds (N = 19). Absolute species richness and estimated species richness using Chao–1 was similar (Table 3) indicating sampling was adequate. While the Shannon-Weiner index (H') shows higher species diversity in upper reaches (Table 3) than in middle and lower reaches. However, Simpsons' index for evenness and dominance was found to be similar across all ecological zones.

Bird species occurrence in different ecological zones

Rare birds were more compared to common and less common birds in all ecological zones. The upper reaches of the river basin reported 45 species of resident, two species of local migrants and four species of long-distance migrant birds as common, while 91 residents, 10 local migrants and eight long-distance migrants were rare. In the middle reaches, 43 residents, two species of local migrants and one species of long-distance migrant birds were common. 58 residents, six local migrants and three long-distance migrants were rare. In lower reaches, 48 residents, two local migrants and five migrant species were common and 48 residents, two local migrants and 10 migrant species were rare (Table 4).

Zipf-Mandlebrot distribution was found to be the best-fit model for upper reaches (deviance = 401.60) and lower reaches (deviance = 465.40). However, bird species in the middle reaches followed a log-normal abundance distribution (deviance = 615.83) (Table 5). Lower reaches had a steeper distribution than upper reaches and middle reaches indicating a high species turnover rate. While upper and lower reaches show shallow slopes, Middle reaches have more even abundances with species ranked with log-normal distribution.

DISCUSSION

Being a human-dominated landscape, some synanthropic birds such as the Common Myna *Acridotheres tristis*, House Crow *Corvus splendens*, and Black Drongo *Dicrurus macrocercus*, were dominant in the three ecological zones of the river basin region. However, Purple-rumped Sunbird *Leptocoma zeylonica*, Red-vented Bulbul *Pycnonotus cafer*, Common Tailorbird *Orthotomus sutorius*, Asian Palm Swift *Cypsiurus balasiensis*, Yellow-billed Babbler *Turdoides affinis*, and White-cheeked Barbet *Psilopogon viridis* were the other common resident birds in the river basin. The wetland associated birds such as Cattle Egret *Bubulcus ibis*, Little Cormorant

Microcarbo niger, Indian Pond Heron *Ardeola grayii*, and White-throated Kingfisher *Halcyon smyrnensis* were also found commonly in the river basin. Most of these birds are generalist feeders and adapt themselves to survive in any condition. Black-bellied Tern *Sterna acuticauda*, Dark-fronted Babbler *Rhopocichla atriceps*, Asian Emerald Dove *Chalcophaps indica*, Indian Spotted Eagle *Clanga hastata*, Cinnamon Bittern *Ixobrychus cinnamomeus*, Striated Heron *Butorides striata*, Yellow Bittern *Ixobrychus sinensis*, Spot-billed Pelican *Pelecanus philippensis*, and Pheasant-tailed Jacana *Hydrophasianus chirurgus* found as rare resident birds in the river basin in which a few of these birds were specific to ecological zones.

Greenish Warbler *Phylloscopus trochiloides*, Grey Wagtail *Motacilla cinerea*, and Barn Swallow *Hirundo rustica* were found to be the common local migrant birds in the river basin. Chestnut-tailed Starling *Sturnia malabarica*, Bar-headed Goose *Anser indicus*, and Gull-billed Tern *Gelochelidon nilotica* were the rare local migrant birds.

Blyth's Reed Warbler *Acrocephalus dumetorum*, Common Sandpiper *Actitis hypoleucos*, and Booted Eagle *Hieraaetus pennatus* were the common long-distance migrants. Booted Warbler *Iduna caligata*, Eurasian Curlew *Numenius arquata*, Whimbrel *Numenius phaeopus*, and Amur Falcon *Falco amurensis* were the rare long-distance migrants.

Malayan Night-heron *Gorsachius melanolophus*, Chestnut-winged Cuckoo *Clamator coromandus*, Black-bellied Tern *Sterna acuticauda*, and Indian Spotted Eagle *Clanga hastata* were some of the important sightings during the study period. The maximum flock size is seen in Little Cormorants with <300 individuals in a single location at Walayar dam. Gull species such as Black-headed Gull *Chroicocephalus ridibundus* and Pallas's Gull *Ichthyaetus ichthyaetus* congregated highly in the estuarine region. Totally, 2,200 individual birds were encountered in a single grid at Ponnani.

The study identified 60 species that are specific to the upper reaches, four to middle reaches and 16 to the lower reaches. 119 birds were common to all regions (Figure 2). Out of these, 17 birds were endemic to Western Ghats including one 'Endangered', seven 'Near Threatened', and four 'Vulnerable' birds as per the IUCN Red List of Threatened Species. This indicates that productive and heterogeneous habitats of the Bharathapuzha River Basin support birds from different niches and foraging guilds from forest to wetland-dependent birds as well as synanthropic species.

Upper reaches show higher species richness than middle and lower reaches because of the presence of primary forests, human habitations, and dams. Hence this region supports different foraging and feeding guilds (Ali & Ripley 1983; Wiens 1989). Also, the presence of dams in the upper reaches and the presence of estuary and check dams in the lower reaches enables to host a large number of migratory birds such as Little-ringed Plover *Charadrius dubius*, Marsh Sandpiper *Tringa stagnatilis* and Barn Swallows *Hirundo rustica*. However, due to the lesser availability of the wintering grounds in the middle reaches, fewer migratory birds were observed.

Ziph-Mandlebrot distribution of rank abundances in upper reaches and lower reaches has steep concave slope indicating that few species occur in high abundances (Figure 3). Species with high abundance ranks in these regions are migratory species like Black-headed Gull *Chroicocephalus ridibundus* and Pallas's Gull *Ichthyaetus ichthyaetus* with flock sizes of <5,000 individuals which dwarf the abundances of resident species. However, in the middle reaches, flock sizes of migratory birds are smaller which shows a more even distribution of rank abundances.

Status of migratory birds in the Bharathapuzha River

Purathur in the Bharathapuzha River basin was identified as one of the major stop-over sites for many migratory birds (Kurup 1991; Kumar 2001). Large flocks of Black-headed Gull, Pallas's Gull, & Brown-headed Gull (<5,000), Whiskered Tern (<100), and resident egrets such as Cattle Egret and Little Egret (<100) were recorded from the Purathur region during the study period. Smaller migratory bird flocks of Little-ringed Plover and Common Sandpipers were reported from the dams and several other parts of the main course. Solitary and passage migrant birds such as the Amur Falcon were reported from the headwater region. There were consecutive sightings of these passage migrants in the river basin from 2017 (Malampuzha Dam), 2018 (Thirunavaya), and 2019 (Malampuzha Dam). This indicates the importance of the river Bharathapuzha and associated habitats for the conservation of migratory and resident birds.

Major Threats

During the study period, natural vegetation near the sampling locations in upper reaches was cleared for expansion of agriculture especially for cash crops like rubber, teak, coffee and coconut. Such deforestation activities for the construction of dams, human settlements and infrastructure development were also reported in various studies (Nossiter 1982; Eapen 1999; Kumar 2005; John et al. 2019).

Bharathapuzha River is one of the most affected river systems due to the predominant sand mining. Legal and

Table 1. Relative abundances and relative frequency of occurrence of bird species in different ecological zones in Bharathapuzha River Basin.

	Species	Upper reaches	Middle reaches	Lower reaches
I	**Anseriformes: Anatidae**			
1	Bar-headed Goose *Anser indicus* ‡ LC	0.01 (4) @	0.00 (0)	0.00 (0)
2	Common Teal *Anas crecca* † LC			*
3	Cotton Teal *Nettapus coromandelianus* LC			*
4	Indian Spot-billed Duck *Anas poecilorhyncha* LC	0.24 (16) @	0.01 (4) @	0.01 (17) @
5	Lesser Whistling Duck *Dendrocygna javanica* LC	0.33 (20) @	0.01 (4) @	0.39 (28) &
II	**Galliformes: Phasianidae**			
6	Indian Peafowl *Pavo cristatus* LC	0.22 (72) ●	0.21 (70) ●	0.08 (50) ●
7	Red Spurfowl *Galloperdix spadicea* LC	0.01 (8) @	0.02 (11) @	0.00 (6) @
8	Jungle Bush Quail *Perdicula asiatica* LC	0.01 (4) @	0.00 (0)	0.00 (0)
9	Grey Francolin *Francolinus pondicerianus* LC	0.02 (20) @	0.00 (0)	0.00 (0)
10	Grey Junglefowl *Gallus sonneratii* LC	0.03 (24) &	0.00 (0)	0.00 (0)
III	**Podicipediformes: Podicipedidae**			
11	Little Grebe *Tachybaptus ruficollis* LC	0.01 (12) @	0.00 (0)	0.01 (6) @
IV	**Columbiformes: Columbidae**			
12	Rock Pigeon *Columba livia* LC	0.12 (44) &	0.94 (93) ●	0.94 (89) ●
13	Nilgiri Wood Pigeon *Columba elphinstonii* VU	0.01 (4) @	0.00 (0)	0.00 (0)
14	Spotted Dove *Streptopelia chinensis* LC	0.39 (96) ●	0.50 (78) ●	0.21 (72) ●
15	Laughing Dove *Streptopelia senegalensis* LC	0.02 (16) @	0.01 (4) @	0.01 (6) @
16	Asian Emerald Dove *Chalcophaps indica* LC	0.01 (8) @	0.00 (4) @	0.00 (0)
17	Grey-fronted Green Pigeon *Treron affinis* LC	0.01 (4) @	0.00 (0)	0.00 (0)
18	Yellow-footed Green Pigeon *Treron phoenicopterus* LC	0.01 (4) @	0.00 (4) @	0.04 (11) @
19	Green Imperial Pigeon *Ducula aenea* LC	0.02 (16) @	0.03 (15) @	0.00 (6) @
V	**Cuculiformes: Cuculidae**			
20	Greater Coucal *Centropus sinensis* LC	0.07 (52) ●	0.08 (63) ●	0.07 (61) ●
21	Blue-faced Malkoha *Phaenicophaeus viridirostris* LC	0.01 (20) @	0.00 (0)	0.00 (0)
22	Chestnut-winged Cuckoo *Clamator coromandus* ‡ LC	*		
23	Pied Cuckoo *Clamator jacobinus* LC	0.00 (0)	0.01 (7) @	>0.01 (6) @
24	Asian Koel *Eudynamys scolopaceus* LC	0.15 (76) ●	0.14 (81) ●	0.07 (61) ●
25	Banded Bay Cuckoo *Cacomantis sonneratii* LC	0.00 (4) @	0.00 (0)	0.00 (0)
26	Grey-bellied Cuckoo *Cacomantis passerinus* LC	0.00 (4) @	0.00 (0)	>0.01 (6) @
27	Fork-tailed Drongo Cuckoo *Surniculus dicruroides* LC	>0.01 (4) @	0.00 (0)	0.00 (0)
28	Common Hawk Cuckoo*Hierococcyx varius* LC	0.02 (28) &	0.01 (19) @	0.02 (39) &
29	Indian Cuckoo *Cuculus micropterus* ‡ LC	0.03 (24) &	0.01 (15) @	0.01 (17) @
VI	**Caprimulgiformes: Caprimulgidae**			
30	Jerdon's Nightjar *Caprimulgus atripennis* LC	0.01 (4) @	0.00 (0)	0.00 (0)
31	Indian Nightjar *Caprimulgus asiaticus* LC	0.00 (0)	>0.01 (4) @	0.00 (0)
32	Savanna Nightjar *Caprimulgus affinis* LC	0.00 (4) @	0.00 (0)	0.00 (0)
	Caprimulgiformes: Apodidae			
33	Indian Swiftlet *Aerodramus unicolor* LC	0.10 (20) @	0.25 (44) &	0.34 (33) &
34	Alpine Swift *Tachymarptis melba* LC	>0.01 (4) @	0.00 (0)	0.01 (11) @
35	Indian House Swift *Apus affinis* LC	0.12 (16) @	0.23 (11) @	0.08 (28) &
36	Asian Palm Swift *Cypsiurus balasiensis* LC	1.66 (76) ●	3.23 (96) ●	2.39 (78) ●
	Caprimulgiformes:Hemiprocnidae			
37	Crested Treeswift *Hemiprocne coronata* LC	0.01 (4) @	0.00 (0)	0.00 (0)
VII	**Gruiformes: Rallidae**			
38	Common Coot *Fulica atra* LC	0.05 (4) @	0.00 (4) @	0.00 (0)

	Species	Upper reaches	Middle reaches	Lower reaches
39	Grey-headed Swamphen *Porphyrio poliocephalus* LC	0.00 (0)	0.02 (15) @	0.34 (17) @
40	White-breasted Waterhen *Amaurornis phoenicurus* LC	0.05 (32) &	0.20 (78) ●	0.04 (50) ●
VIII	**Charadriiformes: Recurvirostridae**			
41	Black-winged Stilt *Himantopus himantopus* LC	0.01 (4) @	0.00 (0)	0.01 (6) @
	Charadriiformes: Charadriidae			
42	Pacific Golden Plover *Pluvialis fulva* † LC	0.00 (0)	0.00 (0)	0.02 (11) @
43	Red-wattled Lapwing *Vanellus indicus* LC	0.26 (56) ●	0.27 (63) ●	0.43 (83) ●
44	Kentish Plover *Charadrius alexandrinus* LC	0.00 (0)	0.00 (0)	0.04 (6) @
45	Common Ringed Plover *Charadrius hiaticula* † LC			*
46	Little Ringed Plover *Charadrius dubius* LC	0.33 (32) &	>0.01 (4) @	0.10 (44) &
	Charadriiformes: Rostratulidae			
47	Greater Painted-snipe *Rostratula benghalensis* LC	>0.01 (4) @	0.00 (0)	0.01 (17) @
	Charadriiformes: Jacanidae			
48	Pheasant-tailed Jacana *Hydrophasianus chirurgus* LC	0.00 (0)	0.00 (0)	0.01 (6) @
49	Bronze-winged Jacana *Metopidius indicus* LC	0.00 (0)	0.15 (44) &	0.10 (33) &
	Charadriiformes: Scolopacidae			
50	Whimbrel *Numenius phaeopus* † LC	0.00 (0)	0.00 (0)	0.01 (6) @
51	Eurasian Curlew *Numenius arquata* † NT	0.00 (0)	0.00 (0)	0.01 (6) @
52	Ruddy Turnstone *Arenaria interpres* † LC			*
53	Curlew Sandpiper *Calidris ferruginea* † NT			*
54	Temminck's Stint *Calidris temminckii* † LC			*
55	Little Stint *Calidris minuta* † LC	0.00 (0)	0.00 (0)	0.04 (11) @
56	Common Snipe *Gallinago gallinago* † LC	0.00 (4) @	0.00 (0)	0.00 (0)
57	Terek Sandpiper *Xenus cinereus* † LC	0.00 (0)	0.00 (0)	0.01 (6) @
58	Common Sandpiper *Actitis hypoleucos* † LC	0.28 (48) &	0.11 (44) &	0.37 (94) ●
59	Green Sandpiper *Tringa ochropus* † LC	0.04 (20) @	0.05 (33) &	0.13 (67) ●
60	Common Greenshank *Tringa nebularia* † LC	0.02 (8) @	>0.01 (4) @	0.04 (11) @
61	Marsh Sandpiper *Tringa stagnatilis* † LC	0.09 (20) @	0.01 (4) @	0.19 (67) ●
62	Wood Sandpiper *Tringa glareola* † LC	0.08 (12) @	0.00 (4) @	0.08 (33) &
63	Common Redshank *Tringa totanus* † LC	0.00 (0)	0.01 (4) @	0.03 (11) @
	Charadriiformes: Glareolidae			
64	Small Pratincole *Glareola lactea* LC	0.03 (4) @	0.00 (0)	0.00 (0)
	Charadriiformes: Laridae			
65	Black-headed Gull *Chroicocephalus ridibundus* † LC	0.00 (0)	0.00 (0)	1.39 (28) &
66	Brown-headed Gull *Chroicocephalus brunnicephalus* ‡ LC	0.00 (0)	0.00 (0)	1.62 (33) &
67	Pallas's Gull *Ichthyaetus ichthyaetus* † LC	0.00 (0)	0.00 (0)	1.31 (22) &
68	Lesser Black-backed Gull *Larus fuscus* † LC	0.00 (0)	0.00 (0)	0.52 (17) @
69	Little Tern *Sternula albifrons* LC	0.02 (4) @	0.05 (15) @	0.00 (0)
70	Gull-billed Tern *Gelochelidon nilotica* ‡ LC	0.00 (0)	0.00 (0)	0.05 (6) @
71	Caspian Tern *Hydroprogne caspia* LC			*
72	Whiskered Tern *Chlidonias hybrida* LC	0.26 (20) @	0.05 (19) @	0.39 (44) &
73	Black-bellied Tern *Sterna acuticauda* EN	0.00 (4) @	0.00 (0)	0.00 (0)
74	River Tern *Sterna aurantia* NT	0.15 (28) &	0.07 (30) &	0.25 (61) ●
IX	**Ciconiiformes: Ciconiidae**			
75	Asian Openbill *Anastomus oscitans* LC	0.40 (52) ●	0.24 (63) ●	0.81 (94) ●
76	Woolly-necked Stork *Ciconia episcopus* VU	0.20 (20) @	0.05 (15) @	0.17 (50) ●
77	Painted Stork *Mycteria leucocephala* NT	0.11 (8) @	0.00 (0)	0.00 (0)
X	**Suliformes: Anhingidae**			

	Species	Upper reaches	Middle reaches	Lower reaches
78	Oriental Darter (*Anhinga melanogaster*) NT	0.04 (16) @	0.05 (41) &	0.08 (56) ●
	Suliformes: Phalacrocoracidae			
79	Little Cormorant *Microcarbo niger* LC	1.82 (52) ●	0.88 (93) ●	2.66 (100) ●
80	Great Cormorant *Phalacrocorax carbo* LC	0.04 (8) @	0.00 (0)	0.01 (17) @
81	Indian Cormorant *Phalacrocorax fuscicollis* LC	0.06 (28) &	0.02 (19) @	0.03 (28) &
XI	**Pelecaniformes: Pelecanidae**			
82	Spot-billed Pelican *Pelecanus philippensis* NT	>0.01 (4) @	0.00 (0)	0.00 (0)
	Pelecaniformes: Ardeidae			
83	Yellow Bittern *Ixobrychus sinensis* LC	>0.01 (4) @	>0.01 (4) @	0.01 (6) @
84	Cinnamon Bittern *Ixobrychus cinnamomeus* LC	0.01 (4) @	0.00 (0)	0.00 (0)
85	Black Bittern *Ixobrychus flavicollis* LC	*		
86	Grey Heron *Ardea cinerea* LC	0.05 (24) &	0.02 (30) &	0.08 (78) ●
87	Purple Heron *Ardea purpurea* LC	0.04 (20) @	0.07 (56) ●	0.10 (67) ●
88	Great Egret *Ardea alba* LC	0.03 (20) @	0.03 (19) @	0.17 (61) ●
89	Intermediate Egret *Ardea intermedia* LC	0.09 (36) &	0.11 (59) ●	0.52 (94) ●
90	Little Egret *Egretta garzetta* LC	0.35 (60) ●	0.43 (85) ●	1.12 (100) ●
91	Western Reef Egret *Egretta gularis* LC	0.00 (0)	0.00 (0)	0.05 (17) @
92	Cattle Egret *Bubulcus ibis* LC	1.10 (84) ●	0.93 (100) ●	1.99 (100) ●
93	Indian Pond Heron *Ardeola grayii* LC	0.42 (88) ●	0.76 (100) ●	0.67 (100) ●
94	Striated Heron *Butorides striata* LC	>0.01 (4) @	0.01 (4) @	0.00 (0)
95	Black-crowned Night Heron *Nycticorax nycticorax* LC	0.01 (12) @	0.02 (15) @	0.04 (28) &
96	Malayan Night Heron *Gorsachius melanolophus* LC	*		
	Pelecaniformes: Threskiornithidae			
97	Glossy Ibis *Plegadis falcinellus* LC	0.01 (4) @	0.00 (0)	0.04 (6) @
98	Black-headed Ibis *Threskiornis melanocephalus* NT	0.52 (44) &	0.04 (22) &	0.36 (56) ●
XII	**Accipitriformes: Pandionidae**			
99	Osprey *Pandion haliaetus* † LC	0.01 (8) @	0.00 (0)	0.00 (0)
	Accipitriformes: Accipitridae			
100	Black-winged Kite *Elanus caeruleus* LC	0.01 (8) @	0.00 (0)	0.01 (11) @
101	Oriental Honey Buzzard *Pernis ptilorhynchus* LC	0.03 (36) &	0.02 (19) @	0.01 (17) @
102	Crested Serpent Eagle *Spilornis cheela* LC	0.09 (56) ●	0.08 (59) ●	0.06 (61) ●
103	Changeable Hawk Eagle *Nisaetus cirrhatus* LC	0.01 (8) @	0.00 (0)	0.00 (0)
104	Legge's Hawk Eagle *Nisaetus kelaarti* NE	0.00 (4) @	0.00 (0)	0.00 (0)
105	Black Eagle *Ictinaetus malaiensis* LC	0.02 (16) @	0.00 (4) @	0.01 (11) @
106	Indian Spotted Eagle *Clanga hastata* VU	0.00 (0)	0.00 (0)	0.00 (6) @
107	Booted Eagle *Hieraaetus pennatus* † LC	0.01 (16) @	0.02 (22) &	0.06 (61) ●
108	White-eyed Buzzard *Butastur teesa* LC	0.00 (4) @	0.00 (0)	0.00 (0)
109	Western Marsh Harrier *Circus aeruginosus* † LC			*
110	Crested Goshawk *Accipiter trivirgatus* LC	*		
111	Shikra *Accipiter badius* LC	0.05 (56) ●	0.02 (19) @	0.02 (39) &
112	Black Kite *Milvus migrans* LC	0.12 (36) &	0.15 (52) ●	1.15 (83) ●
113	Brahminy Kite *Haliastur indus* LC	0.35 (80) ●	0.59 (96) ●	1.73 (100) ●
114	Grey-headed Fish Eagle *Haliaeetus ichthyaetus* NT	*		
XIII	**Strigiformes: Tytonidae**			
115	Common Barn Owl *Tyto alba* LC		*	*
	Strigiformes: Strigidae			
116	Oriental Scops Owl *Otus sunia* LC	0.01 (4) @	0.00 (0)	0.00 (0)
117	Brown Fish Owl *Ketupa zeylonensis* LC	0.01 (8) @	0.00 (0)	0.00 (0)

	Species	Upper reaches	Middle reaches	Lower reaches
118	Jungle Owlet *Glaucidium radiatum* LC	0.01 (12) @	0.00 (0)	0.00 (0)
119	Spotted Owlet *Athene brama* LC	0.04 (24) &	0.01 (11) @	0.01 (11) @
120	Mottled Wood Owl *Strix ocellata* LC	0.00 (4) @	0.00 (0)	0.00 (0)
XIV	**Trogoniformes: Trogonidae**			
121	Malabar Trogon *Harpactes fasciatus* LC	0.02 (16) @	0.00 (0)	0.00 (0)
XV	**Bucerotiformes: Upupidae**			
122	Common Hoopoe *Upupa epops* LC	>0.01 (4) @	0.00 (0)	0.00 (0)
	Bucerotiformes: Bucerotidae			
123	Great Hornbill *Buceros bicornis* VU	0.01 (4) @	0.00 (0)	0.00 (0)
124	Malabar Grey Hornbill *Ocyceros griseus* LC	0.04 (28) &	0.02 (11) @	0.01 (17) @
XVI	**Coraciiformes: Alcedinidae**			
125	Common Kingfisher *Alcedo atthis* LC	0.09 (68) ●	0.14 (81) ●	0.08 (72) ●
126	Stork-billed Kingfisher *Pelargopsis capensis* LC	0.02 (24) &	0.07 (59) ●	0.03 (39) &
127	White-throated Kingfisher *Halcyon smyrnensis* LC	0.35 (92) ●	0.57 (100) ●	0.32 (100) ●
128	Pied Kingfisher *Ceryle rudis* LC	0.04 (20) @	0.11 (52) ●	0.11 (72) ●
	Coraciiformes: Meropidae			
129	Blue-bearded Bee-eater *Nyctyornis athertoni* LC	0.01 (12) @	0.00 (0)	0.00 (0)
130	Green Bee-eater *Merops orientalis* LC	0.48 (64) ●	0.56 (85) ●	0.67 (94) ●
131	Blue-tailed Bee-eater *Merops philippinus* LC	0.01 (16) @	0.10 (33) &	0.10 (50) &
132	Chestnut-headed Bee-eater *Merops leschenaulti* LC	0.11 (28) &	0.15 (44) &	0.30 (72) ●
	Coraciiformes: Coraciidae			
133	Indian Roller *Coracias benghalensis* LC	0.03 (36) &	0.05 (33) &	0.00 (0)
134	Dollarbird *Eurystomus orientalis* LC	0.00 (4) @	0.00 (0)	0.00 (0)
XVII	**Piciformes: Megalaimidae**			
135	Malabar Barbet *Psilopogon malabaricus* LC	*		
136	Coppersmith Barbet *Psilopogon haemacephalus* LC	0.12 (52) ●	0.03 (30) &	0.02 (17) @
137	Brown-headed Barbet *Psilopogon zeylanicus* LC	*		
138	White-cheeked Barbet *Psilopogon viridis* LC	0.45 (100) ●	0.34 (96) ●	0.16 (83) ●
	Piciformes: Picidae			
139	Heart-spotted Woodpecker *Hemicircus canente* LC	0.01 (8) @	0.01 (7) @	0.00 (0)
140	Brown-capped Pygmy Woodpecker *Yungipicus nanus* LC	0.03 (32) &	>0.01 (4) @	0.00 (0)
141	Rufous Woodpecker *Micropternus brachyurus* LC	0.01 (12) @	0.00 (0)	0.00 (0)
142	Black-rumped Flameback *Dinopium benghalense* LC	0.07 (52) ●	0.03 (22) &	0.01 (11) @
143	Lesser Yellownape *Picus chlorolophus* LC	0.03 (28) &	0.00 (4) @	0.00 (0)
144	Streak-throated Woodpecker *Picus xanthopygaeus* LC	0.01 (8) @	0.00 (0)	0.00 (0)
XVIII	**Falconiformes: Falconidae**			
145	Common Kestrel *Falco tinnunculus* LC	>0.01 (4) @	>0.01 (4) @	0.01 (6) @
146	Amur Falcon *Falco amurensis* † LC	0.00 (0)	0.00 (0)	0.01 (6) @
147	Peregrine Falcon *Falco peregrinus* LC	*		
XIX	**Psittaciformes: Psittaculidae**			
148	Rose-ringed Parakeet *Psittacula krameri* LC	0.33 (84) ●	0.48 (93) ●	0.11 (78) ●
149	Plum-headed Parakeet *Psittacula cyanocephala* LC	0.05 (20) @	0.05 (11) @	0.02 (11) @
150	Malabar Parakeet *Psittacula columboides* LC	0.18 (56) ●	0.07 (19) &	0.00 (0)
151	Vernal Hanging Parrot *Loriculus vernalis* LC	0.14 (48) &	0.01 (11) @	0.02 (22) &
XX	**Passeriformes: Pittidae**			
152	Indian Pitta *Pitta brachyura* ‡ LC	0.01 (20) @	0.01 (7) @	0.00 (0)
	Passeriformes: Campephagidae			
153	Orange Minivet *Pericrocotus flammeus* LC	0.21 (44) &	0.02 (7) @	0.01 (6) @

	Species	Upper reaches	Middle reaches	Lower reaches
154	Large Cuckooshrike *Coracina macei* $_{LC}$	0.04 (28) $^{\&}$	0.01 (15) $^{@}$	0.01 (6) $^{@}$
155	Black-headed Cuckooshrike *Lalage melanoptera* $_{LC}$	0.02 (20) $^{@}$	>0.01 (4) $^{@}$	0.02 (28) $^{\&}$
	Passeriformes:Oriolidae			
156	Indian Golden Oriole *Oriolus kundoo* ‡ $_{LC}$	0.04 (24) $^{\&}$	0.04 (22) $^{\&}$	0.06 (44) $^{\&}$
157	Black-naped Oriole *Oriolus chinensis* † $_{LC}$	0.02 (20) $^{@}$	0.01 (15) $^{@}$	0.02 (28) $^{\&}$
158	Black-hooded Oriole *Oriolus xanthornus* $_{LC}$	0.27 (88) ●	0.18 (74) ●	0.12 (67) ●
	Passeriformes:Artamidae			
159	Ashy Woodswallow *Artamus fuscus* $_{LC}$	0.12 (44) $^{\&}$	0.23 (37) $^{\&}$	0.17 (72) ●
	Passeriformes:Vangidae			
160	Malabar Woodshrike *Tephrodornis sylvicola* $_{LC}$	0.02 (16) $^{@}$	>0.01 (4) $^{@}$	0.01 (11) $^{@}$
161	Common Woodshrike *Tephrodornis pondicerianus* $_{LC}$	*	*	
	Passeriformes:Aegithinidae			
162	Common Iora *Aegithina tiphia* $_{LC}$	0.19 (68) ●	0.09 (70) ●	0.08 (67) ●
	Passeriformes: Dicruridae			
163	Black Drongo *Dicrurus macrocercus* $_{LC}$	0.51 (96) ●	0.50 (100) ●	0.43 (94) ●
164	Ashy Drongo *Dicrurus leucophaeus* ‡ $_{LC}$	0.02 (20) $^{@}$	0.00 (0)	>0.01 (6) $^{@}$
165	Bronzed Drongo *Dicrurus aeneus* $_{LC}$	>0.01 (4) $^{@}$	0.00 (0)	0.01 (11) $^{@}$
166	Greater Racket-tailed Drongo *Dicrurus paradiseus* $_{LC}$	0.27 (64) ●	0.08 (37) $^{\&}$	0.10 (44) $^{\&}$
	Passeriformes: Monarchidae			
167	Black-naped Monarch *Hypothymis azurea* $_{LC}$	0.04 (28) $^{\&}$	0.01 (4) $^{@}$	0.00 (0)
168	Indian Paradise-flycatcher *Terpsiphone paradisi* ‡ $_{LC}$	0.07 (48) $^{\&}$	0.02 (19) $^{@}$	0.01 (11) $^{@}$
	Passeriformes: Laniidae			
169	Brown Shrike *Lanius cristatus* † $_{LC}$	0.03 (20) $^{@}$	>0.01 (4) $^{@}$	0.03 (22) $^{\&}$
170	Bay-backed Shrike *Lanius vittatus* $_{LC}$	>0.01 (4) $^{@}$	0.00 (0)	>0.01 (6) $^{@}$
171	Long-tailed Shrike *Lanius schach* $_{LC}$	0.01 (8) $^{@}$	0.02 (30) $^{\&}$	>0.01 (6) $^{@}$
	Passeriformes: Corvidae			
172	Rufous Treepie *Dendrocitta vagabunda* $_{LC}$	0.30 (84) ●	0.30 (85) ●	0.14 (89) ●
173	White-bellied Treepie *Dendrocitta leucogastra* $_{LC}$	0.02 (12) $^{@}$	0.00 (0)	0.00 (0)
174	House Crow *Corvus splendens* $_{LC}$	1.34 (100) ●	2.77 (100) ●	4.46 (100) ●
175	Large-billed Crow *Corvus macrorhynchos* $_{LC}$	0.57 (84) ●	0.67 (85) ●	0.57 (78) ●
	Passeriformes: Stenostiridae			
176	Grey-headed Canary-flycatcher *Culicicapa ceylonensis* ‡ $_{LC}$	*		
	Passeriformes: Paridae			
177	Cinereous Tit *Parus cinereus* $_{LC}$	0.03 (8) $^{@}$	0.00 (0)	0.00 (0)
	Passeriformes: Alaudidae			
178	Jerdon's Bushlark *Mirafra affinis* $_{LC}$	0.07 (24) $^{\&}$	0.01 (7) $^{@}$	0.01 (11) $^{@}$
179	Oriental Skylark *Alauda gulgula* $_{LC}$	*		
180	Malabar Lark *Galerida malabarica* $_{LC}$		*	*
	Passeriformes: Cisticolidae			
181	Common Tailorbird *Orthotomus sutorius* $_{LC}$	0.39 (96) ●	0.61 (100) ●	0.31 (94) ●
182	Jungle Prinia *Prinia sylvatica* $_{LC}$	0.03 (16) $^{@}$	0.00 (0)	>0.01 (6) $^{@}$
183	Ashy Prinia *Prinia socialis* $_{LC}$	0.01 (12) $^{@}$	0.08 (48) $^{\&}$	0.12 (67) ●
184	Plain Prinia *Prinia inornata* $_{LC}$	0.07 (40) $^{\&}$	0.21 (70) ●	0.14 (72) ●
185	Zitting Cisticola *Cisticola juncidis* $_{LC}$	0.01 (4) $^{@}$	>0.01 (4) $^{@}$	0.02 (28) $^{\&}$
	Passeriformes: Acrocephalidae			
186	Thick-billed Warbler *Arundinax aedon* † $_{LC}$	0.01 (4) $^{@}$	0.00 (0)	0.00 (0)
187	Booted Warbler *Iduna caligata* † $_{LC}$	>0.01 (4) $^{@}$	0.00 (0)	0.00 (0)
188	Blyth's Reed Warbler *Acrocephalus dumetorum* † $_{LC}$	0.45 (96) ●	0.48 (93) ●	0.34 (89) ●

	Species	Upper reaches	Middle reaches	Lower reaches
189	Clamorous Reed Warbler *Acrocephalus stentoreus* LC	0.05 (32) &	0.01 (11) @	0.01 (11) @
	Passeriformes: Hirundinidae			
190	Barn Swallow *Hirundo rustica* ‡ LC	0.44 (48) &	0.51 (63) ●	0.81 (67) ●
191	Wire-tailed Swallow *Hirundo smithii* LC	0.00 (0)	0.00 (0)	0.11 (17) @
192	Red-rumped Swallow *Cecropis daurica* LC	0.30 (28) &	0.48 (52) ●	1.11 (72) ●
193	Streak-throated Swallow *Petrochelidon fluvicola* LC	0.00 (0)	0.02 (4) @	0.00 (0)
	Passeriformes: Pycnonotidae			
194	Flame-throated Bulbul *Rubigula gularis* LC	0.14 (24) &	0.00 (0)	0.00 (0)
195	Red-vented Bulbul *Pycnonotus cafer* LC	1.00 (100) ●	0.86 (96) ●	0.57 (100) ●
196	Red-whiskered Bulbul *Pycnonotus jocosus* LC	0.63 (88) ●	0.62 (89) ●	0.46 (89) ●
197	White-browed Bulbul *Pycnonotus luteolus* LC	0.15 (52) ●	0.03 (19) @	0.06 (28) &
198	Yellow-browed Bulbul *Acritillas indica* LC	0.21 (64) ●	>0.01 (4) @	0.01 (11) @
	Passeriformes: Phylloscopidae			
199	Green Leaf Warbler *Phylloscopus nitidus* † LC	0.05 (44) &	0.02 (15) @	0.02 (22) &
200	Greenish Leaf Warbler *Phylloscopus trochiloides* ‡ LC	0.42 (84) ●	0.14 (67) ●	0.10 (72) ●
201	Large-billed Leaf Warbler *Phylloscopus magnirostris* ‡ LC	0.01 (4) @	>0.01 (4) @	0.00 (0)
	Passeriformes: Zosteropidae			
202	Indian White-eye *Zosterops palpebrosus* LC	0.17 (20) @	0.00 (0)	>0.01 (6) @
	Passeriformes: Timaliidae			
203	Tawny-bellied Babbler *Dumetia hyperythra* LC	0.04 (16) @	0.00 (0)	0.00 (0)
204	Dark-fronted Babbler *Rhopocichla atriceps* LC	0.03 (4) @	0.00 (0)	0.00 (0)
205	Indian Scimitar Babbler *Pomatorhinus horsfieldii* LC	0.04 (20) @	0.00 (0)	0.00 (0)
	Passeriformes: Pellorneidae			
206	Puff-throated Babbler *Pellorneum ruficeps* LC	0.04 (16) @	0.00 (0)	0.00 (0)
	Passeriformes: Leiothrichidae			
207	Jungle Babbler *Argya striata* LC	0.61 (60) ●	0.05 (11) @	0.03 (11) @
208	Yellow-billed Babbler *Argya affinis* LC	1.43 (100) ●	1.40 (93) ●	0.54 (72) ●
209	Common Babbler *Argya caudata* LC	0.02 (4) @	0.00 (0)	0.00 (0)
210	Rufous Babbler *Argya subrufa* LC	0.09 (16) @	0.01 (4) @	0.00 (0)
211	Wayanad Laughingthrush *Pterorhinus delesserti* LC	0.07 (4) @	0.00 (0)	0.00 (0)
	Passeriformes: Sittidae			
212	Velvet-fronted Nuthatch *Sitta frontalis* LC	0.07 (24) &	0.00 (0)	0.00 (0)
	Passeriformes: Sturnidae			
213	Common Hill Myna *Gracula religiosa* LC	0.33 (24) &	0.00 (0)	0.00 (0)
214	Rosy Starling *Pastor roseus* † LC	0.08 (12) @	0.02 (4) @	0.17 (17) @
215	Brahminy Starling *Sturnia pagodarum* LC	0.01 (4) @	0.04 (11) @	0.00 (0)
216	Chestnut-tailed Starling *Sturnia malabarica* LC	0.01 (8) @	0.00 (0)	0.06 (11) @
217	Malabar Starling *Sturnia blythii* NE	0.04 (12) @	0.01 (4) @	0.02 (6) @
218	Common Myna *Acridotheres tristis* LC	1.12 (100) ●	1.45 (100) ●	1.14 (100) ●
219	Jungle Myna *Acridotheres fuscus* LC	0.33 (64) ●	0.04 (15) @	0.02 (6) @
	Passeriformes: Turdidae			
220	Nilgiri Thrush *Zoothera neilgherriensis* NE	0.01 (8) @	0.00 (0)	0.00 (0)
221	Orange-headed Thrush *Geokichla citrina* LC	0.05 (28) &	0.01 (19) @	0.02 (28) &
	Passeriformes: Muscicapidae			
222	Asian Brown Flycatcher *Muscicapa dauurica* LC	0.01 (8) @	0.00 (0)	0.00 (0)
223	Brown-breasted Flycatcher *Muscicapa muttui* † LC	0.10 (52) ●	0.01 (11) @	0.02 (28) &
224	Indian Robin *Copsychus fulicatus* LC	0.06 (28) &	0.02 (11) @	0.01 (11) @
225	Oriental Magpie Robin *Copsychus saularis* LC	0.26 (84) ●	0.19 (78) ●	0.07 (61) ●

	Species	Upper reaches	Middle reaches	Lower reaches
226	White-rumped Shama *Copsychus malabaricus* LC	*		
227	White-bellied Blue Flycatcher *Cyornis pallidipes* LC	0.03 (16) @	0.00 (0)	0.00 (0)
228	Tickell's Blue Flycatcher *Cyornis tickelliae* LC	0.03 (24) &	0.00 (0)	0.00 (0)
229	Nilgiri Flycatcher *Eumyias albicaudatus* LC	*		
230	Verditer Flycatcher *Eumyias thalassinus* ‡LC	>0.01 (4) @	0.00 (0)	0.00 (0)
231	Malabar Whistling Thrush *Myophonus horsfieldii* LC	0.18 (44) &	0.01 (7) @	0.00 (0)
232	Black-and-orange Flycatcher *Ficedula nigrorufa* LC	*		
233	Rusty-tailed Flycatcher *Ficedula ruficauda* †LC	0.01 (12) @	0.00 (0)	0.00 (0)
234	Taiga Flycatcher *Ficedula albicilla* †LC	*		
235	Blue-capped Rock Thrush *Monticola cinclorhyncha* ‡LC	0.02 (8) @	0.00 (0)	0.00 (0)
236	Pied Bushchat *Saxicola caprata* LC	0.11 (48) &	0.05 (30) &	0.05 (33) &
	Passeriformes: Dicaeidae			
237	Thick-billed Flowerpecker *Dicaeum agile* LC	0.02 (12) @	0.00 (0)	0.00 (0)
238	Pale-billed Flowerpecker *Dicaeum erythrorhynchos* LC	0.35 (92) ●	0.29 (85) ●	0.17 (83) ●
239	Nilgiri Flowerpecker *Dicaeum concolor* LC	0.01 (4) @	0.00 (0)	0.00 (0)
	Passeriformes: Nectariniidae			
240	Purple-rumped Sunbird *Leptocoma zeylonica* LC	0.93 (100) ●	0.83 (100) ●	0.44 (100) ●
241	Crimson-backed Sunbird *Leptocoma minima* LC	0.08 (32) &	0.00 (0)	0.00 (0)
242	Purple Sunbird *Cinnyris asiaticus*) LC	0.23 (84) ●	0.22 (74) ●	0.17 (72) ●
243	Loten's Sunbird *Cinnyris lotenius* LC	0.18 (76) ●	0.06 (41) &	0.05 (39) &
244	Little Spiderhunter *Arachnothera longirostra* LC	0.05 (20) &	>0.01 (4) @	0.00 (0)
	Passeriformes: Irenidae			
245	Asian Fairy-bluebird *Irena puella* LC	0.05 (16) @	0.00 (0)	0.00 (0)
	Passeriformes: Chloropseidae			
246	Jerdon's Leafbird *Chloropsis jerdoni* LC	0.13 (56) ●	0.05 (37) &	0.04 (39) &
247	Golden-fronted Leafbird *Chloropsis aurifrons* LC	0.04 (20) @	0.02 (19) @	0.01 (11) @
	Passeriformes: Ploceidae			
248	Streaked Weaver *Ploceus manyar* LC	0.00 (0)	0.01 (4) @	0.00 (0)
249	Baya Weaver *Ploceus philippinus* LC	0.00 (0)	0.23 (7) @	0.00 (0)
	Passeriformes: Estrildidae			
250	Red Munia *Amandava amandava* LC			*
251	Indian Silverbill *Euodice malabarica* LC	0.01 (4) @	0.00 (0)	0.00 (0)
252	White-rumped Munia *Lonchura striata* LC	0.00 (0)	0.01 (4) @	0.01 (11) @
253	Scaly-breasted Munia *Lonchura punctulata* LC	0.06 (8) @	0.08 (19) @	0.27 (33) &
254	Tricoloured Munia *Lonchura malacca* LC	0.15 (24) &	0.24 (30) &	0.34 (39) &
	Passeriformes: Passeridae			
255	House Sparrow *Passer domesticus* LC	0.00 (0)	0.04 (19) @	0.01 (6) @
256	Yellow-throated Sparrow *Gymnoris xanthocollis* LC	0.01 (4) @	0.00 (0)	0.00 (0)
	Passeriformes: Motacillidae			
257	Forest Wagtail *Dendronanthus indicus* †LC	0.02 (16) @	0.00 (0)	0.00 (0)
258	Grey Wagtail *Motacilla cinerea* ‡LC	0.10 (52) ●	0.04 (33) &	0.01 (17) @
259	Western Yellow Wagtail *Motacilla flava* †LC	0.04 (24) &	0.01 (7) @	0.01 (22) &
260	White-browed Wagtail *Motacilla maderaspatensis* LC	0.16 (56) ●	0.33 (78) ●	0.29 (83) ●
261	Paddyfield Pipit *Anthus rufulus* LC	0.05 (36) &	0.02 (15) @	0.01 (28) &
	Passeriformes: Fringillidae			
262	Common Rosefinch *Carpodacus erythrinus* ‡LC			*

Migratory status: †—long distance migrant | ‡—local migrant | IUCN Status: LC—Least Concern | NT—Near Threatened | VU—Vulnerable | EN—Endangered | NE—Not Evaluated. *—Opportunistic sightings. Rarity: ●—Common | &—Less common | @—Rare.

Table 2. Ecological zone-wise sampling effort for avifauna diversity survey in Bharathapuzha River Basin.

Ecological zone	Grids (n)	Point counts (n)	Total effort (Hours)	Species observed (n)	Individuals encountered (n)
Upper reaches	25	300	75	209	11,280
Middle reaches	27	324	81	145	10,602
Lower reaches	18	216	54	155	14,929
Overall	70	840	210	235	36,811

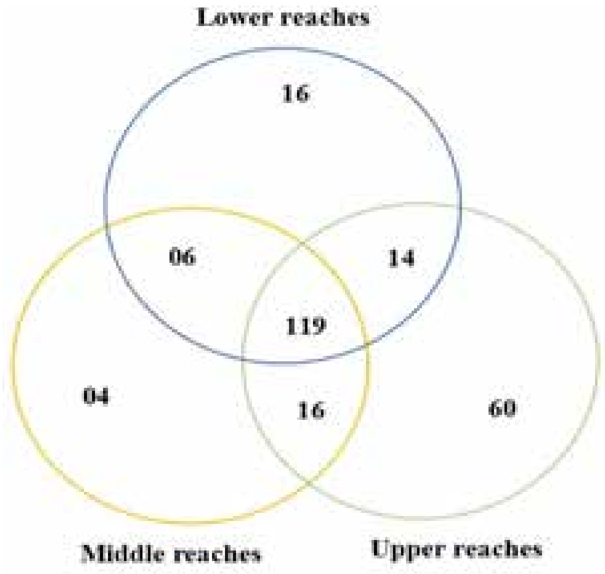

Figure 2. Occurrence of various bird species in different ecological zones.

Table 3. Diversity indices calculated for various ecological zones.

	Upper reaches	Middle reaches	Lower reaches
Dominance (D)	0.021	0.038	0.035
Simpson (1-D)	0.98	0.96	0.96
Shannon (H')	4.35	3.82	3.88
Chao-1	220.70	158.20	158.50
Observed species richness	209	145	155

illegal sand mining altered the river ecosystem, especially in the mainstream. The illegal sand mining and over-exploitation of sand destroyed the river ecosystem (Sreedhar & Irfan 2016). There were several sighting reports and nesting records of 'Endangered' Black-bellied Tern in the river basin (Susanthkumar 2004; Aarif et al. 2010). However, in this study, we couldn't find nesting of these birds in the river basin. Sand mining is still prevalent in the lower reaches of the Bharathapuzha River Basin. It can be detrimental to the benthic ecosystem on which many bird species are dependent. Hence sand mining may have cascading effects on the biodiversity of the entire river basin.

Due to the strong opposition by the local people, nature enthusiasts and NGOs, there have been various regulations and restrictions imposed on sand mining activities. Even though, illegal sand mining is prevalent in several locations in the river basin. Interestingly, legal sand mining in the estuary region, at Ponnani is also observed (Image 4).

CONCLUSION

The study covered 48% of the total bird species recorded from Kerala (Chandran et al. 2020). The last published checklist of birds of the region by Bijukumar (2006) has reported 143 bird species from the river basin. This study updates the checklist and increases the number of bird species on the list to 262.

The holistic approach of the river as a single ecological entity helps to understand the changes in the avian diversity in different regions of the river over time. The headwater region of the river basin supports the resident birds. The main course and estuary regions play a pivotal role in the conservation of migratory birds. Hence protection of the forests in the upper reaches and all-natural habitats in the lower reaches are equally important for the conservation of birds. Bringing back the natural ecosystem of the river is everyone's responsibility. Hence community-mediated policy interventions are very much required to reduce sand mining and rebuild the riverine ecosystem, which ultimately protects the biodiversity.

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Table 4. Common and rare birds reported in each ecological zone.

Migratory status	Upper reaches			Middle reaches			Lower reaches		
	Common	Less common	Rare	Common	Less common	Rare	Common	Less common	Rare
Resident	45	39	91	43	18	58	48	25	48
Local migrant	2	5	10	2	3	6	2	5	7
Long distance migrant	4	1	8	1	3	9	5	7	10

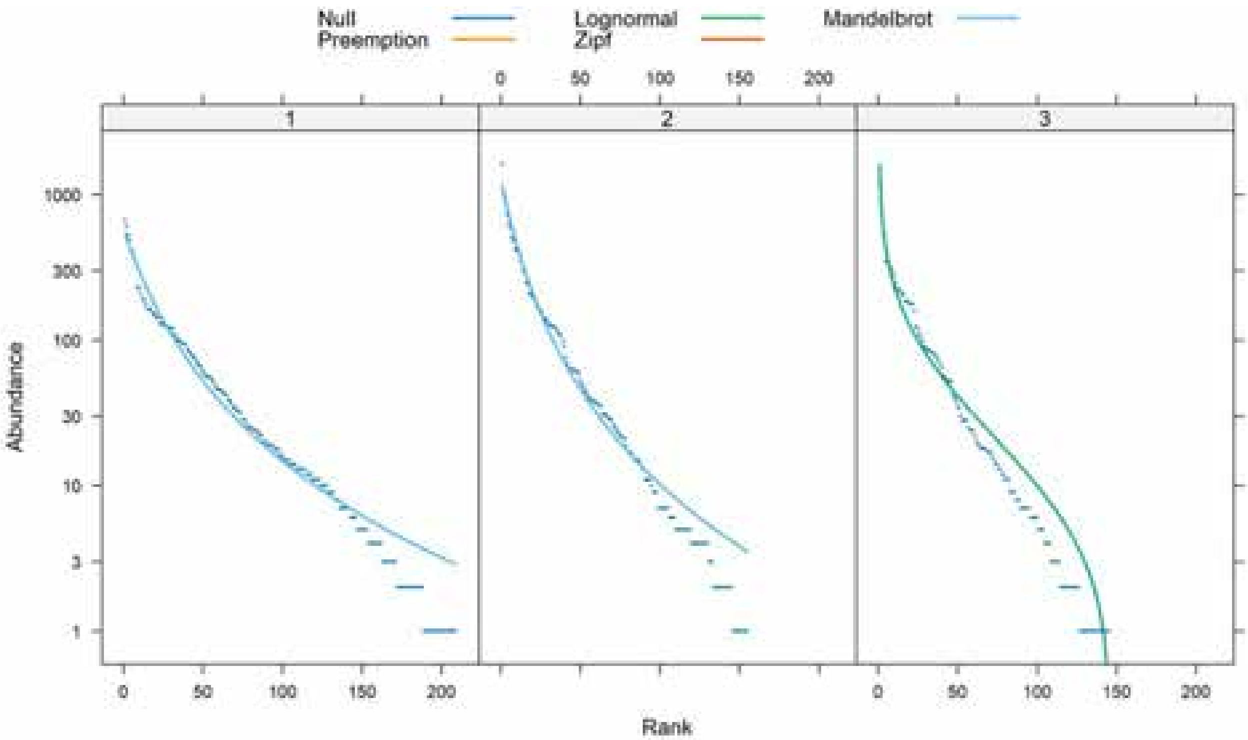

Figure 3. Best fit rank abundance model for birds observed in different regions of Bharathapuzha River Basin: 1—Upper reaches | 2—Lower reaches | 3—Middle reaches.

Table 5. Estimated RAD of bird species from distinct ecozones based on stream order in Bharathapuzha River Basin.

		Null	Log-normal	Pre-emption	ZIpf	Zipf-Mandlebrot
Upper reaches	Deviance	3698.84	622.88	1028.77	2780.50	401.60*
	AIC	4660.40	1588.44	1992.32	3746.05	1369.15
	ΔAIC	3291.25	219.29	623.17	2376.9	0
Middle reaches	Deviance	5204.45	615.83*	1280.85	2491.06	1280.85
	AIC	5876.61	1291.99	1955.01	3167.22	1959.01
	ΔAIC	4584.62	0	663.02	1875.23	667.02
Lower reaches	Deviance	7401.81	742.92	1571.21	3466.99	465.40*
	AIC	8163.55	1508.65	2334.94	4232.73	1233.14
	ΔAIC	6930.41	275.51	1101.80	2999.59	0

AIC—Akaike information criterion

Image 4. Sand dredging along the coast of Ponnani estuary in lower reaches of Bharathapuzha River Basin. © P.N. Anoop Raj.

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ARTICLE

A review of the status of vultures in the southern state of Karnataka, India

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Abstract: Vultures are vital scavengers that maintain ecological balance by feeding on carcasses. Among the nine vulture species in India, four are categorised as 'Critically Endangered', one as 'Endangered', three as 'Near Threatened', and one as 'Least Concern' as per the IUCN Red List. The vultures have experienced a global decline, while in India, majorly due to the use of diclofenac, a non-steroidal anti-inflammatory drug (NSAID). A review of all available literature on vultures from 1838 to December 2022 and extracting of all sight records from eBird to understand their status, occurrence, and distribution for the Indian state of Karnataka. The study reveals a total of seven vulture species recorded from the state, of them, one was misidentified, two are vagrants, and the other four species, namely Egyptian Vulture, White-rumped Vulture, Indian Vulture, and Red-headed Vulture, are residents. The resident vulture population in the state is experiencing a consistent decrease and has been confined in recent years to in and around Bandipur and Nagarahole tiger reserves, while Egyptian Vulture is mostly observed in human-inhabited areas. In contrast to the gradual recovery of the *Gyps* vulture population across the country, the population in the Ramadevarabetta Vulture Sanctuary remains relatively low or decreasing. Periodic systematic population assessments and monitoring of nest sites, evaluating breeding patterns, and ensuring the availability of undisturbed carcasses for vultures to feed on are suggested.

Keywords: Conservation status, conservation strategy, endangered species, *Gyps*, population status, Ramadevarabetta Vulture Sanctuary, scavengers.

Kannada: ರಣಹದ್ದುಗಳು ಪರಿಸರದಲ್ಲಿರುವ ಸತ್ತ ಪ್ರಾಣಿಗಳನ್ನು[ಕಳೇಬರ] ತಿನ್ನುವ ಮೂಲಕ ನಿಸರ್ಗದಲ್ಲಿ ಪರಿಸರದ ಸ್ವಚ್ಛತಾ ಕರ್ಮಿಗಳಾಗಿ ತಮ್ಮದೇ ಆದ ಕೊಡುಗೆ ನೀಡುತ್ತವೆ. ಭಾರತದಲ್ಲಿ 9 ಜಾತಿಯ ರಣಹದ್ದುಗಳು ನೆಲೆಸಿವೆ. ಐಯುಸಿಎನ್ ತಯಾರಿಸಿರುವ ಕೆಂಪು ಪಟ್ಟಿಯ ಪ್ರಕಾರ ನಾಲ್ಕು ಹದ್ದುಗಳು 'ತೀವ್ರವಾಗಿ ಅಳಿವಿನಂಚಿನಲ್ಲಿರುವ' , ಒಂದು ಜಾತಿಯ ರಣಹದ್ದು 'ಅಳಿವಿನಂಚಿನಲ್ಲಿರುವ' , ಮೂರು ಜಾತಿಯ ರಣಹದ್ದುಗಳು 'ಆತಂಕಕ್ಕೆ ಸಮೀಪವಿರುವ' ಮತ್ತೊಂದು 'ಕಡಿಮೆ ಕಾಳಜಿ' ಹೊಂದಿರುವ ಎಂದು ವರ್ಗೀಕರಿಸಲಾಗಿದೆ. ಭಾರತದಲ್ಲಿ ತೀವ್ರಗತಿಯಲ್ಲಿ ರಣಹದ್ದುಗಳ ಸಂಖ್ಯೆ ಕಡಿಮೆಯಾಗುತ್ತಿದ್ದು, ವಿವಿಧ ಕಾರಣಗಳಲ್ಲಿ ಪ್ರಮುಖವಾಗಿ ನಾಡಿನ [ಜನರಿರುವ] ಪ್ರದೇಶದಲ್ಲಿ ಡೈಕ್ಲೋಫಿನಾಕ್ ಎಂಬ ನೋವು ನಿವಾರಕ ಔಷಧವಿರುವ ಜಾನುವಾರುಗಳ ಕಳೇಬರ ತಿಂದ ನಂತರ ರಣಹದ್ದುಗಳು ಮೃತಪಡುತ್ತವೆ. ರಣಹದ್ದುಗಳ ಕುರಿತು 1838 ರಿಂದ ಡಿಸೆಂಬರ್ 2022ರ ತನಕ ದೊರೆತಿರುವ ಅಂಕಿಅಂಶಗಳು, ಮಾಹಿತಿಗಳನ್ನು ಮತ್ತು ಇ-ಬರ್ಡ್ ನಲ್ಲಿರುವ ಅವುಗಳು ಇರುವಿಕೆ ಮತ್ತು ಕಾಣಿಸಿಕೊಂಡಿರುವ ಕುರಿತು ಮಾಹಿತಿಗಳನ್ನು ಸಂಗ್ರಹಿಸಲಾಗಿದೆ. ಈ ಮಾಹಿತಿಯಿಂದ ರಣಹದ್ದುಗಳ ಸ್ಥಿತಿಗತಿ, ಅವುಗಳ ಆವಾಸಸ್ಥಾನ, ವ್ಯಾಪ್ತಿ ಮತ್ತು ವಿಸ್ತಾರ ಅರ್ಥ ಮಾಡಿಕೊಳ್ಳಲಾಗಿದೆ. ಈ ಅಧ್ಯಯನ ಪ್ರಕಾರ ಕರ್ನಾಟಕದಲ್ಲಿ ಏಳು ಜಾತಿಯ ರಣಹದ್ದುಗಳಿವೆ ಎಂಬ ಅಂಶ ಬೆಳಕಿಗೆ ಬಂದಿದೆ. ಒಂದು ಜಾತಿಯ ರಣಹದ್ದನ್ನು ತಪ್ಪಾಗಿ ಗುರುತಿಸಲಾಗಿದೆ. ಇನ್ನೆರೆಡು ಜಾತಿಯ ರಣಹದ್ದುಗಳು ಅಪರೂಪಕ್ಕೆ ಮಾತ್ರ ಕಾಣಿಸಿಕೊಂಡಿವೆ. ಅಲೆಮಾರಿ ರಣಹದ್ದುಗಳಾಗಿದ್ದು, ಇವುಗಳ ಮೂಲ ಮತ್ತು ವಲಸೆ ಜಾಗ ಬೇರೆಯಾದರೂ ದಕ್ಷಿಣಭಾರತದತ್ತ ದಾರಿ ತಪ್ಪಿ ಬಂದಿವೆ. ಇನ್ನು ನಾಲ್ಕು ಯಾವುವೆಂದರೇ ಈಜಿಪ್ಟಿಯನ್ ರಣಹದ್ದು, ಬಿಳಿಬೆನ್ನಿನ ರಣಹದ್ದು, ಭಾರತೀಯ ರಣಹದ್ದು ಮತ್ತು ಕೆಂಪುತಲೆ ರಣಹದ್ದು ಇವು ಸ್ಥಳೀಯವಾಗಿ ರಾಜ್ಯದಲ್ಲಿ ಸಿಗುವಂತದ್ದೆ. ಆದರೂ ಕರ್ನಾಟಕದಲ್ಲಿ ಈ ರಣಹದ್ದುಗಳ ಸಂಖ್ಯೆಯಲ್ಲಿ ತೀವ್ರಗತಿಯಲ್ಲಿ ಕಡಿಮೆಯಾಗುತ್ತಿದ್ದು, ನಾಗರಹೊಳೆ ಮತ್ತು ಬಂಡೀಪುರದಂತಹ ಅರಣ್ಯದ ಸಮೀಪದಲ್ಲಿ ಸೀಮಿತವಾಗಿ ಕಾಣಸಿಗುತ್ತಿವೆ. ಆದರೆ ಈಜಿಪ್ಟಿಯನ್ ರಣಹದ್ದು ಮಾತ್ರ ಜನವಸತಿ ಪ್ರದೇಶಗಳ ಬಳಿ ಹೆಚ್ಚಾಗಿ ಕಂಡುಬರುತ್ತಿದೆ. (ಜಿಪ್ಸ್ ವಲ್ಚರ್ಸ್) ಹಳೇ ರಣಹದ್ದು ಗಳ ಸಂಖ್ಯೆ ಕೊಂಚ ಮಟ್ಟಿಗೆ ಹೆಚ್ಚಾಗುತ್ತಿದೆ ಎಂದು ಹೇಳಲಾಗುತ್ತಿದ್ದರೂ ರಾಮನಗರದ ರಾಮದೇವರ ಬೆಟ್ಟ ಈ ರೀತಿಯ ರಣಹದ್ದುಗಳ ಸಂಖ್ಯೆ ಕ್ರಮೇಣ ಕಡಿಮೆಯಾಗುತ್ತಿದೆ. ನಿಯಮಿತವಾಗಿ ರಣಹದ್ದುಗಳ ಸಂಖ್ಯೆಯ ಮೌಲ್ಯಮಾಪನ, ಅವುಗಳ ಗೂಡುಗಳ ಮೇಲ್ವಿಚಾರಣೆ, ಸಂತಾನೋತ್ಪತ್ತಿಯ ಕುರಿತ ಅಧ್ಯಯನ ಮತ್ತು ಮುಖ್ಯವಾಗಿ ಅವುಗಳು ತಿನ್ನುವ ಕಳೇಬರಗಳಲ್ಲಿ ಅಂದರೆ ಜಾನುವಾರಗಳ ದೇಹದೊಳಗೆ ಡೈಕ್ಲೋಫಿನಾಕ್ ನಂತಹ ಔಷಧ ಸೇರದಂತೆ ನೋಡಿಕೊಳ್ಳಬೇಕು ಎಂದು ಸೂಚಿಸಲಾಗಿದೆ

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INTRODUCTION

Scavenger bird populations are quickly dropping all over the world, with some populations already on the verge of extinction (Straub et al. 2015; Munstermann 2022). Among all raptors, vultures are the ones that scavenge, and their ecological importance cannot be overstated. Among vultures, old-world vultures are the most endangered (McClure et al. 2018). Any harm to them disrupts the natural balance, increasing the risk of pollution and illness in wildlife, humans, and livestock (Jha & Jha 2021). Thus, vultures provide vital ecological services and contribute significantly to ecosystem balance (Jha & Jha 2021). Vultures are spiritually, economically, and ecologically significant. They have traditionally been crucial in maintaining environmental health by clearing animal and human carcasses (Markandya 2008). Vultures are thought to be the most threatened functional guild on the planet (Sekercioğlu et al. 2004). Sixteen out of the world's 23 vulture species are classified as endangered, facing imminent risk of extinction in the wild (Şekercioğlu et al. 2004; Buechley & Şekercioğlu 2016) and nine of them are recorded in India (Ali & Ripley 1987), including White-rumped Vulture *Gyps bengalensis*, Indian Vulture *Gyps indicus*, Slender-billed Vulture *Gyps tenuirostris*, Red-headed Vulture *Sarcogyps calvus*, Egyptian Vulture *Neophron percnopterus*, Bearded Vulture *Gypaetus barbatus*, Himalayan Vulture *Gyps himalayensis*, Cinereous Vulture *Aegypius monachus*, and Griffon Vulture *Gyps fulvus*. The first four of the nine species have been classified as 'Critically Endangered', the fifth as 'Endangered', the next three as 'Near Threatened', and the last as 'Least Concern' in the IUCN Red List of Threatened Species (Bowden 2018).

Gyps vultures were formerly common and widespread over most of India, and their numbers were very high (Wilbur & Jackson 1983; Prakash et al. 2003). They are important scavengers, reaching particularly high abundance in human-dominated landscapes, where carrion from domestic ungulate corpses was their principal source of food (Pain et al. 2003). Further research has shown that the likelihood of transmission of zoonotic disease among people, cattle, and other animals grows with the duration of exposure and the variety of mammals present in the carcass (Heever et al. 2021). The vulture numbers began to fall in the early 1990s to 2007s in the Indian subcontinent (Cunningham et al. 2003; Prakash et al. 2003, 2007, 2012). It has been postulated that vulture population declines may result in an increase in the facultative scavenger community and ecological cascades due to increased predation, competitiveness, and incursion (Buechley & Şekercioğlu 2016). It has been studied that replacing the natural process of carcass removal (usually performed by vultures) may increase greenhouse gas emissions, resulting in additional environmental and economic costs (Morales-Reyes et al. 2015).

In India, the fall of Gyps vultures, especially the White-rumped Vulture, Long-billed Vulture, and Slender-billed Vulture (Oaks et al. 2004), along with other vultures including the Egyptian Vulture and the Red-headed Vulture (Shultz et al. 2004; Cuthbert et al. 2006), was linked mostly to the intake of tissue from the remains of cattle that had been given the nonsteroidal anti-inflammatory medication (NSAID) diclofenac (Green et al. 2004, 2007; Oaks et al. 2004; Galligan et al. 2014; Cuthbert et al. 2015). This drug induces visceral gout, renal failure, and mortality in Gyps vultures (Swan et al. 2006). Secondary poisoning also induced high mortalities in them, compounded by vultures' inherently very low reproductive rate (Sarrazin et al. 1994).

The drop in population was observed by comparing results from road transect surveys of raptors in northern and central India in 1991–93 and 2000 (Prakash et al. 2003). Results indicated yearly drop rates of 33% for White-rumped Vultures and 27% for Long-billed Vultures (Green et al. 2004). Repeat surveys in 2000, 2003, and 2007 indicated that the decrease persisted, at unusual rates of 44% and 16% for White-rumped and Long-billed Vultures, respectively (Green et al. 2004). The estimated population drop for 1992–2007 was 96.8% for Long-billed Vultures and 99.9% for White-rumped Vultures (Prakash et al. 2007). It was also seen that there was a 35% decrease in the Egyptian Vulture population every year from 1999 and a 41% decrease concerning Red-headed Vultures, but there was no direct evidence linking this decline to diclofenac poisoning, but their range and rate of decline were similar to the Gyps species (Cuthbert et al. 2006). While in the Moyar valley there were abundant cattle species, the major diet of vultures was wild animal carcasses (90%) rather than cattle carcasses (Ramakrishnan et al. 2010, 2018); thus, they persist in the Nilgiri Biosphere.

While in southern India, efforts were made by Manigandan (2023) to assess the accuracy of vulture population estimation using three different methods: road transect surveys, counts from nesting sites, and camera trap carcass monitoring. The study identified fluctuations in the population of *Gyps bengalensis* during road transect surveys. Nest surveys revealed the existence of tree-nesting colonies of *G. bengalensis* and rock-cliff-nesting colonies of *Gyps indicus*. The estimated population range of *G. bengalensis* in these nesting colonies varied from

49 to 104 individuals, with maximum flock sizes observed ranging from 47 to 82 birds. While the population of *Gyps indicus* in the three breeding colonies remained relatively stable. For the account of the local migratory species, *S. calvus* was largely detected during road transect surveys, and *N. percnopterus* was mostly reported during carcass attendance counts.

The need to conserve the vulture population was taken up government and many research groups worldwide, including India. The conservation action plan was conceived to avert the extinction of the three endemic Gyps species, beginning with the removal (through effective prohibition) of the veterinary diclofenac, the finding of safe alternatives, and the initiation of an ex-situ breeding program for an ecological reintroduction (Bowden 2018). Following this, the Government of India prioritised an action plan for Vulture Conservation considering these major objectives: (1) removing diclofenac, the primary cause of vulture mortality; (2) preventing the transfer of diclofenac in its human form to the veterinary industry; (3) monitoring vulture conservation and recovery; (4) establishing and expanding a breeding and rehabilitation facility for vultures; (5) limiting additional mortality; (6) creating awareness among users of the veterinary diclofenac; and (7) monitoring the action plan's execution (MoEFCC 2020). These priority measures were achievable with agencies like the Drug Controller General of India (DCGI), which further banned the veterinary use of diclofenac in 2006, and later, with technical evidence from the agencies in 2015, the vial size for humans was also reduced to prevent misuse of the drugs. Further, with recommendations from the Drugs Technical Advisory Board, the Government of India legally banned two additional veterinary drugs, Ketoprofen and Aceclofenac, as well as their formulations for both human and animal use, as these drugs have also been identified as highly toxic to vultures (Government of India No. S.O. 3448(E) dt. 31-07-2023). The Central Zoo Authority of India, with support from the Bombay Natural History Society (BNHS), contributed to the monitoring, conservation breeding, and population estimation of vultures in India. They established eight breeding centres to breed three Gyps species. These breeding centres now house 731 vultures, of which 363 are White-rumped Vultures, 262 are Indian Vultures, and 106 are Slender-billed Vultures (MoEFCC 2020).

Further, the Indian Veterinary Research Institute (IVRI) in Lucknow, BNHS, and The Royal Society for the Protection of Birds (RSPB), suggested the use of meloxicam, which proved to have no ill effects on the vulture species (MoEFCC 2020). Although there was evidence of ongoing poisoning (Cuthbert et al. 2015), later surveys indicated that the decrease in population was halted and populations are showing the first signs of recovery due to the implementation of various measures (Chaudhary et al. 2012; Prakash et al. 2012).

The remnant wild populations that are not exposed to diclofenac poisoning play an important role in population recovery (Majgaonkar 2018). Aiding to this, the creation of Vulture Safe Zones (VSZ) for the Gyps vulture species has aided in its recovery, and its additional plan to create VSZ in nine different states, including Madhya Pradesh, Uttar Pradesh, Assam, Jharkhand, Gujarat, West Bengal, Haryana, Tamil Nadu, and Kerala, would further aid in the long-term survival of these species in India (MoEFCC 2020).

In southern India, the population assessment, breeding, and nesting of vultures are from Moyar Valley of Nilgiri Biosphere Reserve in Tamil Nadu (Davidar & Davidar 2002; Ramakrishnan et al. 2010, 2012, 2014, 2018; Samson et al. 2015, 2016b, 2016c; Venkitachalam & Senthilnathan 2015, 2016; Chandrasekaran 2018) apart from few sight records (Gajamohanraj 2020; Kumaraguru 2021). The population assessment and nest count were done for Wayanad Wildlife Sanctuary in Kerala (Shashikumar 2001; Sashikumar & Vishnudas 2018) and distribution pattern and population status for a large part of Andhra Pradesh (Umapathy et al. 2009; Manchiryala & Hussain 2018). However, the documentation in Karnataka is highly limited to sight records and reports of breeding locations. Although these southern states harbor small populations of vultures, it is crucial to comprehensively assess changes in their population status over time. This includes identifying potential gaps such as population status, breeding sites, foraging grounds and conservation issues. To achieve this goal, we reviewed all possible literature on vultures and here provided a comprehensive understanding of vultures to date for the state of Karnataka.

MATERIALS AND METHODS

Study Area

Karnataka is geographically located on a tableland where the Western and Eastern Ghat ranges meet to form the Nilgiri hill complex. The state of Karnataka is broadly bounded by latitudes of 11.516^{0}N & 18.750^{0}N and longitudes of 74.200^{0}E & 78.683^{0}E. The geography of Karnataka includes high mountains, plateaus, remnant hills, and coastal plains. To the west, east, and south, the state is bounded by mountain ranges. The northern region is mostly plateau with elevation ranging 600–900 m. The elevation highly varies up to 2,000 m with many peaks in the Western and Eastern Ghats.

Data Collection and Compilation

To search relevant literature, we used the keywords vulture, Karnataka, district names of Karnataka, and each vulture name while looking for literature on the Egyptian Vulture *Neophoran percnopterus ginginianus*, we used the search keywords 'Egyptian Vulture,' *'Neophoran percnopterus ginginianus*,' Vulture, and Ranahaddu (Kannada word for the same), as well as Karnataka in Google scholar (https://scholar.google.com), and National Ornithological Database (https://www.sacon.in/nod/). We collected eBird data for each species and their location. We examined annotated databases, such as newsletters, magazine articles, and grey literature, all in conjunction with a snowball sampling method that covered all literature that discussed vultures.

The extracted data were categorised into 1) sight records and checklist records, 2) diversity and distribution studies, 3) ecological studies, 4) behavioural observation/record, and 5) conservation action or awareness. We recorded the 'Year of Publication and Study Period'. The ecological components were initially investigated by gathering information on the general emphasis of the study, the number of species (checklists recorded individually), the study region or location, and the geographical scope, i.e., whether the study was limited to one state or encompassed many states/districts, forest status, and habitat type.

Analysis

We compiled a checklist of species found in the state of Karnataka based on all possible literature, and eBird data from 1970 to December 2022 (Supplementary Table S1). The eBird is often opportunistic, thus, we carefully considered the data and used considering its limitations. We provided the conservation status as in the IUCN Red List and Indian Wild Life (Protection) Act, 1972 for each species. Using the location of each detection, we depicted the spatiotemporal distribution pattern for all the species. We summarised the details available on breeding locations of the species and conservation initiatives taken up and their outcomes in the state.

RESULTS

A total of seven species of vultures have been recorded from Karnataka, including Egyptian Vulture, Indian Vulture or Long-billed Vulture, White-rumped Vulture, Red-headed Vulture, Cinereous Vulture, Griffon Vulture, and Himalayan Griffon Vulture. Among them, the last three species are vagrant and occasionally recorded. The conservation status of all seven species in the Indian Wildlife (Protection) Act is 'Schedule-I' (Table 1).

Species account in Karnataka

Egyptian Vulture (Image 1): The vulture used to be seen on the plains of Manjrabad in Sakaleshpur (Taylor 1887), and also eastern plains of Kanara region, nevertheless birds were sighted at the edges of the forests and coasts of Honnavara and Kumta (Davidson 1898). During the birding visit to Mysore province in 1939-40, Ali & Whistler, (1943) reported that the bird is resident of the deciduous biotope, and intermediate zones close to human inhabits, the bird is common in coffee estates of the Biligiriranganatha Hills, Bandipur Tiger Reserve, Satanur, Mysore, Chitradurga, Bangalore, Doddaballapur, and Kolar gold fields. Two birds, one in Breeding plumage and another juvenile were sighted on the outskirts of Mysore, and later three individuals were recorded from the same location in 2000–01 (Pittie 2000a, 2001a). Though exploited by urbanization, the foothills of Chamundi Hills in Mysore city serve as roosting sites for the Egyptian vultures. The city dump yard in the foothills serves as a feeding area for these vultures. These dump yards also had cattle carcasses thrown in, and the vulture was seen feeding on them in 2012 (Samson et al. 2014). The scavenger was seen in Kodagu in mid-2000 (Pittie 2000a), four vultures were spotted in 2013 on the outskirts of Bellary and the adjoining Raichur districts (Martin 2013). Around 123 vultures including 79 adults, 22 sub-adults, and 22 juveniles were reported from in and around Ramadevarabetta of Ramanagara during the survey in December 2013 and April 2014 and reported that

Table 1. The status of vultures (Accipitriformes: Accipitridae) that are recorded from Karnataka in the IUCN Red List, all the listed species occur in Schedule I of the Indian Wildlife Protection Act.

Common name	Scientific name	IUCN status
Egyptian Vulture	*Neophron percnopterus*	Endangered
White-rumped Vulture	*Gyps bengalensis*	Critically Endangered
Indian Vulture	*Gyps indicus*	Critically Endangered
Himalayan Griffon Vulture	*Gyps himalayensis*	Near Threatened
Griffon Vulture	*Gyps fulvus*	Least Concern
Cinereous Vulture	*Aegypius monachus*	Near Threatened
Red-headed Vulture	*Sarcogyps calvus*	Critically Endangered

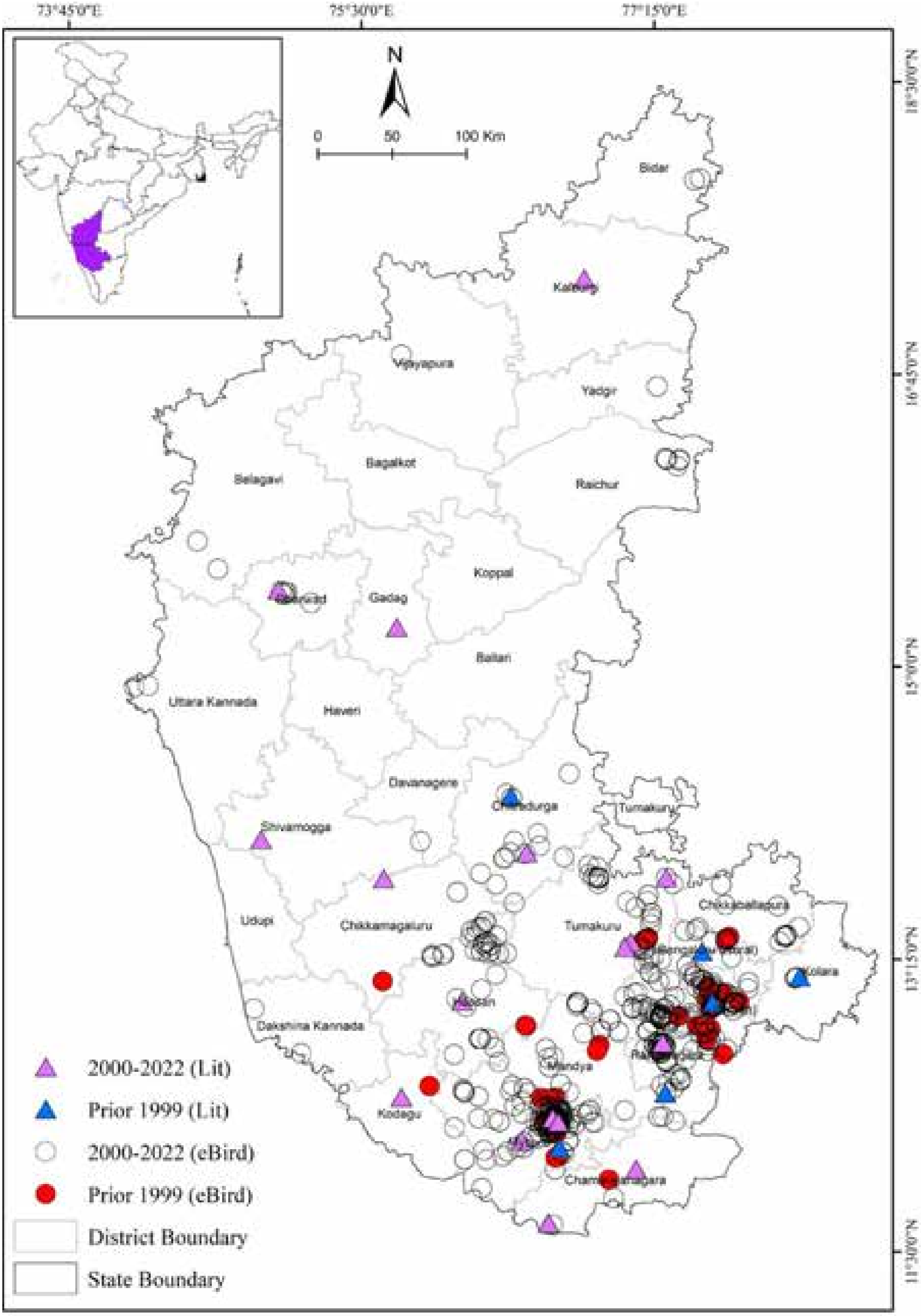

Figure 1. Sight record of Egyptian Vultures in Karnataka from 1838 to 2022.

they were dependent on silk processing sites and a dump yard of slaughterhouse waste (Samson & Ramakrishnan 2016a). Few individuals were sighted from 2003 to 2016 in the Mangala and Melukamanahalli area of Bandipur (Rajkumar 2018). Although the eBird data added more locations in the last two decades, more recordings were from southern districts, i.e., Mysuru, Mandya, Ramanagara, Bengaluru, Kolar, and Chitradurga, nevertheless, occasional sightings were recorded from the rest of the state (Figure 1).

White-rumped Vulture (Image 2): The initial record of the species was in the late 18th Century, e.g., Manjrabad fort area in Sakaleshpur (Taylor 1887) and several birds and their nests from the forests of Kanara (Davidson 1898). Later in the first half of the 19th Century, the species was recorded from many locations in the state, e.g., frequent sightings from Londa of Belagavi in 1938 (Koelz 1942), a good number of birds and nesting in moist forests of Shettihalli in 1939–40 and the evergreen forest of the Gersoppa falls (Ali & Whistler 1943). More records of the sighting were from the second half of the 19th century e.g., sighted frequently in Chikkamagaluru town in the 1990s (Chakravarthy & Tejasvi 1992), a mixed flock of 300 vultures were observed on a carcass in Bangalore between 1984 and 1988 (Satheesan 1990). The sightings in the last two decades (2000 - 2022) include six birds in the IISC campus in Bangalore in 2001 (Pittie 2001b), and two birds in September 2000 at Naryanadurga hills of Melkote WS (Thejaswi 2003), frequent sightings from Nagarahole, e.g., 30–40 birds and later few were recorded with other vultures on elephant carcass during January 2000 (Pittie 2000b; Sarath 2000), 90 birds on a deer carcass in June 2005 (Ramesh 2005), three birds with other vultures in January 2014 (Robson 2014), and Bandipur, e.g., frequently sighted from Byladkuppe cliffs, Rampura and Banur, and also reported them to nest and reproduce in the park (Rajkumar 2018), and Ankola and Karwar, e.g., 12 birds at Hattikeri Timber Depot in 2007 (Praveen 2007). Anoop et al. (2020) reported that these vultures occupy and nest on trees with good girth, especially on Arjuna trees in the riparian habitat, and predicted suitable habitat for the reintroduction in several protected areas of southern Western Ghats. The eBird data also indicate occasional sightings from the entire state but most of the sightings are confined to a few southern districts, especially to the forests of Bandipur and Nagarahole (Figure 2).

Indian Vulture (Image 3): Inhabitant of open areas and forested landscapes. The bird has been recorded from different parts of Karnataka, i.e., Kanara, Londa, and Tumkur (BirdLife International 2001), In December 1935, a few birds were seen nesting on cliffs opposite Jog Falls (Abdulali 1936; Ali & Whistler 1943). In January 2000, 40–50 birds were feeding on the carcass of an elephant along with other vultures in Nagarahole (Sarath 2000; BirdLife International 2001). In January 2013, 16 vultures were recorded on the outskirts of Bellary (Martin 2013). Three nests with chicks and successful nestlings growing to adulthood were reported in 2006 from rocky edges of Ramadevarabetta of Ramanagara hills (Subramanya & Naveen 2006). However, only seven birds and two nesting were recorded in 2015–16, and one nest in 2016–17 but no chicks were observed from the same hills (Ashok 2018). In Bandipur, breeding was recorded from Moolehole in Rampura along with white-backed vultures in 1996 (Rajkumar 2018), and the continued monitoring of these nests reported breeding in 2002–03 and 2008–11 in Moolehole and Banur in the Gundre range (Rajkumar 2018). Prior to 1999, the species was infrequent throughout the southern part of the state. The sight record of the bird in the eBird shows that most of the sightings are reported from southern Karnataka except few sightings in the rest of the state, of them, most of the sightings are from Ramadevarabetta Vulture Sanctuary, Bandipur, and Nagarahole (Figure 3).

Himalayan Griffon Vulture (Image 4): The bird is spread over the Himalayan landscape and is an infrequent visitor to South India. Two individual birds were seen simultaneously in the Ramanagara Vulture Sanctuary and the Hesaraghatta Grasslands in February 2013 (Praveen et al. 2014). A juvenile was sighted in the Halga-Ulga region of Uttara Kannada District in January 2016 (Surve 2016) (Figure 4).

Cinereous Vulture (Image 5): The Cinereous vulture usually winters in North India and is a rare visitor to Peninsular India (Ali & Ripley 1987). The bird was sighted for the first time at Harangi Dam in Kushalnagara in December 1998 (Subramanya 2001), on the bank of Lakshman Thirta River in Krishnaraja Sagar Reservoir near Mysore in January 2002 (Shivanand 2004), and sighted between December 2016 and January 2017 at Kabini backwaters of the Nagarahole while feeding along with Long-billed Vultures and Red-headed vultures (Samson et al. 2019) (Figure 4).

Red-headed Vulture (Image 6): Except for a few sight records of the species, no other information is available on the species from the state. In the late 18th Century, three vultures were seen feeding on a donkey carcass and later one specimen was collected in and around Manzrabad fort in Sakaleshpur (Taylor 1887). The bird was speculated to be a resident of the Kanara region as it was sighted occasionally in all seasons and parts of

Image 1.Egyptian Vulture

Image 2. White-rumped Vulture

Image 3. Indian Vulture

Image 4. Himalayan Griffon Vulture

Image 5. Cinereous Vulture

Image 6. Red-headed Vulture.

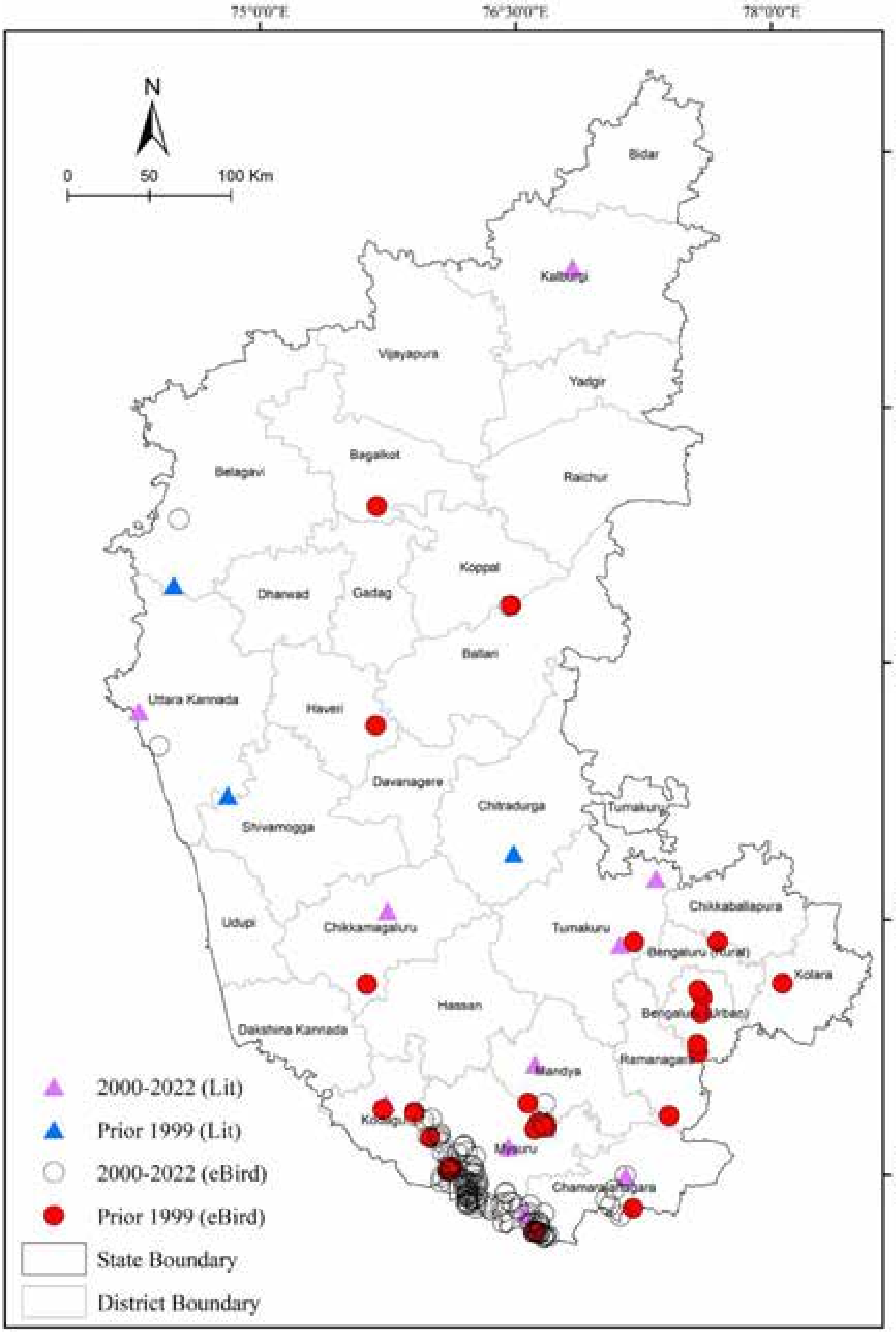

Figure 2. Sight record of White-rumped Vultures in Karnataka from 1838 to 2022.

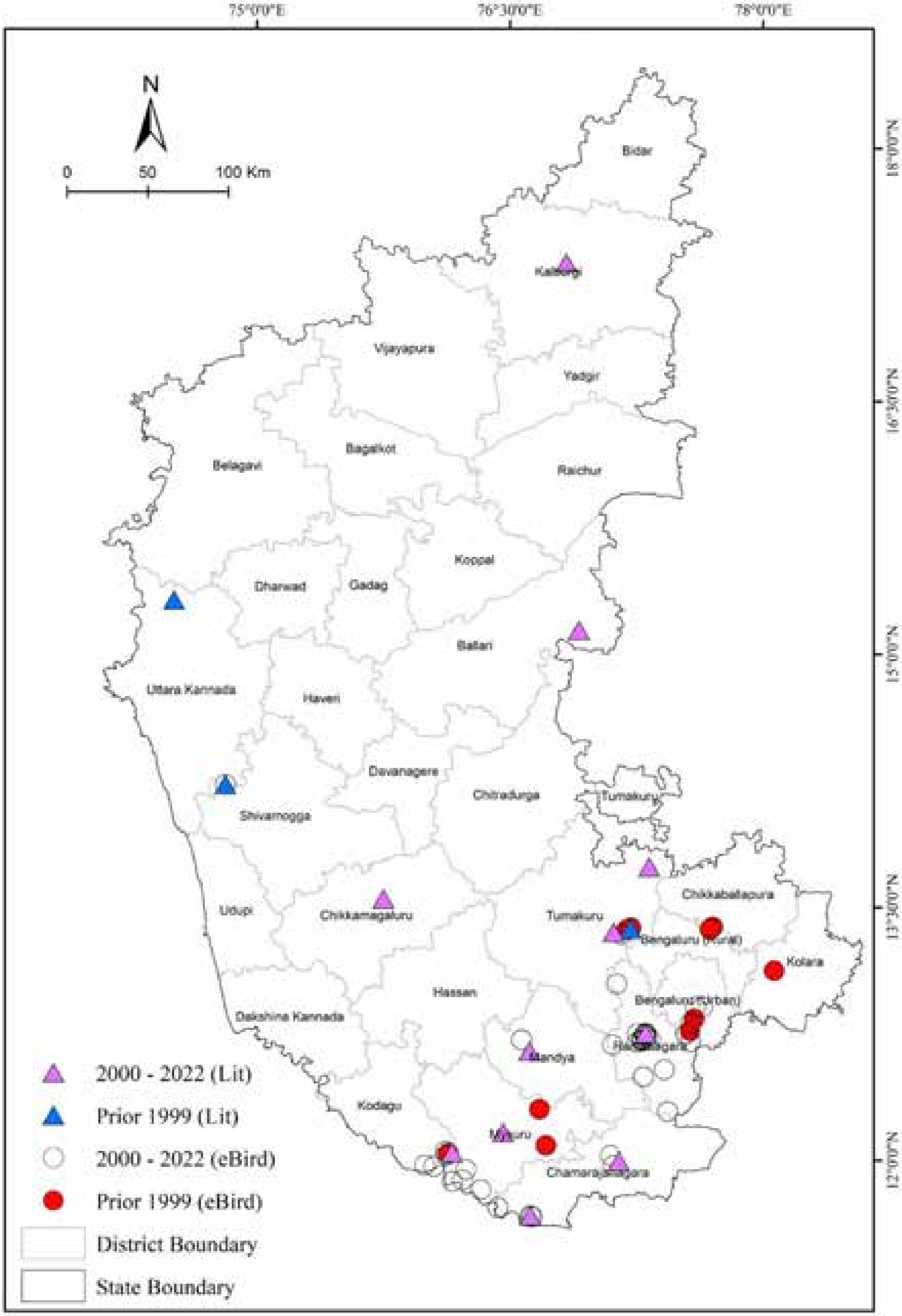

Figure 3. Sight record of Indian Vultures in Karnataka from 1838 to 2022.

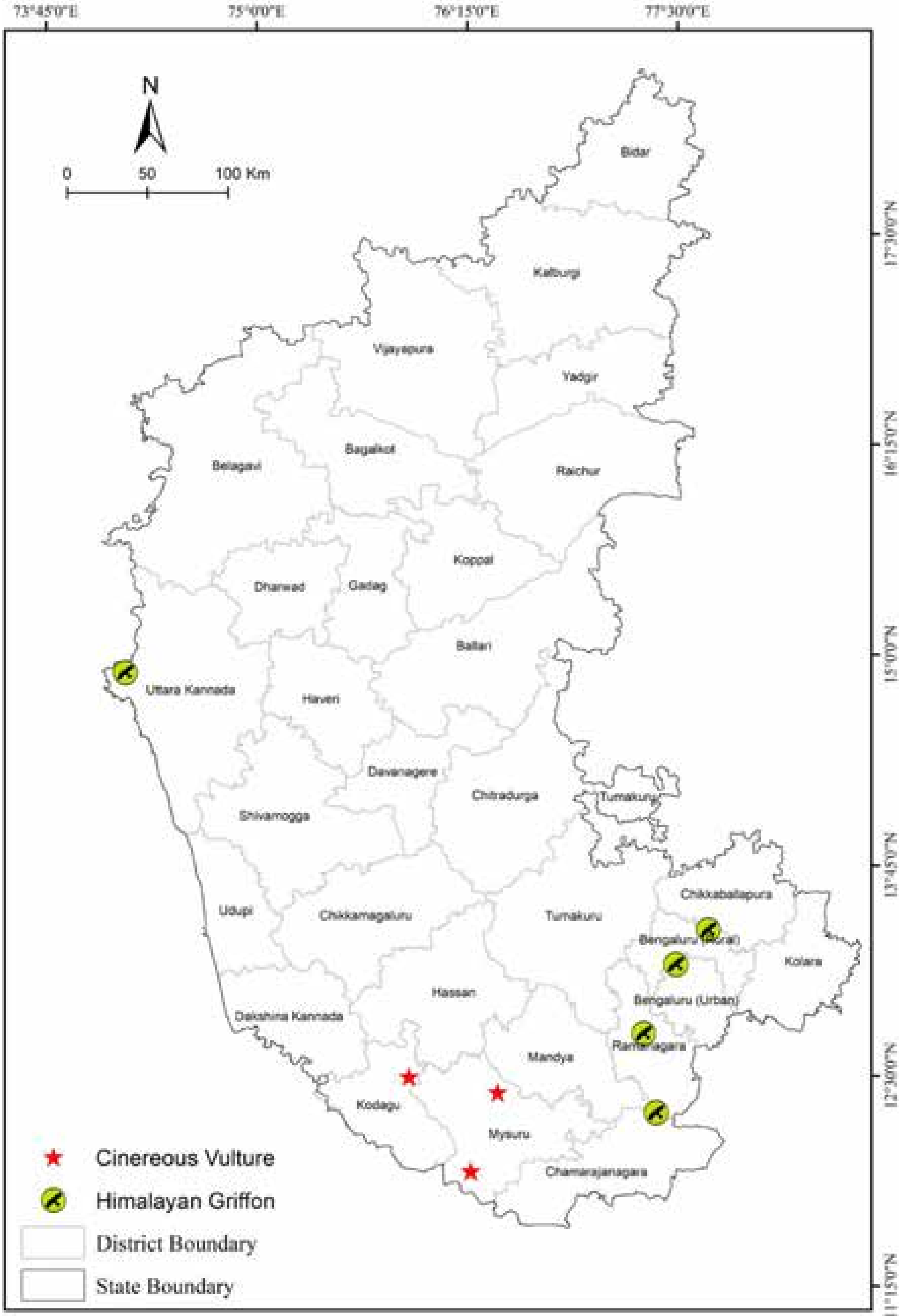

Figure 4. Sight record of Himalayan Griffon and Cinerous Vulture in Karnataka from 1838 to 2022.

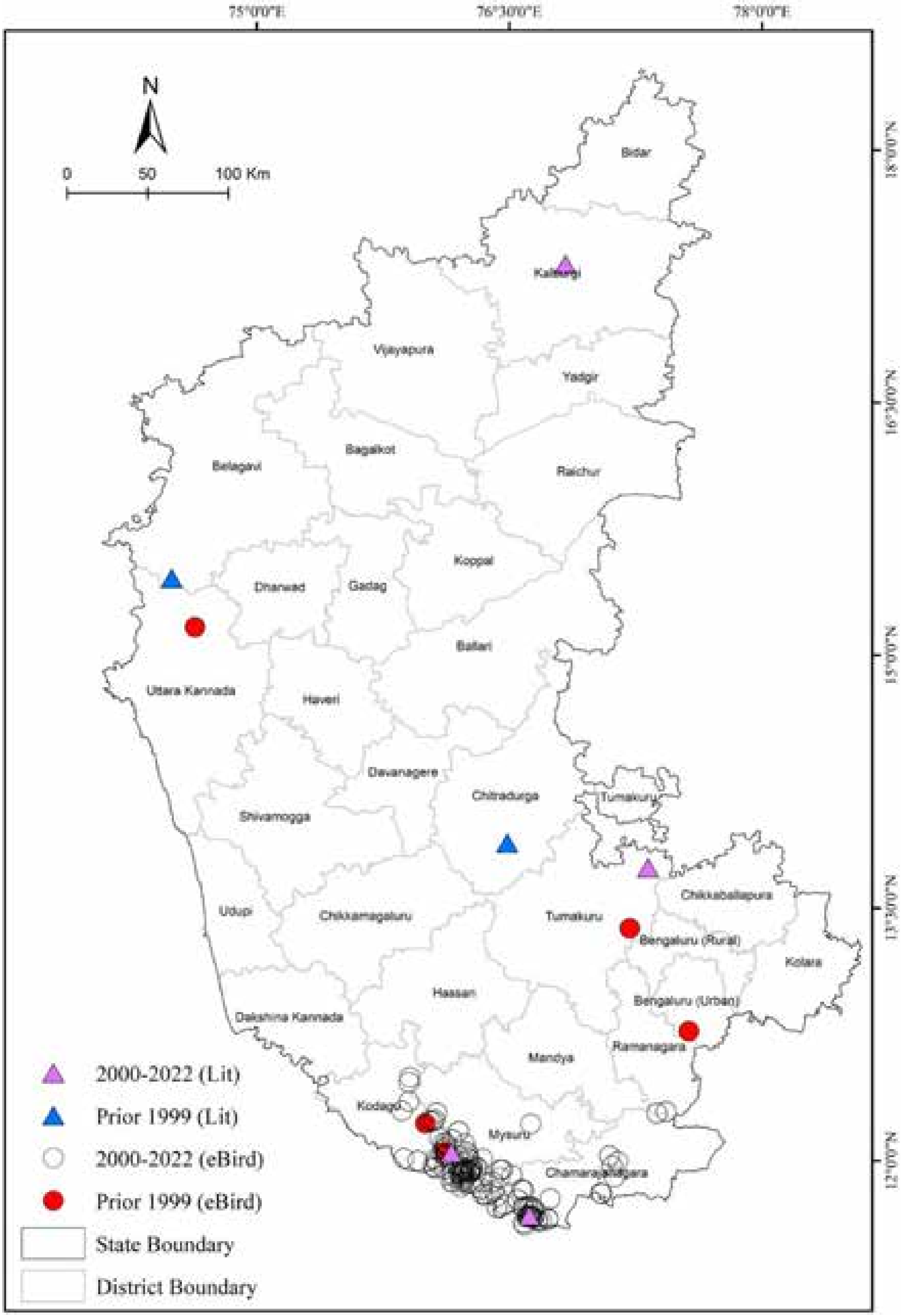

Figure 5. Sight record of Red-headed Vultures in Karnataka from 1838 to 2022.

the region (Davidson 1898). Single birds were occasionally seen in Bandipur and Maarikanive during 1939–40 (Ali & Whistler 1943). Intermittent sighting of the vulture was reported from Nagarahole, e.g., 8–10 vultures were observed feeding on elephant carcasses in January 2000 (Sarath 2000), two vultures were sighted later in 2000 (Pittie 2000b), one vulture was seen feeding on deer carcasses in January 2005 (Ramesh 2005) and two vultures in late January 2014 (Robson 2014). Rajkumar (2018) reported that the bird is a resident, usually single or two individuals are sighted frequently in Bandipur, but the population status is not available for the park. The eBird data also shows except for one or two recordings from northern and south-eastern Karnataka, many of the sightings are confined to forested areas of Kodagu, Mysuru, and Chamarajanagar, especially at Bandipur and Nagarahole (Figure 5).

Griffon Vulture (Image 7): Occasional reports of the species are recorded from the state, e.g., one bird was collected from a flock of 50 in 1938 from Jagalbet, Uttara Kannada District (Koelz 1942), and several pairs were sighted on ledges of rocky patches near the Gersoppa falls during 1939–40 (Ali & Whistler 1943b), and an individual was sighted with a mixed flock of vultures in Nagarahole in 2000 (Pittie 2000b).

Image 7. Griffon Vulture

Sight records of different vulture species in protected areas and non-protected areas

From 1838 to December 2022, among all the seven species of vultures, the sighting record of the Egyptian vulture (n = 1802) was more than all other species (White-rumped Vulture: 522; Red-headed Vulture: 521; Indian Vulture: 465; Himalayan Griffon: 5; and Cinereous Vulture: 3). Of them, more than 80% of the sight records of Red-headed Vulture, White-rumped Vulture, and Indian Vulture were from protected areas, while only 14% of sight records of the Egyptian Vulture was from protected areas (Figure 6).

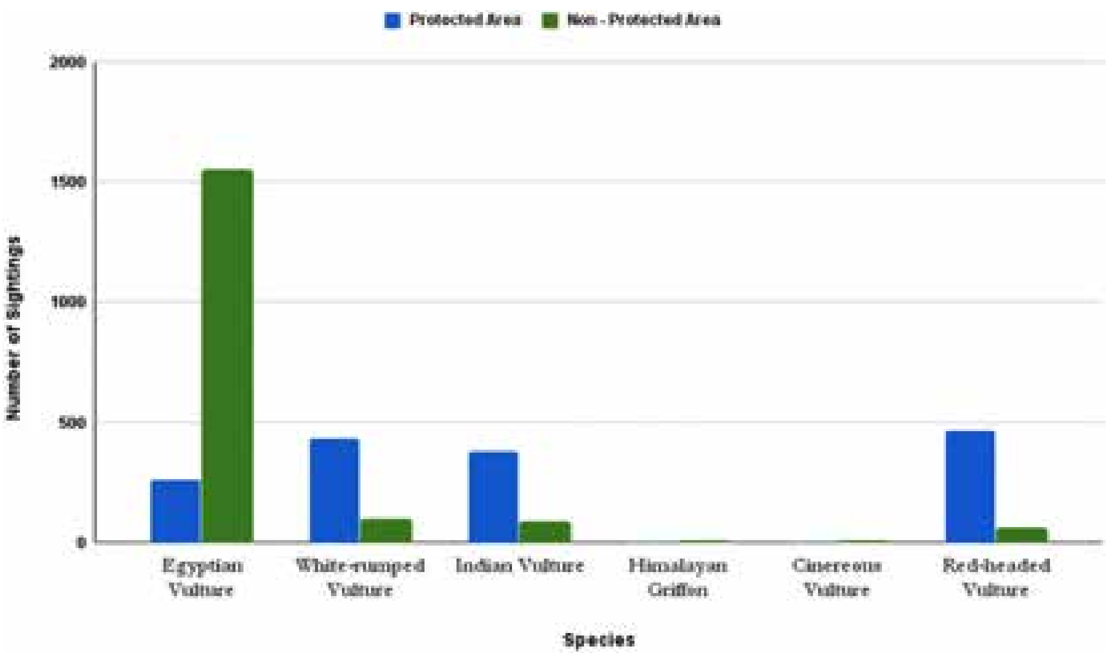

Figure 6. Sight records of different vulture species in protected areas and non-protected areas from 1838 to 2022.

Record of nest sites

Although nests of Egyptian Vultures, Indian Vulture, Red-headed Vulture, and White-rumped Vultures were recorded over a period of one century in different parts of the state, most of the recordings are largely from Ramanagara, Bandipur, and a few other locations in southern Karnataka (Supplementary Table S2). But in the last decade, the recordings of nest sites are only from Ramanagara, Bandipur, and their surroundings.

Conservation Initiatives

Considering the constant sightings and breeding records from Ramanagara Hills, Forest Department, Karnataka, declared this region for the conservation of vultures in January 2012 as 'Ramadevarabetta Vulture Sanctuary' (Government of Karnataka No. F.E.E.234.S.W.L. 2009, dated 31 January 2012).

DISCUSSION

In Karnataka, seven vulture species are recorded, with the Cinereous Vulture and Himalayan Griffon Vulture being occasional visitors, as documented by Praveen et al. (2014) and Samson et al. (2019), while the Egyptian Vulture, White-rumped Vulture, Indian Vulture, and Red-headed Vulture are permanent residents. This distribution pattern extends to the neighboring southern Indian states of Tamil Nadu and Kerala, with the additional presence of the Griffon Vulture as an infrequent visitor, as reported by Gajamohanraj (2020), Kumaraguru et al. (2021), and Roshnath & Sashikumar (2021). Most vulture sightings are concentrated in southern Karnataka, with sporadic observations in the central and northern regions. Notably, the Egyptian Vulture is the most prevalent species in the state, primarily outside of protected areas, while the White-rumped Vulture and Red-headed Vulture, previously sighted across various regions, have been mainly documented in Bandipur and Nagarahole over the past two decades. Similarly, the Indian Vulture is known to inhabit Bandipur, Nagarahole, and the Ramadevarabetta Vulture Sanctuary.

Before 2000, vulture sightings in Karnataka were scarce, likely due to a lack of birdwatchers and awareness. However, since 2000, platforms like eBird and iNaturalist have facilitated increased birdwatching and record-keeping, resulting in a higher number of bird sightings, including vultures. Nevertheless, this data hasn't yet covered every corner of the state or the country, which is essential for a comprehensive understanding of vulture occurrence, spatial distribution, and sighting frequency. Despite these limitations, the findings have been carefully considered (Supplementary Figure S1).

The occasional vagrant sightings of Griffon vultures have raised concerns in Karnataka. Historical sightings reported by Ali & Whistler (1943) were later retracted due to misidentification, as was the case with Ali & Abdulali (1945) and their opinions on specimens collected from Koelz (1942) and the sighting of 50 vultures. Furthermore, the specimen collected by Koelz (1942) could not be located, leading to its omission from Rasmussen & Anderton's (2012) 'Ripley Guide to Birds of South Asia.' Gajamohanraj (2020) recommended removing this species from the checklist of Birds of Karnataka as per Praveen et al. (2016). While this species is also recorded in the Moyar Gorge of Mudumalai Tiger Reserve in Tamil Nadu, adjoining Karnataka (Gajamohanraj 2020), the bird's presence or visits in the state cannot be disregarded. Some evidence suggests long-distance vagrancy, with Himalayan Griffon vultures being sighted in southern India (Kumaraguru et al. 2021; Praveen et al. 2014; Surve 2010), possibly indicating a decline in their regular Himalayan breeding range's food supply coupled with the inexperience of immature birds in foraging and navigation (Ding Li & Kasornkorkbua 2008). Recently, a suspected case of electrocution of a Himalayan Griffon Vulture was documented in the nearby Mudumalai Tiger Reserve (Manigandan et al. 2021).

In recent times, India has seen a decrease in the rate of vulture population decline (Prakash et al. 2019), with some regions showing a slow recovery, such as a 12% increase in vulture population in Madhya Pradesh (Jha 2017). Prakash et al. (2019) reported significantly lower densities of the Indian vulture and White-backed vulture in southern India compared to the north. Unfortunately, the review highlights the absence of a comprehensive scientific population assessment in Karnataka, with available data stemming from sporadic records, eBird entries from the last two decades, and opportunistic sightings, except for one population monitored in Ramanagara by Ashok (2018). Given the significant population of Indian vultures in Ramanagara, the rocky outcrops in this region were declared the "Ramadevarabetta Vulture Sanctuary." However, the decrease in vulture numbers and breeding failures pose significant concerns, as the primary Indian vulture population in the state is centred around these hills.

White-backed vultures and Red-headed vultures, although occasionally sighted in various parts of the state, are now primarily concentrated in Bandipur, Nagarahole, and their surroundings, likely due to the availability of uncontaminated carcasses in these areas (Prakash et al. 2012; Galligan et al. 2014). Conversely, the Egyptian vulture is predominantly found outside protected areas and is recorded over a more extensive region in South Karnataka. In South India, their abundance seems better in Karnataka than in Tamil Nadu (Byju & Raveendran 2022) and Kerala (Sashikumar & Vishnudas 2018). However, the population trend of this species in South India, including Karnataka, remains unclear. Although recent records of nest sites for Egyptian Vultures are lacking, sightings of juveniles in various locations suggest that they are breeding in nearby areas.

White-rumped vultures (Gadhvi & Dodia 2006; Thakur & Narang 2012; Khan 2013; Ramakrishnan et al. 2014; Majgaonkar et al. 2018) and Red-headed vultures (Chhangani 2007; Dhakal et al. 2014) typically construct their nests on tall trees. Several nest sites for White-rumped Vultures have been identified in Bandipur, Nagarahole, and adjacent areas in Tamil Nadu and Kerala. For instance, approximately 68 nests were documented in the riparian habitat of the Nilgiri North Forest Division (Ramakrishnan et al. 2014). Later, 36 pairs of an active nesting population were observed in the same area and the adjoining Mudumalai Tiger Reserve (Venkitachalam & Senthilnathan, 2016). Furthermore, a population range of 49 to 104 individuals was recorded in nesting colonies across the Mudumalai Tiger Reserve (Manigandan et al. 2023). Additionally, 12 nests were recorded in the Wayanad Wildlife Sanctuary in Kerala (Sashikumar & Vishnudas 2014). In recent years, a single nest of the Red-headed vulture has been identified in Bandipur.

Indian Vultures in Karnataka are known to nest on rocky cliffs, particularly in Ramanagara. However, previous studies also indicated that they occasionally build their nests on trees, for example, in Moyar Gorge in Tamil Nadu and various locations in Andhra Pradesh. This adaptability is likely driven by the availability of a good food resource (Prakash et al. 2012). In Mudumalai Tiger Reserve, three Indian vulture breeding colonies—Ebbanad, Nilgiri Eastern Slopes, and Kallampalayam—recorded 92 (2020–21), 142 (2019–2020), and 144 (2019–2020) vultures, respectively, with remarkable population stability over the three years (Manigandan et al. 2023).

The review underscores the ongoing vulture population decline in Karnataka, emphasising the necessity for systematic population assessment and monitoring in the state. Identifying vulture nest sites and monitoring their breeding success are crucial steps for effective management interventions, particularly given the major surviving vulture populations around Bandipur, Nagarahole Tiger Reserves, and Ramadevarabetta Vulture Sanctuary. Ensuring the availability of uncontaminated food resources in their habitat is essential to guarantee their survival.

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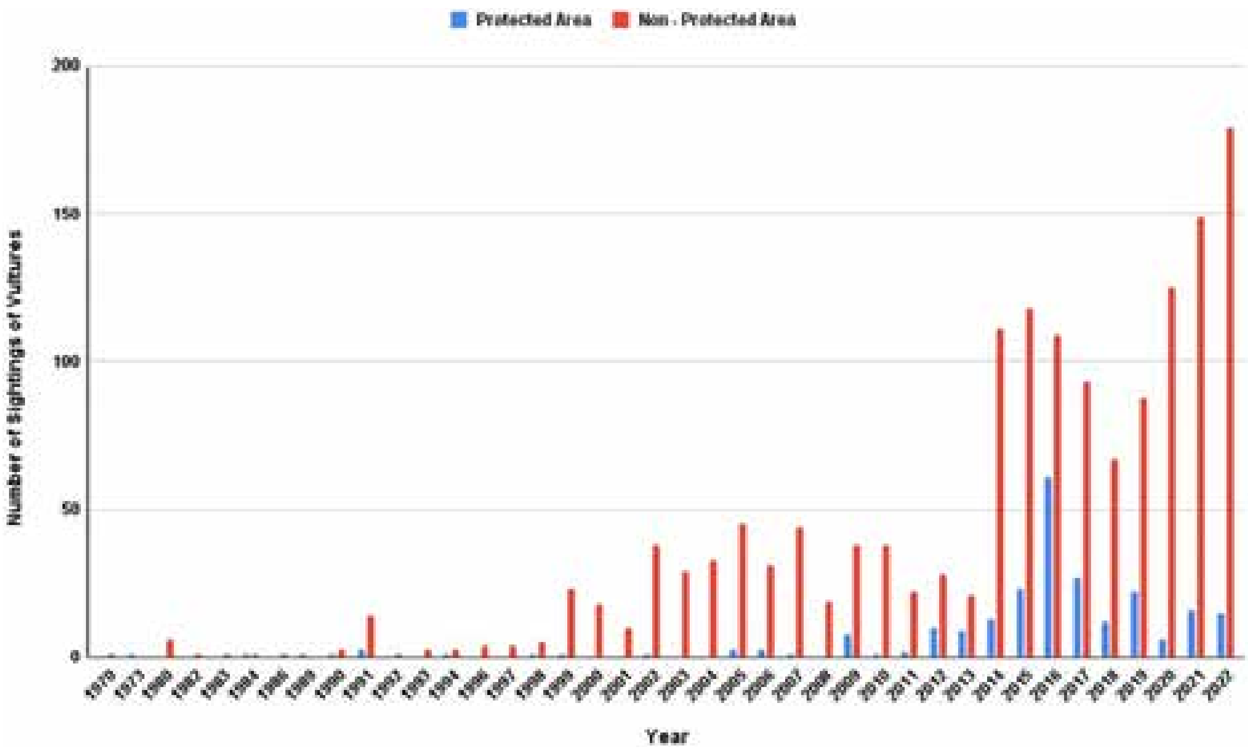

Supplementary Figure S1. Sight record of vultures as per eBird records in different years from 1970 to 2022.

Supplementary Table S1. Published literature and Ebird Data from 1838 to 2022.
The supplementary table has been deposited in the repository:
<https://data.mendeley.com/datasets/n3ytyc6rdx/1/files/868459fa-0112-43f7-b0fd-7c1fa49b94d3>

Supplementary Table S2. The nesting location of all vulture species in Karnataka recorded in the literature.
The supplementary table has been deposited in the repository:
<https://data.mendeley.com/datasets/n3ytyc6rdx/1/files/78f67410-004b-43d0-ba46-9d70b7574162>

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ARTICLE

Spatial, temporal and trophic resource partitioning among the four egret species (Aves: Pelecaniformes: Ardeidae) in a tropical wetland ecosystem, India

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Abstract: The diversity of micro-habitats in tropical wetlands allows the coexistence of several species. These sympatric species interact with each other, either directly or indirectly, to optimally use the available resources. They achieve this through niche separation or minimal overlap to avoid competition. India's wetland ecosystems are home to various sympatric species, such as the Great Egret *Ardea alba* (GE), Median Egret *Ardea intermedia* (IE), Little Egret *Egretta garzetta* (LE) and Cattle Egret *Bubulcus ibis* (CE). These egret species are closely related, and as a result, have similar niche requirements, which could lead to high intra-specific competition. However, there have been few studies on how these species utilize resources. This study aims to understand the possible mechanisms that enable the coexistence of these species in a tropical wetland. We have examined habitat characteristics, feeding behaviour, timings of seasonal and daily activities, and spacing patterns to evaluate possible models of species coexistence. We discovered that these four sympatric egret species have differences in microhabitat selection, activity patterns, both daily and seasonally, and feeding preferences. The study further indicates that there is a relationship between the niche dimensions, but it is only partially dependent on each other.

Keywords: Co-existence of sympatric species, competition, interspecific interaction, niche separation.

ان آبی علاقوں میں جو کرہ ارض کی استوانی زمین پر پائے جاتے ہیں، باریک فرق والی رہائش گاہوں کا تنوع متعدد انواع کے بقائے باہمی کی اجازت دیتا ہے- یہ انواع ایک دوسرے سے دیرینہ تعلق رکھتے ہیں اور دستیاب وسائل کو بہترین طریقے سے استعمال کرنے کے لیے براہ راست یا بالواسطہ طور پر ایک دوسرے کے ساتھ تعامل کرتے ہیں- مقابلہ سے بچنے کے لیے وہ طاق علیحدگی یا کم سے کم مخل کے ذریعے اپناتے ہیں- ہندوستان کے دَل دَل، جھیل اور تالاب کے ماحولیاتی نظام مختلف ایسی انواع کی پناہ ہیں، جیسے یہ چار بگلے جن کے نام ہیں عظیم بگلا یا آرڈیا البا (GE)، درمیانہ بگلا یا آرڈیا انٹرمیڈیا (IE)، چھوٹا بگلا یا ایگریٹا گارزیٹا (LE)اور مویشی بگلا یا بوبلکس اِبیس (CE)- ان چاروں بگلوں کی نسلوں کا آپس میں گہرا تعلق ہے، اور اس کے نتیجے میں، اسی طرح کے مخصوص تقاضے ہیں، جو اعلیٰ درجہ کے بین انواع مقابلہ کا باعث بن سکتے ہیں- تاہم، اس مقالہ میں کچھ مطالعات ہوئے ہیں جو ان نسلوں کے وسائل کے استعمال کے اسلوب پر روشنی ڈالتے ہیں- اس مطالعے کا مقصد ان ممکنہ اقدام کو سمجھنا ہے جو آبی زمین میں ان انواع کے بقائے باہمی کے لیے قدرت میں رایج ہیں- اس نظام کا جائزہ لینے کے لیے رہائش کی خصوصیات، خوراک کی روش، موسمی اور روزمرہ کی سرگرمیوں کے اوقات، اور وقفہ کاری کے نمونوں کا مطالعہ کیا گیا ہے- ہم نے دریافت کیا کہ ان چار دیرینہ بگلوں میں باریک سطح پر رہائش کا انتخاب،روزانہ اور موسمی طور پر سرگرمی کے رموز، اور اکل و شرب کی ترجیحات میں باریک فرق ہے- مطالعہ مزید اشارہ کرتا ہے کہ طاق طول و عرض کے درمیان تعلق ہے، لیکن یہ صرف جزوی طور پر ایک دوسرے پر منحصر ہے-

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ALIGARH MUSLIM UNIVERSITY

INTRODUCTION

Tropical wetland ecosystems are important habitats for migratory birds and also support the avian diversity of native species (Junk 2006). The great diversity of micro-habitats allows the coexistence of the species in the wetland (Junk 2006). The species' coexistence is generally perceived as a consequence of the interspecific interactions among the sympatric species (Siepielski 2021). The sympatric species may or may not have direct interaction but the chances of interspecific interactions in terms of competition for resource utilization (in spatial, temporal and trophic dimensions) increase in the case of closely related species (Ye et al. 2021). The Lotka-Volterra approach suggested that the stable coexistence of competitive species is only possible when intraspecific competition is stronger than interspecific competition (MacArthur 1967; Gavina et al. 2018). Further, the behaviour of the species such as pattern of habitat use, daily activity, foraging and interspecific behaviours also govern the social spacing and tolerance, to allow biologically similar sympatric species to coexist (Perri & Randall 1999; Oviedo et al. 2018).

Great Egret *Ardea alba* (GE), Median Egret *Ardea intermedia* (IE), Little Egret *Egretta garzetta* (LE), and Cattle Egret *Bubulcus ibis* (CE) are ubiquitous in the wetland ecosystems across India. As generalist top predators, the egrets exert a top-down influence on the structure of lower trophic levels, altering the abundance and distribution of multiple prey species and, in turn, the effects of their prey on other species (Huang et al. 2015). Studies focusing on their habitat and behaviour ecology are critical in understanding their ecological requirements and their role as top predators in sustaining the richness of life in wetland ecosystems (Jennings 2017).

Despite the separate studies on feeding ecology, habitat selection and seasonal or daily behaviour of the species, a comprehensive understanding of niche partitioning that integrates the temporal, spatial and trophic dimensions of sympatric egret species is still lacking (Ye et al. 2021). Hence, the possible mechanism permitting the coexistence of GE, ME, LE, and CE in a tropical wetland has been studied.

Habitat characteristics, feeding behaviour, timings of seasonal and daily activities and spacing patterns have been examined to evaluate possible models of species coexistence. The research has been carried out to understand the partitioning of niche dimensions based on niche theory and inter-specific effects as the primary mechanism to structure the communities (Hairston et al. 1960; Schoener 1982; Kelt et al. 1985; Bardsley & Beebee 1998; Beckerman 2000). It appears that the four sympatric egret species in the study area are using the resources available to them in the tropical wetland habitat. However, due to variations in their microhabitat selection, daily and seasonal activity patterns, and feeding preferences, it is hypothesized that there exists some form of niche separation over the spatial, temporal and trophic scales amongst them.

MATERIALS AND METHODS

Study Area

Sheikha lake is situated in the Gangetic Plains (Rodgers & Panwar 1988) between 78.204°–78.234° N & 27.870°–27.839° E at about 17 km from Aligarh district (Uttar Pradesh, India) and it is a perennial lake spread over 2.50 km^2 (Image 1). The region experiences extreme temperature conditions with a maximum of 47°C during summers and 0°C during winters. Average annual rainfall ranges from 650–750 mm. The lake is home to a large number of waterfowl both migratory and resident. The site has also been designated as IBA (Important Bird Area) as it provides a good habitat for the birds (Islam & Rahmani 2004).

The Upper Ganga Canal (UGC) divides the area into two blocks i.e. 'A' and 'B'. The main lake is in Block A on the western side of the canal. Block B becomes patchy in the dry season and segregates into several small pools. The permanent waterbody and seasonal expansion of the water lodging in surrounding areas, diverse weather conditions, shelter belt trees and agriculture field around the lake and the canal going through the wetland favour a broad spectrum of living conditions for diverse life forms. The major tree species on the periphery of the lake are *Terminalia arjuna, Syzygium cumini*, *Acacia leucocephala, Acacia nilotica, Holoptelia integrifolia, Ficus religiosa, Dalbergia sissoo, Azadirachta indica* and *Prosopis juliflora* (Saxena 1999). These trees provide good roosting and heronry sites for the egrets.

The lake is surrounded by agricultural fields and livestock grazing is also common in the area. A small amount of fishing, fuel wood, fodder extraction and utilization of the Block B pools for the cultivation of water chestnut *Trapa bispinosa* by the local communities, are a few minor anthropogenic disturbances in the area.

Methods

Data Collection

The study was conducted between August 2000

Image 1. Location map of Sheikha Lake, a tropical perennial wetland in Gangetic Plains.

and March 2004 in Sheikha Lake (Image 1). Field data collection was conducted three days a week in all study years, which amounts to 140 to 160 days. Therefore, in each season namely spring, summer, monsoon and winter, 45 to 50 days were spent in the field studying the egrets. Observation shifts of four hours each for focal animal sampling in the morning, noon and afternoon were done once a week in all seasons.

To cover all possible habitat types used by the egrets, the trails were identified and monitored on a bi-weekly basis. Seasonal data on the population, spatial distribution, activity budgeting and feeding preferences of the four sympatric species of egrets were collected through repeated sampling during the study period. Data on foraging and feeding was recorded during the observations of the egrets. Ocular estimation for prey type identification was done during the feeding attempt, and prey size was estimated using the bill length method following Bayer (1985). Established bill lengths were taken from Grimmett et al. (1998).

Spatial dimension of niche

The population of egrets were estimated using the point count method on the selected trails on a seasonal basis. Each count took place three days a week in all study years. The birds flying overhead were not recorded as per the standard point count method (Bibby et al. 1992). The seven micro-habitats were identified as open water, paddy field, grassland, lake shore, reed bed, canal bank, and ploughed field. The habitat characteristics, disturbance factors, and distance from the closest human habitation were also recorded.

Temporal dimension of niche

Focal animal observations on activity budgets of egrets in non-roosting hours during the off-breeding seasons of the year were taken (Altman 1973). Seven major types of activities such as Preening (PR), Siesta (seizure of all activities during the daytime) (ST), Resting (intermittent rests during foraging) (RS), Foraging (FR), Chasing (CH), Display (DS) and Miscellaneous (The short duration activities such as defecating, scratching the body with feet, tilting the neck and fluttering their wings) (MS) were recorded.

Observations were made in three shifts of four hours a day. The morning shift ranged between 0600 h and 1000 h, the noon shift from 1000 h to 1400 h and the evening shift from 1400 h to 1800 h (Lehner 1979; Yahya 1980; Maheswaran 1998). All observations of activity patterns were recorded at the lake rather than the nest or roosting sites.

Trophic dimension of niche

The foraging behaviour of the egrets was identified as walking slowly, standing, foot stirring, chasing prey, probing & pecking, walking quickly, hopping, and gleaning following Hancock & Kushlan (1984). These occurrences and time allocation for these behaviours were recorded during the species-wise focal animal sampling of general activity budgeting. Following Recher & Recher (1969), Seigfried (1971), Krebs (1974), Willard (1977), Kushlan (1978), Caldwell (1979), Quinney & Smith (1980), Hom (1983), Mock et al. (1987) and Forbes (1989), the prey type and its size was also recorded during the sampling. Each species was given equal observation time in a particular shift to avoid bias. The total observation time devoted to all species was 1622 hours in the entire study period.

Data Analysis

Spatial dimension of niche

The relative abundance of each of the four species of egrets in different habitats was compared using the Student's t-test (independent sample). Chi-square contingency analysis was performed to test the significance of associations between a species of egret and the micro-habitat type and different habitat parameters (Seigel 1956; Fowler & Cohen 1986) using SPSS ver. 7.3 (Norusis 1994). The niche relationships were analysed using the programme NICHE (Krebs 1989). Estimation of the micro-habitat niche breadth for all four species was performed by using the Shannon-Weiner Measure (Colwell & Fuentes 1975; Krebs 1989).

Temporal dimension of niche

The difference in the time allocation for different activities by the sympatric egret species was assessed using the One-way ANOVA with Post hoc Tukey Test following Fowler & Cohen (1986). The seasonal and diurnal variations in the activity patterns of each sympatric egret species were also analysed using One-way ANOVA with Post hoc Tukey Test, in SPSS ver. 7.3 (Norusis 1994).

Trophic dimension of niche

A comparison was made of the frequency with which each species used a foraging behaviour, food item and prey size with χ^2 for 'k' independent samples. Chi-square contingency analysis was performed to test the significance of associations between a species and a behaviour, prey item and prey size following Seigel (1956) and Fowler & Cohen (1986).

Food item and prey size in the categories of food and foraging behaviour in the categories of behaviour were considered as one resource type each and resource matrices for all species were structured following Pianka (1986). Levins' (1968) diversity index was used to estimate the extent of behaviour and resource use.

RESULTS

Spatial dimension of niche

The relative abundance measure indicated the population of the CE was highest (265.6 ± 54.5) followed by ME (114.6 ± 20.9), GE (12.6 ± 6.7) and LE (4.51 ± 3.5). Chi-square contingency analysis of the frequency with which each species used the micro-habitat types revealed that significant associations exist between the species and the micro-habitat types (Table 1). The CE used a variety of habitat types both aquatic and terrestrial and dry grassland amongst terrestrial habitat types while amongst the aquatic types, it preferred reed beds with low height vegetation growth and irrigated paddy fields (χ^2 = 213.6, P <0.05, df = 288). The LE mostly remained in open sheets of water within the lake and at the shore

Table 1. The percentage utilization of nine microhabitats by the four sympatric species of egrets and their micro-habitat niche breadth.

	Habitat Type	*Proportion of individuals (Relative abundance)			
		CE	LE	ME	GE
1	Marsh	6	14	9	10
2	Ploughed field	27	4	8	0
3	Pool	0	6	0	23
4	Open water	0	31	11	42
5	Paddy field	7	13	12	7
6	Dry grassland	34	7	12	0
7	Lakeshore	0	22	8	18
8	Reed bed	21	0	36	0
9	Canal bank	5	3	4	0
Shannon-Weiner's niche breadth index H'		**325.05**	**301.96**	**313.29**	**305.48**

Table 2. Habitat niche overlap (Morisita's measure of niche overlap) amongst the four sympatric species of egrets.

Species pairs	C (Morisita's measure of niche overlap)							
	Overall Habitat niche overlap	Aquatic habitat			Terrestrial habitat			
		Water depth	Water stretches	Vegetation cover	Tree height	Canopy cover	Ground cover	Distance from lake
CE-LE	0.030	0.108	0.170	0.000	0.214	0.422	0.240	0.085
CE-ME	0.016	0.675	0.682	0.000	0.237	0.464	0.425	0.115
CE-GE	0.011	0.054	0.076	0.000	0.319	0.568	0.384	0.100
ME-LE	0.062	0.411	0.129	0.235	0.280	0.411	0.506	0.794
ME-GE	0.024	0.260	0.057	0.212	0.422	0.556	0.634	0.864
LE-GE	0.045	0.274	0.028	0.979	0.363	0.492	0.957	0.948

(χ^2 = 232.7, P <0.05, df = 288). Amongst its less preferred ventures into the terrestrial area, it remained in short grasslands. The ME, however, (χ^2 = 256.8, P <0.05, df = 288) showed a high preference for reed beds (χ^2 =139.1, P <0.05, df = 288) and made equal use of paddy fields, lake shore and marshes. The GE (χ^2 = 297.3, P <0.05, df = 288) seemed to be specializing in open water feeding making use of the clear sheet of water within the lake and other pools.

The utilization pattern of resources within these micro-habitat types by the sympatric species of egrets was also found to be different (Table 2). The CE preferred to remain in shallow reaches (χ^2 = 234.2, P <0.05, df = 288) when feeding in water and treaded over vegetation, while the LE (χ^2 = 477.8, P <0.05, df = 288) and the ME (χ^2 = 285.4, P<0.05, df = 288) mostly stayed in water up to 30 cm deep. Owing to its longer legs, the GE (χ^2 = 274.3, P<0.05, df = 288) was the only species of the four, that ventured up to 70 cm.

The aquatic vegetation cover was also differentially used by the four species for foraging. The CE (χ^2 = 184.5, P <0.05, df = 288) and the ME (χ^2 = 109.6, P <0.05, df = 288) fed in highly vegetated areas, whereas the LE (χ^2 =119.2, P <0.05, df = 288) and the GE (χ^2 = 122.4, P <0.05, df = 288) fed in scantily vegetated areas. Out of the several categories of available water stretch in the wetland, there was a differential association of the four species with various categories. The CE (χ^2 = 248.6, P <0.05, df= 288) frequented the wetland with less than 50% open water while the LE (χ^2 = 194.7, P <0.05, df = 288) preferred the wetland with only 25% open water. The ME (χ^2 = 233.1, P <0.05, df = 288) frequented the lake when open water was up to 75% and the GE (χ^2 = 242.9, P <0.05, df = 288) fed in the lake when the open water was more than 50% and even while the lake was overflowing due to heavy rains.

The CE (χ^2 = 274.3, P <0.05, df = 288) frequented ground vegetation cover only where it was more than 30%, whereas the LE (χ^2 = 146.2, P <0.05, df = 288) frequented areas with less than 30% ground vegetation. The ME did not exhibit a significant association with the ground cover but the GE (χ^2 = 203.5, P <0.05, df = 288) showed a significant preference for ground vegetation cover of up to 60%. Significant associations were also found between the species and their distance to the lake. While the CE (χ^2 = 266.4, P <0.05, df = 288) was mostly found feeding away from the lake. The LE (χ^2 =313.5, P <0.05, df = 288) maintained strict proximity to the lake area. The ME (χ^2 = 186.7, P <0.05, df = 288) did venture away from the lake but remained within a distance of one kilometre. The GE (χ^2 = 302.8, P <0.05, df = 288) was found to feed only in the close vicinity of the lake and its adjoining pools and never beyond one kilometre distance.

Analysis of the niche breadth (Table 1) shows that the CE and the ME use a wide spectrum of habitat types hence they have a larger niche breadth. While the GE has a lesser diversity of habitat types used and a smaller niche breadth followed by the LE.

The degree of habitat niche overlap between the four sympatric species of egrets (Table 2) indicates that the maximum overlap exists between the LE and the GE. The CE has very little overlap with any of the species for all habitat parameters, in fact, no overlap exists between the CE and the other three species in the case of vegetation cover. The ME shows moderate habitat overlap with LE and GE. However, niche overlap inference cannot be made with regard to tree height and canopy cover, because the Chi-square contingency analysis used to derive Morisita's Index of niche overlap revealed that there was no significant correlation between the species and these habitat parameters.

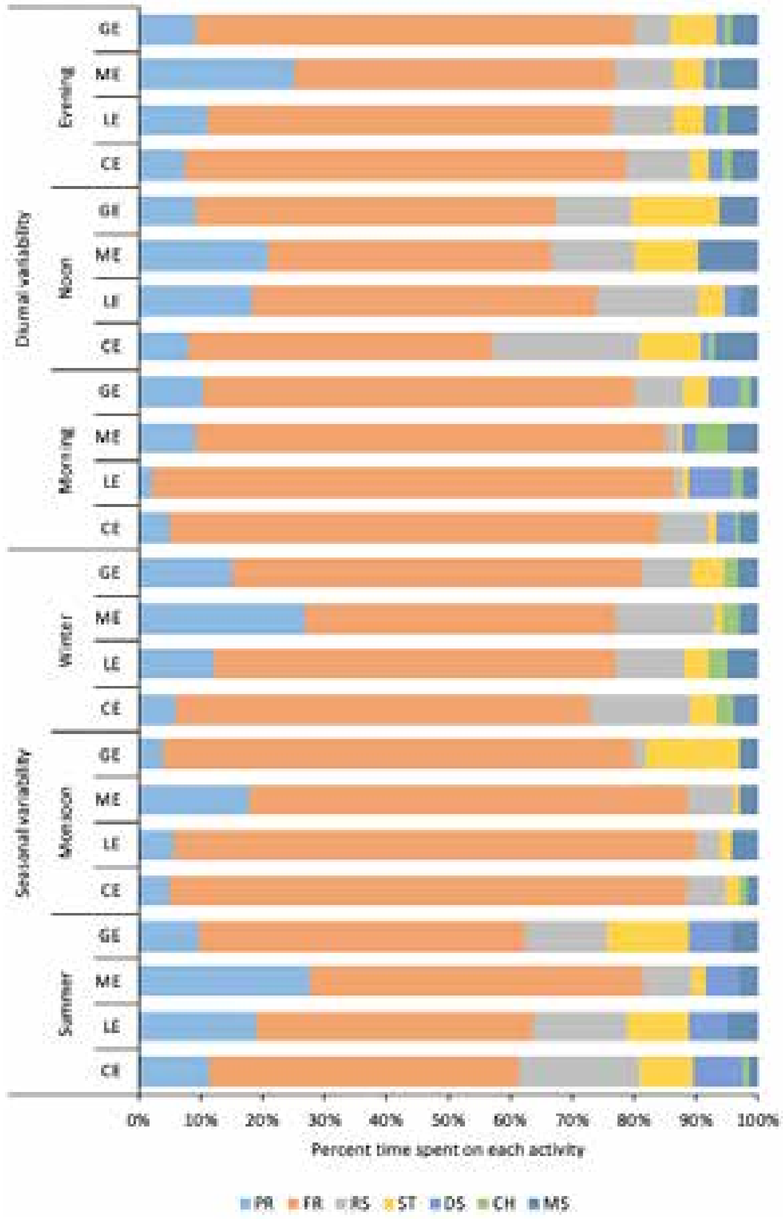

Figure 1. Seasonal and diurnal variability in the activity patterns among the egret species.

Temporal dimension of niche

All species of egrets were found to be variably utilizing the diurnal period throughout different seasons (Figure 1). In general, a significantly high proportion of their time was spent on foraging activity followed by preening and resting (Figure 1). Since the display behaviour was only recorded during the summers, therefore, its seasonal comparison was not possible.

The post hoc analysis of diurnal activity pattern suggested that preening time differs between all species except between LE and GE. Only CE & ME and LE & ME differ in foraging activity. Resting time differs between CE-ME, CE-LE and CE-GE while siesta and time devoted to miscellaneous activities differ amongst all species. Differences were also found between the display and chasing activity of CE-LE, LE-ME and ME-GE (Figure 2).

The post hoc analysis of significant seasonal variability in the activity pattern showed that during winters all species except LE-GE differ in the preening activity. The ME and CE, LE and GE differ in their foraging time. For the resting activity CE-LE, CE-GE and LE-ME differed significantly while for the rest of the activities in the time budget, only ME-GE showed a significant difference regarding the siesta activity (Figure 2). In

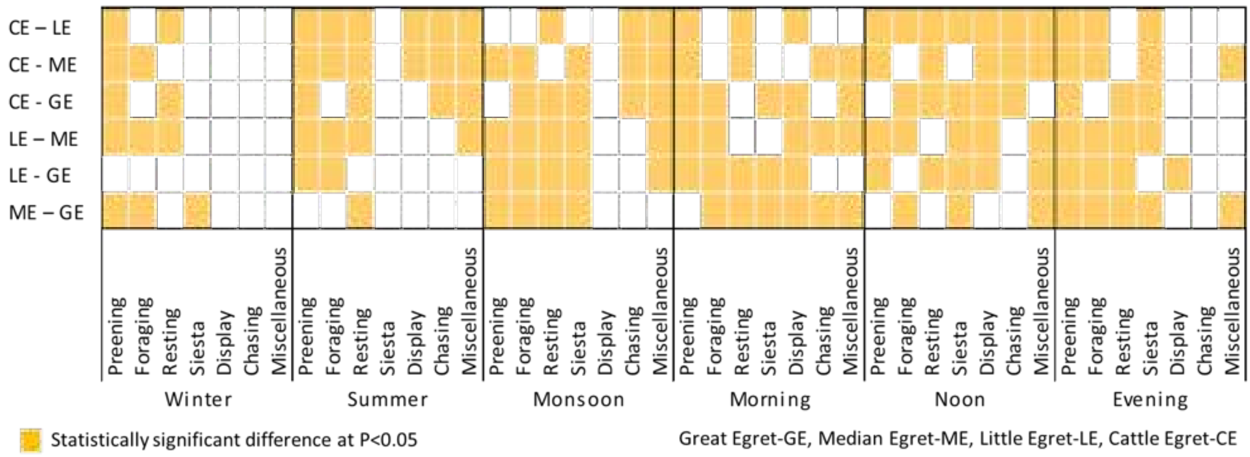

Figure 2. Significant differences in the seasonal and diurnal activity pattern between the sympatric species of egret.

the summer season, the preening activity pattern was different between all pairs of species except LE-GE. The time spent on foraging was also different between all pairs of species except CE-GE and ME-GE. Resting and miscellaneous activity patterns were different in all species pairs except LE-GE. The CE-LE, CE-ME and ME-GE differed significantly in their display behaviour whereas CE-ME, CE-LE and CE-GE adopted differential time budgets for chasing (Figure 2).

In monsoon, all pairs of species except the CE-LE and CE-GE were different in preening activity pattern. Time spent on foraging was significantly different between all pairs of species except CE-LE. In time allocation to the resting, siesta and miscellaneous types of activities, half of the pairs of species differed significantly (CE-GE, ME-LE and LE-GE) and the remaining half performed without any significant differences (CE-LE, CE-ME and ME-GE). The chasing time was found significantly different between the pair CE-LE, CE-ME and CE-GE (Figure 2).

Trophic dimension of niche

The Chi-square contingency analysis of the frequency suggested that associations between the species and the behaviour types are highly significant. CE used a variety of feeding behaviours such as walking slowly, standing and walking quickly most often (χ^2 =32.7, P <0.05, df = 21) and LE used walking quickly and foot stirring most often (χ^2 =33.4, P <0.05, df = 21). The behaviour of foot stirring was unique to the LE. The ME used walking slowly most often but gleaning, probing and pecking and standing were also used with an equal thrust (χ^2=37.9, P <0.05, df = 21). The GE almost specialized in using the walking slowly and standing behaviour (χ^2 =34.3, P <0.05, df = 21) with minuscule use of probing and pecking and chasing.

A total of 7,826 observations on the foraging behaviour of the different egret species were possible during the study period (Figure 3). The chi-square suggested a significant association between species and preferred prey items. CE preyed mostly upon terrestrial insects and small vertebrates such as amphibians, molluscs and crustaceans (χ^2 = 44.5, P <0.05, df = 30), the LE was most significantly associated with small fish but also include crustaceans, amphibians and aquatic insects (χ^2 =48.9, P <0.05, df = 30) in its diet, the ME most often fed upon small fish but larger fish and aquatic insects too formed a considerable portion of the diet (χ^2 = 46.2, P <0.05, df = 30), whereas the GE almost exclusively fed upon large sized (more than 8 cm) fish (χ^2 = 43.8, P <0.05, df = 30). The rest of the dietary items were also consumed by the GE but in smaller quantities (Figure 4).

A clear preference of prey size has been indicated by the egret species (Figure 5). CE subsisted on smaller prey of less than 6 cm (χ^2 =22.8, P <0.05, df = 12), prey eaten by LE ranged from 2 cm to 8 cm (χ^2 =27.1, P <0.05, df = 12); similarly, the ME too preyed upon intermediate size fish and crustaceans less than 8 cm in size (χ^2 =25.2, P <0.05, df = 12) but the GE maximized on fish larger than 8 cm (χ^2 =24.7, P <0.05, df = 12) (Figure 5). However, since they fed on small fish as well, some of their prey was less than 6 cm.

The measurement of niche breadth (Table 3) indicates that CE and ME use almost the same diversity of foraging behaviours and the LE and GE use a very small variety of behaviours – practically only walking quickly and foot stirring, and walking slowly and standing. The CE and LE showed equal diversity in the choice of food items and the ME and GE showed a lower diversity than the former two. Regarding prey size, the LE showed a very high diversity followed by the ME, and the GE and CE

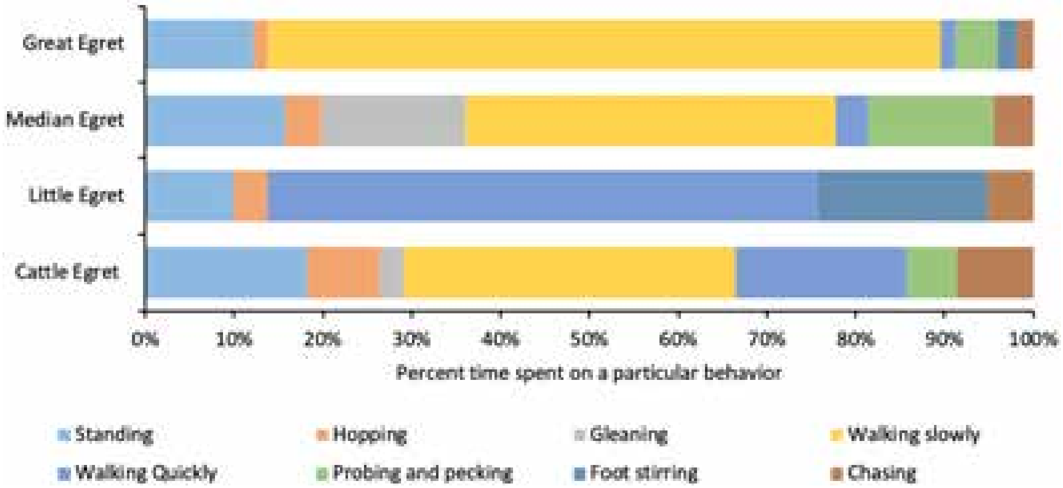

Figure 3. Time devoted to different foraging behaviours by four sympatric species of egrets.

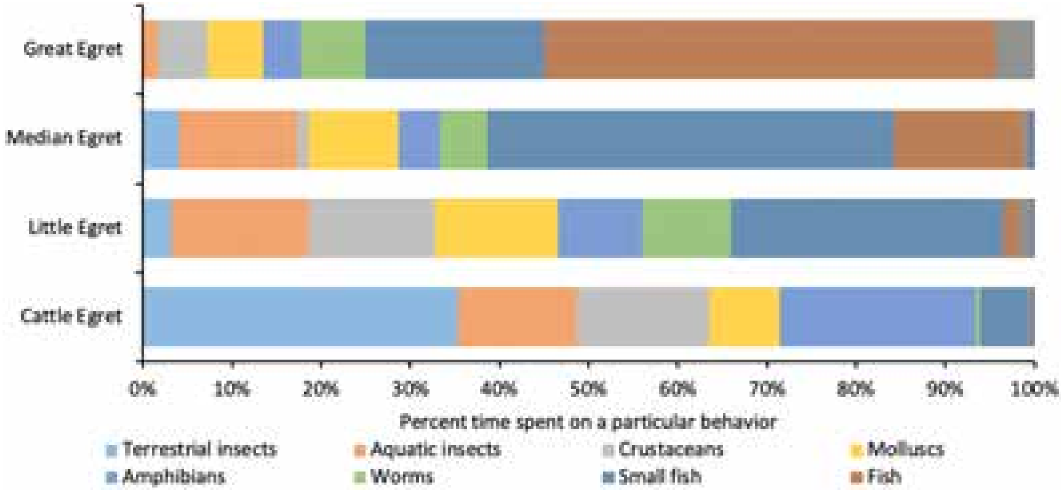

Figure 4. Food resource matrix for prey items of the four sympatric species of egrets.

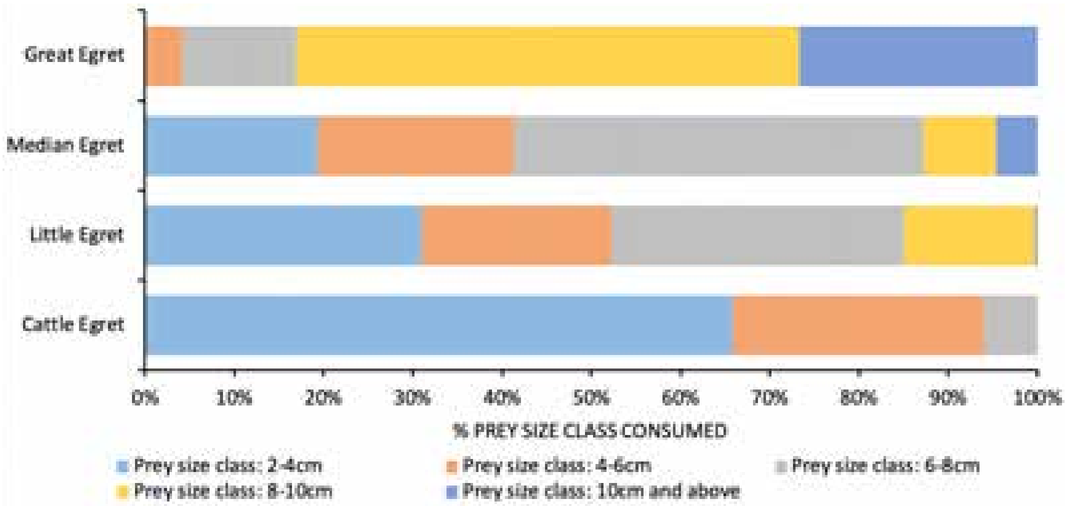

Figure 5. Food size matrix for prey size of the four sympatric species of egrets.

Table 3. Levin's measure of niche breadth (B) and Hulbert's standardized measure of niche (B_A) diversity of foraging behaviour and food resource of four sympatric species of egrets.

Species	Resource state					
	Foraging behaviour		Prey item		Prey size	
	(B)	(B_A)	(B)	(B_A)	(B)	(B_A)
CE	4.3835	.4834	4.8105	.3811	2.0022	.2506
LE	2.3195	.1885	4.3534	.3353	3.5845	.2461
ME	3.9776	.4254	3.8184	.4818	3.2688	.5672
GE	1.6683	.0955	3.1491	.2149	2.4621	.3655

exhibited a comparatively lower diversity.

Analysis of resource overlap amongst the four sympatric egrets (Table 4) reveals high overlap between CE and GE regarding behaviour, moderate overlap with prey type but very little overlap in prey size. GE and ME showed a high overlap in foraging behaviour and considerable overlap in prey size and prey type. ME and LE exhibited almost total overlap in prey type but little overlap in foraging behaviour. GE and LE coexist with very little overlap in foraging behaviour and considerable overlap in prey type and prey size. LE and CE have a high overlap in prey type and prey size and a moderate overlap in foraging behaviour. CE and ME have high degrees of overlap in all categories.

Table 4. Horn's resource overlap (R_0) between the sympatric species of egrets for foraging behaviour, prey type and prey size. The overall overlap between the species in resources dependent and resource independent conditions.

Species pairs	Resource state			Overall resource overlap (dependent conditions)	Overall resource overlap (independent conditions)
	Foraging behaviour	Prey type	Prey size	Product	Mean
CE- GE	.825	.492	.180	.073	.499
GE-ME	.841	.677	.549	.312	.689
ME-LE	.313	.935	.959	.280	.735
GE-LE	.269	.677	.549	.099	.498
LE-CE	.573	.807	.808	.373	.729
CE-ME	.895	.742	.720	.478	.785

DISCUSSION

The study demonstrated significant differences in habitat use, diurnal time utilization and feeding habits among the four species of egrets at Sheikha lake. Thus, they segregated in the use of the temporal, spatial and trophic niche dimensions, resulting in reduced interspecific competition.

Given the lack of interspecific territoriality and aggression, this suite of ardeid assemblage exhibits a pattern of spatial segregation that relies on slight differences in micro-habitat utilization with a varying overlap in various spatial niche dimensions (Table 1 & 2). A positive correlation has been found between Shannon-Weiner's niche breadth of the egret species and their local abundances (Table 1). CE and ME were using both the terrestrial as well as water-based micro-habitats hence their niche breadths are wider so do their population abundance. Whereas the GE and LE are more wetland-oriented species therefore narrower niche breadth and lower local abundance. These results are in line with the ecological phenomenon proposed by Hanski (1982) that the species occupying most sites (i.e., wider habitat-based niche) also have higher local abundances within those sites and vice versa.

The egret species were found to be variably utilizing the daytime throughout different seasons and shifts of the day (Figure 1). In general, a significantly high proportion of their time was spent on foraging activity followed by preening and resting (Figure 1). The results are the first example of diurnal temporal partitioning in the four major egret species of tropical wetlands. Such partitioning is likely to be driven by a combination of physiological and morphological constraints of each species and behavioural mechanisms, including a species' potential for behavioural plasticity (Lear et al. 2021). Due to varied body sizes there use to be a hierarchy in the Egret species in which the bigger body sizes have the advantage to get the most suitable place for hunting. Hence the egrets make opportunistic adjustments in their activity patterns in response to the sympatric species exploiting the same habitat. Perhaps to avoid interspecific conflict the egrets use temporal niche partitioning as a mechanism for co-existence in the overlapped portion of microhabitats (Ye et al. 2019), which could also maximize their fitness (Sanz-Aguilar et al. 2015).

The Egrets are visual predators that use the sit-and-wait technique (Kushlan & Hancock 2005). They are predominantly small fish and insect eaters. The dependency on the smaller prey is reasonable as they are usually r-selected species and suffice the energy requirements of the species (Britto & Bugoni 2015). Furthermore, during breeding, the egrets may select insects to deliver to chicks because they are unable to swallow large fish and other prey (Martinez-Vilalta &

Motis 1992). They are therefore called a biocontrol agent for insects, especially the CE as more than 60% of CE's diet comprise items less than size of 4cm (Seedikkoya et al. 2007). The size of consumed prey varies among the species and it is in accordance with their own body sizes, i.e., bigger egrets feed on big-size prey. 69.3% diet of CE (smallest of the studied egrets) comprised of prey size 2–4 cm. Similar to this, prey between the sizes of 2 and 8 cm made up 86.4% and 87.5% of the diets of LE and ME, respectively. Whereas the GE (largest of the studied egrets) fed on 83% of prey species that were between 8–10cm and above.

The study indicates that there is a relationship between the niche dimensions, but it is only partially dependent on each other. Little overlap existed in food selected by the four species but very different foraging behaviours are adopted. Considering the interplay of habitat selection and the feeding technique adopted, the nature of foraging niche differentiation is multi-faceted and may vary from region to region.

Our results are in agreement with the niche partition hypothesis, whereby morphologically, ecologically and closely related sympatric species segregate in at least one of the niche dimensions to allow coexistence (Ye et al. 2021).

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ARTICLE

Larval descriptions and oral ultrastructures of some anurans (*Duttaphrynus, Minervarya, Nyctibatrachus, Rhacophorus,* & *Polypedates*) (Amphibia) from Wayanad and Vagamon hills, Western Ghats, India

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Abstract: The external and buccopharyngeal morphologies of tadpoles belonging to six anurans (*Duttaphrynus melanostictus*, *Minervarya agricola*, *Nyctibatrachus periyar*, *Rhacophorus malabaricus*, *R. lateralis*, & *Polypedates pseudocruciger*) from Wayanad and Vagamon hills, in Western Ghats are here-in described. Characterizations of larvae are illustrated by detailed images along with morphometric measurements. Four of the larval descriptions (*M. agricola*, *N. periyar*, *R. lateralis*, & *P. pseudocruciger*) are previously unknown, while two (*D. melanostictus* & *R. malabaricus*) are re-descriptions with additional information. Comparisons with congeners of the respective genera are made. This study is a small step towards advancing our knowledge of anuran larvae and supporting future research form Western Ghats and the adjacent regions.

Keywords: Aquatic, Kerala, morphometry, oral disc, scanning electron microscopy, tadpoles.

Abbreviations: BL—body length (distance from the tip of the snout to the body-tail junction) | DFH—maximum height of dorsal fin | INL—inter-narial distance (measured between the narial apertures) | IOL—inter-orbital distance (measured between the pupils) | LTRF—labial tooth row formula | MBD—maximum body width (at the widest point) | MTH—maximum tail height (including fins and musculature) | MTMW—maximum tail muscle width | NED—distance between eye and narial aperture | NSD—distance between snout and narial aperture | ODD—oral disc rostral width/diameter (maximum width of the oral disc) | SEM— scanning electron microscope | SS—snout to spiracle distance | SV—spiracle to vent length | TL—tail length (length of the tail from body tail junction to tail tip) | TMH—tail muscle height (measured at junction of the body and tail) | VFH—maximum height of ventral fin | VTL—vent tube length.

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INTRODUCTION

Western Ghats is a biodiversity hotspot harboring many endemic and unique anuran lineages that are geographically restricted to the region (Myers et al. 2000; Vijayakumar et al. 2019). There are more than 225 species of anurans known from the region of which 80% are endemic (Dahanukar & Molur 2020). Of late, there have been many new taxa described from the region (Dinesh et al. 2021). However, the focus of these works was mainly on their taxonomic and phylogenetic status. The last evaluation of threats for amphibians during Global Amphibian Assessment had found 40% of amphibian fauna from the region threatened with extinction (Biju et al. 2008). Despite recent progress in elucidating anuran diversity in the region, the natural history of most anuran species remains unknown.

Amphibians are unique among tetrapods with their life history characterized by a bimodal lifecycle. Most amphibians have a free-swimming aquatic larval stage that undergoes a major modification in their body plan through metamorphosis (Noble 1927; Orton 1957). Larval anurans are generally referred to as tadpoles. Similar to adults, tadpoles experience selection pressures that tend to shape their ecological and morphological adaptations in aquatic habitats (McDiarmid & Altig 1999). There has been a need to properly identify and characterize anuran larvae (Orton 1953; McDiarmid & Altig 1999; Haas 2003; Altig 2007). However, morphological terminology associated with anuran larvae was standardized only recently (McDiarmid & Altig 1999). In recent times, there has been a growing interest in research on larval morphology of anurans (McDiarmid & Altig 1999; Roelants et al. 2011). However, there are still many knowledge gaps pertaining to the life history patterns of anurans.

With many evolutionary radiations, anurans from Western Ghats can act as a good model group for comparative studies on tadpoles. Western Ghats presents varied landscapes, offering different larval habitats, which have led larval anurans from the region to evolve diverse morphologies (Bossuyt et al. 2004; Das & Dutta 2006). The diversity of larval morphology is not yet fully understood from the region. Of the ~225 species of anurans known from Western Ghats, only 30% have described larval forms (Das & Dutta 2006). This situation is compounded by the fact that very few taxonomic identification keys are available for species-specific larval identification (Raj et al. 2012, 2023). For Western Ghats anurans, there had been a considerable amount of work published on larval anurans in the first half of the 20th century by Annandale (1913, 1918, 1919), Annandale & Rao (1917, 1918), Rao (1914, 1915, 1918, 1922, 1937, 1938), and Ramaswami (1932, 1933, 1934, 1936, 1938, 1940, 1943, 1944). This work follows Bhaduri & Kripalani (1954), Chari (1962), Daniel (1963a,b, 1975), Pillai (1978), Inger et al. (1984), Sekar (1990a,b, 1992), Das (1996), Hiragond & Saidapur (1999), Kuramoto & Joshy (2002), and Dutta et al. (2004). In the past decade, there has been renewed interest in anuran larval studies from the region which resulted in the descriptions of tadpoles for few species (Biju et al. 2011; Raj et al. 2012; Wewelwala et al. 2013; Chandramouli & Kalaimani 2014; Abraham et al. 2015; Priti et al. 2015; Chandramouli et al. 2014; Biju et al. 2016; Senevirathne et al. 2016a,b). However, many of the description are brief and only few species have accurate larval descriptions, and there is a need for more comprehensive work on larval anurans from the region.

The current study presents larval morphologies of some anurans from the Wayanad and Vagamon hills in the Western Ghats. In the current paper, I describe the tadpoles of six species, *Duttaphrynus* cf. *melanostictus*, *Minervarya* cf. *agricola*, *Nyctibatrachus* cf. *periyar*, *Polypedates pseudocruciger, Rhacophorus lateralis*, and *R. malabaricus*. Two of the species, *D.* cf. *melanostictus* and *R. malabaricus,* were described earlier. However, the current descriptions are more detailed and also include the descriptions of buccopharyngeal morphology that are discussed.

MATERIALS AND METHODS

Specimen collection and larval identity

Field sampling was performed on 11 and 17 August 2011 at six locations in the Western Ghats of Kerala State, India: 1) Banasuramala Hills, Kalpetta, Wayanad, 11.62348°N, 75.93157°E, WGS84; 2) Vythiri, near Banasura Sagar Dam, Wayanad, 11.62466°N, 75.99011°E, WGS84; 3) Edatara, Wayanad, 11.62096°N, 75.99955°E, WGS84; 4) Vythiri, near Banasura Sagar Dam, Wayanad, 11.62903°N, 75.96925°E, WGS84; 5) Soochipara, Meppadi, Wayanad, 11.485322°N, 76.151828°E, WGS84; 6) Vagamon, Kottayam, 9.68266°N, 76.90549°E, WGS84 (Figure 1). Tadpoles were collected using an aquarium dip net. The tadpoles were euthanized by immersing them in 6 g/L solution of MS222. All tadpoles were fixed and preserved in 10% formalin, and currently housed at the Laboratory for Conservation of Endangered Species (LaCONES), Centre for Cellular & Molecular Biology (CCMB), Hyderabad, India. Museum catalogue series

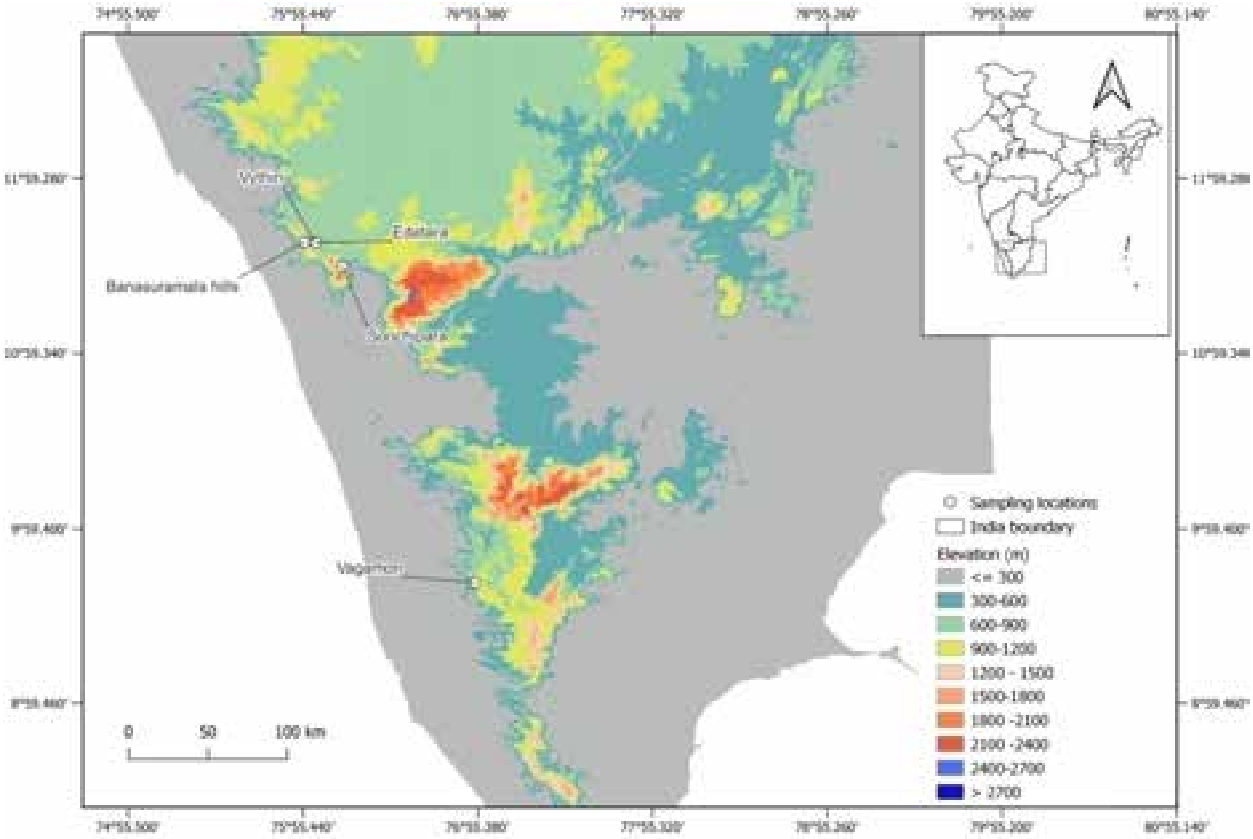

Figure 1. Sampling locations of anuran larvae in the Western Ghats, Kerala, India

of tadpoles examined and data regarding the sampling locations are given along with the descriptions. Freshly preserved tadpoles were photographed using a Nikon D7000 with a macro lens. Tadpoles for three species (*R. lateralis*, *R. malabaricus*, and *P. pseudocruciger*) were reared ex situ until metamorphosis to establish species identity. Due to the unavailability of molecular data, precise species identity of the other three species (*D.* cf. *melanostictus, M.* cf. *agricola*, and *N.* cf. *periyar*) could not be established. However, the taxonomic identity of these three species of tadpoles was based on sympatric adult anurans encountered and collected at the respective sampling locations. Generic-level taxonomy and nomenclature follows Frost (2021), while species definitions follow Das & Ravichandran (1998), Dubois & Ohler (1999), Biju et al. (2011, 2013; but see Abraham et al. 2022), Ganesh et al. (2017), and Chandramouli et al. (2019).

External and buccopharyngeal descriptions for larval anurans are provided based on an advanced larval development stage for each species. Developmental stages of tadpoles were staged using Gosner's table (Gosner 1960). The format of the description and measurements follows Raj et al. (2012). The terminology used in descriptions follows Altig & Johnston (1989) for external morphology, and Wassersug (1976, 1980) and Inger (1985) for buccopharyngeal morphology. Morphology of the buccopharyngeal region for the tadpoles was studied using methylene blue staining and scanning electron microscopy (SEM). For staining of buccopharyngeal structures, 2% Methylene blue solution was brushed on the oral structures. For SEM, methods used by Raj et al. (2012) were followed. External characters were observed using a LEICA EZ4 stereo zoom microscope (8–35 X). Sixteen morphometric measurements were taken using a SPI plastic dial caliper (precision: 0.1 mm).

RESULTS

Genus: ***Duttaphrynus*** Frost, Grant, Faivovich, Bain, Haas, Haddad, de Sá, Channing, Wilkinson, Donnellan, Raxworthy, Campbell, Blotto, Moler, Drewes, Nussbaum, Lynch, Green & Wheeler, 2006

Species: *Duttaphrynus* cf. *melanostictus* (Schneider, 1799).

Larval series examined: WT139/19711

(Banasuramala Hills, Kalpetta, Wayanad, Kerala, India, 11.62348°N; 75.93157°E; WGS84). Tadpoles were collected from a pool that was 1.5–1.8 m in depth. The tadpoles were restricted towards the fringes of the pool taking cover along the emergent vegetation. Tadpoles were found feeding on decaying plant material.

Taxonomic note: Adults of both *Duttaphrynus melanostictus* and *D. parietalis* were recorded from the location where tadpoles were collected. Externally, the tadpoles morphologically resemble those of *D. melanostictus* descriptions (Khan 1965, 1982). However, they vary in few characters, which are discussed. There are no descriptions for tadpoles of *D. parietalis* for comparison.

External morphology: Description of tadpole (Gosner Stage 35): Body oval and elliptical in dorsal and lateral views (Image 1A–B). Dorsal contour is convex and ventral contour of the body is flat or slightly concave at the anterior region and convex at the abdominal region; BL is 40.9% (40.8%–41%) of the total length; MBD is at the middle of the body. The snout is rounded in dorsal and lateral views. Eyes are large; located, and oriented dorsolaterally; the distance between the eye and the nostril represents 27.7% (26.3%–29.4%) of the distance between the eye and the snout. The nostril opening is reniform with the rim elevated, closer to eyes than to snout; placed parallel to the eye in dorsal view; INL is 62.1% (52.9%–71.4%) of IOL; NSD is 16.8% (15.7%–17.9%) of BL. Spiracle sinistral; inner wall of the tube not completely formed; tube orientation is posterolateral and the opening located approximately at the middle of the body; SS is 70.7% (69.7%–71.7%) of BL. Vent tube opening is median and short. Tail tip round; TMH is greatest at body tail junction after which it tapers. The dorsal fin originates at the body tail junction and the ventral fin at the ventral terminus; both the fins are of equal height for most of the length. MTH is at mid-length; TMH is almost equal to MTMW at the tail-body junction. TMH accounted for 34.7% (32.3%–37.1%) of MTH. Dermal pores of the lateral lines on the body faintly

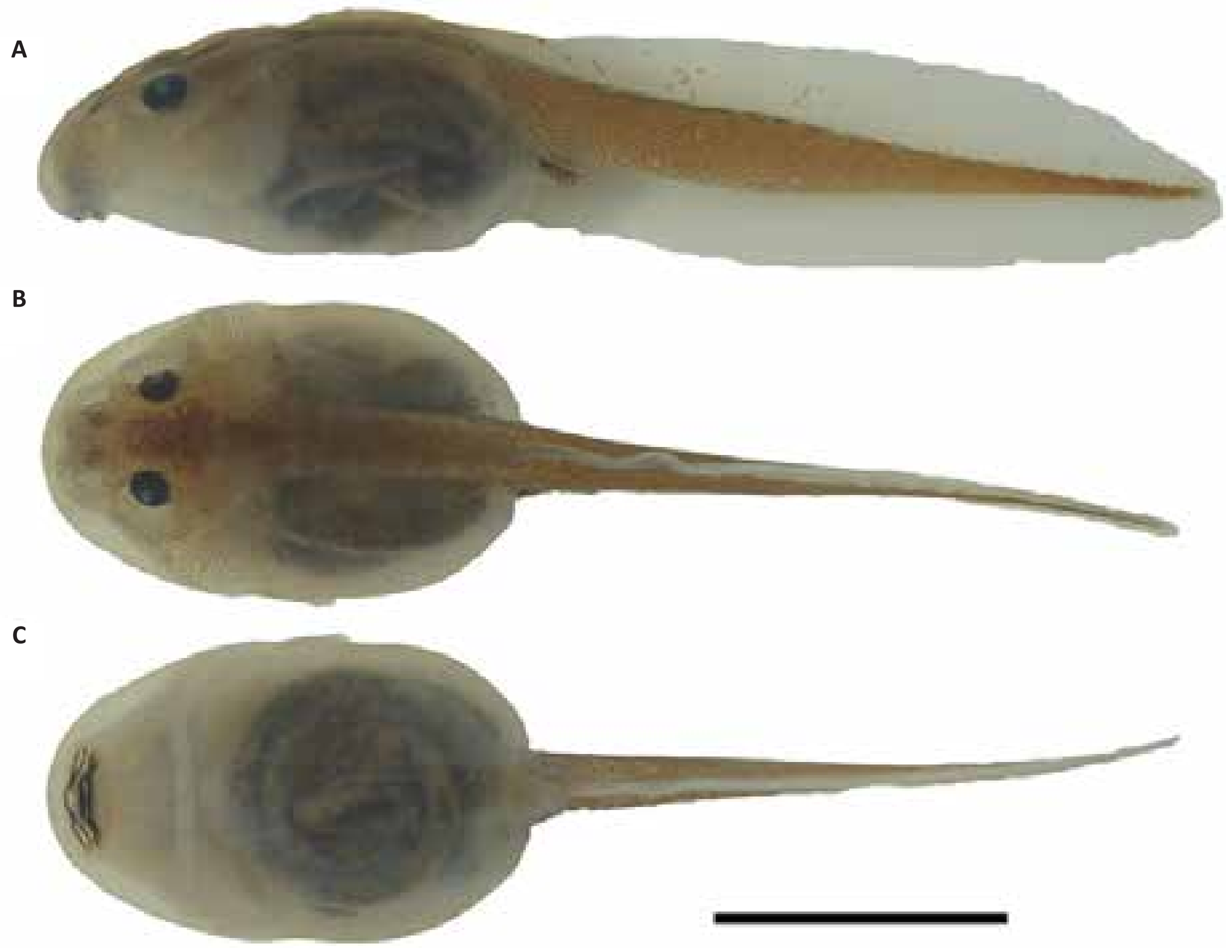

Image 1. *Duttaphrynus* cf. *melanostictus*, Gosner stage 37. External morphology: A—Lateral view| B—Dorsal view | C—Ventral view. Scale = 10 mm. © Prudhvi Raj.

Table 1. Morphometric measurements of *Duttaphrynus* cf. *melanostictus* tadpoles given in mm as mean ± SE.

Gosner stage	IOL	INL	NED	NSD	SS	SV	BL	TL	MBD	MTH	MTMW	TMH	ODD	VTL	DFH	VFH
26(5)	0.7±.03	0.5±.02	0.2±.02	0.7±.03	3.3±.13	1.6±.14	4.6±.22	6.8±.35	2.8±.09	1.8±.06	0.4±.03	0.7±.03	1.3±.07	0.5±.04	0.6±.04	0.7±.03
27(3)	1.2±.11	0.8±.05	0.3±.03	1.0±.08	4.3±.13	2.5±.24	6.1±.33	8.6±.43	3.8±.21	2.4±.13	0.8±.06	1±.05	3.7±1.9	0.8±.05	0.9±.08	0.9±.08
28(3)	1.0±.13	0.8±.06	0.3	1.1	4.5±.13	2.8±.10	6.5±.13	9.1±.83	4.1±.03	3.1±.10	0.9	1.2	1.8±.03	0.8±.07	1.1±.03	1.0±.03
29(2)	1.5±.10	0.9	0.3±.05	1.1±.05	4.6±.10	2.7±.20	6.6±.45	9.5±.20	4.3±.40	2.9±.15	0.9±.05	1.2	1.9±.05	1.0±.05	1.1±.10	1.1±.10
30(4)	1.3±.15	1.0±.09	0.3±.02	1.2±.12	4.6±.31	3.0±.13	7.2±.19	10.5±.32	4.5±.13	3.1±.07	0.9±.08	1.2±.10	1.9±.10	1±.10	1.2±.06	1.0±.09
31(4)	1.5±.07	0.9±.04	0.4±.02	1.2±.08	5.1±.23	2.9±.25	7.1±.15	10.5±.43	4.7±.10	3.3±.07	1±.04	1.2±.08	2.1±.07	1.1±.08	1.2±.04	1.2±.02
32(3)	1.4±.15	1±.05	0.3±.03	1.2±.06	5.3±.32	3.0±.31	7.4±.12	11.6±.39	4.7±.15	3.2±.08	0.9±.08	1.3±.18	1.9±.03	0.9±.03	1.0±.03	1.1±.03
33	1.6	0.9	0.4	1.3	5.2	3	7.2	11.5	4.7	3.6	1	1.3	2.3	0.9	1.2	1.2
34(3)	1.5±.18	0.9±.08	0.4	1.2±.08	5.0±.12	3±.15	7.0±.29	10.7±.17	4.7±.14	3.2±.12	0.9±.06	1.2±.05	1.9±.05	1.1±.05	1.2±.05	1.2±.08
35(2)	1.5±.15	0.9±.05	0.5	1.3±.10	5.4±.15	3.1±.10	7.7±.10	11.1±.20	4.8±.20	3.4±.05	1.3±.35	1.2±.10	2.1±.20	1.2±.10	1.2	1.1±.05
36(4)	1.6±.02	1.0±.07	0.4±.04	1.3±.09	5.4±.09	3.2±.07	7.8±.13	11.0±.23	5.0±.14	3.6±.11	1.0±.02	1.3±.09	2.1±.06	1.1±.08	1.2±.04	1.2±.02
37	1.2	1.1	0.4	1.4	5.9	3.1	8.1	10.9	5	3.6	1.1	1.3	2	0.8	1.5	1.4
38(4)	1.7±.02	1±.07	0.4±.02	1.3±.09	5.1±.12	3.0±.07	7.5±.16	11.3±.23	4.9±.02	3.5±.12	1.0±.02	1.2±.04	2.1±.07	1.1±.08	1.2±.02	1.2±.06
39(2)	1.6±.15	0.9±.05	0.5	1.3±.10	5.1±.10	3.3±.15	7.5±.15	11.2±.85	4.9±.10	3.2±.25	1.1±.10	1.4±.20	2.1±.05	0.9±.10	1.2±.10	1.1±.05
40(2)	1.6±.15	1	0.4±.05	1.3±.10	5.4±.10	3.4±.15	7.6±.20	11.3±.15	4.9±.20	3.1±.10	1.0±.05	1.2±.10	2.1±.05	1.0±.15	1.2	1.2

visible. No glands are present on the outer integument.

Oral disc is anteroventral in location (Image 1C); ODD is 44% (43.1%–45.1%) of the body width; disc emarginated; single row of marginal papillae spread on the lateral corners of the oral disc and none seen on both the labia; four to five submarginal papillae seen at the lateral corners; both labia are of equal size. The labial tooth row formula (LTRF) is 2(2)/3. Order of the length of tooth rows is A-1 > P-1 > A-2 > P-2 > P-3. Jaw sheaths are feeble and both are moderately keratinized. Jaw sheaths are serrated with uniform-sized small serrations; supra-rostrodont is convex, longer with the median slightly broad and tapering to long thin lateral processes; infra-rostrodont is U-shaped, convex laterally and concave medially.

Measurements: Measurements of 42 tadpoles belonging to various Gosner stages (Gosner stages 26–40) are presented in Table 1.

Colouration: In life, tadpoles were black with many closely spaced tiny melanophores and many golden speckles distributed randomly on the outer integument which otherwise are not present in *D. melanostictus* tadpoles; the inner integument had few large melanophores. In lateral view, the flanks were spotted with many tiny melanophores. Ventrally, the integument was transparent with gut coils visible; the throat was spotted on the lateral sides. Both the fins were transparent and the dorsal fin was spotted at the anterior portion. The entire tail muscle was spotted with tiny melanophores, mostly along the posterior region of the tail. Spiracle, oral disc and the vent tube were translucent, however, dotted with few melanophores.

Buccopharyngeal morphology

Buccal roof (Image 2A–B): Prenarial arena of the buccal roof comprises a triangular transverse ridge with tiny papillae on the lateral corners. Internal nares transverse and oriented anteromedially; the gap between the nares narrow and is about half of the length of an individual nare; anterior narial wall pustulose with few tiny pustules and no papilla; posterior wall is tall, smooth with no pustules and valvular. The post narial arena comprises three pairs of papillae arranged in an inverted "v" shape oriented antero-medially. The second and the third post narial papillae are conical and pustulose, with the second papilla being the longest; the first papilla is stubby. Median ridge papilla is triangular with a smooth margin and a bifid tip. There is a single trifid pustulose lateral ridge papilla perpendicular to the median ridge on both sides. Buccal roof arena demarcated with three pairs of long conical papillae present on the lateral border of the roof; about 30 tiny pustules are spread across the entire buccal roof arena. Glandular zone is thick and prominent. The dorsal velum is moderately raised with few tiny projections medially; however, the margin is continuous.

Buccal floor (Image 2C–D): Prelingual arena comprises a single dilated infralabial palp on each side of the posterior lateral corners of the jaw sheath. Each palp is divided into two equal wide projections with many

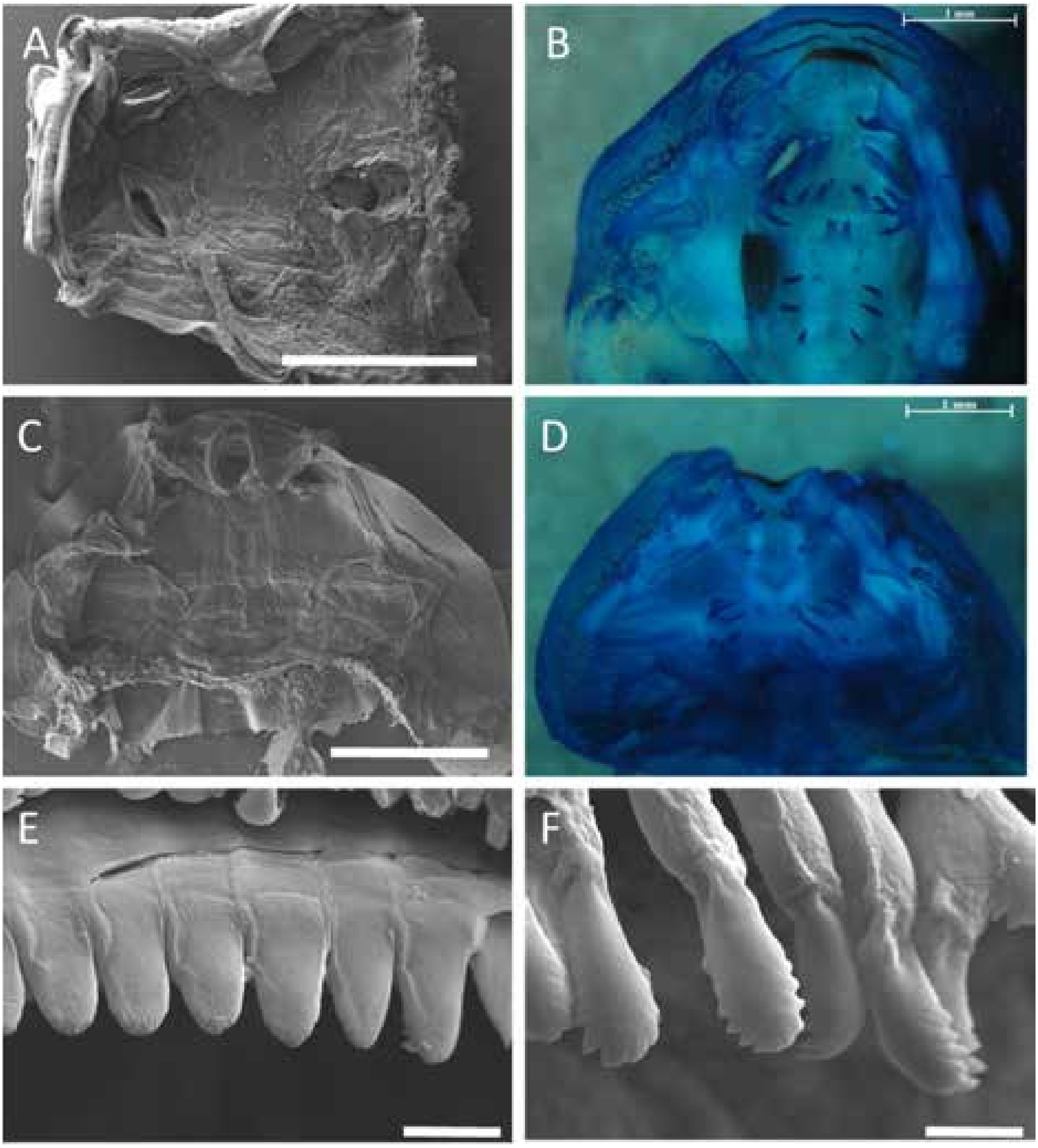

Image 2. ***Duttaphrynus*** **cf.** ***melanostictus,*** **Gosner stage 37. Buccopharyngeal and denticles: A— Buccal roof, SEM photograph, scale = 1 mm | B—Buccal roof, Alcian blue stained photograph, ventral view, scale = 1 mm | C—Buccal floor, SEM photograph, scale = 1 mm | D—Buccal floor, Alcian blue stained photograph, ventral view, scale = 1 mm | E—Individual denticles, scale = .1 mm | F—Jaw sheath serrations = .1 mm. © Prudhvi Raj.**

pustules on the margin. Tongue anlage round and low; two pairs of smooth lingual papillae present, one at the center projecting inwards and the other on the lateral corner of the tongue anlage projecting outwards. Buccal floor arena well defined; anterior region of the buccal floor arena smooth; six long conical papilla commence from the mesad of the buccal floor arena and spread till the posterolateral corners; the second buccal floor arena papilla is the largest and bifid; posterior region of the buccal floor arena composed of 20 pustulations. The buccal pocket opening is narrow and oblique; few pustulations occur in the region between the tongue anlage and the buccal pockets; no pre-pocket papilla present. Ventral velum smooth with about 10 projections. The outer two projections on either side are widely placed and the rest are concentrated at the center. Median notch is not prominent. The glottis opens immediately posterior to the ventral velum.

Denticles (Image 2E) are closely packed and curved towards the mouth at the apex. The oral angle is more or less straight except for the slightly curved apex. The sheath and the body are broad; about 14–16 long and pointed cusps are present on each denticle. Each serration (Image 2F) on the jaw sheath has a wide base and a rounded head.

Genus: ***Polypedates*** Tschudi, 1838.
Species: *Polypedates pseudocruciger* Das & Ravichandran, 1998.

Larval series examined: WT140/22711 (Vythiri, near Banasura Sagar Dam, Wayanad, Kerala, India, 11.62466°N; 75.99011°E; WGS84). Tadpoles were collected from a pool, which was approximately 1.5 m in depth. The tadpoles were restricted to 0.5–1 m depth of the pool feeding on emergent vegetation occasionally surfacing. Tadpoles of this species were found in pools inhabited by *D.* cf. *melanostictus*, *R. lateralis*, and *R. malabaricus*

Taxonomic note: Fresh metamorphs morphologically matched *P. pseudocruciger*. No tadpole description for this species is available.

External morphology: Description of tadpole (Gosner stage 38): Body oval in dorsal and lateral views (Images 3A–B). Dorsal contour slightly convex with most of the dorsum flattened and ventral contour of body convex and broad at abdominal region; BL is 36.4% of the total length; an indentation is seen immediately behind the eye; MBD at the posterior end of the body. The snout is oblique and rounded in dorsal and lateral views. Eyes are large; located and oriented laterally; distance between the eye and nostril represents 63.2% of the distance between the eye and snout. The nostril opening is oval with the rim elevated, closer to the snout; placed wide

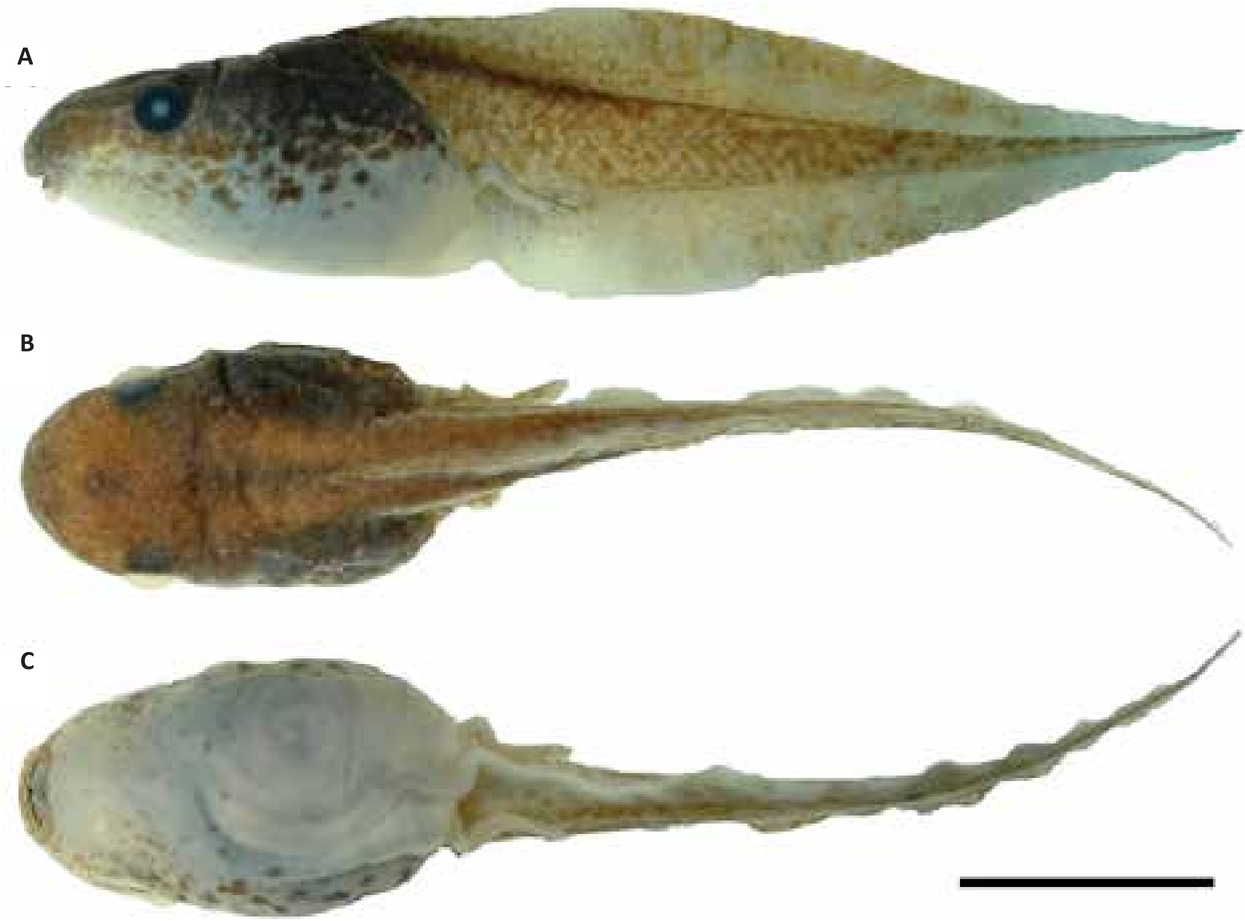

Image 3. *Polypedates pseudocruciger*, Gosner stage 37. External morphology: A—Lateral view | B—Dorsal view | C—Ventral view. Scale = 10 mm. © Prudhvi Raj.

Table 2. Morphometric measurements of *Polypedates pseudocruciger* tadpoles given in mm as mean ± SE.

Gosner stage	IOL	INL	NED	NSD	SS	SV	BL	TL	MBD	MTH	MTMW	TMH	ODD	VTL	DFH	VFH
26(3)	4.7±.08	2±.15	1.7±.03	1.2±.05	6.1±.21	4.9±.20	10.1±.15	17.2±.53	5.1±.08	5.1±.55	1.6±03	2.3±.18	2.2±.03	0.6±.03	2.1±.08	2.1±.08
27(5)	5.5±.16	2.5±.05	2.2±.07	1.2±.05	7.6±.39	6.4±.50	12.5±.59	22.4±1.04	6.7±.41	6.9±.57	2.5±.25	3.1±.08	2.8±.06	0.8±.11	2.2±.17	2.5±.27
28(5)	5.8±.10	2.7±.08	2.5±.10	1.3±.12	7.9±.13	6.7±.18	13.6±.26	23.1±.49	7.2±.18	7.8±.22	2.2±.13	3.4±.14	3±.08	0.9±.19	2.5±.11	2.8±.10
30	5.9	2.9	2.6	1.5	8.7	7.5	14.1	25.2	7.4	8.5	2.3	3.2	3	0.7	3.1	3.1
31(3)	6.2±.05	2.6±.26	2.4±.08	1.4±.15	8.6±.17	7.3±.28	14.6±.35	24.8±.49	7.4±.54	8.5±.24	2.4±.14	3.4±.23	3.1±.20	1.1±.31	2.8±.05	3.2±.15
32(4)	6.5±.11	3.1±.10	2.7±.07	1.4±.11	9.1±.11	7.9±.22	14.8±.34	25±1.29	10.5±2.73	8.5±.08	2.6±.12	3.5±.19	3.1±.02	0.7±.05	2.7±.08	3±.07
33	6.5	3.3	3.1	1.5	9.3	8.8	15.7	27.2	8.6	9.3	3.1	3.9	3.1	1	3.3	4.1
34(3)	6.7±.38	3±.08	2.7±.08	1.7±.03	9.1±.64	8.4±.79	15.6±.54	28.3±1.83	8.3±.24	9.1±.31	3±.20	3.5±.08	2.8±.38	1.2±.31	2.9±.05	3.1±.08
36	6.5	3	2.8	1.5	9.3	7.7	13.9	25.1	7.3	7.8	3	3.7	2.9	2.5	2.5	2.6
38	7	3.2	3.1	1.8	9.3	8.8	17.3	30.2	8.7	8.3	3.4	4.1	3.4	2.3	2.3	2.3
39(4)	7.2±.22	3.1±.16	3.2±.12	1.8±.13	10.3±.33	9.6±.66	16.3±.83	31±1.35	9±.45	8.7±.83	3.2±.18	3.8±.34	3.3±.19	1.5±.52	2.8±.44	2.9±.49
40(5)	7±.14	2.9±.14	2.8±.20	1.8±.06	10.2±.20	9±.49	16.1±.70	32.4±.59	9.7±.21	9.08±.31	3.1±.10	4±.10	3.4±.06	2±.40	3.1±.14	2.9±.08
41(3)	7±.20	2.4±.14	2.8±.03	2±.05	10.4±.12	8.1±.48	16.5±.56	34.7±.48	9.4±.63	8.6±.18	3.5±.29	4.4±.14	3.5±.16	2.1±.12	2.8±.05	3±.08
42(3)	5.9±.25	2.2±.08	2.5±.12	*	*	*	16.2±.26	31.3±1.56	7.1±.23	6.4±.58	3.2±.31	3.3±.14	2.5±.16	*	2.3±.26	1.5±.17

apart and linear to the eye in dorsal view; INL is 45.7% of IOL; distance between the nostril and the snout is 10.4% of BL; naso-lacrimal gland visible between the eye and the nostrils. Spiracle is sinistral with an inner wall of the tube not present; tube orientation is posterolateral and its opening is located below to the lateral median; SS is 53.7% of BL. Vent tube opening is dextral as a small tube and not attached to the tail fin. Tip of the tail acutely pointed; TMH is greatest at the body tail junction and tapers thereafter. The dorsal fin originates anterior to the body tail junction and the ventral fin at the ventral terminus; the ventral fin is taller than the dorsal fin. MTH is at about 1/3rd length from the body tail junction; TMH is about 1.2 times of MTMW at the tail-body junction. TMH accounted for 49.3% of MTH. Lateral line is conspicuous. No glands are present on the outer integument.

Oral disc is at the anteroventral end of the body (Image 3C); ODD is 40.9% of the body width and emarginated. Marginal papillae are single row on the lateral corners of the upper labium and double row on the lower labium; a wide gap is present medially on the upper labium and a small gap medially on the lower labium; three submarginal papillae seen at the lateral corners; both labia are of equal size. The LTRF is 5(2–5)/3(1). Order of the length of tooth rows is P-1 > P-2 > P-3 > A-1 > A-2 > A-3 > A-4 > A-5. Jaw sheaths are well developed and both jaw sheaths are moderately keratinized. Jaw sheaths completely serrated with uniform-sized serration; supra-rostrodont is longer than wide and convex with long lateral process; infra-rostrodont broad U-shaped, convex laterally and concave medially.

Measurements: Measurements of 42 tadpoles belonging to various Gosner stages (Gosner stages 26, 27, 28, 30, 31, 32, 33, 34, 36, 38, 39, 40, 41, 42) are presented in Table 2.

Colouration: In life, tadpoles were olive on the dorsum and the lateral sides, with many tiny melanophores uniformly distributed. In lateral view, the flanks were comparatively lighter than the dorsum. Ventrally, the integument was white and opaque. Dorsal and ventral fins were dirty and translucent with many melanophores; the anterior portion was more spotted than the posterior. Laterally, the tail muscle was white with many melanophores patches of various sizes. Spiracle and oral disc were dotted with few melanophores, and the vent tube was translucent.

Buccopharyngeal morphology

Buccal roof (Image 4A–B): Prenarial arena comprises an arched pustulose ridge with about six pustulations; bordering the ridge are two to three pustules on either side posterolateral to the ridge. Internal nares transverse and oriented slightly posteromedially; both nares separated by a distance of about two-third the length of each nare; anterior narial wall rather smooth with about two to three pustules and a tall, pustulated papilla originating near the lateral corner of the wall; posterior wall tall, smooth and valvular. Post narial arena consists of a tall conical papilla present immediately behind the posterior narial wall oriented medially;

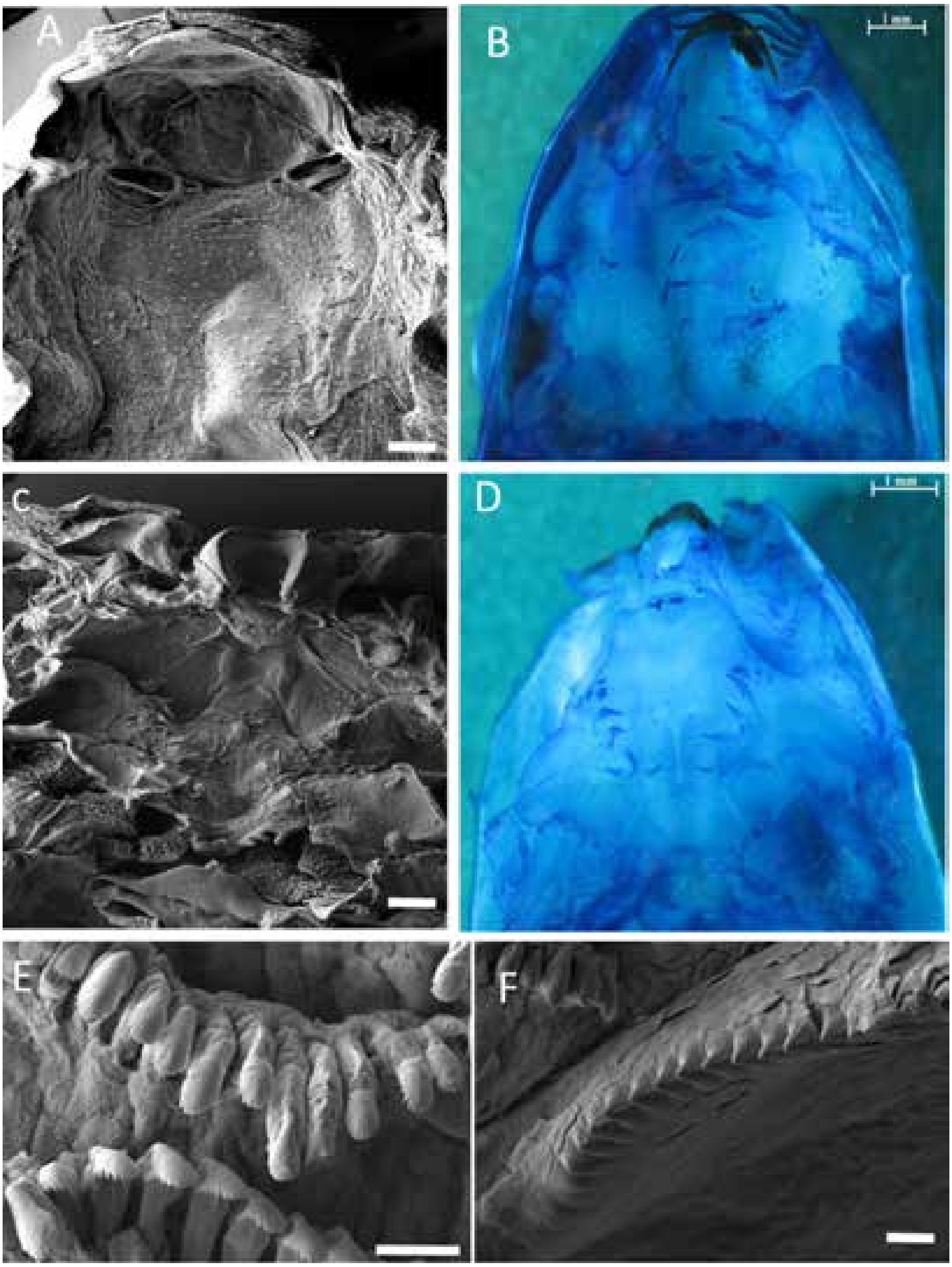

Image 4. *Polypedates pseudocruciger*, Gosner stage 38. Buccopharyngeal and denticles A— Buccal roof, SEM photograph, scale = .2 mm | B—Buccal roof, Alcian blue stained photograph, ventral view, scale = 1 mm | C—Buccal floor, SEM photograph, scale = .2 mm | D— Buccal floor, Alcian blue stained photograph, ventral view, scale = 1 mm | E—Individual denticles, scale = .02 mm | F—Jaw sheath serrations = .02 mm. © Prudhvi Raj.

anterior surface of this papilla is rugose; four pustules are present in front of the median ridge. Median ridge papilla is a triangular flap with a pustulated margin and a long projection medially. A long lateral ridge papilla with a rugose anterior surface is present on the lateral wall on each side perpendicular to the median ridge. Buccal roof arena demarcated with four pairs of long, conical papillae present on the lateral border of the roof; about

50 tiny pustules are spread across the entire buccal roof arena with density higher at the posterior end of the arena. Glandular zone conspicuous; anterior margin of the glandular zone is demarcated by tiny pustules and two to three papillae arranged linearly to the posterior margin of the buccal roof arena. Secretory pits spread throughout the glandular zone. The margin of the dorsal velum is raised, broken medially, and slightly pustulose on the surface.

Buccal floor (Image 4C–D): Prelingual area comprises five pairs of pustules at the anterior end and three pairs of infralabial papillae in the posterior region. Of the three pairs of infralabial papillae, two pairs are located along the posterolateral corners, and the third pair of stubby papillae are located posteromedially between the two posterior papillae; the posterior papillae at the posterolateral corners are elongated and conical with a rugose surface. Tongue anlage broad and raised; two pairs of smooth long lingual papillae are present at the center of the tongue anlage; the inner pair of papillae are longer than the outer. Buccal floor arena delineated by five pairs of buccal floor arena papillae; the buccal floor arena papillae commence from the lateral corners of the floor anterior to the buccal pockets and converge down towards the posteromedial region of the floor, however, the papillae do not meet posteriorly; these papillae are unequal in size, conical and tall; the second papilla from the anterior is the tallest; buccal floor arena composed of about 30 pustulations spread across the floor uniformly. A few papillae and pustules are found beyond the lateral sides of the buccal floor arena. Space between the tongue anlage and the buccal pockets constitutes 14–16 pustulations on each side. Buccal pockets are oblique and wide, orienting linearly towards the anterior; no pocket papillae are present. The region behind the buccal floor arena and the margin of the ventral velum composed of a few pustules sparsely spread medially; ventral velum is wide and sinuate. Ventral velum margin constitutes six projections on each side. The median three projections are closer and concentrated around the center; outer three projections are widely placed apart. Median notch is prominent; the outer margin is granular with many secretory pits. Glottis opens posterior to the ventral velum.

Denticles (Image 4E) are spaced moderately between each other and strongly curved towards the mouth at the apex. The oral angle is straight with a slight curve anteriorly; the sheath is narrow and the body slightly broader; the head is broader with the tip curved. 10–12 short and moderately curved cusps present on each denticle. Serration (Image 4F) on the jaw sheath spaced with a wide base and shot triangular pointed head.

Genus: ***Rhacophorus*** Kuhl & Hasselt, 1822.
Species: *Rhacophorus lateralis* Boulenger, 1883.

Larval series examined: WT142/22711 (Edatara, Wayanad, Kerala, India, 11.62096°N, 75.99955°E; WGS84). Tadpoles were collected from a water tank of about 1 m in depth. The tadpoles were benthic occasionally surfacing. Tadpoles of this species were found along with tadpoles of *P. pseudocruciger* and *R. malabaricus* in some of the pools that were visited during the study.

Taxonomic note: Taxonomic identity of tadpoles was based on fresh metamorphs that morphologically matched taxonomically identified adult *R. lateralis*. No tadpole description for this species is available.

External morphology: Description of tadpole (Gosner stage 36): Snout rounded on both dorsal and lateral profile (Image 5A,B). Body shape oval in both dorsal and lateral views with the body flattened on the dorsum; BL is 36.4% of the total length. Nostril opening is oval-shaped and placed dorsolaterally midway between the eye and the snout; rim of the nasal opening not elevated; NSD is 12.2% of BL. Large bulging eyes oriented dorsolaterally; NED represents 51.1% of the distance between the eye and the snout; INL is 47.1% of IOL. Ventral side is translucent, with the gut coils visible. No glands on the outer integument present. MBD is at the posterior part of the body. Spiracle is sinistral and directed anteroposteriorly, with the inner wall of the spiracle partly formed and attached to the body wall; SS is 52.9% of BL. Vent tube opening is dextral. The tail tapers to a rounded end. The dorsal fin is taller than the ventral fin; MTH is at the mid-length of the tail; TMH is 1.23 times of MTMW at the tail-body junction. TMH accounted for 57.1% of MTH; TMH is tallest at the tail-body junction and continuing till the 1/3rd tail length and thereafter tapering to the tail tip. Origin of the dorsal tail fin at the body tail junction and that of the ventral fin at the ventral terminus. Dermal lines consisting of minute dermal are seen running parallel on either side of the dorsum till the tail tip.

Oral disc (Image 5C) is located terminally at the anteroventral region of the snout. Oral disc is not entire (emarginated) and is bifurcated at the lateral corners; ODD is 27.6% of the body width. Marginal papillae are double rowed on both the labia; distribution of the papillae is not entire with a gap on the upper and lower labia, and papilla distributed till 2/3rd of the labium; papillae on the upper labium is restricted to the lateral

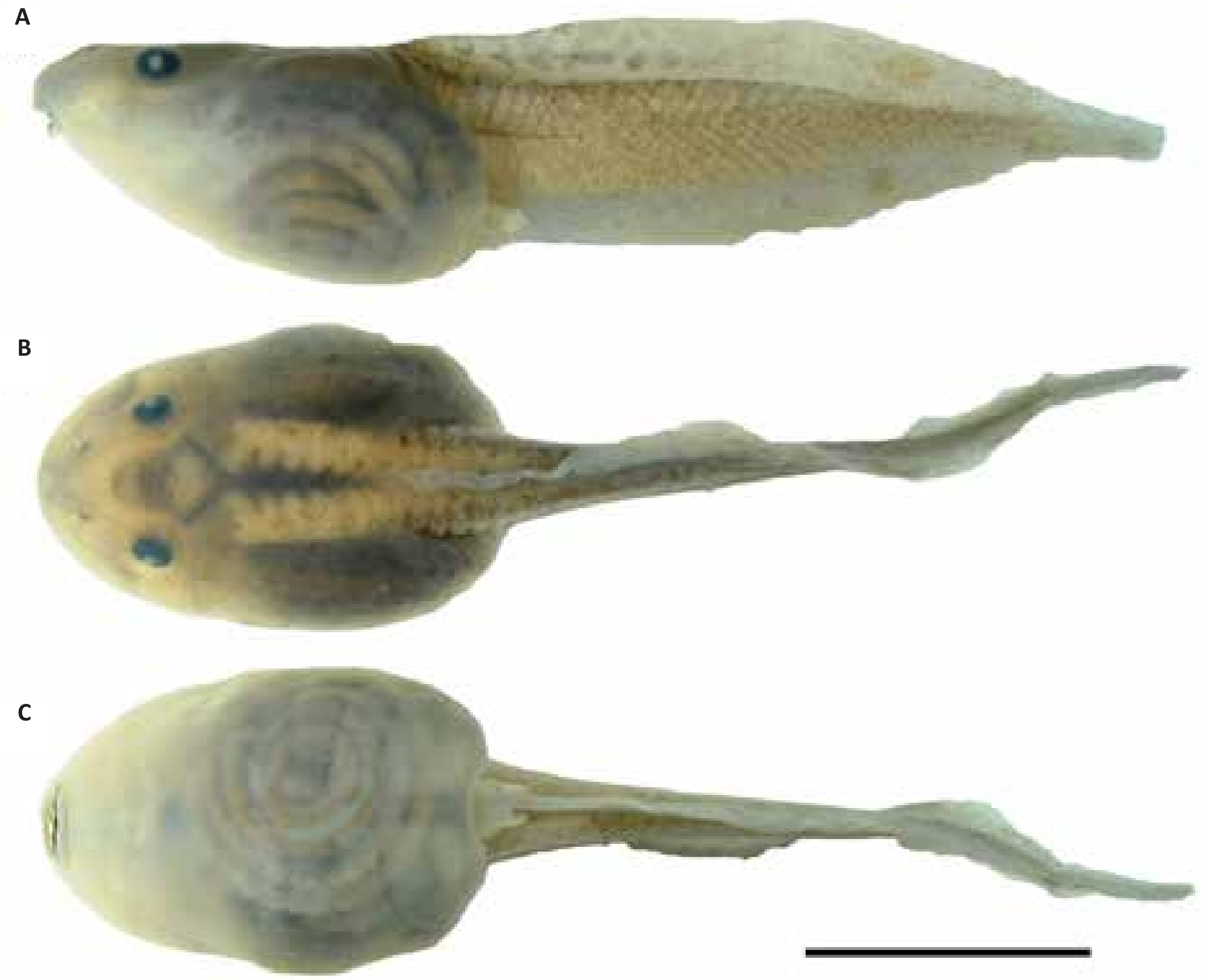

Image 5. *Rhacophorus lateralis*, Gosner stage 35. External morphology: A—Lateral view | B—Dorsal view | C—Ventral view. Scale = 10 mm. © Prudhvi Raj.

corners. Four to six submarginal papillae are present on the lateral corners of the oral disc. The LTRF is 6(3–6)/3(1); two rows of the upper labium (A-1 and A-2) are continuous and the rest bifurcated (A-3 to A-6); the length of each row decreases in descending order from A-1 to A-6; lower labium consisting three-tooth rows of which the P-1 is marginally divided; length of P-1 greater than P-2 row and P-3 being the smallest; tooth rows single. Order of the length of the tooth row is P-1 > P-2 > P-3 > A-2 > A-1 > A-3 > A-4 > A-5 > A-6. Both jaw sheaths are moderately keratinized; uniform-sized minute serrations are present on both the jaw sheaths

Colouration: When freshly collected, the dorsum and the tail were sulphurous-yellow with few tiny melanophores scattered randomly on the dorsum; ventral side was white with no melanophores and translucent. However, the color changed to brown-grey on preservation in 10% formalin. In life, both the dorsal and ventral tail fins were transparent with many blotches present on both fins. The anterior tail fin was dotted with numerous tiny melanophores. Many small blotches were spread across the tail muscle.

Measurements: Measurements of 60 tadpoles belonging to various Gosner stages (Gosner stage 25–Gosner stage 38, 40, 41, 42) are presented in Table 3.

Buccopharyngeal morphology

Buccal roof (Image 6A–B): Prenarial arena of the buccal roof comprises a pustulose transverse ridge arched forward, with the median pustule being the largest. Internal nares transverse and oriented medially, gap between the nares wide with about the length of an individual nare; anterior narial wall pustulose with several tiny pustules and a tall, pustulose papilla stemming from its center; posterior wall is tall, smooth, valvular and smooth. Behind each nare, a tall, broad and

Table 3. Morphometric measurements of *Rhacophorus lateralis* tadpoles given in mm as mean ± SE.

Gosner stage	IOL	INL	NED	NSD	SS	SV	BL	TL	MBD	MTH	MTMW	TMH	ODD	VTL	DFH	VFH
25(3)	2.6±.10	1.6±.18	1.1±.12	1.3±.10	5.7±.12	4.2±.17	8.2±.49	13.0±.49	5.7±.06	4.2±.10	1.3±.12	1.7±.08	2.4±.21	0.9±.08	1.4±.06	1.2±.03
26(2)	3.7±.10	2.4±.05	1.5±.50	1.8±.20	8.3±.25	7.3±.45	12.9±.85	20.9±2.80	7.7±.70	6.3±.95	2.4±.50	2.9±.65	3.1±.55	1.3±.25	2.7±.30	2.1±.50
27(6)	4.0±.18	2.3±.05	1.9±.09	1.8±.10	8.1±.28	6.4±.35	13.1±.49	20.6±.71	8.6±.33	6.5±.27	2.4±.11	2.9±.13	3.4±.13	1.3±.12	2.1±.17	1.8±.16
28(3)	4.8±.10	2.4±.08	2.2±.08	2.1±.05	9.8±.14	7.5±.40	14.5±.54	24.4±1.17	9.7±.34	7.9±.12	2.9±.23	3.7±.17	3.7±.28	1.4±.06	2.7±.13	2.2±.10
29(4)	4.4±.16	2.5±.06	2.1±.08	2.0±.07	9.7±.41	7.9±.48	14.6±.42	25.1±.86	9.4±.40	7.9±.23	3.2±.26	3.6±.08	3.5±.04	1.4±.05	2.6±.14	2.0±.09
30(4)	4.5±.23	2.5±.09	2.1±.06	2.1±.04	9.8±.23	8.3±.45	14.3±.21	25.3±1.23	10.2±.55	8.2±.29	3.1±.29	3.4±.13	4.0±.17	1.4±.09	2.5±.06	2.2±.12
31	4.8	2.6	2.1	2.1	10	7.9	16.7	27.7	10.2	8	3.9	4	4.2	1.5	2.6	2.3
32(2)	4.9±.15	2.6±.10	2.2	2.1	11.3±.25	8.2±.15	16.1±.20	29.3±.25	10.7±.10	8.8±.65	3.6	4.1±.10	4.0±.15	1.2±.05	2.8±.15	2.3±.15
33(2)	4.8±.05	2.7±.10	2.0±.05	2.3±.15	10.8±.25	8.1±.40	15.2±.55	29.9±1.15	11.1±.35	9.1±.50	4.2	4.9	3.9±.05	1.8±.05	2.9	2.1±.10
34	5.6	2.5	2.3	2.4	11.2	10.2	15.9	30.9	11.6	8.2	3.6	4.2	4.3	1.6	2.6	1.9
35(2)	4.8±.10	2.5±.10	2.2	2.0±.05	10.2±.25	9.9±.05	16.6±.60	28.3±.10	12.0±.50	8.9±.10	3.6±.10	4.7±.45	3.2±.15	1.6±.10	2.3±.15	2.2±.20
36	5.3	2.5	2.2	2.1	9.1	8.4	17.2	30	11.2	9.1	4.2	5.2	3.1	1.5	3.2	2.1
37(4)	5.2±.15	2.6±.06	2.2±.15	2.2±.09	10.5±.20	9.2±.12	16.7±.43	29.9±1.33	11.6±.54	9.1±.22	4.2±.06	4.9±.17	3.±.09	1.6±.12	2.4±.04	2.2±.07
38(7)	5.5±.10	2.6±.05	2.2±.04	2.2±.05	10.8±.20	9.4±.44	16.1±.36	30.1±.78	11.2±.21	9.1±.30	3.9±.22	4.6±.18	3.9±.11	1.7±.08	2.8±.12	2.4±.09
40(2)	5.5±.05	2.6±.20	2.3±.05	2.4	11.1±.25	9.1±.40	17.1±.30	31.9±.75	11.5±.25	8.6±.10	4.3±.40	4.7±.20	4.0±.10	1.8±.10	2.7±.05	2.5±.05
41(7)	5.2±.21	2.4±.09	2.1±.11	2.3±.06	11.0±.14	8.6±.36	16.2±.27	30.7±.76	10.7±.34	8.9±.48	3.8±.22	4.0±.25	3.±.15	2.1	2.8±.13	2.2±.17
42(3)	4.7±.15	2.1±.03	2.1±.06	*	*	*	15.8±.63	23.1±2.94	31.0±23.35	4.5±1.02	2.8±.21	3.0±.18	*	*	*	*

curved pustulose papilla is present; the papilla is taller than the papillae on the anterior narial wall and is present immediately behind the posterior narial wall; there are about two to three tiny papillae spread in the post narial arena immediately in front of the median ridge papillae. Median ridge papilla is broad with bifid tip; margin is pustulated. A short and a long, pustulate lateral ridge papilla present perpendicular to the median ridge; the lateral ridge papillae are the longest papillae on the buccal roof. Buccal roof arena demarcated with five pairs of long pustulated papillae present on the lateral border of the roof; about 60 tiny pustules are spread across the entire buccal roof arena. A few non-pustulated smaller papillae are found scattered on the lateral sidewall. A broad glandular zone is present immediately behind the buccal roof arena, with secretory pits present through the glandular zone. The dorsal velum is low and not complete with the medial broken.

Buccal floor (Image 6C–D): Prelingual area comprises of six infralabial papillae, with two long and four tiny papillae on each side; papillae arranged in an oblique row along the margin and lateral sides of the prelingual arena; the second and the posterior papillae are long, broad and pustulose, and the rest of the papillae are diminutive. Tongue anlage round and raised; two smooth lingual papillae present at the center of the tongue projecting outwards. Buccal floor arena is well defined; anterior region of the buccal floor arena smooth; five papilla present on the posterolateral area of the arena; posterior region of the buccal floor arena composed of about 14 pustulations and about six to eight conical papilla evenly spread across on each side of the mesad plane. The buccal pocket opening is wide; region between the tongue and the buccal pockets is coarse with several tiny pustulations; pair of pustulated pre-pocket papilla oriented anteriorly followed by a long, pustulated, curved papillae on the posterior margin of the buccal pocket are present. Ventral velum is smooth with about 12 projections. The outer three projections on either side are widely placed and the rest are concentrated at the center. Median notch is not prominent. Glottis opens slightly posterior to the ventral velum.

Denticles (Image 6E): The denticles are moderately spaced among one another. The oral angle is obtuse; the sheath and the body are narrow; the head is very broad and curved with about 14–16 moderately curved cusps. Each serration (Image 6F) on the jaw sheath is broad with a triangular head.

Species: *Rhacophorus malabaricus* Jerdon, 1870.

Larval series examined: WT138/21711 (Banasuramala hills, Kalpetta, Wayanad, Kerala, India,

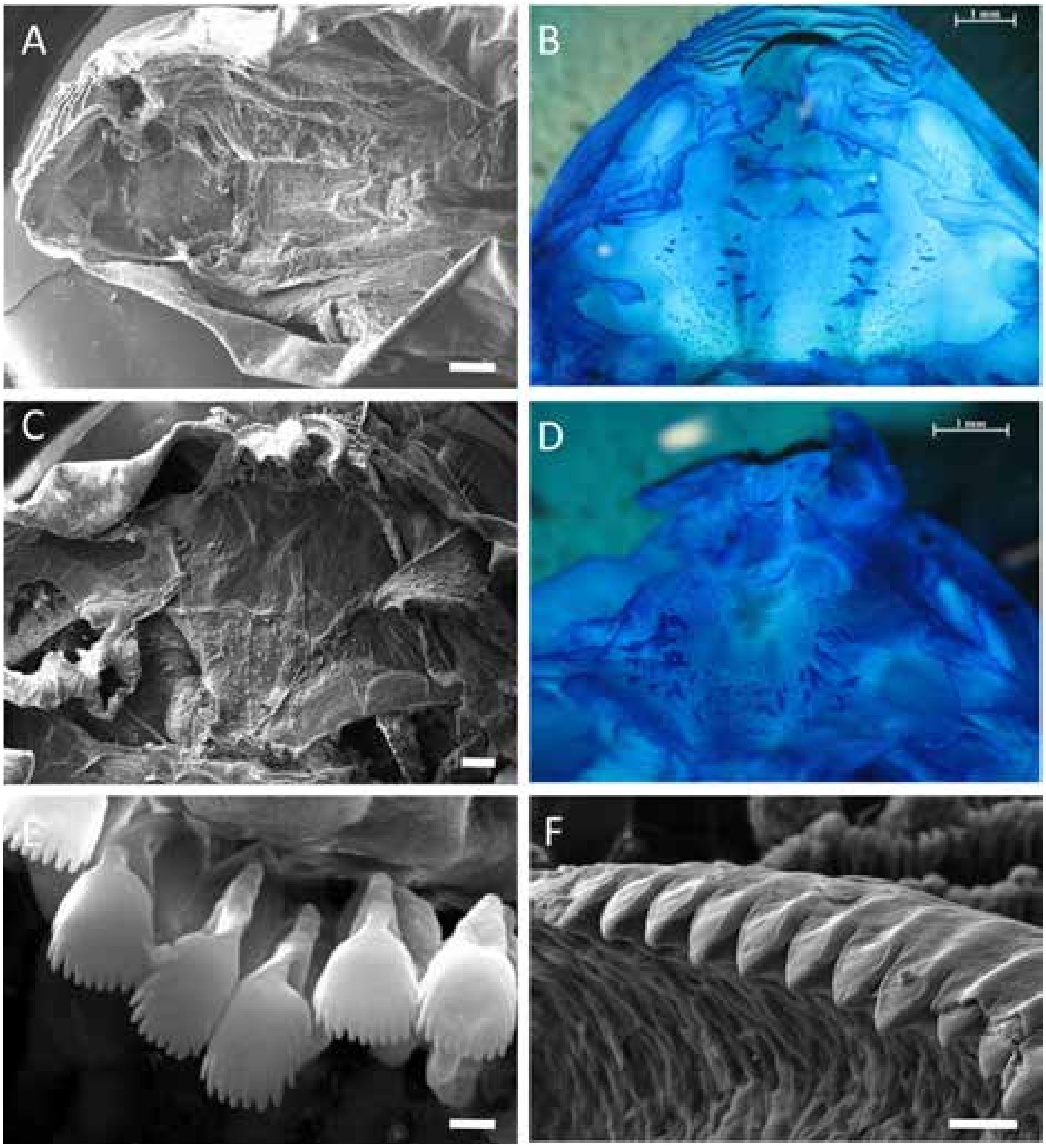

Image 6. *Rhacophorus lateralis*, Gosner stage 37. Buccopharyngeal and denticles: A—Buccal roof, SEM photograph, scale = .2 mm | B—Buccal roof, Alcian blue stained photograph, ventral view, scale = 1 mm | C—Buccal floor, SEM photograph, scale = .2 mm | D—Buccal floor, Alcian blue stained photograph, ventral view, scale = 1 mm | E—Individual denticles, scale = .002 mm | F—Jaw sheath serrations = .02 mm. © Prudhvi Raj.

11.63676°N; 76.0132°E; WGS84), WT143/21711 (Vythiri, near Banasura sagar Dam, Wayanad, Kerala, India, 11.62903°N; 75.96925°E; WGS84). Both the locations were ~10 km apart from each other. Tadpoles were collected from an agricultural water tank that was about 1 m deep. Tadpoles were benthic and fed on benthic detritus material. Tadpoles of this species were found in pools inhabited by *P. pseudocruciger* and *R. lateralis.*

Taxonomic note: Taxonomic identity of tadpoles was based on fresh metamorphs that morphologically matched adult *Rhacophorus malabaricus.* A brief description on external morphological of tadpoles for this species was made by Sekar (1990a) and the current morphological description matches with the description made earlier.

External morphology: Description of tadpole at Gosner stage 36 (Image 7A–B): Snout is rounded on both dorsal and lateral profile; body is oval; BL is 33.2% (31.6%–36.5%) of the total length. Nostril opening oblong and placed dorsolaterally midway between the snout and the eye; fringe of the nasal opening bulged with the dorsal portion slightly elevated; NSD is 14.8% (12.8%–15.9%) of BL. Large bulging eyes oriented dorsolaterally; NED represents 47% (43.9%–52.6%) of the distance between the eye and the snout; INL is 53.6% (46.1%–56.5%) of IOL. Ventral side translucent with the circular gut coils faintly visible; no glands on the outer integument present. MBD is at the back of the abdomen. Spiracle is sinistral directed antero-posteriorly with the inner wall of the spiracle fully formed but attached to the body wall; SS is 68.1% (64.2%–72.2%) of BL. Vent tube is dextral in opening. The tail tapered to a pointed end. Dorsal and ventral fins are of equal height; TMH is 1.2 times (1–1.4) of MTMW at the tail-body junction; TMH accounted for 55.5% (48.9%–65.8%) of MTH; MTH is at about 1/3 rd of the length. Origin of the dorsal tail fin is at the body tail junction and that of the ventral fin at the ventral terminus. A pair of dermal pore lines run parallel on either side of the dorsum till the tail tip.

Oral disc (Image 7C) is located terminally at the anteroventral region of the snout. Oral disc is not entire (emarginated) and is bifurcated at the lateral corners; ODD is 37.2% (31%– 46.4%) of the body width. Marginal papillae are double rowed on the lower labium and present on the entire lower labium and till the lower quarter of the upper labium (single row). The front portion of the upper labium is without marginal papillae. Three–four submarginal papillae found on the lateral corners of the oral disc. The LTRF is 7(3–7)/3(1), with P1

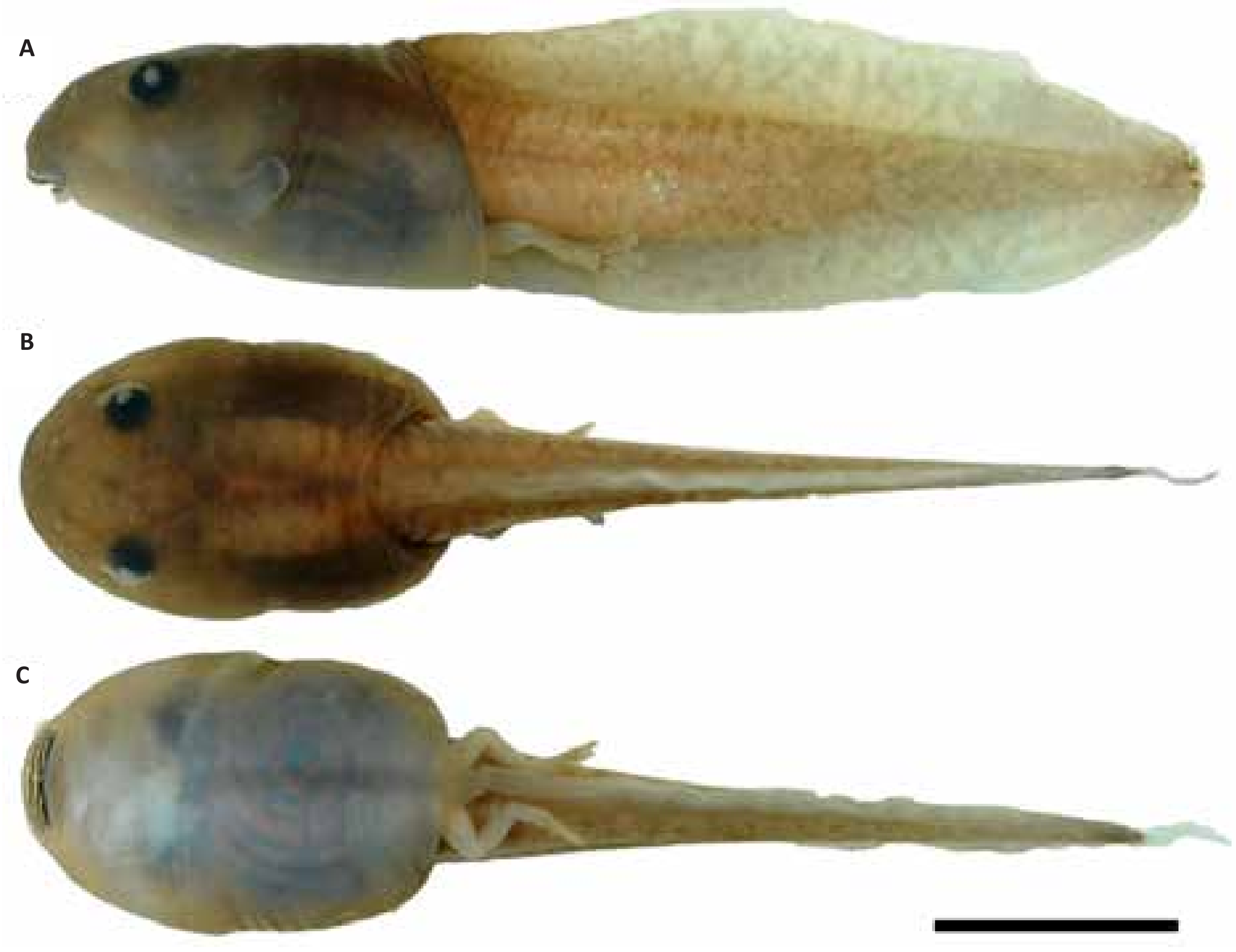

Image 7. *Rhacophorus malabaricus,* Gosner stage 37. External morphology: A—Lateral view | B—Dorsal view | C—Ventral view. Scale = 10 mm. © Prudhvi Raj.

Table 4. Morphometric measurements of *Rhacophorus malabaricus* tadpoles given in mm as mean ± SE.

Gosner stage	IOL	INL	NED	NSD	SS	SV	BL	TL	MBD	MTH	MTMW	TMH	ODD	VTL	DFH	VFH
25(5)	2.7±.17	1.7±.06	1.1±.06	1.3±.06	5.6±.21	4.0±.19	8.4±.30	13.2±.87	5.2±.17	5.1±.36	1.3±.07	1.9±.18	2.4±.10	0.9±.08	2.1±.13	1.7±.11
26(5)	3.3±.07	2.0±.04	1.5±.08	1.6±.05	7.0±.15	4.9±.21	10.6±.13	17.3±.43	6.2±.23	6.5±.15	1.5±.13	2.6±.13	2.9±.05	0.9±.07	2.3±.06	1.9±.09
27	3.4	2.3	1.6	1.7	7.7	4.9	10.1	17.6	6.5	7	1.6	2.5	3.2	0.9	3.1	2.5
28	3.9	2.3	1.7	1.7	7.3	5.9	12.3	20.9	7.1	7	2	2.6	3.6	1.4	2.5	1.8
29	4.6	2.3	2	2.5	8.4	6.4	12.7	23.3	7.9	6.9	2.1	2.9	3.6	1.1	2.4	2.1
30	4.7	2.5	2	2.1	8.7	7.7	14.7	25.1	8.1	7.7	2.2	3.3	3.6	1.3	2.5	2.1
31(4)	3.1±.33	2.0±.03	1.5±.03	1.5±.15	7.3±.29	6.2±.36	11.5±.35	19.7±.79	7.5±.26	6.8±.25	2.7±.19	3.5±.32	2.6±.14	1.4±.17	2.2±.07	2.0±.11
33	4.9	2.5	2	2.3	8.6	7	14.4	26	8.4	7.7	2.9	4.5	4.1	1.4	2.9	2.4
35(2)	4.8±.15	2.5±.15	1.9±.10	2.2±.15	9.0±.70	8.0±.90	14.5±.10	26.0±.10	9.2±.75	8.1±.10	3.9±.65	4.8±.80	3.4±.40	1.8±.15	2.5±.50	2.0±.45
36(5)	4.6±.18	2.5±.08	1.9±.06	2.1±.09	9.7±.18	8.1±.24	14.3±.27	29.0±1.15	9.4±.33	8.7±.30	3.9±.15	4.4±.52	3.4±.14	1.7±.17	2.9±.09	2.6±.10
37(6)	4.5±.13	2.5±.04	1.8±.07	2.0±.04	9.6±.20	8.2±.34	14.6±.27	30.5±.39	9.9±.24	9.1±.21	4.4±.09	5.5±.12	3.4±.08	1.6±.11	2.8±.12	2.5±.07
38(5)	4.9±.15	2.6±.04	2.1±.14	2.0±.07	9.7±.22	7.8±.27	15.1±.44	30.7±.78	9.9±.38	8.6±.34	4.1±.25	5.1±.34	3.6±.07	1.8±.06	2.9±.12	2.6±.11
40(3)	5.6±.06	2.8±.07	2.1±.03	2.7±.07	11.4±.06	8.6±.48	17.8±.28	31.7±.94	10.7±.20	11.2±.42	4.2±.35	5.2±.13	4.6±.13	1.7±.38	3.9±.19	2.8±.07
41	5.8	2.1	2.2	2	11.7	9.6	16.7	35.6	9.8	8.4	3.6	4.5	3.7		3	2.1
42	4.3	2.3	1.8	1.3			16.7	24.1	7.5	5.8	5.4	3.4	3.1		1.8	1.4

row divided (Image 8C). Upper labium has seven rows of denticles; two undivided upper rows (A-1 and A-2) and five lower rows bifurcating (A-3 to A-7); the length of each row decreases in descending order from A-1 to A-7. Lower labium has three denticle rows, of which the P-1 is marginally divided and which P-3 being the smallest. Tooth rows single. Both the jaw sheaths are moderately keratinized with tiny serrations.

Colouration: Body olive in life, with a dirty white venter containing few scattered melanophores; coloration was lost in preserved specimens. Dorsal side of the body and the tail were mottled with several tiny melanophores. The dorsal tail fin was more mottled than the ventral fin. Ventral side of the body was translucent.

Measurements: Measurements of 44 tadpoles belonging to various Gosner stages (Gosner stage 25–Gosner stage 31, 33, 35–38 and 40–42) are presented in Table 4.

Buccopharyngeal morphology

Buccal roof (Image 8A–B): Prenarial arena composed of a thick pustulated transverse ridge arched forward with uniform-sized pustules. Internal nares transverse and oriented slightly posterior; both nares separated by a distance of about half the length of each nare; anterior narial wall smooth with very few tiny pustules and a tall, pustulated papilla originating at the center; posterior wall is tall, valvular and smooth. A tall, conical and pustulated papilla present immediately behind the posterior narial wall; taller than the papilla on the anterior narial wall; the papilla is the largest of all papillae on the buccal roof. Three tiny papillae spread in the post narial arena immediately in front of the median ridge papilla arrange in an inverted V shape pattern. Median ridge papilla is triangular, having a broad base with a serrated margin. A short and long, pustulate lateral ridge papillae present perpendicular to the median ridge. Both the lateral ridge papillae are pustulated on the anterior face. Buccal roof arena is demarcated with five pairs of short stubby papillae present on the lateral border of the roof; further three pairs of small papillae are found on the lateral wall parallel to the buccal roof arena papillae; about 50–60 tiny pustules are spread across the entire buccal roof arena. A glandular zone is seen immediately behind the buccal roof arena. Observations on the dorsal velum cannot be made.

Buccal floor (Image 8C,D): Prelingual area comprises of five pairs of long infralabial palpillae. Four pairs are located on the posterolateral corners and the fifth pair is located posteromedially of the prelingual area. Size of the papillae on the posterolateral corners follows an ascending order, with the anterior-most palp being the smallest and the posterior palp being the largest and dilated at the tip. All papillae have projections placed equidistantly on their anterior face. Two pairs of papillae are seen just ahead of the tongue anlage oriented medially. Tongue anlage round and raised; anterior portion of the anlage broad and tapers towards the posterior side; two lingual papillae with pustulated tip present at the center of the tongue projecting

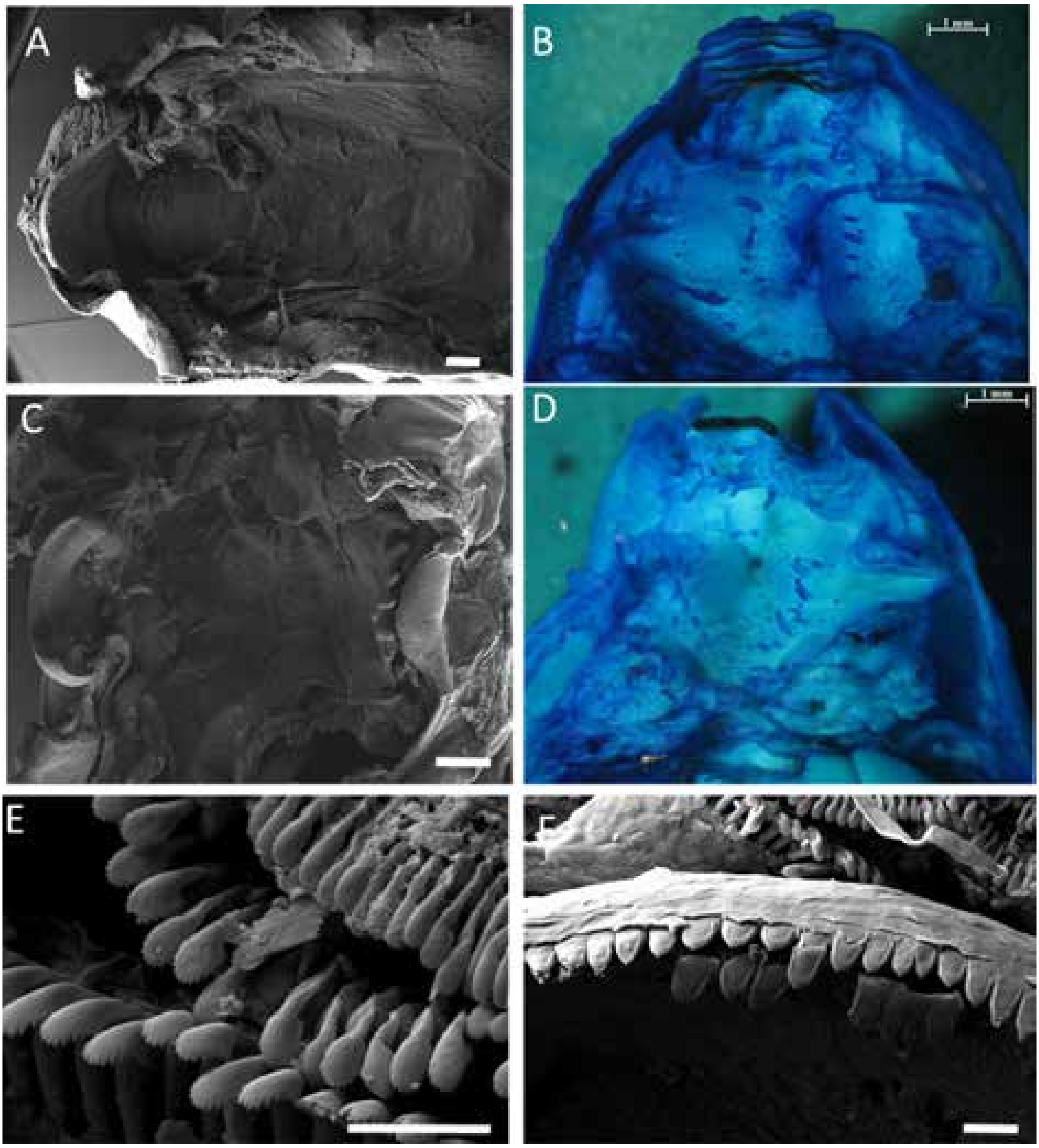

Image 8. *Rhacophorus malabaricus,* Gosner stage 37. Buccopharyngeal and denticles: A— Buccal roof, SEM photograph, scale = .2 mm | B—Buccal roof, Alcian blue stained photograph, ventral view, scale = 1 mm | C—Buccal floor, SEM photograph, scale = .2 mm | D—Buccal floor, Alcian blue stained photograph, ventral view, scale = 1 mm | E—Individual denticles, scale = .02 mm | F—Jaw sheath serrations = .01 mm. © Prudhvi Raj.

outwards. Buccal floor arena delineated by buccal floor arena papillae; anterior region of the buccal floor arena smooth; five papillae starting from the posterior of buccal pocket and continuing along the posterolateral area on each side of the arena; anterior papillae are long, curved and pustulated; a second row of four papillae present on the laterally to the buccal floor arena papillae; buccal floor arena composed of six–eight papillae and about 40 pustulations. Space between the tongue anlage and the buccal pockets consisting of 12–14 pustulations on each side. Buccal pockets are oblique and wide; a pair of pustulated pre-pocket papillae oriented anteriorly followed by a long, pustulated, curved papillae on the posterior margin of the buccal pocket are present. Region behind the buccal floor arena and the margin of the ventral velum composed of about 16 pustulations evenly spread across; Ventral velum is wide and sinuate. Margin constitutes six projections on each side. The median three projections are closer and concentrated around the center, outer three projections are widely placed and the rest are concentrated at the center. Median notch is not prominent; the outer margin is smooth with no spicules with many secretory pits visible. Observation on the glottis and brachial baskets could not be made. Glottis opens immediately posterior to the ventral velum.

Denticles (Image 8E): The denticles are moderately spaced between one another. The oral angle is obtuse; the sheath is narrow and the body slightly broader; the head is very broad and curved with about 12–14 moderately curved cusps. Each serration (Image 8F) on the jaw sheath is broad and long with a triangular pointed head.

Genus: ***Minervarya*** Dubois, Ohler & Biju, 2001.
Species: *Minervarya* cf. *agricola* (Jerdon, 1853)

Larval series examined: WT136/20711 (Soochipara, Meppadi, Wayanad, India, 11.485322°N; 76.151828°E; WGS84). Tadpoles were collected from a temporary pool that is less than 0.5 m deep. Substratum in the pool was sandy without any aquatic vegetation.

Taxonomic note: Adults of *Minervarya agricola* were collected at the locality from where the tadpoles were collected. Tadpoles of this species are not described (Ganesh et al. 2017; Chandramouli et al. 2019).

External morphology: Description of tadpole (Gosner stage 38): Body elliptical in dorsal and lateral profiles respectively (Image 9A–B). Dorsal contour convex and ventral contour of the body flat anteriorly with a slight concavity, and convex at abdominal region; BL is 34.3% of the total length; MBD at the middle of the body. The snout is rounded in dorsal and lateral views. Eyes are large; located and oriented dorsolaterally; NED represents 46% of the distance between the eye and snout. The nostril opening is oblong with the rim of the narial opening elevated, nearer to the eyes than the snout; placed wide apart from each other and near to the eye in dorsal view; INL is 46.4% of IOL; NSD is 16.3% of BL. The opening of the spiracle is sinistral; inner wall of the tube is completely formed but attached to the body wall with the aperture free; tube orientation is

Image 9. *Minervarya* cf. *agricola*, Gosner stage 36. External morphology: A—Lateral view | B—Dorsal view| C—Ventral view. Scale = 10 mm. © Prudhvi Raj.

Table 5. Morphometric measurements of *Minervarya* cf. *agricola* tadpoles given in mm as mean ± SE.

Gosner stage	IOL	INL	NED	NSD	SS	SV	BL	TL	MBD	MTH	MTMW	TMH	ODD	VTL	DFH	VFH
28(3)	1.2±.05	0.7±.03	0.5±.08	0.7±.12	3.5±.26	2.1±.08	5.0±.08	8.2±.39	3.1±.08	2.3±.37	0.7±.03	1.1	1.2±.20	0.7±.08	0.8	0.6±.03
29	1.4	0.8	0.7	1.1	4.1	2.6	6.3	10.7	3.5	2.2	1.2	1.6	1.3	1.2	1	0.7
30	1.4	1	0.8	1	4.2	2.7	6.9	12.3	4.3	2.7	1.1	1.3	1.5	1.1	1	0.7
31(3)	1.8±.17	1.1±.05	0.8±.03	1.1±.03	5.1±.15	3.2±.23	7.4±.29	13.3±.86	4.7±.17	2.9±.17	1.3±.13	1.4±.13	1.4±.03	1.3±.12	1.0±.08	0.8±.05
32(4)	2±.08	1.1±.06	1.0±.06	1.1±.04	5.2±.11	3.2±.14	7.9±.16	14.7±.53	7.4±2.66	3.7±.47	1.9±.54	1.6±.06	1.3±.08	1.5±.17	1.3(±.05)	0.9(±.04)
33(8)	2.0±.06	1.2±.03	1.0±.03	1.3±.04	5.7±.10	3.6±.10	8.5±.12	16.2±.36	5.4±.16	3.5±.07	1.6±.05	1.9±.05	1.4±.04	1.5±.05	1.3±.04	0.9±.04
34(7)	2.1±.06	1.2±.04	1.0±.04	1.3±.03	5.8±.10	3.8±.16	8.5±.13	15.9±.47	5.5±.14	3.8±.09	1.7±.04	1.9±.02	1.5±.06	1.6±.06	1.4±.07	0.9±.05
35(4)	2.1±.10	1.1±.07	1.1±.04	1.2±.02	6.0±.12	3.9±.10	8.6±.18	17.1±.44	5.4±.08	3.7±.04	1.6±.15	2.0±.06	1.5±.06	1.6±.05	1.4±.05	0.9±.04
36(2)	2.3±.25	1.2	1.1±.10	1.3±.10	5.8±.45	3.8±.20	8.9±.30	17.8±.65	5.3±.60	3.9±.15	1.8	2.2	1.6±.05	1.8±.35	1.3	1.1±.10
37	2.2	1.1	1	1.3	5.2	4.6	8.9	15.4	4.9	3.4	1.4	1.9	1.5	1.7	1.2	1
38	2.4	1.3	1.3	1.5	6.1	4.2	9.2	17.6	5.2	4.2	1.8	2.1	1.5	1.7	1.5	1.2
40	2.3	1	1.2	1.3	5.9	5	10.5	17.9	6.3	3.8	1.8	1.7	1.6	1.8	1.5	1
41(2)	3±.10	1.2±.20	1.0±.15	1.4±.40	6.9±.35	4.1±.50	10.2±.95	19.5±1.05	6.3±.35	4.3±.15	2.1±.25	2.2±.15	1.8±.05	1.1	1.4±.05	0.9±.05

posterolateral and its opening is located approximately above the medial of the lateral side of the body; SS is 59.2% of BL. Vent tube opening is dextral and slanting; the right wall is attached posteriorly than to the left wall. Tail tip acute and sharp; musculature is linear till 1/3rd length of the tail after which it tapers. The dorsal fin originates at the body tail junction and the ventral fin at the ventral terminus; the dorsal fin is wider and slightly convex than the ventral fin, which is parallel to tail musculature for most of the length of the tail. MTH is at 2/3rd length from the body tail junction; TMH is 1.16 times of MTMW at the tail-body junction; TMH accounts for 50% of MTH. Lateral line on the body and the tail is visible. No glands are present on the outer integument.

Oral disc is anteroventral in location (Image 9C); ODD is 28.8% of the body width, emarginated; not visible dorsally; single row of marginal papillae spread on lateral corners of the upper labium and double row on the lower labium; medial gaps are seen on both the labia of which the anterior gap is transformed into A-1; no submarginal papillae are present; both labia are of equal size. The LTRF is 2(2)/3(1). Order of the length of denticle rows is A-1 > P-1 > P-2 > P-3 > A-2. Jaw sheaths are well developed and moderately keratinized. Jaw sheaths are completely serrated with small uniform-sized serrations; supra-rostrodont is wide and convex with an arched outline; infra-rostrodont is U-shaped with a concave median.

Measurements: Measurements of 37 tadpoles belonging to various Gosner stages (Gosner stages 28–38, 40, 41) are presented in Table 5.

Colouration: In life, tadpoles were dirty yellow on the dorsum, with many tiny melanophores spread on the dorsal side. Ventrally the belly was dirty yellow with no melanophores and translucent. Laterally, the tail muscle was unicoloured, having a yellow background with many tiny melanophores on the entire length. Dorsal and ventral tail fins were translucent with many tiny melanophores, with the dorsal fin more spotted than the ventral fin; the posterior tip of the tail was pigmented black. Oral disc and the vent tube were translucent with no pigmentation; however, the spiracle was dotted with few melanophores.

Buccopharyngeal morphology

Buccal roof (Image 10A,B): Prenarial arena comprises an arched tri-lobed pustulose median ridge; two pustules are present laterally on either side of the ridge. Internal nares transverse and directed medially; both nares separated by a distance of about half the length of each nare; anterior narial wall studded with few pustules and a short papilla with a rugose margin originating at lateral corner of the wall; posterior wall smooth and valvular with a tiny narial valve projection near to the medial region of the roof. Post narial arena consists of two tall, broad papillae situated immediately behind the posterior narial wall oriented medially; anterior margin of the papilla is rugose. Median ridge papilla is a triangular flap with a pustulated margin. Two flattened lateral ridge papillae pustulated on the anterior margin present perpendicular to the median ridge. The anterior papilla is short and serrated on the margin, while the posterior papilla is longer, broader and bifid with a rugose margin. Buccal roof arena

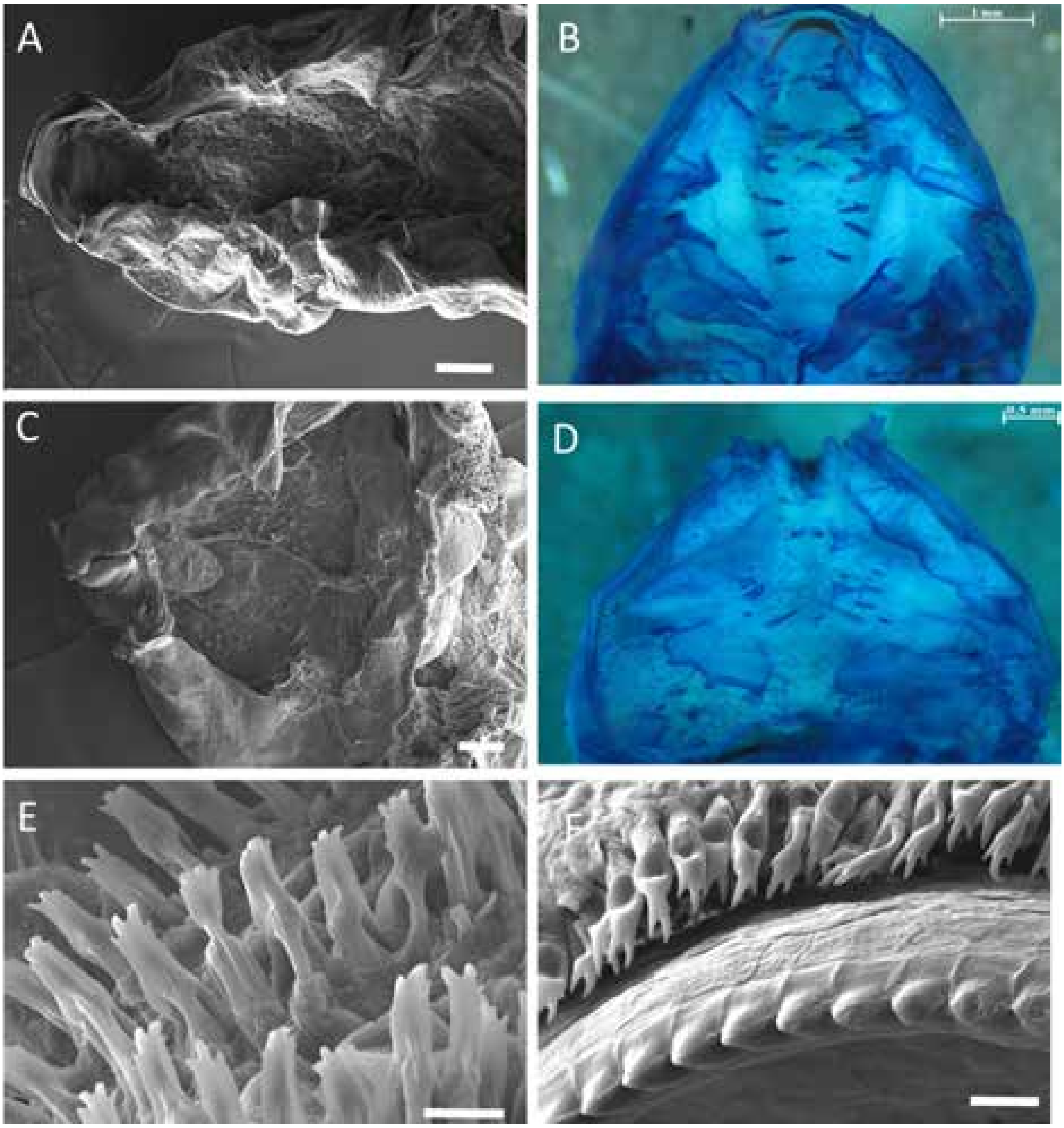

Image 10. ***Minervarya* cf. *agricola*, Gosner stage 36. Buccopharyngeal and denticles: A—Buccal roof, SEM photograph, scale = .2 mm | B—Buccal roof, Alcian blue stained photograph, ventral view, scale = 1 mm | C—Buccal floor, SEM photograph, scale = .1 mm | D—Buccal floor, Alcian blue stained photograph, ventral view, scale = .5 mm | E—Individual denticles, scale = .01 mm | F—Jaw sheath serrations = .01 mm. © Prudhvi Raj.**

demarcated with three pairs of long conical pustulated papillae present along the lateral border of the roof; about 30 tiny pustules spread across the entire buccal roof arena. Glandular zone is broad and distinctive, with the anterior margin consisting of pustules; secretary pits sparse and found medially. Dorsal velum margin is conspicuous and oriented posteriorly. The margin of the velum is pustulated and interrupted medially.

Buccal floor (Image 10 C,D): Prelingual area comprises of three pairs of infralabial papillae located along the posterolateral and postero-medial corners; anterior papillae is short with attenuate projections, while the posterior papillae are larger, broader and rugose located at the posterolateral corners of the prelingual arena; third pair of papillae are located posteromedially between the two posterior papillae on the prelingual arena. Tongue anlage broad and low; two pairs of long conical lingual papillae with pustulated tips are located medially. Buccal floor arena delineated by five pairs of buccal floor arena papillae; the papillae commence anteromedial to the buccal pocket and continue parallel to the mesad plane; all papillae are conical, tall, rugose and of unequal size; the second papilla from the anterior is taller than other papillae; buccal floor arena is smooth with about ten pustules. Space between the tongue anlage and the buccal pockets is free of pustules. Buccal pockets are wide, shallow and transverse orienting towards the mesad; no pocket papillae are present. Region behind the buccal floor arena and the margin of the ventral velum is broad and smooth; ventral velum is wide and sinuate. Ventral velum margin constitutes six projections on each side. The outer three projections are larger and spaced wide apart, while the other three are smaller and concentrated around the center. Median notch is not prominent; the outer margin is smooth with no spicules. Glottis opens posterior to the ventral velum.

Denticles (Image 10E) are moderately spaced and moderately curved towards the mouth at the apex. Oral angle is slightly obtuse. The head of the denticle is short, flattened and slightly curved with 3–4 long, wide, and moderately rounded cusps present on each denticle. Each serration (Image 10F) on the jaw sheath has a short base and a triangular pointed head.

Genus: *Nyctibatrachus* Boulenger, 1882.
Species: *Nyctibatrachus* cf. *periyar* Biju, Bocxlaer, Mahony, Dinesh, Radhakrishnan, Zachariah, Giri & Bossuyt, 2011.

Larval series examined: WT145, WT156/151011 (Small stream in tea plantation, Vagamon, Kotayam, India, 9.68266°N, 76.90549°E; WGS84). Tadpoles were collected from a small stream with a muddy substratum.

Taxonomic note: Adults of *Nyctibatrachus periyar* were recorded from the stream where the tadpoles were collected. However, other species of *Nyctibatrachus* are known to occur in the locality where the tadpoles were collected (Biju et al. 2011, but see Abraham et al. 2022; Garg et al. 2017). Tadpoles of *N. periyar* are not described.

Image 11. *Nyctibatrachus* cf. *periyar,* Gosner stage 37. External morphology: A—Lateral view | B—Dorsal view | C—Ventral view. Scale = 10 mm. © Prudhvi Raj.

Table 6. Morphometric measurements of *Nyctibatrachus* cf. *periyar* tadpoles given in mm as mean ± SE.

Gosner stage	IOL	INL	NED	NSD	SS	SV	BL	TL	MBD	MTH	MTMW	TMH	ODD	VTL	DFH	VFH
25(8)	2.2±.17	1.5±.06	0.8±.09	1.1±.09	5.0±.25	4.4±.25	8.7±.49	17.0±.89	5.2±.22	3.6±.17	2.1±.10	2.6±.13	1.6±.11	1.5±.08	1.0±.06	0.7±.04
26(2)	1.6±.25	1.2±.05	0.5±.05	1.2±.05	4.3±.05	3.9±.20	8±.10	14.7±.60	4.0±.15	3.3	1.6±.25	1.7±.05	1.6±.05	1.8	1.2±.10	0.9
27(2)	2.5±.25	1.8±.05	1.3±.45	1.4±.05	6.0±.25	5.4±.50	10.4±.30	21±.60	7.05±.55	4.3±.30	2.6±.05	2.9±.10	2.4±.55	1.7±.05	1.3±.25	0.8±.15
28(2)	2.1±.35	1.5±.30	0.8±.40	1.5±.20	5.5±.80	4.4±.75	9.0±1.15	16.7±2.40	5.8±.95	3.7±.50	2.3±.65	2.7±.85	1.9±.40	1.9	1.3±.20	0.9±.05
29	2.2	1.5	0.6	1.3	4.8	4.2	8.6	16.7	4.5	3.3	1.8	2	1.8	2	1.4	1
30(3)	2.5±.47	1.5±.15	0.8±.15	1.4±.24	5.6±.91	5.1±.88	9.9±1.33	19.0±2.43	5.7±.85	3.9±.48	2.3±.50	2.5±.53	2.0±.20	6.7±4.66	1.1±.08	0.9±.05
31	1.6	1.2	0.5	1.2	4.7	4.1	8.7	15.1	4.3	3.2	1.7	1.9	1.7	1.6	1.3	1.1
35(2)	2.1±.05	1.5	0.7	1.2±.10	4.9±.25	4.5±.25	8.8±.40	18±.40	4.8±.05	3.4±.35	1.9±.10	2.2±.05	1.6±.15	2.0±.05	1.1±.10	0.9±.05
36(2)	2.4±.05	1.4±.05	0.7±.05	1.5	5.7±.20	4.6±.25	9.5±.25	19.3±.25	5.4±.05	4.2±.20	2.1±.05	2.4±.05	1.8±.05	2	1.5±.10	1.1±.10
37(2)	2.4±.15	1.6±.10	0.7±.10	0.8±.25	6±.50	5.5±.40	10.2	18.8±1.10	5.6±.15	3.9±.10	2.3±.20	2.5±.10	1.8±.40	2.2±.30	1.1±.10	0.9±.20
38(2)	2.3±.20	1.6±.05	0.6±.15	1.3	5.7±.45	5.1±.20	10±.20	20.6±.80	5.7±.60	4.2±.25	2.3±.35	2.5±.25	1.8±.05	1.8±.30	1.2±.15	1±.10
39	2.9	1.8	0.9	1.5	6.2	5.1	10.8	22.8	6	4.1	2.6	2.7	1.9	2.2	1.2	0.9
41(5)	2.7±.10	1.5±.05	0.9±.03	1.3±.02	5.7±.08	4.6±.15	9.5±.27	20.0±.76	5.7±.12	4.0±.12	2.4±.08	2.5±.05	1.9±.04	*	1.4±.06	1±.04

External morphology: Description of tadpole (Gosner stage 37): Body elliptical in dorsal and lateral views (Image 11A,B). Dorsal contour convex and ventral contour of body flattened; BL is 35.2% (33.8%–36.5%) of the total length; MBD at mid-length of the body. The snout is rounded in dorsal and lateral views. Eyes are large; located and oriented dorsolaterally; NED represents 46% (42.1%–50%) of the distance between the eye and snout. The nostril opening is oval with the rim elevated; there is a small protuberance at the dorsal most region of the nostril; they are located closer to the eyes than the snout; placed parallel to the eye in dorsal view; INL is 65.3% (65.2%–65.3%) of the IOL. Spiracle sinistral and short; inner wall of the tube completely formed but attached to body wall; tube orientation is posterolateral and its opening located just below the medial on the lateral side of the body; SS is 58.8% (53.9%–63.9%) of BL. Vent tube is dextral with the opening of the aperture towards the right side; both the walls meet each other at the same point. Tail tip acute; musculature is tallest at the body tail junction and tapers to the tip of the tail. The dorsal fin originates behind the body tail junction and the ventral fin at the ventral terminus; the dorsal fin is wider and concave than the ventral fin; MTH is at about mid-length; TMH is 92% (91.1%–93%) of MTMW at the tail-body junction; TMH accounted for 64.1% (63.1%–65%) of the MTH. Lateral line formed by the dermal pores visible. No glands are present on the outer integument.

Moderately large oral disc, which is near ventral in located and opening ventrally (Image 11C); ODD is 32.4% (30% –34.8%) of the body width, emarginated; not visible dorsally; the entire labium is multi-lobed with about eight lobes; the anterior lobe is the largest followed by those on the lateral sides and the posterior; posteriorly, the labium is divided into four lobes. The margins of the labia are with a uniserial row of large marginal papillae spread along the margin of the oral disc; sharp submarginal papillae are seen above the upper jaw sheath as well as on the lobes, both laterally and ventrally; the submarginal papillae above the upper jaw sheath are arranged in two rows and are smaller; the submarginal papillae on the lateral and ventral lobes are larger, fewer and widely placed; about four to five submarginal papillae are seen on each lateral and ventral lobes. No labial tooth rows are present and submarginal papillae are seen in place of denticle rows on the upper labium. Jaw sheaths are well developed and both the jaw sheaths are massively keratinized; supra-rostrodont is longer than wide and convex with long lateral processes; infra-rostrodont is U-shaped, convex laterally and concave medially. Both the jaw sheath are serrated, however, the serrations on the infra-rostrodont are larger than those on the supra-rostrodont.

Measurements: Measurements of tadpoles belonging to various Gosner stages (Gosner stages 25–31, 35–39 and 41) are presented in Table 6.

Colouration: In life, tadpoles were light beige brown with moderate-sized dark brown spots on flanks and dorsum. The inner integument along the lateral sides was found to be dotted with numerous melanophores giving the region a darker appearance than the rest. Ventrally the integument was dirty white and transparent with

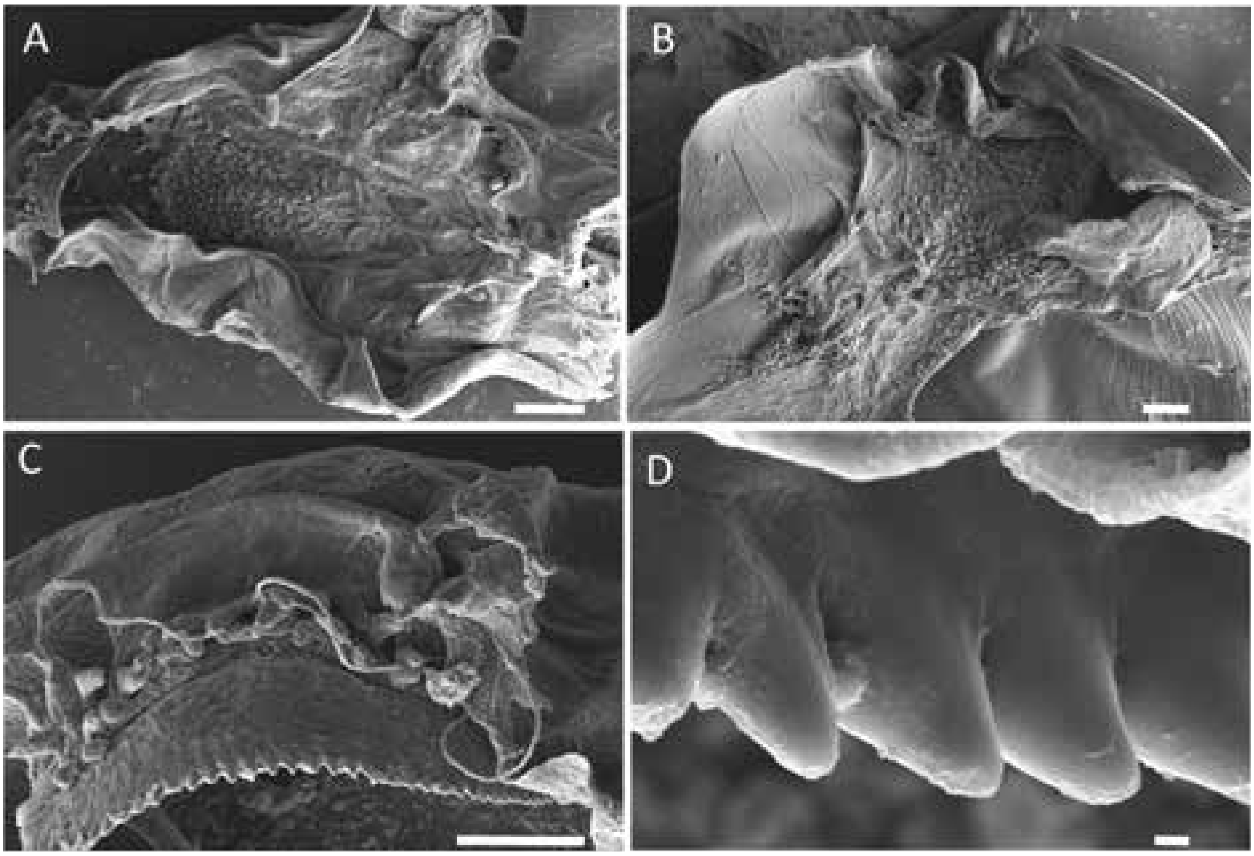

Image 12. *Nyctibatrachus* cf. *periyar*, Gosner stage 38. Buccopharyngeal and denticles: A— Buccal roof, SEM photograph, scale = .2 mm | B—Buccal floor, SEM photograph, scale = .1 mm | C—Jaw sheath with oral papillae, scale = .1 mm | D—Jaw sheath serrations = .002 mm. © Prudhvi Raj.

gut visible. The tail muscle has a white background and is mottled with many medium-sized irregular-shaped blotches of moderate-sized melanophores spread across the tail muscles. Dorsal and ventral tail fins were white and translucent with many bands of melanophores, mostly along the posterior region of the tail. Spiracle, oral disc and the vent tube were translucent with no melanophores. Few melanophores were found on the dorsal side of the hind limb.

Buccopharyngeal morphology

Buccal roof (Image 12A): Prenarial arena comprises of nine papillae; about eight papillae are arranged in a diamond shape anteriorly; a short papilla is present along the medial axis posterior to these anterior papillae; all anterior papillae are more or less of equal height. Internal nares transverse and directed medially; both nares broadly separated by a distance of about more than the length of a nare; a short papilla is present medially between the nares; anterior narial wall is pustulose with many tiny pustules and a stubby projection origination at the middle; posterior wall tall, smooth and valvular; two projections of which one is seen at the middle of the wall and the other at the medial end; both the projections are conical and pustulose; the projection seen near the mesad is longer than the projection at the middle of the posterior narial wall. Post narial arena constituted two pairs of papillae arranged behind the posterior narial wall linearly from the mesad plane; all papillae are long with a rugose surface; size wise, the papillae show an ascending order with the papillae near to the mesad plane being slightly shorter and the papillae on the lateral corners being longer. There is no median ridge; however, there are many tiny conical papillae at its location. A long trifid pustulose lateral ridge papillae is present. Buccal roof arena is delineated by about 20 pairs of closely arranged short buccal roof arena papillae. More than 300 pustulations dot the entire buccal roof arena; the posterior region of the buccal roof arena is demarcated by broad bifid papillae on each side. Observations on the glandular zone could not be made and is not prominent as seen in tadpoles of other genus. The dorsal velum is raised and there appears to be a deep grove in front of the margin of the velum; the margin is not entire and broken medially; margin of the velum along the lateral sides had few tiny projections spaced widely and medially there are numerous projections oriented posteriorly.

Buccal floor (Image 12B): Prelingual area comprises of four pairs of infralabial papillae located along the posterolateral corner of the prelingual area; the first two pairs are moderately long and rugose on the surface; the third pair is trifid and has three thick projections with a rugose surface; the fourth pair has numerous long conical projections (~10). Tongue anlage low and constituted two pairs of papillae; the medial pair of papillae are attached to each other at the base and longer; both pairs of papillae are spread wide apart. The entire floor is dotted with numerous pustules which are bordered anterolaterally by long papillae spread linearly from the lingual arena and posterolaterally by the buccal floor arena papillae; more than 400 pustules are spread across the entire floor; about four to five conical papillae of unequal size are arranged linearly from the lingual arena to the buccal pockets; buccal floor arena is demarcated laterally by about six to eight buccal floor arena papillae; these buccal floor arena papillae are broadly dilated at the tips forming multiple projections. Buccal pockets are small and narrow-oriented anteromedial; no pocket papillae are present. The region between the buccal floor arena and the margin of the velum is smooth. Ventral velum margin is smooth, with about eight to ten long projections mainly concentrated around the medial region on the velum. Glottis opens immediately posterior to the velum.

The serrations (Images 12C–D) on the jaw sheaths are large and, each serration had a wide base and triangular pointed head.

DISCUSSION

Duttaphrynus melanostictus is the most widely distributed toad in southern and southeastern Asia and is a species complex (Dubois & Ohler 1999). Descriptions of morphology for tadpoles of *D. melanostictus* made earlier (Boulenger 1912; Bourret 1942; Kirtisinghe 1957; Daniel 1963a; Khan 1982; Ye et al. 1986; Ray & Tilak 1994; Deuti & Goswami 1995; Chou & Lin 1997; Leong & Chou 1999; Ray 1999; Khan 2001; Anders 2002; Daniel 2002) are brief and do not mention diagnostic features of *D. melanostictus* which distinguish it from other *Duttaphrynus* tadpoles. While resolving the taxonomy of the species is beyond the scope of this paper, morphological comparison for tadpoles is being done with published descriptions of the species and its congeners (Annandale & Rao 1918; Kirtisinghe 1957; Daniel 1963; Khan 1965; Bhati 1969; Inger 1985; Khan & Mufti 1994; Ray 1999; Anders 2002; Khan 2002, 2003a; Daniels 2005; Fei et al. 2005; Inthara et al. 2005; Aran et al. 2012). The external and buccopharyngeal morphologies of the tadpoles of *D.* cf. *melanostictus* are very similar to those of other known *Duttaphrynus* tadpoles. External character states of *D.* cf. *melanostictus* tadpoles that are consistent with other *Duttaphrynus* tadpoles are: oval body with a rounded head; dorsolateral eyes; spiracle opening sinistral; vent tube opening medial; a lanceolate feeble tail with a rounded tip; emarginated oral disc with five tooth rows (2/3). Likewise, *Duttaphrynus* tadpoles share the following buccopharyngeal character states: a prominent transverse semicircular or triangular ridge in the prenarial arena; pustulose anterior narial wall with no papilla; smooth posterior narial wall; a triangular median ridge; branched lateral ridge of papilla; a prominent glandular zone with an elevated dorsal velum; dilated infralabial papillae; two pairs of lingual papillae; well-defined buccal floor arena; projections on the ventral velum. Tadpoles of *D.* cf. *melanostictus* can be diagnosed on the basis of: dark coloured tadpole (uniformly pigmented with black melanophores and speckled with gold); tail musculature black with fins translucent; spiracle with partially formed inner wall; emarginated oral disc with marginal papillae spread only at the lateral corners; labial tooth row formula is 2(2)/3 with the order of tooth rows length being A1>P1>A2>P2>P3; triangular prenarial ridge; trifid lateral ridge papillae; buccal roof arena demarcated by three pairs of papillae; a pair of bifid dilated infralabial papillae; buccal floor arena demarcated by six long conical papilla; both arenas with 20–30 pustulations.

On mainland India, 12 species of *Polypedates* are known to occur, among which tadpoles of *Polypedates maculatus, P. taeniatus* and *P. teraiensis* have been described. *P. pseudocruciger* and *P. occidentalis* are endemic to the Western Ghats. Tadpoles of *P. pseudocruciger* are similar to those attributed to the nektonic morphotype tadpoles of *Polypedates* (Inger 1985; Mohanty-Hejmadi & Dutta 1988; Grosjean 2004; Haas & Das 2008; Chakravarty et al. 2011). External character states of *P. pseudocruciger* tadpoles that are consistent with other *Polypedates* tadpoles are: an anteroventral oral disc; LTRF with multiple tooth rows and strongly keratinized jaw sheaths; body cylindrical with eyes positioned laterally and widely spaced nares; spiracle opening sinistral; vent tube opening dextral; tail fins arched and tapper posteriorly. Buccopharyngeal character states of *P. pseudocruciger* tadpoles that are consistent with other *Polypedates* tadpoles are:

broad buccal roof and floor; an arched prenaial ridge; elongated pre and postnarial papillae oriented medially; median ridge low; buccal roof and buccal floor arena delineated by papillae; presence of glandular zone; tongue anlage with lingual papillae; oblique buccal pockets; ventral velum with projections on margin of velum. Diagnostic characters of *P. pseudocruciger* tadpoles are: body colouration olive with many tiny melanophores on dorsal and lateral sides; tail fins with numerous melanophores, more spotted at the anterior end of the tail; nasal opening oval shaped and elevated; inner wall of spiracle absent; emarginated oral disc with marginal papillation having a wide gap on the upper labium and a small gap on the lower labium; three submarginal papillae at the lateral corners; LTRF is 5(2–5)/3(1); order of the length of tooth rows is P-1>P-2>P-3>A-1>A-2>A-3>A-4>A-5; a pustulated arched ridge arched with about six pustulations; nares separated by a distance of about two-third the length of each nare; median ridge with a pustulated margin and a long medial projection; prelingual area comprising of five pairs of pustules and two pairs of infralabial papillae; two pairs of smooth long lingual papillae; buccal floor arena delineated by five pairs buccal floor arena papillae with 30 pustulations in the arena.

Four species of *Rhacophorus* are endemic to the Western Ghats, of which tadpoles for two species are being described in the current study. Tadpoles of *R. lateralis* and *R. malabaricus* have similar morphological features to those attributed to pond-type *Rhacophorus* (Grosjean & Inthara 2016; Vassilieva et al. 2016). External character states of *R. lateralis* and *R. malabaricus* tadpoles that are consistent with other *Rhacophorus* tadpoles are: an anteroventral oral disc; LTRF with multiple tooth rows and strongly keratinized jaw sheaths; body ovoid with eyes oriented dorsolateral; spiracle opening sinistral; vent tube opening dextral; robust muscular tail. The above characters of *Rhacophorus* tadpoles can be attributed to a benthic feeding larval morphotype (Altig & Johnston 1989). The LTRF 7(3–7)/3(1) of *R. malabaricus* tadpoles from the current description matches with the LTRF for the species given by Sekar (1990a). Similarly, comparisons of tadpole buccopharyngeal morphology with congeners revealed broad similarities (Inger 1985; Grosjean & Inthara 2016). Buccopharyngeal character states of *R. lateralis* and *R. malabaricus* tadpoles that are consistent with other *Rhacophorus* tadpoles are: broad buccal roof and floor; prenarial arena bearing a broad prenarial ridge; elongated postnarial papillae oriented medially; presence of an elevated median ridge; buccal roof and buccal floor arena delineated by papillae; presence of glandular zone; prelingual arena bearing infralabial papillae; tongue anlage with lingual papillae; oblique buccal pockets; ventral velum with projections on margin of velum. Diagnostic characters of *R. lateralis* tadpoles are: body colouration sulphurous yellow with few tiny melanophores dorsally; and tail fins with many blotches; nasal opening depressed; spiracle with the inner wall partly formed and attached to the body wall; emarginated oral disc with marginal papillation having a wide gap in the upper labium and six submarginal papillae at the lateral corners; Labial Tooth Row Formula (LTRF) is 6(3–6)/3(1); a pustulated arched ridge arched forward with the median pustule being the largest in the prenarial arena; nares widely separated by a distance of about the length of each nare; median ridge with a bifid tip; six pairs of infralabial papillae with the second and the fourth papillae large and pustulose; buccal floor arena delineated by five pairs buccal floor arena papillae with 14 pustulations in the arena. Likewise, diagnostic characters of *R. malabaricus* tadpoles are: body and tail olive-coloured, and mottled with several tiny melanophores dorsally; nasal opening elevated; spiracle with the inner wall fully formed but attached to the body wall; emarginated oral disc with marginal papillation having a wide gap on the upper labium and four to five submarginal papillae at the lateral corners; LTRF is 7(3–7)/3(1); a pustulated arched ridge arched forward with uniform sized pustules in the prenarial arena; nares narrowly separated by a distance of about half the length of each nare; median ridge with a serrated margin; four pairs of infralabial papillae with the fourth pair largest and dilated; buccal floor arena delineated by five pairs of buccal floor arena papillae with 16 pustulations in the arena.

The tadpoles of cricket frogs of Asia sensu lato (including the genera *Fejervarya* and *Minervarya*) have been studied earlier (Heyer 1971; Dutta 1997; Leong & Chou 1999; Leong 2005; Stuart et al. 2006). However, detailed morphological descriptions are few. Only recently was systematics of cricket frogs from South and Southeast Asia resolved by phylogenies using multiple molecular markers, which resulted in extensive changes in the taxonomy of the group (Kuramoto et al. 2008 "2007"; Ohler et al. 2009; Purkayastha & Matsui 2012; Dinesh et al. 2015; Howlader et al. 2016; Garg & Biju 2017, 2021; Raj et al. 2018). External character states of *M.* cf. *agricola* tadpoles that are consistent with other cricket frog tadpoles are: an elliptical body with a moderate tail; anteroventral oral disc; marginal papillation of oral disc having medial gaps on both labia; two labial tooth rows on the upper labium and three rows on the lower labium; dorsolateral eyes; spiracle opening sinistral with the inner wall of the tube completely formed but attached to the body wall; opening of anal tube dextral; fin heavily pigmented only at the distal end. Buccopharyngeal character states of *M.* cf. *agricola* tadpoles that are consistent with other Cricket frog tadpoles are: elongated buccal roof and floor; an arched prenarial ridge; median ridge low; buccal roof and buccal floor arena delineated by papillae and with many pustulations in the arena; tongue anlage with lingual papillae; oblique buccal pockets; ventral velum with projections on margin of velum. Externally, the current description broadly agrees with the descriptions made by Khan (1982, 2003b) and Khan & Mufti (1994) on the general morphology of *Fejervarya*; however, the taxonomic identity of those tadpoles needs to be ascertained. The external larval morphology of various cricket frog species is perplexing since most species have similar body colouration patterns and LTRF. The buccopharyngeal character states in the current descriptions differ from those made by Khan (1991, 1996) in having a tri-lobed pustulose prenarial ridge, nares separated by a distance of half the length of each nare, two pairs of tall post narial papillae and two flattened lateral ridge papillae and having two pairs of infralabial papillae.

Tadpoles of *Nyctibatrachus* species were described earlier (Annandale 1918, 1919; Bhaduri & Kripalani 1955; Pillai 1978) but comparative studies on morphology could not be made using those descriptions. In recent times, detailed morphological descriptions on *Nyctibatrachus* tadpoles were made by Priti et al. (2015). One of the most prominent characters of *Nyctibatrachus* tadpoles is having a multilobed oral disc that is devoid of labial teeth but with keratinized jaw sheaths. Other morphological characters shared by tadpoles of the genus are: an elliptical body with a robust tail; dorsolateral large eyes; acute tail tip; sinistral spiracle; Vent tube opening dextral. Diagnostic characters of *N.* cf. *periyar* tadpoles are: eight lobed oral discs with the anterior lobe largest; two rows of submarginal papillae immediately above the upper jaw sheath; body light beige brown with moderate-sized dark brown spots on flanks and dorsum, and tail mottled with many medium-sized irregular-shaped blotches. Descriptions on larval buccopharyngeal morphology for *Nyctibatrachus* species are unavailable and therefore no comparisons could be made. Tadpoles of *Nyctibatrachus* are morphologically highly derived with unique oral morphology. Unlike tadpoles of other groups, the oral disc labia of *Nyctibatrachus* tadpoles are divided with multiple folds and are devoid of keratodonts that are replaced by conical papillae. This ecomorphological guild is referred to as "psammonic" and is shared by tadpoles of very few anuran groups that are adapted to live in habitats with predominantly sandy substratum (Altig & Johnston 1989). Since, labial tooth row formula cannot be used for larval identity of *Nyctibatrachus* tadpoles, taxonomic identity using oral structures is found to be challenging. Further comparative works on tadpoles of this genus can help to identify characters that can be useful for taxonomic identification. Also, with the buccopharngeal morphology, tadpoles of *N.* cf. *periyar* is unique in have numerous papillae and pustulations spread across the buccal roof and buccal floor arenas. This character of having numerous BRA and BFA papillae/pustulations is shared with psammonic tadpoles of *Boophis picturatus* (Grosjean et al. 2011) that live in habitats with sandy substrate. Recently, from Western Ghats, tadpoles of *Micrixalus* were found to have derived morphology with reduced oral structures similar to that of *Nyctibatrachus* (Senevirathne et al. 2016b). This warrants the need for more studies to understand the unique larval morphologies of these groups from Western Ghats.

Anuran larvae unlike their adult forms are generally overlooked in scientific works and are therefore poorly understood. There has been a call for research on anuran larval forms for long to understand their morphology, both at the assemblage and guild level they occupy, internal anatomy, and developmental patterns. Such information can be helpful in resolving anuran systematic issues, understanding inter-species competition, improving inventorisation of anurans and conservation efforts. Also, in the past forty years, many tadpole studies had focused on describing internal oral structures that are phylogenetically informative. Larval characters are useful to investigate the systematic relationships among anurans (Sokol 1975; Maglia et al. 2001; Haas 2003; Púgener et al. 2003) and can be helpful in getting a greater resolution for presently known systematic relationships.

The current paper describes six species, of which two are re-descriptions. Larval forms of *D.* cf. *melanostictus*, *P. pseudocruciger*, *R. lateralis*, *R. malabaricus*, and *M.* cf. *agricola* were collected from lentic pools. Species other than *P. pseudocruciger* have typical lentic/benthic forms (Altig & Johnson 1989) with spheroid bodies and dorsolateral eyes and an anterolateral mouth, while tadpoles of *P. pseudocruciger* have a typical lentic/nectonic form have laterally oriented eyes. Larvae of *N.*

cf. *periyar* are of lotic/benthic form with spheroid bodies and dorsolateral eyes, and an anterolateral mouth.

Identification of anuran larvae in Western Ghats has been a challenge due to the poor availability of morphological characterization for anuran larvae from the region. Most of the published descriptions of tadpoles from the region were mainly done nearly a century ago and needs thorough review. In recent times, systematics and taxonomy of many anurans from this region had been resolved (Dinesh et al. 2015; Garg & Biju 2017, 2021). External morphology of tadpoles is conserved within a group (genus) and using additional characters like those of the buccopharyngeal region would help in improving species diagnosis and resolving problems in anuran systematics problems (Wassersug 1976; Das 1994). Knowledge on anuran larval morphology can be useful in understanding the diversification patterns and evolution of anurans in the region. Further comparative morphological and developmental studies of larval anurans from the region will likely provide many evolutionary insights since many endemic anuran lineages are known to occur in Western Ghats. Most endemic lineages from the region like *Indirana* (semi-terrestrial tadpoles), *Micrixalus* (fossorial tadpoles), *Nasikabatrachus* (Rheophilous tadpoles), and *Nyctibatrachus* (psammonic tadpoles) tend to have derived tadpoles. Many of these tadpoles morphotypes are rarely seen elsewhere and it is also interesting to find such morphotypes only in these ancient lineages from the region. Since life history patterns for much of the anuran fauna from Western Ghats remain insufficiently understood, larval descriptions from the current study make a significant contribution to the knowledge of the biology of these species. This study opens the door to future studies on larval anurans from the region, which are necessary to understand life history patterns of species. Knowledge of larval forms (morphology and ecology) will be helpful in assessing conservation priorities for anurans of the region, thereby aiding in the conservation of biota in Western Ghats.

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ARTICLE

Flies in the high for floral hike? Altitudinal variation in species diversity and composition of Diptera (Insecta) in the eastern Himalaya, India

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Abstract: Species diversity and composition enable us to understand the conservation and management of an ecosystem. There is scarcity of knowledge in understanding the diversity change across the gradients of elevation, especially in the Himalaya. Here, we focused in the eastern Himalaya to investigate the patterns of taxonomic and functional diversity of true flies with relation to variation in altitude. The study was conducted in protected area (Neora Valley National Park) in the eastern Himalaya, India and the survey was conducted at five altitudinal zones (from 500 to 3,000 m). A total of 201 species of Diptera, with 105 genera and 33 families were recorded, of which 25 species are new to the state of West Bengal and seven species are new to India. The species diversity increased with elevation (maximum was near 2,500 m) and most of the flies preferred to be close to bushes with flowers, with a substantial percentage of them being pollinator species. Flies adapt to the various vegetation and climate patterns, which was evident by the abundance of fly species at high altitudes (1,500–2,500 m). Hence, it is very important to implement appropriate actions to protect the diversity of true flies in this Himalayan landscape.

Keywords: Elevation gradient, insect diversity, pollination, species composition, West Bengal.

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Author contributions: Study conception and design, field surveys and communication – SKS; Assistant and support in field surveys – PH, UG & SB; Lab work – SKS, PH, NJ & SM; Data compilation – SM, SO, NJ, NP & AH; Data analysis & the first draft of manuscript – SM & SO; Comments on draft of the manuscript – SKS, AH, UG & SB; All authors read and approved the final manuscript.

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INTRODUCTION

Patterns of species composition and diversity, along with environmental and elevational gradients, provide insights into our understanding of ecosystem conservation. Research trends have shifted toward a greater understanding of the elevation gradient and its impact on species diversity across various geographic regions (Terborgh 1977; Brown 2001; Sanders & Rahbek 2012; Acharya & Vijayan 2015; Marathe et al. 2021). Furthermore, changes in landscape physiology and climatic conditions due to the different gradients of elevation effects the species diversity (Sundqvist et al. 2013). Many studies have documented and described the mechanisms on patterns of diversity with respect to elevational gradient (Acharya et al. 2011a,b; Kraft et al. 2011; Sundqvist et al. 2013; Chun & Lee 2018). In harsher environments at higher elevations, niche differences and relative fitness differences may drive the presence of fewer species (HilleRisLambers et al. 2012; Kraft et al. 2015). Understanding such patterns and their underlying mechanisms is important for understanding the implications of insect conservation, particularly in the Himalayan regions that are vulnerable to climate change. The Himalaya is unique for examining such gradients and their impact on a variety of habitats with steep altitudinal gradient and unstable climate.

Biogeographical studies of multiple taxa have increased in recent years in various parts of the Himalayas. Most of the studies are focused on birds, plants, and pollinating insects such as butterflies. In the eastern Himalaya, bird species richness is greatest at intermediate elevations (Acharya et al. 2011b), whereas low elevations (<2,000 m) are important for butterfly conservation (Acharya & Vijayan 2015). When it comes to plants, elevation and high temperature have a considerable influence on the distribution and growth of trees (Acharya et al. 2011a). The reduction in tree height and richness noticed beyond 2,300 m, allows herbs to dominate due to climatic constraints (Sharma et al. 2019). In this context, a comprehensive study of true flies (Diptera) is also useful for identifying habitats with conservation value in the Himalayan mountain landscape.

The observed trends showed that most of the current studies focused on Lepidoptera (Joshi & Arya 2007; Bhardwaj et al. 2012; Acharya & Vijayan 2015; Dey et al. 2017; Sharma et al. 2020) and Hymenoptera (Bharti et al. 2013; Streinzer et al. 2019; Subedi & Budha 2020; Dewan et al. 2021; Marathe et al. 2021). Besides, Hymenoptera, Lepidoptera, and Coleoptera, Diptera is considered one of the principal orders of pollinating insects. Furthermore, flies of families such as Asilidae, Bibionidae, Muscidae, Stratiomyidae, Tabanidae, Tipulidae, Rhagionidae, Limoniidae, Sciaridae also act as bio-indicators of climate change (Frouz 1999; Bizzo et al. 2010; Mezgebu et al. 2019; Montoya et al. 2021) and the main potential pollinators (biotic vector) at high altitudes and latitudes, like in alpine, arctic and subarctic ecosystems where bees are less abundant (Elberling & Olesen 1999; Tiusanen et al. 2016; Lefebvre et al. 2018). Studies also indicate that species diversity and richness of Diptera change with elevation for example, species composition changes along the altitudinal gradient (700–2,500 m) and partitioning between seasonally dry lowland and moist montane evergreen forests on the Doi Inthanon mountain in northern Thailand (Plant et al. 2012; Chatelain et al. 2018), species richness and distribution of Hemerodromiinae and Clinocerinae are changing with the elevational gradient on the Pieniny Mountains in central Europe (Słowińska & Jaskuła 2021). Therefore, it is important to investigate their community composition across different environmental and elevational gradients in the Himalayas. The objective of this study was to investigate the variation of species composition and distribution of Diptera fauna in the eastern Himalaya between 500 m and 3,000 m elevation gradient.

MATERIALS AND METHODS

Study area

The study was conducted in the Neora Valley National Park which covers an area of 159.78 km^2. The park has diverse ecosystems with a wide range of elevation gradients (183–3,200 m), located near the ecological tri-junction of West Bengal, Sikkim (India) and Bhutan on the northeast (26.8675–27.1263 ^{0}N; 88.750–88.8333 ^{0}E). It is considered as crowning glory of the state of West Bengal (Mallick 2010). The study area is an east Himalayan moist mixed deciduous forest (Champion & Seth 1968), with lower areas (up to 1,800 m) recognized as subtropical mixed broadleaf forest, lower temperate evergreen forest, and upper areas (1,800–3,200 m) recognized as upper temperate mixed broadleaf forest and Rhododendron forest (Mallick 2012). The study area was divided into five categories based on the vegetation composition—Lower Hill Forest (<762 m), Middle Hill Forest (762–1,676 m), Broad-leaved Forest (1,676–2,133 m), Oak Forest (2,133–2,500 m) and Rhododendron Forest (>2,500 m) (Figure 1).

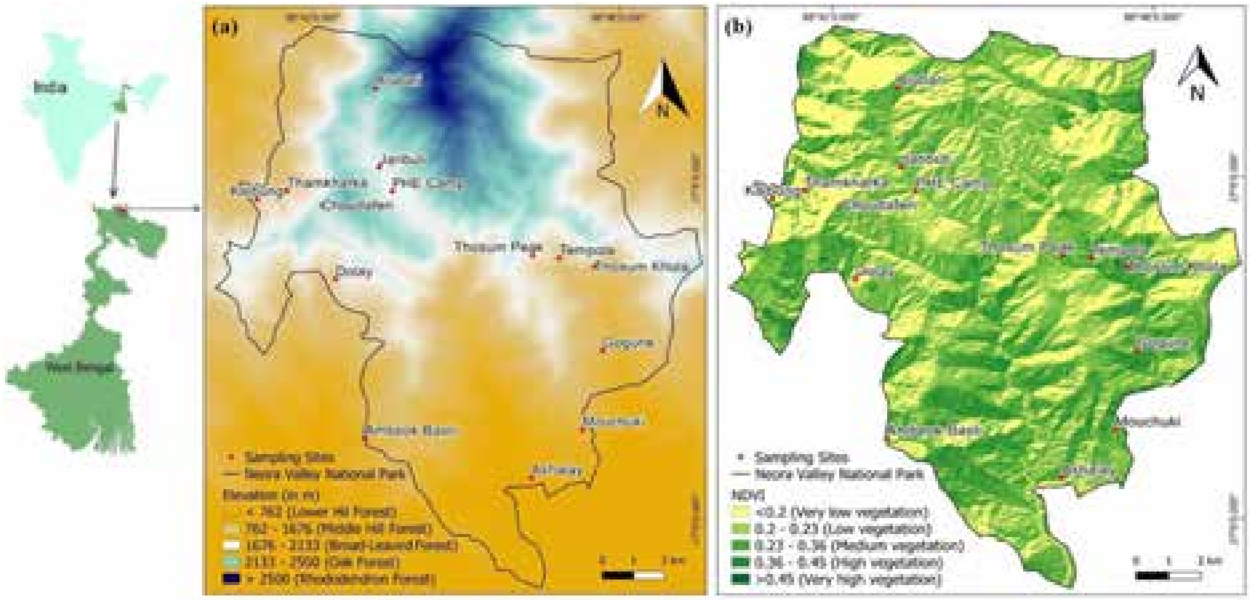

Figure 1. Sampling sites in the Neora Valley National Park, West Bengal, India: a—area with elevational gradient categorized as different forest types | b—area with normalized difference vegetation index (NDVI).

Field methods

The survey was conducted at 14 different locations (forest camps) between March 2018 and September 2021 as part of the Biodiversity Assessment Programme (organized by the Department of Forest, Government of West Bengal), using pre-set representative trail transects in representative elevations (Table 1). In each camp sites, four to five surrounding areas were surveyed from 0800 to 1500 h (7 hours). The flies in the different habitats were observed and collected by the first author, which were then classified (Table 2). During the field survey, insect collecting hand nets and one malaise trap were used to collect true flies. Average hand net collection time was 3–4 hours and malaise trap was used accordingly to the suitability of the terrains. Insect hand net specimens were paralyzed by benzene vapour in a killing jar and stored in an envelope for future use. Specimens were also pinned (No. 2) in the field and stored in an insect box. Specimens collected by malaise trap were sorted by sub-family and stored in 70% alcohol.

Identification of species

In the laboratory, collected insects were placed in a wet chamber overnight before being pinned by inserting an insect-pin slightly laterally through the pro-thoracic segment. Pinned specimens were labeled with the location of collection, date, altitude, and substances on which the flies were found. The flies were taxonomically identified using chaetotaxy key (Senior-White et al. 1940; Emden 1965; Shinonaga & Kano 1971; Crosskey 1976; Nandi 2002; Scudder & Cannings 2006; Buck et al. 2009; Joseph & Parui 2012) under a stereoscopic binocular microscope, and genitalia of male individuals were dissected in some cases for confirmation of identification. The specimens of *Culicoides* were separated and stored in different microcentrifuge tubes (1.5 ml) containing 70% ethyl alcohol. After mounting the adults on a slide using the phenol-balsam technique mentioned by Wirth & Marston (1968), the midges were identified using the identification keys used by Wirth & Hubert (1989) under a compound microscope. Following the identification keys used by Borror & Delong (1970), specimens were identified up to the suborder level, Nematoceran flies were identified up to the family level, and rest of the flies were identified up to the order level.

Analysis

A map of the study area indicating all sampling sites was prepared using QGIS software (version 3.16.11). The normalized difference vegetation index (NDVI) was calculated using a December 2019 (Landsat 8) satellite image. This month was chosen for its peak forest vegetation as it is just post-monsoon and to minimize the effect of atmospheric load on remote sensing data due to lower moisture content in the air. The remote sensing data (Landsat 8 image) was obtained from USGS Earth Explorer (https://earthexplorer.usgs.gov/). In ENVI software, the captured image was radiometrically corrected and normalized. The NDVI was employed to determine vegetation on the ground. It is used to

Table 1. Detail of the sampling sites in Neora Valley National Park, India.

Site no.	Site names	Latitude	Longitude	Elevation (m)	Forest Types
S1	Ashalay	27.013	88.769	686	Lower Hill Forest
S2	Ambeok Basti	27.025	88.713	952	Middle Hill Forest
S3	Mouchuki	27.027	88.786	1170	Middle Hill Forest
S4	Gogune	27.049	88.826	1525	Middle Hill Forest
S5	Tempola	27.077	88.779	1757	Broad-leaved Forest
S6	Kolbung	27.095	88.681	1810	Broad-leaved Forest
S7	Thosum Khola	27.074	88.791	1861	Broad-leaved Forest
S8	Thamkharka	27.098	88.691	1952	Broad-leaved Forest
S9	Thosum Peak	27.078	88.771	2043	Broad-leaved Forest
S10	Dolay	27.072	88.706	2050	Broad-leaved Forest
S11	PHE Camp	27.097	88.725	2158	Oak Forest
S12	Jaributi	27.104	88.721	2196	Oak Forest
S13	Choudaferi	27.093	88.702	2356	Oak & Rhododendron Forest
S14	Alubari	27.128	88.720	2540	Rhododendron Forest

Table 2. Types of Habitats found in the study sites.

No.	Habitat type	Codes
1	Animal, human dung, decaying fruits	AD
2	Bushes	B
3	Flowering plant	F
4	Human settlement	HS
5	Moist surface	MS
6	Near stream	NS
7	Open spaces/ Rock surface	OS
8	Shade area	S

monitor and detect changes in vegetation and land cover. The image was classified based on the NDVI value.

The indices like α-diversity index, Simpson's index and Shannon-Weiner Index were measured to understand the species richness and species evenness of flies in the study area (Krebs 1999). The correlation between the diversity indices like Shannon-Weiner Index and Simpson's Index with the elevation of all sites were done. Pearson's correlation coefficients were estimated between altitude for all the study sites and the occurrence of fly species (Bhardwaj et al. 2012). IBM SPSS Statistics 20, PAST Version 4 software and Microsoft Excel were used for analyzing the data and preparing different diagrams. A QQ-plot was done to understand the distribution pattern of all species in 14 sites. This has been done using elevation and Simpson's Index.

RESULTS

Collection and identification of 201 species belonging to 105 genera and 33 families were enumerated (Table 3). Members of the Muscidae dominated the area with 66 species followed by Syrphidae (33), Calliphoridae (17), and Tachinidae (12). A total of 25 species are reported as new records to West Bengal and seven being new to India (Table 3). Within the newly reported species in West Bengal, 13 belonged to Muscidae.

When the total number of native species (201 species) was taken into account, the accumulation curve tended to stabilize after 12 sampling efforts (Figure 2). Spatial patterns of species distribution over various habitats were observed (Figure 3). It was found that the

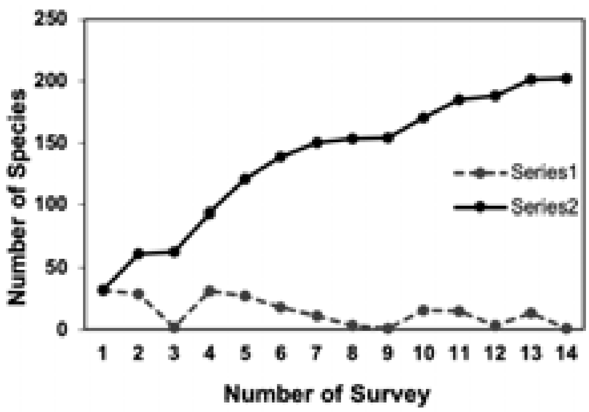

Figure 2. Temporal variation in the frequency of Diptera species in all sites: Series 1— Number of new species found in each survey | Series 2—Total number of species.

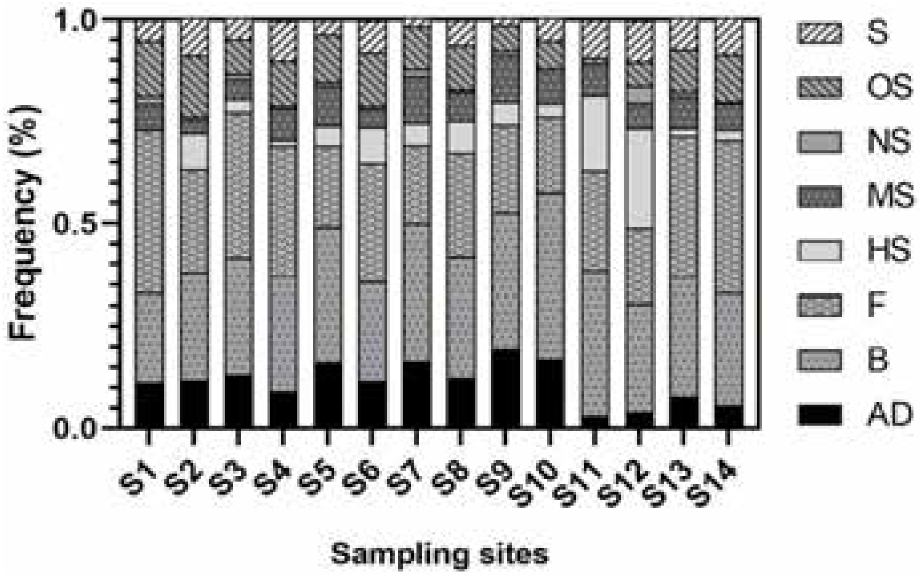

Figure 3. Distribution of species of flies in different habitats of all sampling sites: S—Shade area | OS—Open spaces/ Rock surface | NS—Near stream | MS—Moist surface | HS—Human settlements | F—Flowering plants | B—Bushes | AD—Animal, human dung, decaying fruits.

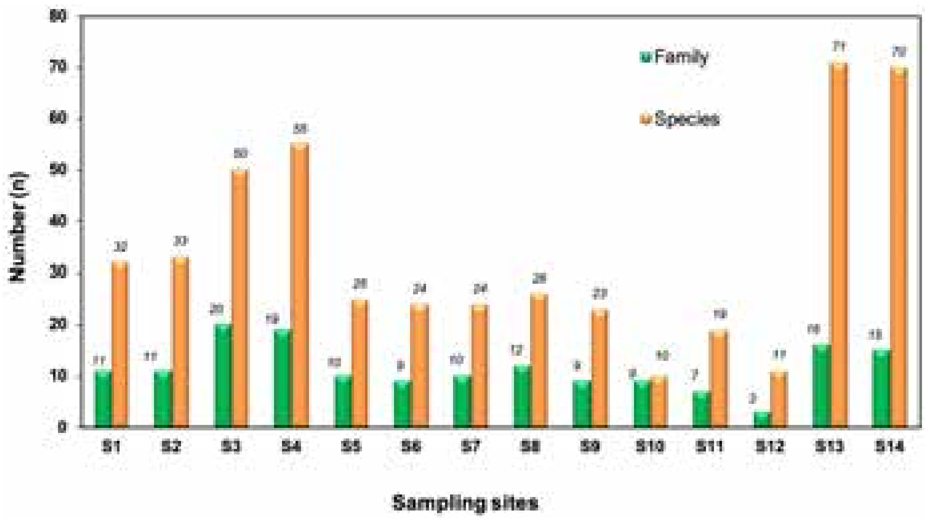

Figure 4. Distribution of the species and families across all 14 sites.

most of the flies preferred flowering plants (32.77%), followed by non-flowering plants (27.14%) throughout the region, and the least number of flies (1.41%) were found in areas near streams.

In general, comparison of distribution of species and families across all 14 sites revealed that Chaudaferi (S13) and Alubari (S14) were high in diversity with respect to families, in the higher elevation (Figure 4). On the other hand, Mouchuki has the highest number of families, having moderate number of species.

A graphical representation is made with respect to centroid position of both the variables (indices and elevation) in Figure 5. The centroid is the intersection point of means of both Simpson's index and elevation. It is the same in case of Shannon-Weiner index and elevation. It shows that, the Simpson's indices of most of the sites are near the centroid, indicating it is in a normal distribution. Here, maximum number of flies are found within the range of 1,500–2,500 m. Likewise, the Shannon-Weiner indices of most of the sites are very near to the centroid and similarly, the maximum number of flies are found within the range of 1,500–2,500 m. So, Pearson's correlation test (Figure 6) between Simpson's Index and elevation was performed which reveals

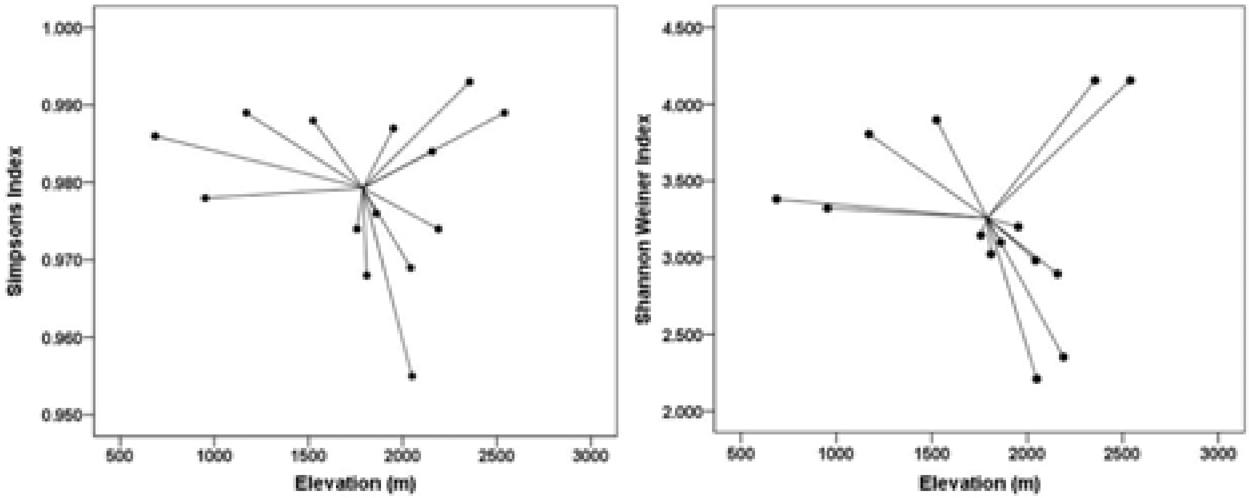

Figure 5. Scatter-plots showing the Simpson's Index and Shannon-Weiner Index of all flies on basis of elevation where most of the flies were observed in elevation ranging from 1,500–2,500 m.

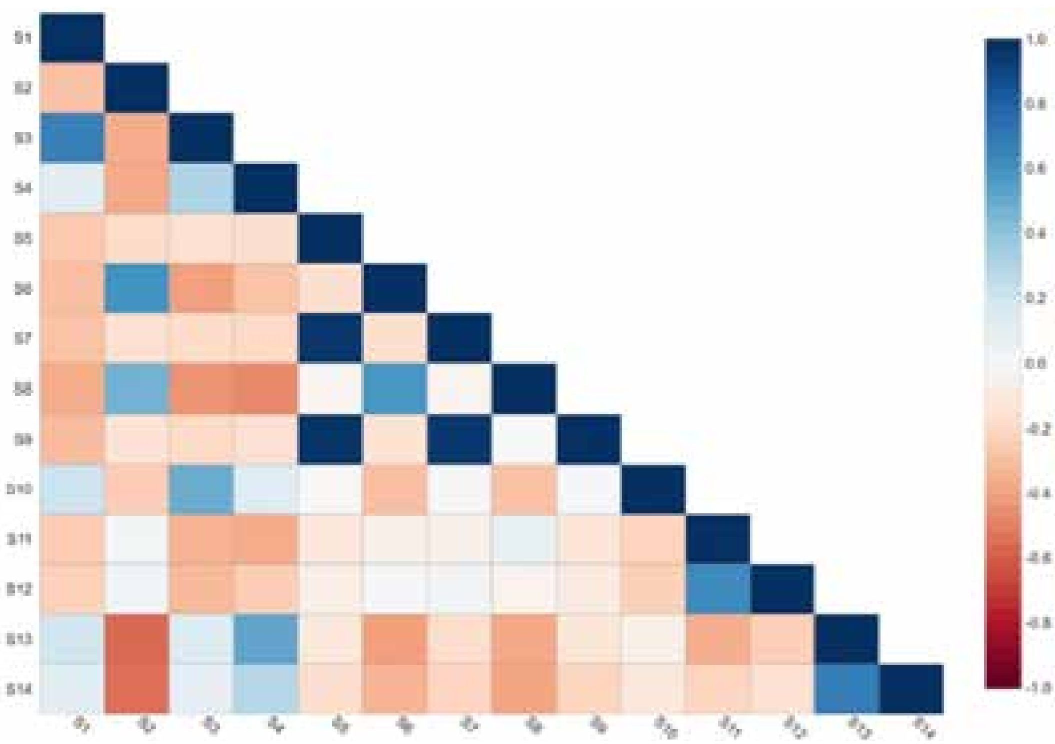

Figure 6. Correlation matrix displaying Pearson correlation analysis results. Data from the presence of fly species in 14 sampling sites were used in the analysis. Pearson correlation coefficient values and directions are color-coded: positive correlation—blue, light to dark | negative correlation—red, light to dark (see color-bar next to the matrix).

that, there is a negative correlation between them (r = -0.108). On the other hand, a correlation test between Shannon-Weiner Index and elevation reveals that there is a positive correlation but very less association between them (r = 0.092). Another correlation was done among the 14 sampling sites to find out what kind of association prevails on basis of abundance of flies. A QQ-plot showed that the observed values (estimated quantiles) were normalized (Figure 7). A rarefaction curve was generated on the basis of all 14 sites, which showed the abundance and species richness at high altitude sampling sites (Figure 8).

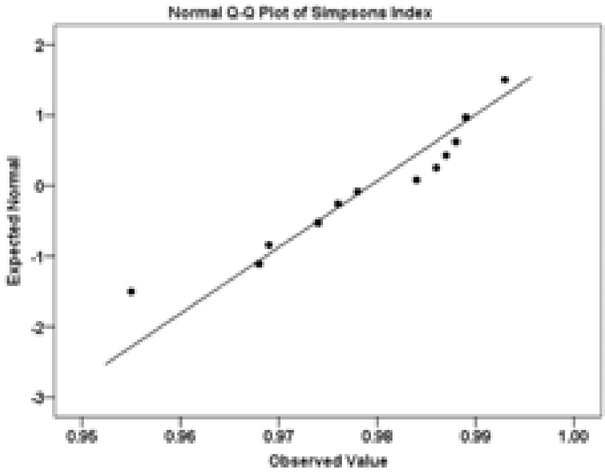

Figure 7. QQ-plot showing the distribution pattern of all Diptera species across 14 sites.

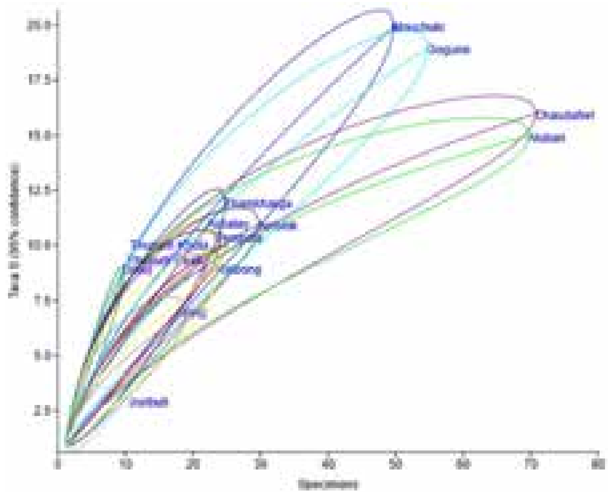

Figure 8. Rarefaction curve (taxa vs. abundance) based on 14 sites.

DISCUSSION

This is the first elaborate survey of dipteran fauna from the Neora Valley National Park along the elevation gradient. A total of 201 flies from 105 genera and 33 families were documented. Recently, Sinha et al. (2021) reported 31 species of family Muscidae from Neora Valley, including two species, *Limnophora* (*Heliographa*) *ceylanica* and *Neomyia pacifica* recorded for the first time in India. A new species, *Heligmonevra paruii* (family Asilidae) was described and illustrated from Neora Valley by Naskar et al. (2019), but it was not recorded in the present investigation.

Diptera are the primary potential pollinators at high altitudes and latitudes where bees are scarce. In the eastern Himalaya, the diversity of Syrphidae reflected the supremacy of these flies over other pollinator insects such as honeybees at the higher altitudes (Sinha et al. 2022). Studies found a similar pattern in the tropical region, such as Doi Inthanon mountain in northern Thailand (Plant et al. 2012; Chatelain et al. 2018). Even as we move farther north, the proportion of dipteran species in the total pollinator fauna grows with latitude, and they are the most common families of flower-visiting insects in the arctic (Elberling & Olesen 1999; Tiusanen et al. 2016; Lefebvre et al. 2018). In the light of this, we assessed the species richness and distribution pattern of Diptera at various elevations in the eastern Himalaya, with the highest number of flies found between 1,500 and 2,500 m. This is most likely because there are large amount flowering plants. On the contrary, in the lower elevation (1,500 m), there is dense forest with fewer fly species. Less fly species live in higher elevation areas comprising Maling bamboo forests. Furthermore, it becomes windy higher up (>2,500 m), and that area is covered with Rhododendron and wild rose plants, which reduces fly activity.

Muscidae (32.83%) and Syrphidae (16.41%) were the most abundant families at all of our sample sites. This could be due to their ability to survive in environments ranging from extremely low to extremely high elevation. Members of these families can also be found at all of the sites in a habitat that is relatively bushy and densely populated with flowering plants. Muscidae is the most common family of flower-visiting insects in the Arctic region, and they are much more abundant and widespread than the insects of other dipteran families which like to visit flowers (Elberling & Olesen 1999).

Pollinator communities are changing dramatically as a result of climate change (González-Varo et al. 2013; Rafferty 2017). However, there are large gaps in our understanding of the role of Diptera in pollination networks in the Himalaya in relation to climate change. Although our findings suggest that more sampling is required to obtain a complete picture of the study area, plant-Diptera interactions also need to be examined.

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Table 3. Detail of recorded Diptera species in Neora Valley National Park, India.

No.	Family	Subfamily	Species	Records*	Sources
1	Anthomyiidae	Anthomyiinae	*Anthomyia* sp.1		
2	Anthomyiidae	Anthomyiinae	*Anthomyia* sp.2		
3	Anthomyiidae	Anthomyiinae	*Delia platura*		
4	Anthomyiidae	Anthomyiinae	*Paregle densibarbata*		
5	Anthomyiidae	Pegomyinae	*Pegomya* sp.	WB	Suwa 1981
6	Asilidae	Laphriinae	*Maira longirostrata*		
7	Asilidae	Laphriinae	*Maira* sp.		
8	Asilidae	Laphriinae	*Nusa bengalensis*		
9	Asilidae	Laphriinae	*Nusa* sp.		
10	Asilidae	Stenopogoninae	*Microstylum* sp.		
11	Bibionidae	Pleciinae	*Penthetria japonica*		
12	Bibionidae	Pleciinae	*Plecia assamensis*	WB	Mukhopadhyay et al. 2015
13	Blephariceridae	Blepharicerinae	*Blepharocera* sp.		
14	Bombyliidae	Anthracinae	*Anthrax* sp.		
15	Bombyliidae	Anthracinae	*Villa* sp.		
16	Calliphoridae	Ameniinae	*Silbomyia asiatica*		
17	Calliphoridae	Calliphorinae	*Aldrichina grahami*		
18	Calliphoridae	Calliphorinae	*Calliphora* sp.		
19	Calliphoridae	Calliphorinae	*Calliphora pattoni*		
20	Calliphoridae	Calliphorinae	*Calliphora vicina*		
21	Calliphoridae	Calliphorinae	*Calliphora vomitoria*		
22	Calliphoridae	Chrysomyiinae	*Chrysomya pinguis*		
23	Calliphoridae	Luciliinae	*Lucilia illustris*		
24	Calliphoridae	Melanomyinae	*Melinda scutellata*		
25	Calliphoridae	Polleniini	*Dexopollenia* sp.		
26	Calliphoridae	Polleniini	*Polleniopsis pilosa*		
27	Calliphoridae	Rhiniinae	*Idiella mandarina*		
28	Calliphoridae	Rhiniinae	*Isomyia* sp.		
29	Calliphoridae	Rhiniinae	*Rhinia apicalis*		
30	Calliphoridae	Rhiniinae	*Stomorhina sp.*		
31	Calliphoridae	Rhiniinae	*Strongyloneura* sp.1	WB	Senior White et al. 1940
32	Calliphoridae	Rhiniinae	*Strongyloneura* sp.2		
33	Cecidomyiidae	Lestremiinae	*Allarete spatuliformis*		
34	Cecidomyiidae	Porricondylinae	*Camptomyia* sp.1	WB	Ahad Najam et al. 2009; Gagne & Jaschhof 2021
35	Ceratopogonidae	Ceratopogoninae	*Culicoides* sp. 1		
36	Ceratopogonidae	Ceratopogoninae	*Culicoides pararegalis*		
37	Ceratopogonidae	Ceratopogoninae	*Culicoides pseudoregalis*		
38	Ceratopogonidae	Ceratopogoninae	*Culicoides regalis*		
39	Ceratopogonidae	Ceratopogoninae	*Culicoides subregalis*		
40	Ceratopogonidae	Ceratopogoninae	*Culicoides* sp.2		
41	Chironomidae	Unidentified	Unknown		
42	Culicidae	Culicinae	*Culex* sp.1		
43	Culicidae	Culicinae	*Culex* sp.2		
44	Diopsidae	Unidentified	Unknown		

No.	Family	Subfamily	Species	Records*	Sources
45	Dolichopodidae	Diaphorinae	*Chrysotus* sp.		
46	Dolichopodidae	Diaphorinae	*Diaphorus* sp.		
47	Dolichopodidae	Dolichopodinae	*Dolichopus* sp.1		
48	Dolichopodidae	Dolichopodinae	*Dolichopus* sp.2		
49	Drosophilidae	Drosophilinae	*Drosophila* sp.		
50	Drosophilidae	Unidentified	Unknown		
51	Hybotidae	Hybotinae	*Hybos culiciformis*	IND	Shamshev et al. 2015; Zouhair & Kettani 2022
52	Lauxaniidae	Homoneurinae	*Homoneura* sp.1	IND	Miller 1976; Sasakawa 1992; Shatalkin 1996; Gao & Yang 2004; Lee & Han 2015
53	Lauxaniidae	Homoneurinae	*Homoneura* sp. 2		
54	Lonchopteridae	Unidentified	Unknown		
55	Muscidae	Atherigoninae	*Atherigona orientalis*		
56	Muscidae	Atherigoninae	*Atherigona* sp.		
57	Muscidae	Coenosiinae	*Coenosia plumiseta*	WB	Bharti 2008
58	Muscidae	Coenosiinae	*Coenosia* sp.1	WB	Rahman et al. 2017
59	Muscidae	Coenosiinae	*Coenosia* sp.2		
60	Muscidae	Coenosiinae	*Coenosia* sp.3		
61	Muscidae	Coenosiinae	*Limnophora latiseta*		
62	Muscidae	Coenosiinae	*Limnophora brunnescens*		
63	Muscidae	Lispinae	*Lispe bengalensis*		
64	Muscidae	Lispinae	*Lispe sericipalpis*		
65	Muscidae	Lispinae	*Lispe orientalis*		
66	Muscidae	Lispinae	*Lispe* sp.1		
67	Muscidae	Lispinae	*Lispe* sp.2		
68	Muscidae	Phaoniinae	*Dichaetomyia nubiana*		
69	Muscidae	Phaoniinae	*Dichaetomyia* sp.1		
70	Muscidae	Muscinae	*Morellia nigrisquama*	WB	Emden 1965; Mitra 2011; Sinha et al. 2021
71	Muscidae	Muscinae	*Morellia pectinipes*	WB	Emden 1965; Mitra 2011; Sinha et al. 2021
72	Muscidae	Muscinae	*Morellia* sp.1		
73	Muscidae	Muscinae	*Morellia* sp.2		
74	Muscidae	Muscinae	*Musca convexifrons*	WB	Mitra 2006
75	Muscidae	Muscinae	*Musca domestica*		
76	Muscidae	Muscinae	*Musca hervei*		
77	Muscidae	Muscinae	*Musca tempestiva*	WB	Emden 1965; Shina et al. 2021
78	Muscidae	Muscinae	*Musca* sp.1		
79	Muscidae	Muscinae	*Musca* sp.2		
80	Muscidae	Muscinae	*Neomyia gavisa*		
81	Muscidae	Muscinae	*Neomyia coerulea*		
82	Muscidae	Muscinae	*Neomyia claripennis*		
83	Muscidae	Muscinae	*Neomyia fletcheri*		
84	Muscidae	Phaoniinae	*Phaonia kambaitiana*	WB	Emden 1965; Mitra 2011; Sinha et al. 2021
85	Muscidae	Muscinae	*Pyrellia cadaverina*	WB	Emden 1965
86	Muscidae	Muscinae	*Rypellia flavipes*	WB	Emden 1965; Sinha et al. 2021
87	Muscidae	Muscinae	*Rypellia malaisei*	WB	Shina et al. 2021
88	Muscidae	Mydaeinae	*Brontaea ascendens*		
89	Muscidae	Mydaeinae	*Brontaea distincta*		

No.	Family	Subfamily	Species	Records*	Sources
90	Muscidae	Mydaeinae	*Brontaea lasiopa*		
91	Muscidae	Mydaeinae	*Graphomya maculata*	WB	Emden 1965; Mitra 2011; Sinha et al. 2021
92	Muscidae	Mydaeinae	*Graphomya rufitibia*		
93	Muscidae	Mydaeinae	*Hebecnema* sp.		
94	Muscidae	Mydaeinae	*Myospila bina bina*		
95	Muscidae	Mydaeinae	*Myospila tenax*		
96	Muscidae	Mydaeinae	*Myospila* sp.1		
97	Muscidae	Mydaeinae	*Brontaea* sp.1		
98	Muscidae	Mydaeinae	*Brontaea* sp.2		
99	Muscidae	Phaoniinae	*Dichaetomyia quadrata*		
100	Muscidae	Phaoniinae	*Dichaetomyia* sp.2		
101	Muscidae	Phaoniinae	*Helina appendiculata*		
102	Muscidae	Phaoniinae	*Helina iwasai*	IND	Shinonaga & Singh 1994; Sinha et al. 2021
103	Muscidae	Mydaeinae	*Myospila lenticeps*		
104	Muscidae	Phaoniinae	*Helina* sp.1		
105	Muscidae	Phaoniinae	*Helina* sp.2		
106	Muscidae	Phaoniinae	*Hydrotaea unispinosa*		
107	Muscidae	Phaoniinae	*Hydrotaea sp.*		
108	Muscidae	Coenosiinae	*Limnophora tonsa*		
109	Muscidae	Coenosiinae	*Limnophora* sp.1		
110	Muscidae	Coenosiinae	*Limnophora* sp.2		
111	Muscidae	Coenosiinae	*Limnophora* sp.3		
112	Muscidae	Mydaeinae	*Mydaea longiscutellata*		
113	Muscidae	Mydaeinae	*Myosplia meditabunda meditabunda*	WB	Jana et al. 2023
114	Muscidae	Mydaeinae	*Mydaea* sp.		
115	Muscidae	Phaoniinae	*Phaonia* sp.1		
116	Muscidae	Phaoniinae	*Phaonia* sp.2		
117	Muscidae	Phaoniinae	*Phaonia* sp.3		
118	Muscidae	Phaoniinae	*Phaonia* sp.4		
119	Muscidae	Phaoniinae	*Spilogona* sp.	WB	Emden 1965
120	Muscidae	Stomoxydinae	*Stomoxys calcitrans*		
121	Mycetophilidae	Mycetophilinae	*Rhymosia* sp.	WB	Banerjee et al. 2018
122	Phoridae	Metopinini	*Megaselia pallicornis*		
123	Phoridae	Phorinae	*Dohrniphora aequididtans*		
124	Pipunculidae	Unidentified	Unknown		
125	Psychodidae	Psychodinae	*Clogmia albipunctata*		
126	Psychodidae	Psychodinae	*Psychoda* sp.		
127	Psychodidae	Psychodinae	*Telmatoscopus lacteitarsis*		
128	Ptychopteridae	Ptychopterinae	*Ptychoptera* sp.		
129	Sarcophagidae	Sarcophaginae	*Bercaea cruentata*		
130	Sarcophagidae	Sarcophaginae	*Boettcherisca nepalensis*	WB	Sinha 2014
131	Sarcophagidae	Sarcophaginae	*Ravinia pernix*		
132	Sarcophagidae	Sarcophaginae	*Robineauella (Jantiella) kanoi*		
133	Sarcophagidae	Sarcophaginae	*Sarcophaga albiceps*		

No.	Family	Subfamily	Species	Records*	Sources
134	Sarcophagidae	Sarcophaginae	*Sarcophaga coei*		
135	Sarcophagidae	Sarcophaginae	*Sarcophaga* sp.1		
136	Sarcophagidae	Sarcophaginae	*Sarcophaga* sp.2		
137	Sarcophagidae	Sarcophaginae	*Sinonipponia baruai*	IND	Pape 1996; Nandi 2002
138	Scathophagidae	Scathophaginae	*Scathophaga* sp.		
139	Sepsidae	Nemopodatinae	*Nemopoda pectinulata*		
140	Sepsidae	Sepsinae	*Sepsis* sp.		
141	Stratiomyidae	Unidentified	Unknown		
142	Syrphidae	Eristalinae	*Cheilosia* sp.		
143	Syrphidae	Eristalinae	*Chrysogaster* sp.	IND	Dousti & Hayat 2006; Khaghaninia et al. 2012; Dousti 2023
144	Syrphidae	Eristalinae	*Eristalinus taeniops*		
145	Syrphidae	Eristalinae	*Eristalinus* sp.		
146	Syrphidae	Eristalinae	*Eristalis himalayensis*		
147	Syrphidae	Eristalinae	*Eristalis tenax*		
148	Syrphidae	Eristalinae	*Eristalis tristriatus*		
149	Syrphidae	Eristalinae	*Eristalis* sp.		
150	Syrphidae	Eristalinae	*Rhingia binotata*		
151	Syrphidae	Eristalinae	*Rhingia* sp.		
152	Syrphidae	Eristalinae	*Sphegina* sp.		
153	Syrphidae	Syrphinae	*Asarkina africana*	IND	Whittington 1998; Ssymank 2012; Smit et al. 2017; El-Hawagry & Gilbert 2019
154	Syrphidae	Syrphinae	*Asarkina* sp.1		
155	Syrphidae	Syrphinae	*Asarkina* sp.2		
156	Syrphidae	Syrphinae	*Baccha maculata*		
157	Syrphidae	Syrphinae	*Betasyrphus* sp.		
158	Syrphidae	Syrphinae	*Chrysotoxum* sp.		
159	Syrphidae	Syrphinae	*Citrogramma citrinum*		
160	Syrphidae	Syrphinae	*Episyrphus balteatus*		
161	Syrphidae	Syrphinae	*Episyrphus* sp.1		
162	Syrphidae	Syrphinae	*Episyrphus* sp.2		
163	Syrphidae	Syrphinae	*Episyrphus* sp.3		
164	Syrphidae	Syrphinae	*Episyrphus* sp.4		
165	Syrphidae	Syrphinae	*Eupeodes* sp.		
166	Syrphidae	Syrphinae	*Lycastris* sp.1		
167	Syrphidae	Syrphinae	*Lycastris* sp.2		
168	Syrphidae	Syrphinae	*Melanostoma* sp.		
169	Syrphidae	Syrphinae	*Paragus haemorrhous*	IND	Haarto 2014; Turk et al. 2014
170	Syrphidae	Syrphinae	*Paragus* sp.1		
171	Syrphidae	Syrphinae	*Paragus* sp.2		
172	Syrphidae	Syrphinae	*Spherosphoria scripta*	WB	Mitra et al. 2015; Sengupta et al. 2016
173	Syrphidae	Syrphinae	*Syrphus dalhousiae*	WB	Mitra et al. 2015; Sengupta et al. 2016
174	Syrphidae	Syrphinae	*Syrphus torvus*		
175	Tabanidae	Pangoniinae	*Philoliche longirostris*		
176	Tachinidae	Dexiinae	*Prosena* sp.		
177	Tachinidae	Dexiinae	*Thelaira solivaga*	WB	Sathe et al. 2014

No.	Family	Subfamily	Species	Records*	Sources
178	Tachinidae	Dexiinae	*Zelia* sp.		
179	Tachinidae	Tachininae	*Linnaemya* sp.		
180	Tachinidae	Tachininae	*Tothillia asiatica*	WB	O'Hara et al. 2020
181	Tachinidae	Tachininae	*Tachina* sp.1	WB	O'Hara et al. 2020
182	Tachinidae	Tachininae	*Tachina* sp.2		
183	Tachinidae	Tachininae	*Tachina* sp.3		
184	Tachinidae	Tachininae	*Tachina* sp.4		
185	Tachinidae	Tachininae	*Tachina* sp.5		
186	Tachinidae	Tachininae	*Tachina* sp.6		
187	Tachinidae	Tachininae	*Tachina* sp.7		
188	Tephritidae	Unidentified	Unknown		
189	Tipulidae	Chioneinae	*Atarba* sp.		
190	Tipulidae	Dolichopezinae	*Dolichopeza* sp.		
191	Tipulidae	Limoniinae	*Atypophthalmus* sp.		
192	Tipulidae	Limoniinae	*Geranomyia* sp.1		
193	Tipulidae	Limoniinae	*Geranomyia* sp.2		
194	Tipulidae	Limoniinae	*Toxorhina* sp.		
195	Tipulidae	Tipulinae	*Holorusia* sp.		
196	Tipulidae	Tipulinae	*Indotipula* sp.1		
197	Tipulidae	Tipulinae	*Indotipula* sp.2		
198	Trichoceridae	Trichocerinae	*Trichocera* sp.	WB	Alexander 1961
199	Ulidiidae	Otitinae	*Pseudotephritis* sp.1		
200	Ulidiidae	Otitinae	*Pseudotephritis* sp.2		
201	Ulidiidae	Otitinae	*Pseudotephritis* sp.3		

*First time recorded from the state of West Bengal (WB), or India (IND)

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COMMUNICATION

Body growth and condition of endangered *Tor putitora* (Hamilton, 1822) (Actinopterygii: Cypriniformes: Cyprinidae) in the crucially important breeding and nursery grounds of the Ganga stock

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Abstract: The study evaluates seasonal differences in length-weight relationship and relative condition factor (K_n) of *Tor putitora* in the Nayar, a critical breeding and nursery ground in the mountain zone of the Ganga. The growth coefficient of *T. putitora* varies seasonally between 2.86 and 2.99 while relative condition factor between 1.00 ± 0.06 to 1.061 ± 0.3. Mahseer shows negative allometric growth (except the monsoon season) with better condition factor throughout the study period. The present K_n factor for different size groups show deviation from past which may be due to inadequate food resources or excessive fishing in the Nayar.

Keywords: Allometric growth, exploitation, growth coefficient, isometric, juveniles, K_n, Mahseer, length-weight, Nayar, spawning.

यह शोध गंगा के पर्वतीय क्षेत्र में *टॉर पुटिटोरा,* महाशीर के महत्त्वपूर्ण प्रजनन और नर्सरी स्थल, नयार में किया गया हैं जो *टॉर पुटिटोरा* में मौसमी स्तर पर होने वाले लम्बाई–वजन सम्बध और रिलेटिव कन्डिशन फैक्टर का मूल्यांकन करता हैं। मौसमी स्तर पर *टॉर पुटिटोरा* का विकास गुणांक 2.66 से 2.99 के बीच भिन्न था, जबकि रिलेटिव कन्डिशन फैक्टर 1.00 ± 0.06 से 1.061 ± 0.3 के बीच भिन्न था। सम्पूर्ण अध्ययन अवधि के दौरान (मानसून के मौसम को छोड़कर) महाशीर मौसमी स्तर पर नकारात्मक एलोमेट्रिक वृद्धि के साथ बेहतर रिलेटिव कंडिशन फैक्टर दिखाता है। महाशीर के विभिन्न आकार समूहों के लिए वर्तमान का रिलेटिव कंडिशन फैक्टर पूर्व से भिन्नता दिखाता हैं, जो नयार में खाद्य संसाधनों की कमी या अत्यधिक मात्स्यिकी के कारण हो सकता है।

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Author contributions: PR conducted the data collection, performed the statistical analysis, and drafted the initial manuscript. PN played a critical role in reviewing and providing constructive feedback on the initial draft and finalized the content for publication.

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INTRODUCTION

Himalayan Mahseer is an Endangered (Jha et al. 2018) endemic megafauna of Himalayan rivers that completes its migratory cycle within glacier-fed and spring-fed tributaries for spawning/feeding and rearing purposes (Nautiyal 1996; Bhatt et al. 2000; Nautiyal et al. 2001). Presently, the mahseer fishery of Indian subcontinent is declining under continuous threat of indiscriminate fishing, habitat degradation/fragmentation, climate change (Nautiyal 2014) and introduction of non-native fish (Gupta et al. 2019). The coupled effect of all these factors could be reflected in their growth, body condition, mortality, and recruitment of the next cohorts. Length-weight relationship is an easy tool for the assessment of the body growth and condition of the fish at the individual as well as population level. The relationship also offers a measure of the health of the fish population (Safran 1992), as well as a comparison of the life history characteristics of populations living in various geo-climatic regions. Various changes in the expected size, length-weight and hence growth of the fish due to major or minor changes in their life cycle could be perceived through the length-weight relationship (Le Cren 1951). Further, the relative condition factor (K_n) makes an assessment if increase in the body weight is in accordance with the desirable reproductive potential and recruitment rate. The study, therefore, evaluates the present status of the Himalayan Mahseer stock in the breeding and nursery grounds in the Nayar.

Study area

The Nayar is a spring-fed perennial river that originates from the Dudhatoli Hills in the Pauri Garhwal District of Uttarakhand. The confluence of the Nayar with the Ganga is located ~10 km downstream from Devprayag, Uttarakhand. The stock in the Ganga foothills ascends the Nayar annually (Nautiyal et al. 2001).

MATERIALS AND METHODS

The present study was based on the samples (N = 1966) of Putitor Mahseer collected from the local fishermen (Image 1) during July 2021 to October 2022 at weekly intervals. Further, the 1980s data were obtained monthly by the second author (PN), which contributed to a small sample size compared to weekly collection. The samples were cleaned with a cotton cloth. Thereafter, the total length and weight of the individual fish were recorded using measuring tape and a digital balance respectively.

Length-weight relationship was estimated using logarithmic form of the following equation

$$Log\ W = Log\ a + b\ Log\ L$$

Where, W is the weight of the sample in gm, L is the total length of the fish sample in cm while a and b are the intercept and slope respectively. The regression coefficients and the length-weight relationship were analyzed using Microsoft Excel 2016 software.

Significance of b value, i.e., Ho: ß = 3 was evaluated using t-test as

$$t = \frac{|b - 3|}{Sb}$$

where, S_b is the standard error of b.

Relative condition factor was estimated using

$$Kn = \frac{Wo}{Wc}$$

Where, Wo is the observed weight and Wc is the calculated weight obtained from length-weight analysis.

RESULTS

The examined fish samples ranged from 6.2 to 121.9 cm in the length and 2.1 to 25,000 g in weight, among which individuals below 25 cm constituted the resident stock of the Nayar (Table 1) as they were recorded throughout the study period. However, individuals measuring above 25 cm were the migratory brooder stock of mahseer as they were recorded only during the monsoon season (Table 1). Among the resident stock, the fish measuring between 10–15 cm was high in total sample followed by 15–20 cm and 20–25 cm.

The seasonal growth coefficient (b) varied between 2.86–2.99 (Table 2) which is within the expected suitable range of growth (Froese 1998). Except for the monsoon season (2021), mahseer has shown negative allometric growth as t-test analysis rejected the hypothesis i.e., Ho: ß = 3, at 0.05 level (Table 2). However, seasonal analysis of length-weight data of 1980–1981 has shown isometric growth type in winter season while negative allometric growth type for monsoon and summer season (Table 3). The b value was estimated as 2.95, for the pooled data of the present stock of mahseer, showing isometric growth type which was also recorded in earlier studies from the Nayar and other geo-climatic locations (Table 4).

The mean value of monthly relative condition factor for the present Mahseer cohort ranged between 1.00 ± 0.06 to 1.061 ± 0.3 (Table 5 and Figure 1). The peak of K_n

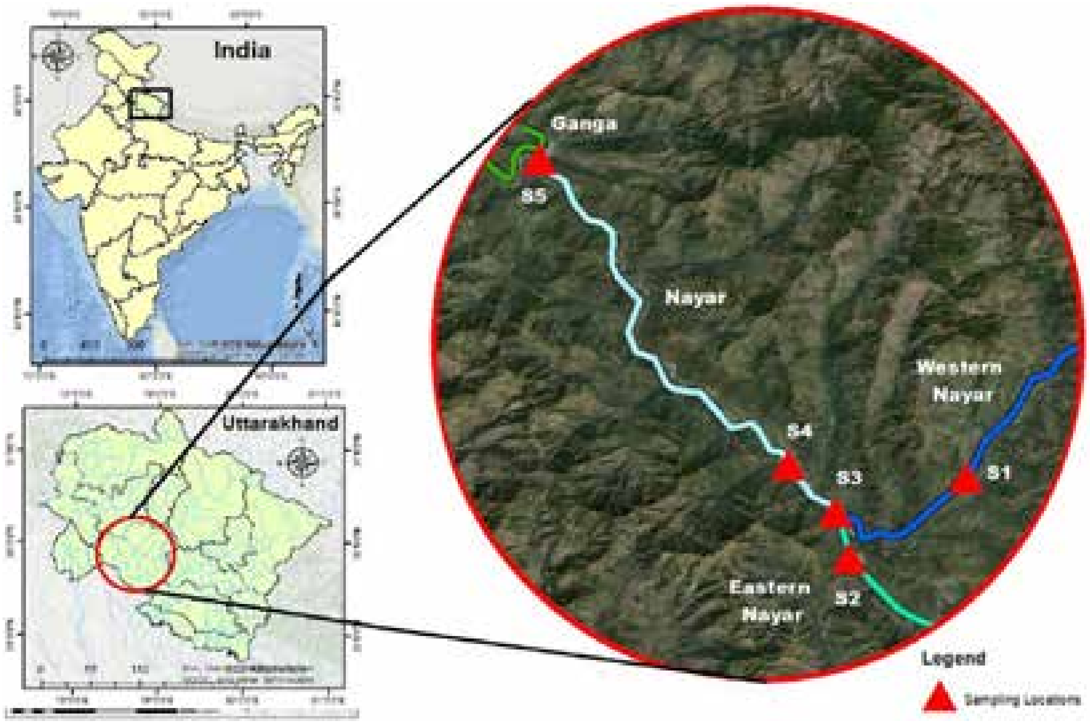

Image 1. Study area map with sampling locations.

was observed during monsoon season (July to August) which usually refers their breeding period as indicated by presence of ripe individuals and fry-fingerlings (Table 1). Further, a moderate relative condition factor ranging between 1.003 ± 0.03 to 1.005 ± 0.09 has been observed in between the monsoon periods. However, the current cohort's juveniles have a relatively high relative condition factor, in contrast to the 1980's cohort, where adults had a greater K_n factor (Figure 2).

DISCUSSION

The largest size of the Himalayan Mahseer encountered during this study was 121.9 cm in August. This was comparatively smaller than the past size (133.7 cm) in 1980–1981 (Nautiyal & Lal 1981). The Mahseer ranging above 40 cm was very low in number as they are part of migratory stock ascending from Ganga into Nayar for breeding purposes. However, other parts of India have also reported a drop in the size of other Mahseer fisheries and a low share in overall fish catches (Minimol 2000).

The resident 1980's cohort of the Nayar (4.1–49 cm) including fingerlings, juveniles and adults have shown negative allometric growth indicating no significant weight gain. However, winter season has shown comparable weight gain with respect to length increment which may be due to availability of food resources as winter is the most productive period of the Nayar (Nautiyal 1986). However, negative allometric growth in 2021–22 cohort throughout the seasons, somehow, indicate depletion of resources. Additionally, the isometric growth in monsoon and pooled data may be attributed to inclusion of large sized brooders with ripe eggs in resident stock (Table 1). Therefore, 1980's cohort has shown negative allometry in monsoon season due to prevalence of fingerlings and juveniles (<25 cm) which do not possess mature gonads. The previous studies on *T. putitora* in different regions have also shown isometric, positive and negative allometric growth patterns with varying geographic and climatic conditions (Table 3). Therefore, the seasonal fluctuations in sample size, maximum length, gonad maturity, food availability, feeding intensity (Le Cren 1951) may have played a major role in the body growth and condition of present cohort of Himalayan Mahseer.

During breeding season large percentage of the total body weight is influenced by increase in gonad size of prospective brooders as gonads undergo rapid development during spawning. Hence K_n attained a peak in monsoon and fell abruptly thereafter. However, a sudden drop in June may be attributed to the decline in the feeding intensity from summer onwards (Nautiyal

Table 1. Monthly variations in frequency (as %) of different size groups (in cm) of *Tor putitora* in the Nayar.

	2021						2022								
	Monsoon				Winter			Summer				Monsoon			
Size-group	**J**	**A**	**S**	**O**	**N**	**D**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**
1–5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5–10	27.0	19.6	-	19.5	6.2	31.3	35.5	-	-	-	0.7	-	35.2	-	28.7
10–15	22.2	19.6	6.7	50.2	52.7	67.2	64.5	18.2	39.8	8.2	35.2	34.5	9.9	5.6	63.2
15–20	19.0	13.7	28.9	25.5	17.8	-	-	41.6	48.9	35.4	35.9	13.8	20.9	21.1	8.0
20–25	9.5	14.7	38.0	2.4	18.6	1.6	-	22.1	9.1	45.6	22.1	17.2	8.8	32.2	-
25–30	7.9	8.8	15.1	0.4	3.1	-	-	5.2	-	8.8	6.2	13.8	6.6	22.2	-
30–35	1.6	3.9	4.9	-	1.6	-	-	7.8	-	1.4	-	6.9	1.1	5.6	-
35-40	3.2	4.9	1.8	0.8	-	-	-	-	0.4	0.7	-	3.4	3.3	3.3	-
40–45	-	2.0	0.4	1.2	-	-	-	2.6	1.3	-	-	-	5.5	3.3	-
45–50	1.6	4.9	0.4	-	-	-	-	1.3	0.4	-	-	6.9	3.3	2.2	-
50–55	1.6	2.9	0.4	-	-	-	-	1.3	-	-	-	-	2.2	1.1	-
55–60	1.6	1.0	0.4	-	-	-	-	-	-	-	-	-	1.1	2.2	-
60–65	1.6	1.0	0.4	-	-	-	-	-	-	-	-	-	-	-	-
65–70	-	1.0	0.7	-	-	-	-	-	-	-	-	-	-	-	-
70–75	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	-
75–80	1.6	1.0	0.4	-	-	-	-	-	-	-	-	3.4	2.2	-	-
80–85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
85–90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90–95	1.6	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-
95–100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
100–105	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-
105–110	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-
110–115	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-
115–120	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-
120–125	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-

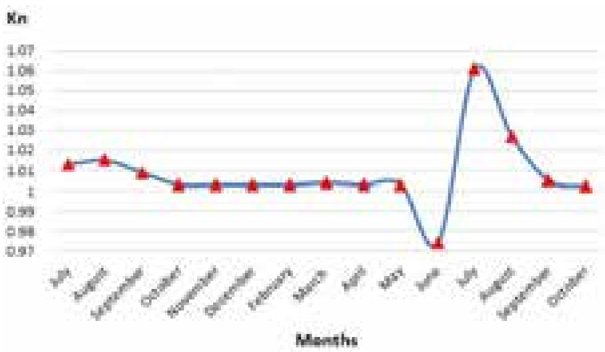

Figure 1. Monthly variations in the relative condition factor of *T. putitora* from the Nayar.

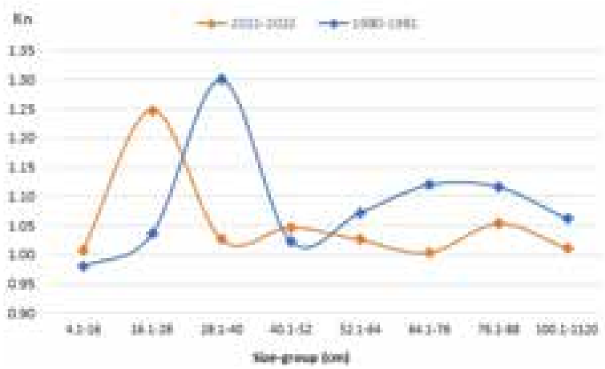

Figure 2. Size-related variations in the Kn factor for *T. putitora* cohort of 1980 and 2022.

Table 2. Seasonal descriptive statistics of length-weight relationship of *T. putitora* in the Nayar (2021–2022).

Season	N	Total length (cm)		Total Weight (gm)		a	b	r^2	$T_{0.05}$	Growth *
		Min.	Max.	Min.	Max.					
Monsoon	700	7.5	121.9	4	25000	-2.07	2.99	0.99	0.84	I
Winter	224	8.9	34.1	6.65	362.64	-1.97	2.91	0.99	4.64	NA
Summer	745	15	51.2	34.01	1167.16	-1.89	2.86	0.98	4.63	NA
Monsoon	297	6.2	78.9	2.1	5000	-1.98	2.91	0.98	4.21	NA
Pooled	1966	6.2	121.9	2.1	25000	-2.01	2.95	0.97	1.77	I

* t—t-test | I—Isometric | NA—Negatively allometric.

Table 3. Seasonal descriptive statistics of length-weight relationship of *T. putitora* in the Nayar (1980–1981).

Season	N	Total length (cm)		Total weight (gm)		a	b	r^2	$T_{0.05}$	Growth *
		Min.	Max	Min.	Max					
Monsoon	59	4.1	25	0.548	113.5	-2.00	2.88	0.98	2.30	NA
Winter	134	4.9	21.6	1.025	83	-1.98	2.91	1.00	0.49	I
Summer	52	7.1	49	2.98	875.5	-0.12	1.33	0.68	2.35	NA

* t—t-test | I—Isometric | NA—Negatively allometric.

Table 4. Growth coefficient of *T. putitora* form the Nayar and other regions of India.

River/Other	State	b	Growth *	Reference
Nayar	Uttarakhand	2.88	I	Lal & Nautiyal 1980
Nayar	Uttarakhand	2.98	I	Nautiyal 1985
Pong Reservoir	Himachal Pradesh	3.15	PA	Johal et al. 2005
Ladhiya	Uttarakhand	2.99	I	Patiyal et al. 2010
Jia Bharoli	Arunachal Pradesh	3.108	I	Ali et al. 2014
Beas	Himachal Pradesh	3.082	I	Ali et al. 2014

* I—Isometric | PA—Positive Allometric | NA— Negatively Allometric.

1996) which coincides with the decline in the food resources from winter afterward. Similar trend in relative condition factor was observed earlier also and was used to infer the monsoon as breeding season (Nautiyal 1985). However, in contrast to 1980's cohort (Nautiyal 1985), the small size groups have shown better fitness while health condition of adults have deteriorated from past (Figure 1) which may be caused by overfishing of potential brooders leading to overexploitation, hampered recruitment, fragmentation of habitat and subsequent degradation, scarcity of food resources and decline in feeding intensity after attaining a length of 22 cm (Nautiyal 1989). However, low K_n for juveniles (<20 cm) and comparatively better in adults (> 20 cm) was recorded form the Khoh, Kolhu, and Mandal (tributaries of Ramganga) in the Uttarakhand (Atkore et al. 2007).

Table 5. Monthly relative condition factor (Kn) of *T. putitora* in the Nayar.

Month	N	K_n ± S. D.
July	63	1.013 ± 0.16
August	102	1.015 ± 0.18
September	284	1.009 ± 0.13
October	251	1.004 ± 0.08
November	129	1.003 ± 0.08
December	64	1.003 ± 0.08
February	31	1.003 ± 0.08
March	77	1.004 ± 0.09
April	231	1.003 ± 0.08
May	147	1.003 ± 0.08
June	290	0.954 ± 0.09
July	29	1.061 ± 0.30
August	91	1.027 ± 0.31
September	90	1.005 ± 0.11
October	87	1.002 ± 0.06
Pooled	**1966**	**1.013 ± 0.16**

CONCLUSION

The Himalayan Mahseer deviated from the past in terms of body growth, condition and fitness. The mahseer of present cohort are not robust compared to past which may be attributed to either lack of food resources, decline in feeding intensity or increasing fishing pressure. Although the Mahseer has shown better condition throughout the present study period but the overall wellness in the adults has declined while inclined in the juveniles which may be related to habitat suitability or overfishing of larger size groups. Therefore, this study provides insight about the declined growth in body size and condition of different size groups of endangered Himalayan Mahseer.

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COMMUNICATION

The arboreal microsnail *Insulipupa malayana* (Issel, 1874) (Gastropoda: Stylommatophora: Vertiginidae) from West Bengal, India

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Abstract: Studies on occurrence, host plant preference and morphometric features of the arboreal microsnail *Insulipupa malayana* (Issel, 1874) (Gastropoda: Stylommatophora: Vertiginidae) were carried out from selected sites of West Bengal, India. The snail species use the stem and bark of five plant species (*Hibiscus rosa-sinensis*, *Mangifera indica*, *Aegle marmelos*, *Swietenia macrophylla*, and *Roseodendron donnell-smithii*) as microhabitat, and the most preferred host plant was *A. marmelos* (Jacobs' selectivity index D_{ia}= 0.5 ± 0.19). The mean ± SE values of shell height (SH), shell width (SW), aperture length (AL), aperture width (AW), body weight, apical angle (AA) and spire ratio (SR) of the collected specimens were measured as 1.95 ± 0.06 mm, 1.03 ± 0.01 mm, 0.54 ± 0.02 mm, 0.74 ± 0.02 mm, 0.86 ± 0.06 mg, 0.55 ± 0.02, and 1.89 ± 0.06, respectively. The present study will be informative to frame conservation strategies for *I. malayana* in India and elsewhere.

Keywords: Conservation, distribution, Jacobs' selectivity index, morphometry, terrestrial snail.

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Author contributions: Conceived by GA; HB and PP carried out the field study, the data collection and analysis of the data. HB, GA and PP drafted the manuscript including the interpretation of the data.

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INTRODUCTION

Terrestrial molluscs are an important biota of the terrestrial ecosystem (Astor et al. 2015), and extensive variation is observed in their shape and size, ranging from the smallest *Angustopila dominikae* (approximately 0.86 mm in shell length) (Páll-Gergely et al. 2015) to the Giant African Land Snail *Lissachatina fulica* (approximately 39.3 cm in shell length). In total, there are about 35,000 described species of terrestrial molluscs globally (Lydeard et al. 2004). Land snails that are less than 5 mm in shell length are considered as microsnails (Panha & Burch 2005), and they are potential bioindicators because of their limited dispersal capacity and need for specific microhabitats (Gheoca et al. 2021), such as caves (Dumrongrojwattana et al. 2021), and tree leaf and bark (Nandy et al. 2022). Although there are several promising studies on the diversity and conservation of Indian land snails (Aravind et al. 2005; Ramakrishna et al. 2010; Sen et al. 2012), only a few studies focused on the micro land snails of the Western Ghats (Aravind et al. 2008) and northeastern part of India (Barman et al. 2021; Das & Aravind 2021).

Indian micro land snails are represented by the genera *Kaliella*, *Rahula*, *Georissa*, *Pupilla*, *Pupa*, *Pupisoma*, and *Nesopupa* (Gude 1914, 1921). Among them, eastern Indian snails in the family Vertiginidae contain a few genera, including *Cylindrovertilla* Boettger, *Costigo* Boetger, *Insulipupa* Pilsbry & C.M. Cooke, and *Nesopupa* Pilsbry (Pilsbry 1900). The genus *Nesopupa* is widespread throughout the tropics in the Ethiopian and Oriental regions and the Pacific islands (Hausdorf 2008). Based on the whorl numbers, aperture shape and size, apertural lamellae and folds, striae and shell colour, the genus *Nesopupa* has been grouped into eight groups designated as I to IV (for islands groups), V (species of India and Sri Lanka), VI (Mascarene Islands and Comoros), VII (African species), and VIII (St. Helena species) (Pilsbry 1919). The taxonomic account of the genera *Vertigo*, *Pupilla*, *Nesopupa*, and *Insulipupa* is quite complicated and perplexing. In most literature, the genus names *Vertigo*, *Nesopupa*, and *Insulipupa* were used erroneously, and emphasis was given to the shell dimension, apertural lamellae and folds for identification (Pilsbry 1919). For instance, the genus *Nesopupa* Pilsbry, 1900 was conserved by suppressing the name *Ptychochilus* Boettger, 1881 (Cowie et al. 1994). Though it was not clear whether the specimen collected by Dr. J.F. Bacon was *Pupilla brevicostis* or *Pupilla barrackporensis* (Gude 1914), the species identification shifted from *Vertigo malayanus*, *Pupilla barrackporensis*, *Nesopupa* (*Insulipupa*) *barrackporensis* to *Insulipupa malayana* (Gittenberger & Bruggen 2013; MolluscaBase 2021). However, the currently accepted name of *Pupilla barrackporensis* (Gude, 1914) (described from Barrackpore, India) is *Insulipupa brevicostis* (Benson 1849; MolluscaBase 2023). Among the micro land snails, *Insulipupa malayana* (Issel, 1874) (Stylommatophora: Vertiginidae) has not yet been evaluated for the IUCN Red List and has no detailed distribution range (GBIF 2022). In comparison to the information on the land snails and particularly the microsnails on a worldwide scale (Vermeulen & Liew 2022), the information in the Indian context is limited, mostly to the Western Ghat (Aravind et al. 2008), and most studies were focused on taxonomy while little is known about the ecology and biology of the micro land snails. Documentation of land snail records in various habitats is necessary to evaluate and prioritise threats and enhance conservation efforts. Hence, the reports on the occurrence and bio-ecology of the micro land snail *I. malayana* will be helpful in this regard.

MATERIALS AND METHODS

In course of land snail surveys in different regions of West Bengal, India, during July 2017 to October 2019 (irrespective of time and season), we encountered the microsnails on the stem of shrubs in Gobordanga, North 24 Parganas (22.879791 °N, 88.760227 °E), under the bark of woody plants in The Acharya Jagadish Chandra Bose Indian Botanic Garden, Howrah (22.554885 °N, 88.292322 °E) and Kansrakatai, Howrah (22.534442 °N, 87.908341 °E) (Figure 1). During the survey, the abundance of the snails on different plants was noted, and the collected snails were brought to the laboratory for identification and morphometric analysis. Initially, the snails were photographed using a microscope digital camera (DGI 510, Dewinter, India) fitted with a binocular microscope (SZ2-ILST, Olympus, Japan) for identification. Few shells were cleaned, dried, and placed in carbon tape and platinum-coated to obtain the scanning electron micrograph through scanning electron microscopy (EVO 18 special edition, Zeiss, Germany). Lamellae and folds in the aperture of the specimens were named as teeth structures and represented with International, Westerland, and Steenberg formulas (Pilsbry 1919). Using a binocular light microscope fitted with an ocular micrometre (Erma, Japan), the shell height (SH), shell width (SW), aperture length (AL) and aperture width (AW) of the collected snails were

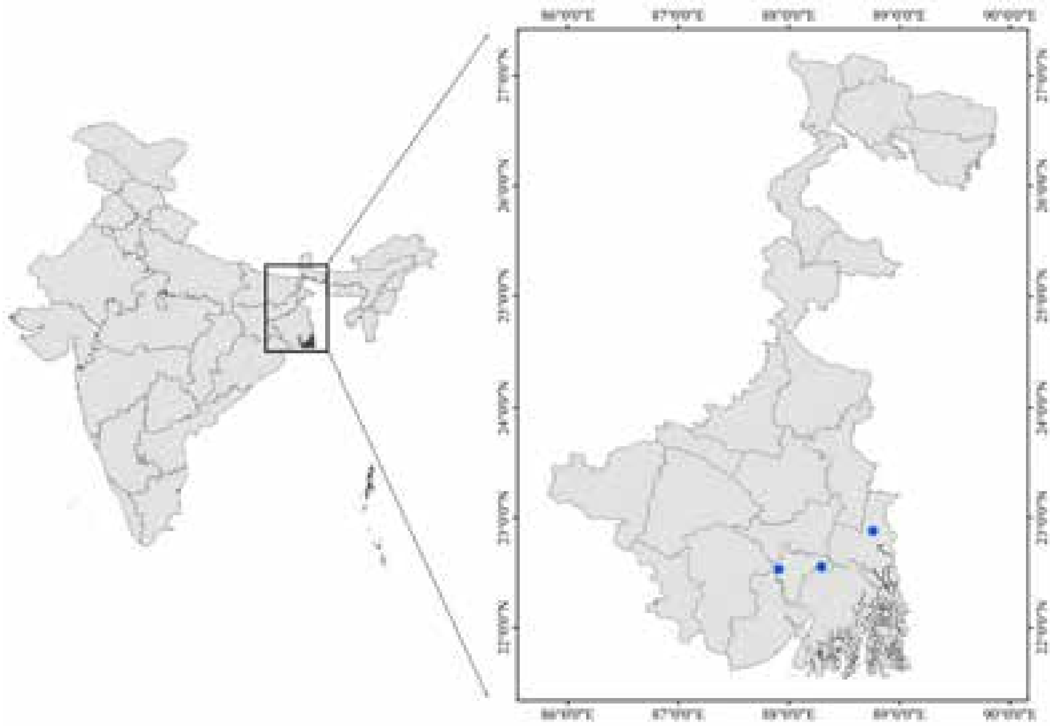

Figure 1. Occurrence points (circles in blue) of *Insulipupa malayana* in West Bengal, India.

measured to the nearest 0.1 mm (Barman et al. 2021). The apical angle (AA) and spire ratio (SR) of the shells were also calculated using the following formula: AA = 2*tan (0.5*SW/SH) (Preston & Roberts 2007) and SR = SH/SW, respectively. Host plant preference was assessed using Jacobs' selectivity index (D_{ia}) (Jacobs 1974), which was calculated using the equation-

$$D_{ia} = \frac{(r_i - p_a)}{(r_i + p_a - 2 r_i p_a)}$$

where D_{ia} is the selectivity index of snail species 'i' on plant 'a', 'r_i' is the ratio of plant type 'a' used to all other plant types used by that species, and 'p_a' is the ratio of plant type 'a' to all other plants available for the individual to use within the local area.

RESULTS AND DISCUSSION

In rainy seasons, the microsnails were observed to be active on the bark and in dry seasons, they were found with epiphragm under the bark. The collected micro land snails were identified as *Insulipupa malayana* (Issel, 1874). This species has a minute, cylindrical shell shape with five whorls, with vermiculated shell sculpture. The body whorl and part of the adjacent whorl are brown, while the remaining part of the shell is dark brown. The last whorl has a broad, shallow impression behind the lip, with the presence of five aperture teeth, comprising relatively low angular teeth and the largest parietal tooth, a quite deeply placed single columellar tooth and two palatal teeth (Pilsbry 1919; MolluscaBase 2021) (Image 1). In total, 53 snail individuals were encountered during the survey. The morphometric features of the collected snails (n = 17) are shown in Table 1. The apertural teeth of *I. malayana* can be represented by the International formula: AP–.–PiPs, Westernlund formula: 2–1–2; and Steenberg formula: $V_{2,3}$–A_1–$G_{3,5}$.

The previous records of *I. malayana* with accepted and different synonymised names from islands of Banggi and Balambangan, Malaysia (Schilthuizen et al. 2011), islet of Misali, off Pemba Island, Zanzibar, Tanzania (Gittenberger & Bruggen 2013), Sabah, Borneo (Phung et al. 2017), Singapore (Sow-Yan & Lup 2019) and other locations are as follows: (i) *Nesopupa* (*Insulipupa*) *malayana* (Pilsbry 1918–1920; Thompson & Dance 1983; Maassen 1997; Vermeulen & Whitten 1998; Clements et al. 2008; Schilthuizen et al. 2011, 2013; Phung et al. 2017), (ii) *Vertigo malayanus* (Issel 1874), (iii) *Pupa malayana* (Pfeiffer 1877; Tenison-Woods 1888; von Martens 1908), and (iv) *Pupa* (*Vertigo*) *malayana* (Pfeiffer & Clessin 1881 – Type from Borneo).

Among the 45 plant species of the present study area, *I. malayana* was found on only five species. The

Table 1. Morphometric features (range and mean ± SE) of the collected living *Insulipupa malayana* (n = 17).

SL (mm)	SW (mm)	AL (mm)	AW (mm)	BW (mg)	AA°	SR
1.44–2.26 (1.95 ± 0.06)	0.94–1.09 (1.03 ± 0.01)	0.36–0.71 (0.54 ± 0.02)	0.56–0.90 (0.74 ± 0.02)	0.31–1.21 (0.86 ± 0.06)	0.44–0.74 (0.55 ± 0.02)	1.42–2.31 (1.89 ± 0.06)

SL—shell length | SW—shell width | AL—aperture length | AW—aperture width | BW— body weight | AA°—apical angle | SR—spire ratio.

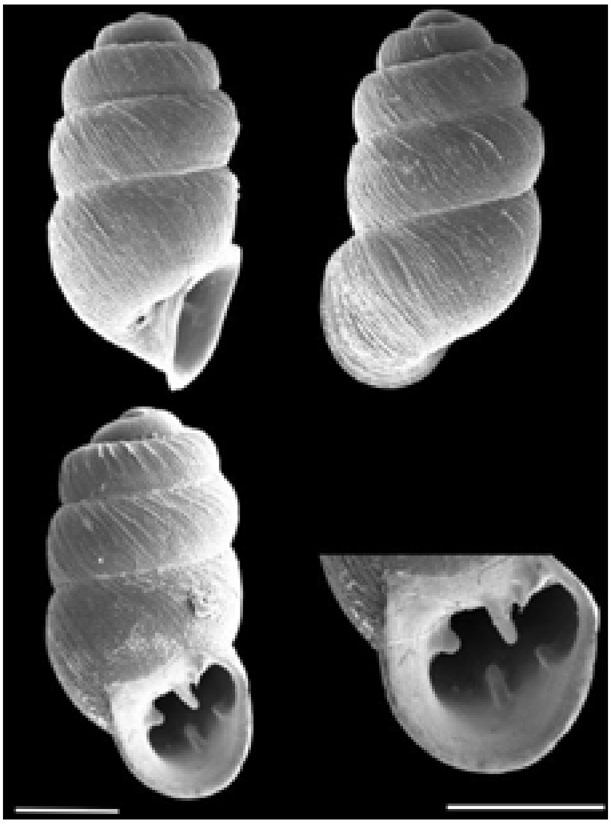

Image 1. Scanning electron microscope micrograph of the shells of *Insulipupa malayana*. Scale bar = 0.5 mm. © Authors.

snails were observed on the stems of *Hibiscus rosa-sinensis* and *Mangifera indica*, under the bark of *Aegle marmelos, Swietenia macrophylla*, and *Roseodendron donnell-smithii*. Among the host plants, *I. malayana* showed the highest selectivity to *A. marmelos* (D_{ia} = 0.5 ± 0.19), followed by *H. rosa-sinensis* (D_{ia} = 0.25 ± 0.16), *R. donnell-smithii* (D_{ia} = 0.12 ± 0.12), *S. macrophylla* (D_{ia} = 0.10 ± 0.10), and *M. indica* (D_{ia} = -0.06 ± 0.15). Although *I. malayana* was previously recorded from twigs, dead leaves and moss-laden concrete walls in Singapore (Sow-Yan & Lup 2019), we observed that this species is completely arboreal in West Bengal, India. The preference for *A. marmelos*, *H. rosa-sinensis*, *R. donnell-smithii*, and *S. macrophylla* as host plants may be for food, as lichens were present on these host plants. Alternatively, the choice of the barks of these plants may be to camouflage against the predators as the underside colour of the bark of these host plants is nearly the same as the shell colour of *I. malayana*. These microsnails were also encountered on *M. indica*, but the Jacobs' selectivity index was negative in the study. The high apical angle and spire ratio support the arboreal life of *I. malayana*, similar to other plant-dwelling snail species of the family Achatinillidae, Amastridae and Pupillidae (Cowie 1995). The present information will be useful in understanding the preferred habitat conditions of *I. malayana* and thus sustenance and conservation of its population.

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OPEN ACCESS

COMMUNICATION

Mapping invasive alien plants through citizen science: shortlisting species of concern for the Nilgiris

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Abstract: Species introduced from elsewhere are known as alien species. They may be introduced as crop plants or ornamental plants, or for timber. A small proportion of introduced species can become invasive thereby spreading at the cost of native species and habitats, negatively affecting biodiversity, food security, and human wellbeing. Despite the growing recognition of the threat of invasive alien species, we still lack information about the distribution and abundance of species widely accepted to be invasive. To address this information gap regarding invasive alien species distributions, we initiated a pilot citizen science effort to create an atlas of invasive plants in the Moyar-Bhavani landscape of the Nilgiri District. We aimed, through this pilot effort, to develop and test user-friendly mapping protocols and develop an interface for citizen scientists to use. Ultimately, we hope to create a model that can be scaled up to large conservation landscapes, such as the Western Ghats, the Central Indian Highlands, and the Himalaya.

Keywords: Biodiversity, conservation, introduced species, India, invasive species database, Moyar-Bhavani watershed, non-native plants, protocol, stakeholder workshop, threat, user-friendly, Western Ghats.

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Author contributions: SMR carried out the compilation of the database of invasive plants for the Nilgiris, prepared the poster on common invasive plants and participated in fieldwork. RR carried out the data analysis and participated in fieldwork. ST participated in fieldwork, was involved in shorlisting and finalization of the invasive plant list, and contributed to poster preparation. MB designed the study, and participated in fieldwork. AV designed and planned the study and participated in fieldwork. AH conceptualized and designed the study and participated in field work. All authors were involved in drafting and revising the manuscript.

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INTRODUCTION

People have moved species around the globe since time immemorial for food, fibre, fuel, sport, and aesthetic reasons. Such species, which have been introduced outside their natural range of distribution, are referred to as 'alien species' (or introduced or exotic species). Most alien species arrive in new environments intentionally, though some can arrive inadvertently as contaminants on known introductions or simply as stowaways. Examples of species introduced intentionally include plants and animals introduced for food (e.g., the African Catfish *Clarias gariepinus*), for timber and fuelwood (e.g., the Black Wattle *Acacia mearnsii*), or those introduced as ornamental plants (e.g., *Lantana camara*), and for the aquarium and pet trade (e.g., the Goldfish *Carassius auratus* and the Red-eared Slider *Trachemys scripta elegans*). An example of an inadvertent or accidental introduction is *Parthenium hysterophorus*, whose seeds are thought to have arrived in India as a seed contaminant of wheat imported from the Americas.

Although the vast majority of introduced species are of great value, a small proportion of these can become invasive. This refers to their becoming widespread and having negative impacts on biodiversity, ecosystem services, food security, or human health and wellbeing. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) identifies invasive alien species as amongst the greatest threats to biodiversity and ecosystem services globally, comparable with climate change, change in land (and sea) use, species overexploitation, and pollution (IPBES 2019).

In India too, we now recognise the threat of invasive alien species. One of India's National Biodiversity Targets (NBT4) focuses on preventing new invasive species introductions and controlling existing invasive species (MoEFCC 2014). Some states have gone further by formulating policy on invasive species management, Tamil Nadu being the first (TN-PIPER 2022).

Despite this growing recognition of the threat of invasive alien species, we still lack information about the distribution and abundance of species widely accepted to be invasive. Such information is vital to prioritise species and habitats for management interventions and provides a baseline against which to assess future invasive species spread.

To address this information gap regarding invasive alien species distributions, we initiated a pilot citizen science effort to create an atlas of invasive plants in the Moyar-Bhavani landscape of the Nilgiri District. Citizen science, which refers to a partnership between scientists and members of the public, is a growing field both in India and globally. Over the last decade the ubiquitousness of smartphones, plus access to the internet, has made it easier for people to record and share observations, leading to a growing number of such researcher-citizen scientist collaborations (see for example, https://citsci-india.org/projects/). In our specific case, scientists working in partnership with naturalists, students, community members, and forest managers could achieve the task of mapping invasive species at a scale, and within a timeframe, that would be meaningful for both researchers and managers—something that scientists on their own could not do. We aimed, through this pilot effort, to develop and test user-friendly mapping protocols and develop an interface for citizen scientists to use. Ultimately, we hoped to create a model that could be scaled up to large conservation landscapes, such as the Western Ghats, the Central Indian Highlands, and the Himalaya.

MATERIALS AND METHODS

Description of the study area

The Nilgiris District has a long history of plant introductions. The cool, temperate upper elevations of the Nilgiris attracted European settlers during the colonial period. They introduced many alien species as garden ornamentals (e.g., *Cestrum aurantiacum*, *Asclepias curassavica*, and *Cytisus scoparius*) and for fuelwood (e.g., *Acacia mearnsii* and *Eucalyptus* spp.). Many of these species have since become invasive, suppressing native species and altering habitats. The introduction of species to the Nilgiris continues to date, as the area is still of great horticultural importance and remains a source of exotic fruits, vegetables, and ornamental plants for the rest of southern India.

Our study area, the Moyar-Bhavani watershed of the Nilgiris, straddles two terrestrial ecoregions—southern Western Ghats moist deciduous forests and the southern Western Ghats montane rainforests. We used the ecoregion information included in the Indian Alien Flora Information database (v1.0 available at https://ilora2020.wixsite.com/ilora2020/data) and identified 378 plant species that have been introduced to these two terrestrial ecoregions (Pant et al. 2021). Of these, about 81 can be considered invasive alien species today, based on expert opinion. However, we felt that mapping the distribution and abundance of these many invasive species was an unreasonable ask of citizen scientists (i.e., volunteers, students, and forest department field staff). We therefore prioritised amongst these 81 species to arrive at a more manageable shortlist of widespread and highly invasive species for citizen scientists to record. Here, we describe the process followed to create that priority list of invasive species as a precursor to creating a pilot citizen science atlas of invasive species.

Compiling, selecting, and shortlisting of invasive species

As a first step, in September 2017, we compiled a database of the 81 invasive plants for the Nilgiris using various sources such as Zarri et al. (2004), Keystone Foundation (2008, 2016), Narasimhan (2009), Khuroo et al. (2012), Hiremath & Sundaram (2013), and from personal observations. For each species, we included additional information on its origin, the range of elevations within which it is found, and its presence (or absence) in various habitats. We created a matrix to indicate species presence in these different habitats, i.e., dry and wet forest, grasslands, plantations, wetlands (marshes, peat bogs), and freshwater habitats (ponds, lakes, rivers, reservoirs) (Annexure 1).

The next step was to select a preliminary short-list of invasive species from amongst this list of 81 species. Our selection was informed by existing definitions of invasive species. The IPBES defines an invasive alien species based on its ecological and socio-economic impacts (IPBES 2019). An alternative definition is proposed by Colautti & MacIsaac (2004), who suggest that an invasive species is one that is both locally abundant, and widespread, distinguishing it from other introduced species. We combined these considerations into the following three criteria:

1. Species that were well known in the landscapes (a measure of the species' impacts and abundance)
2. Species that have spread into multiple habitats (a measure of the species' local abundance).
3. Species that occur over more than one altitudinal zone (a measure of the species' spread).

We shortlisted 34 species that met these three criteria (Annexure 2) and convened a stakeholder workshop later that same month to assess the appropriateness of the shortlist for the Nilgiris landscape. A scoring was done to reflect the presence of the species in different habitats, with '1' denoting a species' presence in only one habitat, '2' denoting its presence in two habitats, and so on.

The stakeholder workshop included participants from local conservation organisations, community-based organisations, academic institutions, and restoration practitioners. We added *Pennisetum clandestinum* and *Polygonum polystachyum* to the final shortlist during the workshop as these species were known to be spreading in the Nilgiris. On the other hand, *Acanthospermum hispidum*, *Argemone mexicana*, *Kalanchoe delagoensis*, *Opuntia stricta, Synedrella nodiflora*, and *Tithonia diversifolia* were excluded from the list because, despite being invasive, these were not considered widespread by the stakeholders. Later, we replaced *Senna alata* with *Senna spectabilis* after observing the rapid spread of *Senna spectabilis* during a field visit to Sathyamangalam Tiger Reserve, and based on expert opinion that *S. spectabilis* is of greater conservation concern.

Based on the workshop discussions, we selected 26 of the 34 shortlisted species for mapping invasive alien species in the Nilgiris (Annexure 3). We then prepared a field identification key with images of the plant parts (habit, twigs, leaves, flower, fruit, seeds) to help individuals identify species while mapping invasive species in the field. A hard copy of the field identification key was printed for reference. The naming of the species has followed the International Plant Name Index (IPNI).

RESULTS AND DISCUSSIONS

Over 70% of the species that we prioritised for the Nilgiris were categorised as 'invasive' in existing databases of invasive alien plants in India, namely the 'Khuroo list' (Khuroo et al. 2012) and the ILORA database (Pant et al. 2021) (Table 1). When comparing our list of 26 invasive alien species with Khuroo's, we found 19 species were assigned the status 'invasive', *Passiflora mollissima* was assigned the status 'naturalised/invasive', while *Senna spectabilis* and *Pennisetum clandestinum*, are considered to be 'cultivated' and 'naturalized', respectively. None of the remaining four species—*Cestrum aurantiacum*, *Gamochaeta purpurea*, *Polygonum polystachyum*, and *Solanum mauritianum* on our list appears on the Khuroo list, though several of their congeners do.

Meanwhile, the ILORA database has additions to the list of alien species that were absent in the Khuroo list. These include C. *aurantiacum* and *S. mauritianum,* which are assigned the status 'invasive' and 'naturalised alien,' respectively. Both species are on our priority list of 26 species. Apart from this, the invasion status of some species from the Khuroo list has been revised in the ILORA database. For example, *Phragmites australis* and *Pistia stratiotes* (again, both on our priority list of 26 species), considered invasive in the Khuroo list, are now listed as native in the ILORA database (ver. 1) and unlisted altogether in an updated version (1.1); this may be due to their cryptogenic origins. Overall, 24 out of the 26 invasive species shortlisted by us can be found in the ILORA database, with the exception of *P. polystachyum* and *G. purpurea*.

Table 1. A comparison of the short-list of 26 priority invasive alien plants of the Nilgiris with existing national invasive species lists (ILORA version 1 and version 1.1).

Accepted scientific name of species	Family	Native region	Invasion status (Khuroo list)	Invasion status (ILORA)
Acacia mearnsii De Wild.	Mimosaceae	Australia	In	In
Ageratina adenophora (Spreng.) R.M.King & H.Rob.	Asteraceae	Central America	In	In
Ageratum conyzoides L.	Asteraceae	South America	In	In
Ageratum houstonianum Mill.	Asteraceae	Mexico	In	In
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	South America	In	In
Asclepias curassavica R.Br. ex. DC.	Asclepiadaceae	Tropical America	In	In
Bidens pilosa L.	Asteraceae	South America	In	In
Cestrum aurantiacum Lindl.	Solanaceae	Central America	-	In
Chromolaena odorata (L.) King & Robin.	Asteraceae	Central America	In	In
Cytisus scoparius (L.) Link	Papilionaceae	Europe	In	In
Datura innoxia Mill.	Solanaceae	South America	In	In
Pontederia crassipes (Mart.) Solms.	Pontederiaceae	Brazil	In	In
Gamochaeta purpurea (L.) Cabrera	Asteraceae	South America	-	-
Lantana camara L.	Verbenaceae	Tropical America	In	In
Mikania micrantha Kunth	Asteraceae	Tropical America	In	In
Opuntia tuna (L.) Mill.	Cactaceae	Mexico	In	In
Parthenium hysterophorus L.	Asteraceae	Central America	In	In
Passiflora mollissima L.H.Bailey	Passifloraceae	Tropical South America	N/I	Nt
Pennisetum clandestinum Hochst. ex Chiov.	Poaceae	Tropical Africa	Nt	Nt
Phragmites australis (Cav.) Trin. ex Steud.	Poaceae	Temperate Eurasia	In	Native (ver.1); absent in ver.1.1
Pistia stratiotes L.	Araceae	North America	In	Native (ver.1); absent in ver.1.1
Polygonum polystachyum Wall. ex Meisn.	Polygonaceae	Himalaya	-	-
Prosopis juliflora (Sw.) DC.	Mimosaceae	Mexico & Central America	In	In
Senna spectabilis (DC.) H.S.Irwin & Barneby	Caesalpiniaceae	Tropical America	Cl	In
Solanum mauritianum Scop.	Solanaceae	South America	-	Nt
Ulex europaeus L.	Papilionaceae	Europe	In	In (ver.1); absent in ver.1.1

Cl—Cultivated | Cs—Casual | C/N— Casual/Naturalised | Nt—Naturalised alien | N/I—Naturalised/Invasive | In—Invasive.

The comparison of our list of priority invasive species for the Nilgiris with the Khuroo list and the ILORA database offers interesting insights. One is that invasion is a dynamic process, and a species' invasion status could change over time. For example, the Khuroo list (published in 2012) considered *Senna spectabilis* to be 'cultivated', but in the short time since, *Senna spectabilis* has become widespread and abundant in several parts of the Western Ghats, including the Nilgiris. Recent work by Anoop et al. (2021) suggests that elephants are aiding in its widespread and rapid dispersal. This change in the species' status is reflected in the ILORA database (see Table 1), which was compiled a decade after the Khuroo list.

Another interesting insight is that a species' 'alien' status is determined by biogeographic boundaries, not by geopolitical ones. In this case, *Polygonum polystachyum* (Himalayan Knotweed), which is native to the Indian Himalaya, does not appear on either the Khuroo list or the ILORA database. However, stakeholders in the upper elevations of the Nilgiris, a region that is biogeographically distinct from the Himalaya, consider the species to be invasive.

Overall, our results highlight the value of the ILORA databases as a starting point for any effort to compile a locally relevant list of invasive species. The ILORA database builds on the earlier Khuroo list, and also incorporates information from other existing databases (see Pant et al. 2021), making it the most comprehensive listing of invasive alien plants for India today. However, this also makes the database unwieldy in smaller regions. For instance, the ILORA database lists a staggering 120 invasive alien species for the Moyar-Bhavani watershed, which barely extends over 4,100 km^2. This might be because the watershed straddles two terrestrial ecoregions (i.e., the southern

Western Ghats moist deciduous forests and the southern Western Ghats montane rainforests). Nevertheless, mapping the distribution and abundance of these many species is a daunting task, even when energised by citizen-scientists. Here, our priority list of 26 invasive alien species for the Nilgiris underscores the value of local expert opinion in shortlisting species that are locally relevant. The ILORA database may still be useful when developing lists for large landscapes or states, but local expertise is invaluable in developing lists for smaller landscapes.

Local expertise is also vital for identifying emerging threats. One illustration of this is the expert inclusion of *Cestrum aurantiacum* and *Solanum mauritianum,* neither of which appears on the Khuroo list. Both species are relatively recent additions to the database on alien species in India (even though they are listed as invasive alien species in global databases such as CABI and GISD). Another is the expert inclusion of *Senna spectabilis,* which was earlier listed as cultivated (in 2012) and has now been listed as invasive (in 2021). Given that published information about invasive species in India is still incipient, and that a large proportion of this information is dominated by a few species (Hiremath & Sundaram 2013), comprehensive databases like ILORA are constrained by the information that they can build on. In such a situation, expert opinion of local community members, forest managers and botanists must continue to inform the listing and prioritising of invasive alien species, in conjunction with existing databases.

CONCLUSION

There are an estimated 220–225 invasive alien plants in India (Khuroo et al. 2012; Pant et al. 2021). A few, such as *Lantana camara* and *Prosopis juliflora* are very widespread (Hiremath & Sundaram 2013). Others are more regional in their distribution, though locally abundant and widespread, e.g., *Acacia mearnsii* in the upper elevation regions of the Western Ghats (Nayak et al. 2023), or *Anthemis cotula* in the Kashmir Himalaya (Reshi et al. 2012). Yet the distribution and abundance of each invasive alien species, and even the number of invasive alien species, is expected to change in time. A citizen-science approach is best placed to track these changes and build an atlas of invasive alien plants for India.

To enable citizen scientists to contribute easily and continuously to such an atlas, it is important that they are not overwhelmed by the large number of invasive alien plants across India. Instead, they need to work with a shorter list of species that is relevant to the area they live in. The process that we have followed for prioritising invasive plants for the Nilgiris could provide a replicable model for other regions as well.

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Annexure 1. Presence of invasive species in different habitats.

	Name of the species	Family	Common name	Native	Elevation	Dry forests	Wet forests	Grasslands	Plantations	Wetlands/ Marshes/ Peat bogs	Freshwater (Ponds/ Rivers/ Lakes/ Reservoirs)	Scoring	Ref
1	*Alternanthera ficoidea* (L.) P.Beauv.	Amaranthaceae	Red threads, Joseph's coat	Brazil	100– 800 m					+		1	1,2
2	*Alternanthera paronychioides* A.St.-Hil.	Amaranthaceae	Smooth joy weed flower	South America & West Indies	Up to 800 m					+		1	1,3
4	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Alligator weed	South America	Up to 1,000 m					+	+	2	1
5	*Alternanthera sessilis* (L.) DC.	Amaranthaceae	Sessile Joy weed	Tropical America	200–1,500 m	+				+	+	3	1
6	*Amaranthus spinosus* L.	Amaranthaceae	Spiny Amaranthus	America	Up to 1,500 m	+						1	1
7	*Gomphrena serrata* L.	Amaranthaceae	Prostrate Gomphrena	South America	Up to 1,000 m	+			+			2	1
8	*Catharanthus roseus* (L.) G.Don.	Apocynaceae	Madagascar Periwinkle, Rosy Periwinkle	Tropical America	Up to 1,800 m	+			+		+	3	1
9	*Cascabela thevetia* (L.) Lippold	Apocynaceae	Yellow Oleander	Peru	Up to 1,400 m				+			1	1
10	*Pistia stratiotes* L.	Araceae	Water Lettuce	South America	Up to 1,400 m					+	+	2	1,2
11	*Asclepias curassavica* L.	Asclepiadaceae	Scarlet Milkweed	Tropical America	>500 m	+				+	+	3	1,2
12	*Acanthospermum hispidum* DC.	Asteraceae	Starbur, Goat's head, Bristly Starbur	Brazil	Up to 1,000 m	+	+		+			3	1,2
14	*Acmella radicans* (Jacq.) R.K.Jansen	Asteraceae	White Spot flower	Southern America	Up to 1,000 m	+				+		2	3
15	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	Asteraceae	Crofton weed	Mexico	300–2,500 m		+	+	+		+	4	1
16	*Ageratum conyzoides* L.	Asteraceae	Goat weed, White weed	South America	Up to 2,000 m	+	+	+	+		+	5	1,3
17	*Ageratum houstonianum* Mill.	Asteraceae	Blue weed	Central America	Up to 1,300 m	+	+	+	+		+	5	1
18	*Ambrosia artemisiifolia* L.	Asteraceae	Common Ragweed	North America	Up to 1,000 m		+	+	+			3	1,2
19	*Anthemis cotula* L.	Asteraceae	Stinking Chamomile, Wild Chamomile	Temperate Eurasia	Up to 1,600 m			+	+			2	1
20	*Bidens biternata* (Lour.) Merr. & Sherff.	Asteraceae	Spanish needles	America	Up to 2,000 m	+	+	+	+			4	1,3

	Name of the species	Family	Common name	Native	Elevation	Dry forests	Wet forests	Grasslands	Plantations	Wetlands/ Marshes/ Peat bogs	Freshwater (Ponds/ Rivers/ Lakes/ Reservoirs)	Scoring	Ref
21	*Bidens pilosa* L.	Asteraceae	Beggar's tick or Spanish needle	America	Up to 3,600 m	+	+	+	+			4	1
22	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	Siam weed	North America	Up to 1,000 m	+	+		+		+	4	1
23	*Crassocephalum crepidioides* (Benth) S.Moore	Asteraceae	Fireweed	Tropical Africa	Up to 1,800 m					+	+	2	1
24	*Erigeron karvinskianus* DC.	Asteraceae	Australian Daisy	Mexico	1,000–2,000 m			+	+			2	1
25	*Flaveria trinervia* (Spreng) C.Mohr	Asteraceae	Sprengel	Central America	Up to 2,000 m	+			+			2	4
26	*Galinsoga parviflora* Cav.	Asteraceae	Gallant soldier	Tropical America	Up to 2,000 m	+	+		+	+		4	1
27	*Gamochaeta coarctata* (Willd.) Kerguélen	Asteraceae	Grey everlasting	South America	1800–2,200 m		+	+	+			4	1
28	*Gamochaeta purpurea* (L.) Cabrera	Asteraceae	Purple Cudweed	North America	500–2,600 m		+	+				3	1
29	*Mikania micrantha* Kunth	Asteraceae	Mile-a-minute	North, Central and South America	Up to 1,000 m	+	+		+			3	1
30	*Parthenium hysterophorus* L.	Asteraceae	Carrot grass, Congress grass	America	Up to 1,400 m	+	+	+	+			3	1,4
31	*Synedrella nodiflora* (L). Gaertn.	Asteraceae	Cinderella weed	West Indies	Up to 800 m	+			+			2	1
32	*Tithonia diversifolia* (Hemsl.) A.Gray	Asteraceae	Mexican Sunflower	South America	500–1,900 m	+	+		+			3	1
33	*Tridax procumbens* L.	Asteraceae	Coat button	Mexico	Up to 1,000 m	+			+			3	1
34	*Cardamine trichocarpa* Hochst. ex A.Rich.	Brassicaceae	Bittercress	Temperate Eurasia	>1,200 m			+	+			3	4
35	*Lepidium didymum* L.	Brassicaceae	Swine Cress	Tropical America	Up to 2,200 m	+			+			2	1,5
36	*Opuntia tuna* (L.) Mill.	Cactaceae	Spiny Pest Pear	Mexico	50– 900 m	+						1	1,2
37	*Opuntia stricta* (Haw.) Haw.	Cactaceae	Pricky Pear	Mexico	300–1200 m	+						1	1
38	*Senna alata* (L.) Roxb.	Caesalpiniaceae	Christmas Candle, Candle brush	South America	Up to 1,200 m	+						1	1
39	*Senna occidentalis* (L.) Link	Caesalpiniaceae	Septic weed, Coffee weed	South America	Up to 1,500 m	+						1	1
40	*Casuarina equisetifolia* L.	Casuarinaceae	Australian Pine	Australia, Malaysia & Pacific Islands	Up to 1,500 m	+			+			2	1
41	*Ipomoea carnea* Jacq.	Convolvulaceae	Pink Morning Glory	South America	Up to 1,000 m	+				+	+	3	1,6

	Name of the species	Family	Common name	Native	Elevation	Dry forests	Wet forests	Grasslands	Plantations	Wetlands/ Marshes/ Peat bogs	Freshwater (Ponds/ Rivers/ Lakes/ Reservoirs)	Scoring	Ref
42	*Ipomoea indica* (Burm.) Merr.	Convolvulaceae	Blue Dawn Flower	South America	Up to 1,500 m			+	+			2	1
43	*Kalanchoe delagoensis* Eckl. & Zeyh.	Crassulaceae	Chandelier plant	Madagascar	Up to 1,000 m	+				+	+	3	1
44	*Chrozophora plicata* (Vahl) A. Juss. ex Spreng.	Euphorbiaceae	_	Tropical Africa	Up to 1,000 m	+						1	2
45	*Croton bonplandianus* Baill.	Euphorbiaceae	Railway weed	South America	Up to 900 m	+						1	4
46	*Euphorbia cyathophora* Murray	Euphorbiaceae	Painted Poinsettia	North and South America	Up to 1,000 m	+						1	1,6
47	*Euphorbia helioscopia* L.	Euphorbiaceae	Sun Spurge	West Asia	1000–2000 m	+	+					2	1,4
48	*Euphorbia hirta* L.	Euphorbiaceae	Common Spurge	Tropical America	Up to 1,400 m	+			+			2	1,4
49	*Aeschynomene americana* L.	Fabaceae	Shyleaf, Common Aeschynomene	Tropical America	Up to 1,000 m	+				+		2	1
50	*Aeschynomene indica* L.	Fabaceae	Indian Joint Vetch	North and Central America	Up to plains to 2,000 m	+	+			+		3	1
51	*Cytisus scoparius* (L.) Link	Fabaceae	Scotch Broom	Western and Central Europe	1,800–2,400 m			+	+			2	1
52	*Prosopis juliflora* (Sw.) DC.	Fabaceae	Algaroba, Mesquite	South America	Up to 1,000 m	+						1	1
53	*Stylosanthes hamata* (L.) Taub.	Fabaceae	Caribbean Stylo	Central America	Up to 1,800 m			+	+	+		3	1,6
54	*Ulex europaeus* L.	Fabaceae	Gorse	Western Europe	1,800–2,000 m			+	+	+		3	1
55	*Miconia crenata* (Vahl) Michelang.	Melastomataceae	Soapbush	Tropical America	Up to 1,200 m		+		+			2	1
56	*Acacia mearnsii* De Wild.	Mimosaceae	Black Wattle	Australia	>1,600 m		+	+	+	+		4	1
57	*Desmanthus virgatus* (L.) Willd.	Mimosaceae	Hedge Lucerne	Tropical America	Up to 1,000 m	+						1	1
58	*Leucaena latisiliqua* (L.) Gillis.	Mimosaceae	Horse Tamarind	Tropical America	Up to 150 m	+			+			2	1
59	*Mimosa pudica* L.	Mimosaceae	Touch-me-not	South America	Up to 1,800 m	+	+			+		3	1
60	*Vachellia farnesiana* (L.) Wight & Arn.	Mimosaceae	Needle bush, Sweet Acacia	Tropical America	Up to 1,000 m	+						1	1
61	*Broussonetia papyrifera* (L.) Vent.	Moraceae	Paper Mulberry	East Asia	Up to 1,000 m	+						1	1
62	*Argemone mexicana* L.	Papaveraceae	Mexican Prickly Poppy	South America	Up to 1,000 m	+			+			2	1

	Name of the species	Family	Common name	Native	Elevation	Dry forests	Wet forests	Grasslands	Plantations	Wetlands/ Marshes/ Peat bogs	Freshwater (Ponds/ Rivers/ Lakes/ Reservoirs)	Scoring	Ref
63	*Passiflora foetida* L.	Passifloraceae	Stinking Passionflower	Brazil & West Indies	Up to 1,800 m	+	+					2	1
64	*Passiflora mollissima* L.H.Bailey	Passifloraceae	Banana Passionfruit	Tropical South America	Up to 1,800 m	+	+		+			3	1
65	*Phalaris minor* Retz.	Poaceae	Little-seeded Canary grass	Mediterranean region	Up to 1,800 m	+	+			+		3	1,2
66	*Phragmites australis* (Cav.) Trin. ex Steud.	Poaceae	Common Reed	Temperate Eurasia	Up to 1,000 m	+	+			+	+	4	1,2
67	*Polypogon monspeliensis* (L.) Desf.	Poaceae	Rabbitfoot grass	Temperate Eurasia	Up to 1,000 m			+		+		2	1
68	*Chloris barbata* Sw.	Poaceae	Swollen windmill grass	Tropical America & Africa	Up to 2,000 m	+				+		2	1
69	*Urochloa panicoides* P. Beauv.	Poaceae	Liverseed grass	Tropical America	Up to 1,700 m	+						1	1
70	*Antigonon leptopus* Hook. & Arn.	Polygonaceae	Coral vine	South America	Up to 1,000 m	+						1	1
71	*Pontederia crassipes* Mart.	Pontederiaceae	Water Hyacinth	South America	Up to 2,000 m					+	+	2	1,2
72	*Monochoria vaginalis* K.B.Presl.	Pontederiaceae	Pickerel weed	Southeast Asia	Up to 1,200 m					+	+	2	1
73	*Calceolaria mexicana* Benth.	Scrophulariaceae	Ladies purse	Mexico	1800–2,000 m			+	+	+		3	2,4
74	*Ailanthus altissima* (Miller) Swingle	Simaroubaceae	Tree of heaven	China	Up to 2,000 m	+						1	1
75	*Cestrum aurantiacum* Lindl.	Solanaceae	Orange Jasmine	North and South America	1,200–2,600 m		+	+	+			3	1
76	*Datura innoxia* Mill.	Solanaceae	Downy Thorn-apple	Tropical and subtropical America	Up to 1,800 m	+	+					2	1
77	*Datura stramonium* L.	Solanaceae	Common Thorn-apple	Tropical America	Up to 2,700 m	+	+		+		+	4	1
78	*Solanum mauritianum* Scop.	Solanaceae	Tobacco tree	South America	Up to 2,200 m		+	+	+		+	4	1,2
79	*Solanum seaforthianum* Andrews	Solanaceae	Brazilian Nightshade	Tropical America	1,300–1,500 m	+						1	1
80	*Lantana camara* L.	Verbenaceae	Big Sage	Central and South America	Up to 2,000 m	+	+	+	+		+	5	1,4
81	*Stachytarpheta jamaicensis* (L.) Vahl.	Verbenaceae	Jamaican Blue Spike	South America	Up to 800 m	+	+					2	1

Ref: 1—www.cabidigitallibrary.org | 2—efloraofindia.com | 3—flowersofindia.net | 4—https://indiabiodiversity.org | 5—https://wgbis.ces.iisc.ac.in/biodiversity/sahyadri_enews/newsletter/issue42/bibliography/The-alien-flora-of-Kashmir-Himalaya.pdf | 6—https://www.gbif.org

Annexure 2. Shortlisted species.

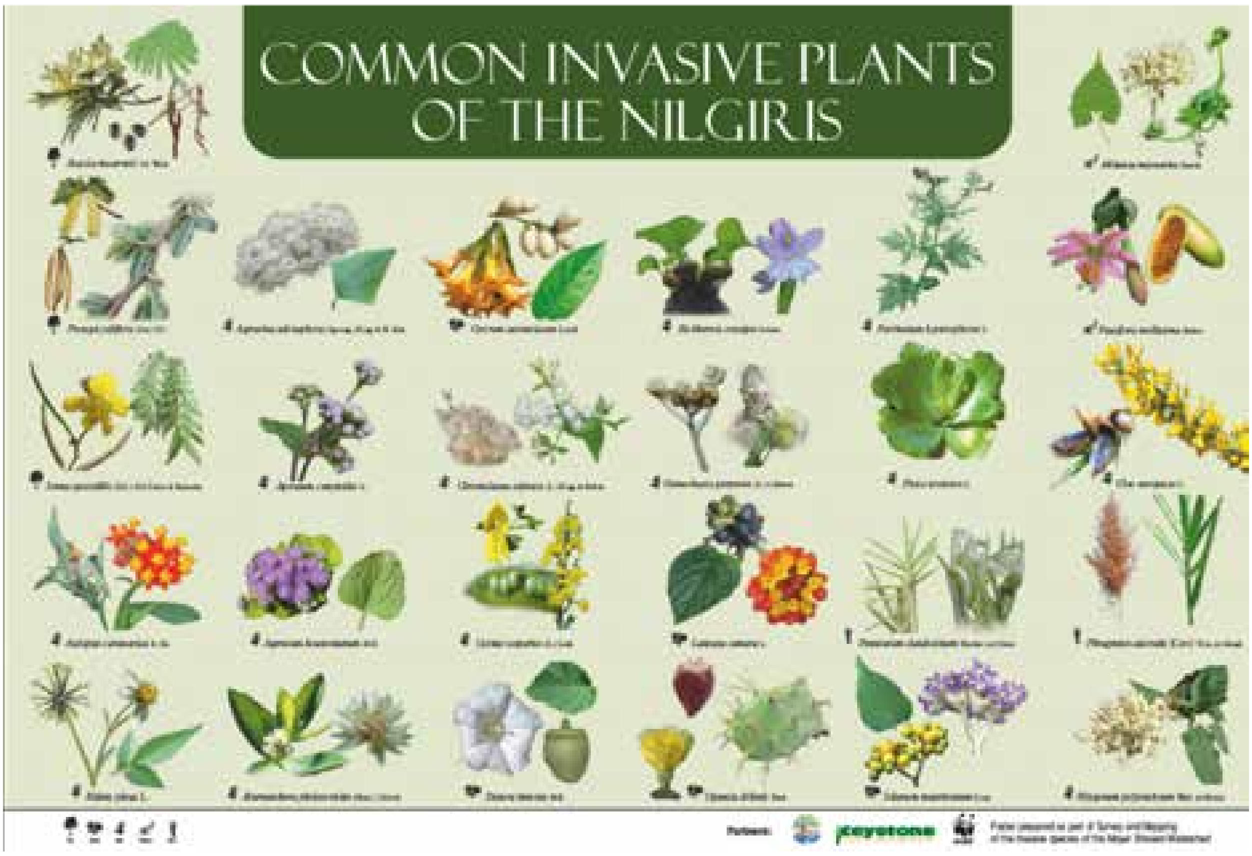
	Name of the species	Criterion 1[1]	Criterion 2[1]	Criterion 3[1]	Reference[2]
1	*Acacia mearnsii* De Wild.	Yes	Yes	Yes	1
2	*Acanthospermum hispidum* DC.	Yes	Yes	Yes	1
3	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	Yes	Yes	Yes	1
4	*Ageratum conyzoides* L.	Yes	Yes	Yes	1
5	*Ageratum houstonianum* Mill.	Yes	Yes	Yes	1
6	*Alternanthera philoxeroides* (Mart.) Griseb.	Yes	Yes	Yes	1
7	*Alternanthera sessilis* (L.) R.Br. ex DC.	Yes	Yes	Yes	1
8	*Argemone mexicana* L.	Yes	Yes	Yes	1
9	*Asclepias curassavica* R.Br.	Yes	Yes	Yes	1
10	*Bidens pilosa* L.	Yes	Yes	Yes	1
11	*Cestrum aurantiacum* Lindl.	Yes	Yes	Yes	1
12	*Chromolaena odorata* (L.) King & H.Rob.	Yes	Yes	Yes	1
13	*Cytisus scoparius* (L.) Link	Yes	Yes, spread widely	High altitudes	1
14	*Datura innoxia* Mill.	Yes	Yes	Yes	1
15	*Pontederia crassipes* Mart.	Yes	Yes	Yes	1
16	*Gamochaeta purpurea* (L.) Cabrera	Yes	Yes	Yes	1
17	*Kalanchoe delagoensis* Eckl. & Zeyh.	Yes	Yes	Yes	1
18	*Lantana camara* L.	Yes	Yes	Yes	1
19	*Mikania micrantha* Kunth	Yes	Yes	Yes	1
20	*Opuntia tuna* (L.) Mill.	Yes	Yes	Yes	1
21	*Opuntia stricta* Haw.	Yes	Yes	Yes	1
22	*Parthenium hysterophorus* L.	Yes	Yes	Yes	1
23	*Passiflora mollissima* L.H.Bailey	Yes	Yes	Yes	1
24	*Phragmites australis* (Cav.) Trin. ex Steud.	Yes	Yes	Yes	1
25	*Pistia stratiotes* L.	Yes	Yes	Yes	1
26	*Prosopis juliflora* (Sw.) DC.	Yes	Yes	Yes	1
27	*Senna alata* (L.) Roxb.	Yes	Yes	Yes	1
28	*Senna occidentalis* (L.) Link	Yes	Yes	Yes	1
29	*Solanum mauritianum* Scop.	Yes	Yes	Yes	1
30	*Synedrella nodiflora* L. Gaertn.	Yes	Yes	Yes	1
31	*Cascabela thevetia* (L.) Lippold	Yes	Yes	Yes	1
32	*Tithonia diversifolia* (Hemsl.) A.Gray	Yes	Yes	Yes	1
33	*Tridax procumbens* L.	Yes	Yes	Yes	1
34	*Ulex europaeus* L.	Yes	Yes	Yes	1

[1] Note on criteria:
Criterion 1—Species that are well known in the landscapes (a measure of the species' impacts and abundance) |
Criterion 2— Species that have spread into multiple habitats (a measure of the species' local abundance) |
Criterion 3—Species that occur over more than one altitudinal zone (a measure of the species' spread).
[2] References: 1—Personal communication, 18 January 2017: V. Anita, H. Ankila, B. Milind, Samuel Thomas, Shiny M. Rehel (corroborated by observation of workshop participants).

Annexure 3. Final list of species for mapping invasive alien species in the Nilgiris.

	Name of the species	Habit	Common name
1	*Acacia mearnsii* De Wild.	Tree	Black Wattle
2	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	Herb	Crofton Weed
3	*Ageratum conyzoides* L.	Herb	Goat Weed
4	*Ageratum houstonianum* Mill.	Herb	Floss Flower
5	*Alternanthera philoxeroides* (Mart.) Griseb.	Herb	Alligator Weed
6	*Asclepias curassavica* L.	Herb	Milk Weed
7	*Bidens pilosa* L.	Herb	Blackjack
8	*Cestrum aurantiacum* Lindl.	Shrub	Orange Cestrum
9	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Herb	Siam Weed
10	*Cytisus scoparius* (L.) Link	Herb	Scotch Broom
11	*Datura innoxia* Mill.	Shrub	Downy Thorn-apple
12	*Pontederia crassipes* Mart.	Herb	Water Hyacinth
13	*Gamochaeta purpurea* (L.) Cabrera	Herb	Purple Spoonleaf everlasting

	Name of the species	Habit	Common name
14	*Lantana camara* L.	Shrub	Wild Sage
15	*Mikania micrantha* Kunth	Shrub	Bitter Vine
16	*Opuntia tuna* (L.) Mill.	Shrub	Prickly Pear
17	*Parthenium hysterophorus* L.	Shrub	Parthenium
18	*Passiflora mollissima* L.M.Bailey	Climber	Banana Passion
19	*Phragmites australis* (Cav.) Trin. ex Steud.	Grass	Common Reed
20	*Prosopis juliflora* (Sw.) DC.	Tree	Mesquite
21	*Senna spectabilis* (DC.) H.S.Irwin & Barneby	Tree	American Cassia
22	*Solanum mauritianum* Scop.	Shrub	Bugweed
23	*Pistia stratiotes* L.	Herb	Water Lettuce
24	*Ulex europaeus* L.	Herb	Common Gorse
25	*Pennisetum clandestinum* Hochst. ex Chiov	Grass	Kikuyu Grass
26	*Polygonum polystachyum* Wall. ex Meisn.	Herb	Himalayan Knotweed



Annexure 4. Poster on common invasive plants of the Nilgiris.

Author details: Shiny Mariam Rehel strategises ecological restoration projects, overseeing native flora nurseries and projects related to pollinators. She builds networks with global forums on biodiversity, and within local government bodies. Reshnu Raj R S is an ecologist, currently undertaking doctoral studies at School of Natural Science, Massey University, where he investigates the effects of anthropogenic activities on the environment. Samuel Thomas supports work focused on regenerating and restoring critical ecosystems in the Hindu Kush Himalaya. Milind Bunyan is a forest ecologist with research interests in invasive alien species, landscape ecology and restoration ecology. Milind uses RS-GIS to characterise ecosystems and communities and develop tools for restoring landscapes. Anita Varghese develops long-term goals, research and action steps on field for the implementation of projects under the Biodiversity and Climate Change programmes. Ankila Hiremath is a plant ecologist with an interest in ecosystem restoration and novel ecosystems. She works in tropical dry forests and savannas on invasive species and their ecological and socio-economic impacts.

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SHORT COMMUNICATION

Chemical immobilisation of free ranging Tibetan Wolf *Canis lupus chanco* (Gray, 1863) (Mammalia: Carnivora: Canidae) with Ketamine-Xylazine combination in Ladakh, India

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Abstract: The Tibetan Wolf *Canis lupus chanco* is one of the two Critically Endangered species of Ladakh, India. Six free-ranging Tibetan wolves were immobilized using ketamine and xylazine mixture as part of the rescue operations. Dose rates of 4.92 ± 0.52 mg/kg body weight and 2.08 ± 0.29 mg/kg body weight for ketamine and xylazine respectively provided good level of anesthesia for carrying out effective capture. Drug induction was recorded at 4.4 ± 1.1 minutes with animal coming into sternal recumbency by 5.6 ± 1.5 minutes and animals were approached at 6.2 ± 1.7 minutes. Duration of anesthesia was 35.25 ± 6.07 minutes. Yohimbine administered for reversal at the dosage of 0.125 mg/kg body weight provided reversal effect with animal standing by 15.5 ± 4.2 minutes. The current information suggests that xylazine and ketamine mixture is effective and safe for capturing the free-ranging Tibetan Wolves for wildlife management interventions.

Keywords: Chemical capture, immobilization, induction, rescue, reversal, revival.

The Tibetan Wolf *Canis lupus chanco* is the largest canid species in India with high conservation priority (Shawl et al. 2008). In India, it is recorded from parts of Kashmir, Changthang plateau of Ladakh and Spiti valley of Himachal Pradesh at elevation range of 3,200–5,600 m (Khan et al. 2023). In Ladakh region, Tibetan Wolf is found in both Leh and Kargil districts and is listed as 'Critically Endangered' species as per the IUCN Red List. Tibetan wolf is protected and included in the Schedule I of India's Wildlife (Protection) Act, 1972 (Shawl et al. 2008). The ambient temperature in the area ranges from -5 to -10°C.

Wild animal rescues involving animal capture is an important wildlife management technique for managing wild animals in distress with conservation implications as it supports management of conflict situations (Nyhus 2016). Chemical immobilization is a safe and effective strategy for capturing wildlife as it causes minimal stress to wild animals (Neilsen 1999). Limited reports are available on anesthetic doses for most of the wild species in India for effective immobilization (Belsare & Vanak 2013).

Ketamine-xylazine drug mixture has been effectively used for immobilization of wild canids (Muliya et al. 2016). We report successful chemical immobilisation of free-ranging Tibetan Wolf *Canis lupus chanco* with ketamine-xylazine combination.

Methods

Ladakh is located between Longitudes of 32.25° to 34.63° N and latitudes of 75.6° to 78.36 ^{0}E at the western

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part of India and falls under Trans-Himalayan region. The altitudinal range of 2,700–7,500 m and total area of Ladakh is 78,000 km^2. It has two districts — Leh and Kargil. Six Tibetan Wolves (one female and five males) were captured from different parts of Leh district of Ladakh as part of the field rescue operations carried by the Wildlife Protection Department, Leh, Union territory of Ladakh. All the animals in this study were captured either due to displacement or distress.

All the animals were chemically immobilised using a combination of xylazine hydrochloride (2 mg/kg) (XYLAMED, 100 mg/ml, Bimeda, Cambridge, Ontario) and ketamine hydrochloride (5 mg/kg) (KETAMINA, 100 mg/ml, Biowet Pulawy, Poland or VETALAR, 100 mg/ml, Parke Davis & Co., P O Box qq8 GPO, Detroit, Michigan 48232, USA). The drug mixture was administered remotely using air pressurised syringe projector (Dan Inject model-JM Syringe projector). Following completion of necessary procedures, yohimbine (0.125 mg/kg) (20 mg/ml; YOHIMBE, 20 ml, Equimed USA) was administered intramuscularly for drug reversal.

Results

All the animals were weighed for accurate body weights after induction and drug dosages were calculated retrospectively. Actual body weight, drug dosage, induction (first sign of induction), time of complete loss of consciousness and total duration required for carrying out field procedures was recorded. Initial signs of drug effect included decreased mentation and progressive ataxia followed by recumbency. Drug induction was rapid and smooth in all the animals. The mean ± standard deviation for actual body weight, actual dose rate of ketamine, actual dose rate of xylazine, induction, approach time, total time for carrying out field procedures were 29.22 ± 5.31 kg, 4.92 ± 0.52 mg/kg, 2.08 ± 0.29 mg/kg, 4.1±1.1 minutes, 5.6 ± 1.5 minutes, and 35.25 ± 6.07 minutes, respectively. All the physiological parameters remained well within the normal range for other canid species during the entire procedure (Malmsten 2007) with no adverse effect observed from any of the animal captured (Table 1).

Following completion of field procedures, the animals were administered yohimbine (0.125 mg/kg) and the sequence of recovery events were recorded. Different parameters recorded for signs of recovery were ear and eye movement time, head raising time and standing time after reversal. The mean ± standard deviation for ear and eye movement time, head raising time and standing time after reversal were 11.75 ± 2.6 minutes, 13.25 ± 2.87 minutes and 15.5 ± 4.2 minutes, respectively.

None of the cases showed any signs of extrapyramidal signs and all the recoveries were smooth.

Discussion

Since there are limited studies on immobilisation of Tibetan Wolf, its immobilisation is a challenge when there is requirement for such intervention. The combination of ketamine hydrochloride and xylazine hydrochloride (4.92 ± 0.52 mg/kg body weight and 2.08 ± 0.29 mg/kg body weight, respectively) was found to be effective for chemical capture of Tibetan wolf in field emergencies. However, Chakraborty & Das (1994) documented use of 10 mg/kg of ketamine and 1.33 mg/kg of xylazine mixture to be effective for immobilisation of Tibetan Wolf in captivity. The dose rate of xylazine and ketamine in the present study are like those documented by Miller & Fowler (2014) for Gray Wolves.

Since there is a lack of existing information on the physiological parameters of Tibetan Wolves, we were unable to make direct comparisons with our results.

Table 1. Mean ±SD and range for physiological parameters observed in Tibetan Wolf *Canis lupus chanco* chemically immobilized with ketamine and xylazine drug combination.

Parameters	Unit	Mean ± SD	Range
Rectal temperature on approach	^{0}F	102.28 ± 0.82	101–103
Rectal temperature after 10 minutes of approach	^{0}F	102 ± 0.4	101.5–102.5
Rectal temperature after 20 minutes of approach	^{0}F	102 ± 0.5	101.5–102.5
Respiration rate on approach	/Minute	19.6 ± 7.3	12–19
Respiration rate after 10 minutes of approach	/Minute	20.2 ± 5.76	12–30
Respiration rate after 20 minutes of approach	/Minute	17.25 ± 4.99	14–26
Heart rate on approach	/Minute	66.25 ± 10.9	58–82
Heart rate after 10 minutes of approach	/Minute	76 ± 16.57	62–100
Heart rate after 20 minutes of approach	/Minute	73 ± 10.39	64–82

Nevertheless, the recorded rectal temperatures throughout the entire procedure were found to be within the normal range observed (Malmsten 2007) though the respiratory rate (12–19 per minute) and heart rate (69–98 per minute) was higher compared to values of Indian Gray Wolf as reported by Muliya et al. (2016).

Conclusion

We conclude that the ketamine and xylazine anesthesia @ 4.92 ± 0.52 mg/kg, 2.08 ± 0.29 mg/kg, respectively was effective for immobilization of Tibetan Wolves and yohimbine @ 0.125 mg/kg act as excellent reversal drug against xylazine. The drug combinations used in the study has been referenced for free ranging Tibetan Wolves and their physiological parameters, which can help in managing emergency rescue situations for free ranging Tibetan Wolves. The study was based on smaller sample size. A larger sample size would be advantageous to make the results more rigorous and insightful.

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SHORT COMMUNICATION

A preliminary observation on the nesting of the Indochinese Roller *Coracias affinis* Horsfield, 1840 (Aves: Coraciiformes: Coraciidae) in Assam and northern West Bengal, India

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Abstract: The nesting of Indochinese Roller was observed in Rani, Kamrup, Assam for 49 days in April–May 2022. The male was noted hunting more frequently compared to the female, but its prey items consisted of smaller biomass than those the female hunted. Opportunistically, more nests were recorded at Buxa Tiger Reserve, West Bengal and Kaziranga National Park, Assam. The preferred tree species for nesting were Sal *Shorea robusta*, Mynah *Tetrameles nudiflora*, and Koroi *Albizia procera*; the preferred nest height was 9.2 m.

Keywords: Buxa, cavity nesting, Kaziranga, parental role, prey base.

The Indochinese Roller *Coracias affinis* Horsfield, 1840 also known as Black-billed Roller and Burmese Roller, has been recently raised to the species level (Johansson et al. 2018; Gill et al. 2021). Formerly it was considered the subspecies of Indian Roller *Coracias benghalensis*. Its 'unstreaked smoky-purplish brown face and breast' differentiate it from the Indian Roller *C. benghalensis*. Its distribution is across Nepal, Bhutan, northeastern India to south-central China, northern Malay Peninsula, and Indochina (Ali & Ripley 1987).

The nesting of Indochinese Roller was observed at Belguri Village (25.9996^{0}N, 91.5484^{0}E), Rani, Assam since 2007 (n = 16). Each year, a pair occupied the same nest in the Sal *Shorea robusta* although we could not ensure it was the pair of the same individuals. In 2022, we followed the focal animal sampling method and recorded the parents' and nestlings' activities once per minute (Altmann 1974; Palmer et al. 2001). The observations were categorised in three sloughs 0600–1000 h (n = 1,417), 1000–1400 h (n = 1,444) and 1400–1800 h (n = 2,151). The activities were compared between these sloughs and significance was checked with chi square test. The observations period was from 13 April–31 May 2022 when two nestlings fledged out (Image 1). The young ones followed the parents for about 90 days during which the begging calls for food were noted (https://xeno-canto.org/819166). We also made opportunistic observation on the nesting of the species in Buxa Tiger Reserve (26.6744^{0}N, 89.7472^{0}E), Alipurduar District, West Bengal and in Kaziranga National Park (26.5758^{0}N, 93.1670^{0}E), Golaghat District, Assam.

The height and girth of the nesting tree Sal was 26.8 m and 2.3 m, respectively, while the nest was at a height of 11.6 m. The parents perched (n = 113) around the nest during the breeding period on 10 trees which were at a distance of 5.2 m to 34.4 m from the nesting tree. Most of the trees were young trees including *Tectona*

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Image 1. Nestlings of Indochinese Roller in the nest cavity.

Image 2. Male Indochinese Roller on ground.

Image 3. Female Indochinese Roller with a cicada kill.

grandis (8), one mature *Shorea robusta*, and one mature *Moringa oleifera.* The tree heights ranged 7.6–27 m and the most frequent perching height was around 11.6 m on all of these trees.

The prey items were photographed and identified with keys and opportunistically similar items were weighed with digital weighing balance to get an idea of the biomass.

Results

Observations of the nesting pair

The male and female have distinct characteristics as follows: females are slightly larger and males possess brilliant blue colour on the throat (Image 2 & 3). The incubating and brooding parents could not be observed, but the activities of the parents were recorded for perching, hunting and carrying the food.

Overall, the male was engaged in hunting for a longer duration throughout the day as compared to the female, which was statistically significant (P <0.0001). The hunting time of the male and the female was recorded for all the time slots throughout the day (0600 h–1000 h, χ^2 = 38.534, df = 1, P < 0.0001; 1000–1400 h, χ^2 = 15.244, df = 1, P <0.0001; 1400h–1800 h, χ^2 = 15.254, df = 1, P <0.0001. Female was found to be perched for significantly (P <0.0001) higher number of times as compared to the male, except for the time slot between 1400 h to 1800 h where both male and female were observed to be perched equally (0600–1000 h, χ^2 = 40.998, df = 1, P <0.0001; 1000–1400 h, χ^2 = 46.815, df = 1, P <0.0001; 1400–1800 h, χ^2= 0.252, df = 1, P = 0.6154) (Figure 1).

The prey base

In all 100 successful hunting and food carrying attempts that were recorded, the male captured 56 prey items and the female captured 44 prey items (Table 1); but, with reference to the biomass, the female captured more biomass than the male (the prey captured by the

Table 1. Prey items captured by the Indochinese Roller pair.

Prey items	Average biomass of prey item in g	Number of preys captured by female	Biomass of prey captured by female in g	Number of preys captured by male	Biomass of prey captured by male in g	Total prey biomass in g	Total number of prey items
Insects	0.1	35	3.5	51	5.1	8.6	86
Spiders	0.1	1	0.1	0	0	0.1	1
Frogs	10	2	20	0	0	20	2
Rats	15	1	15	0	0	15	1
Reptiles	20	3	60	1	20	80	4
Unknown	1	2	2	4	4	6	6
Total		44	100.6	56	29.1	129.7	100

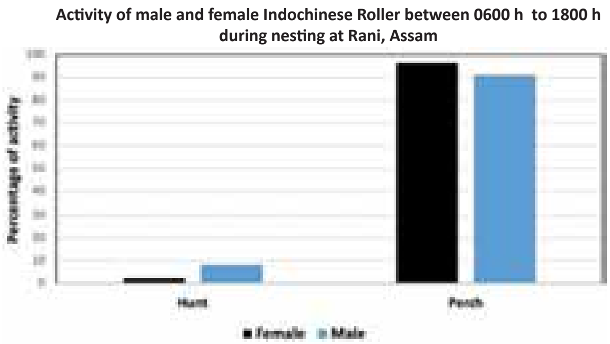

Figure 1. Comparison of activities of male and female Indochinese Roller, Rani, Assam.

female was about 100.6 g while in the case of the male, it was 29.1 g). The female hunted larger prey including mainly frogs (*Fejervarya* spp.), snakes (*Dendrelaphis* spp.), and a lizard (*Calotes* spp.). The male captured more insects, and the cicadas were the most common among the identified insects (*Haphsa scitula* and *Dundubia annandalei*) (Anonymous 2022a,b). Out of the 86 insect prey captured by the pair, 31% were identified while 69% of the prey captures were unknown. The identified prey included cicada (20%), cockroach (1%), dragonfly (5%), mantis (2%), grasshopper (1%,) and termite (alate) (2%).

Preferred nesting trees

The Indochinese Roller's nests were opportunistically recorded in northeast India (n = 38) during 2005 to 2022. Fourteen nest attempts were observed at Buxa Tiger Reserve, West Bengal, 16 nest attempts were recorded at Rani, Assam on the same Sal tree, and six attempts were recorded at Kaziranga National Park, Assam. The tree species preferred were Sal, Mynah, and Koroi. The average height of these preferred trees was 23.7 m and the nest height was 9.2 m.

Discussion

The Indochinese Roller is known to breed in April and May (Ali & Ripley 1987) and our observations exactly match these reports in northern Bengal and Assam. We missed the actual incubation period observation as we avoided checking the nest cavity during this period which might have disturbed the nesting birds (Barve et al. 2020).

The Indian Roller is known to nest at 'moderate height' in the holes in tree trunks as well as in the walls. In the current study, we recorded the nest height as 11.6 m while the mean height of nests on the nine trees was observed to be 9.2 m, ranging between 4.5–14.6 m.

The Indian Roller is known to pounce on frogs, plunge in water for fish, and hunt insects. We noticed and photographed similar behaviour in the Indochinese Roller during the study period. The *C. benghalensis* is known to hunt snakes (Biddulph 1937; Ali & Ripley 1987; Vishnu & Ramesh 2021), our study records the same behaviour in case of *C. affinis* as well. Studies of pellets have suggested that the entomofauna consists major chunk of the food of Indian Roller in south India (Sivakumaran & Thiyagesan 2003). As the prey capture and feeding observations were direct observations, the slightly smaller sized male capturing smaller prey like insects with higher frequency and the slightly heavier female focusing on larger vertebrate prey reminds the reversed sex dimorphism and prey preference in raptors (Schantz & Nilsson 1981), although elaborate data is required in case of *C. affinis*.

The Indian Roller plays an important role in agricultural pest control and similar role is played by the Indochinese Roller as evident from the diet. Though these resident species have stable populations and are included in the 'Least Concern' category of the IUCN Red List of Threatened Species, the migratory species of roller in India, the European Roller *Coracias garrulus*, suffers a moderate decline (Tucker & Heath 1994). Hence it is high time to collect the baseline data on the Indochinese Roller which remains overlooked so far.

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Threatened Taxa

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NOTE

First photographic record of Hoary-bellied Squirrel *Callosciurus pygerythrus* (I. Geoffroy Saint Hilaire, 1832) (Mammalia: Rodentia: Sciuridae) from Banke National Park, Nepal

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The southern and southeastern Asia's forest ecosystems are home to a high diversity and endemism of squirrels (Koprowski & Nandini 2008; Krishna et al. 2016). There are 285 species of squirrels worldwide (Thorington et al. 2012), however, only 12 species including the Hoary-bellied Squirrel have been recorded from Nepal (Thapa 2014). Squirrels contribute significantly to ecosystem services by eating fungal spores, seeds, and other plant material, and they are also important prey for a variety of species in temperate and tropical forests (Koprowski & Nandini 2008). They are primarily forest-dependent creatures that can only adapt to a certain level of habitat loss. Anthropogenic impacts on both small and large mammals in Nepal appear to be increasing threats to the country's wildlife, which is leading to a decline in species numbers (Baral & Shah 2008; Bhandari & Chalise 2016; Bhandari et al. 2020). A large number of rodents and lagomorphs also experience this as a result of the prolonged usage of pesticides on agricultural grounds (Baral & Shah 2008; Aktar et al. 2009). The Hoary-bellied Squirrel dwells in patches of dense to moderately dense evergreen forests in mid-canopy temperate, tropical, and subtropical moist habitats (Molur et al. 2005). The squirrel has been found in Nepal's riverine woodland, mixed broad-leaf forest zone, central and eastern Siwalik foothills, Mahabharat range (Mitchell 1979), as well as modified and altered habitats including settlements and farmlands. This species, being arboreal and diurnal, consumes seeds, nuts, fruits, buds, flowers, and insects (Mitchell 1979) and gathers water from young twigs and bamboo (Karki 2013).

The Hoary-bellied Squirrel is a widely distributed species in southern Asia (Thorington et al. 2012; Karki 2013). It can be found in Nepal's lowlands (300 m or less) and temperate regions (up to 2,500 m) (Baral & Shah 2008; Thapa et al. 2016), Sal forests to mixed broad leaved forests in Mahabharat range (Thapa et al. 2016). The species is distributed throughout the Siwalik (Chure) and Mahabharat ranges (Jnawali et al. 2011); confirmed from several districts and protected areas of Nepal (Thapa et al. 2016) (Figure 1). The main threats to the species in Nepal are habitat loss and hunting for food and medicine (Jnawali et al. 2011). Based on an array

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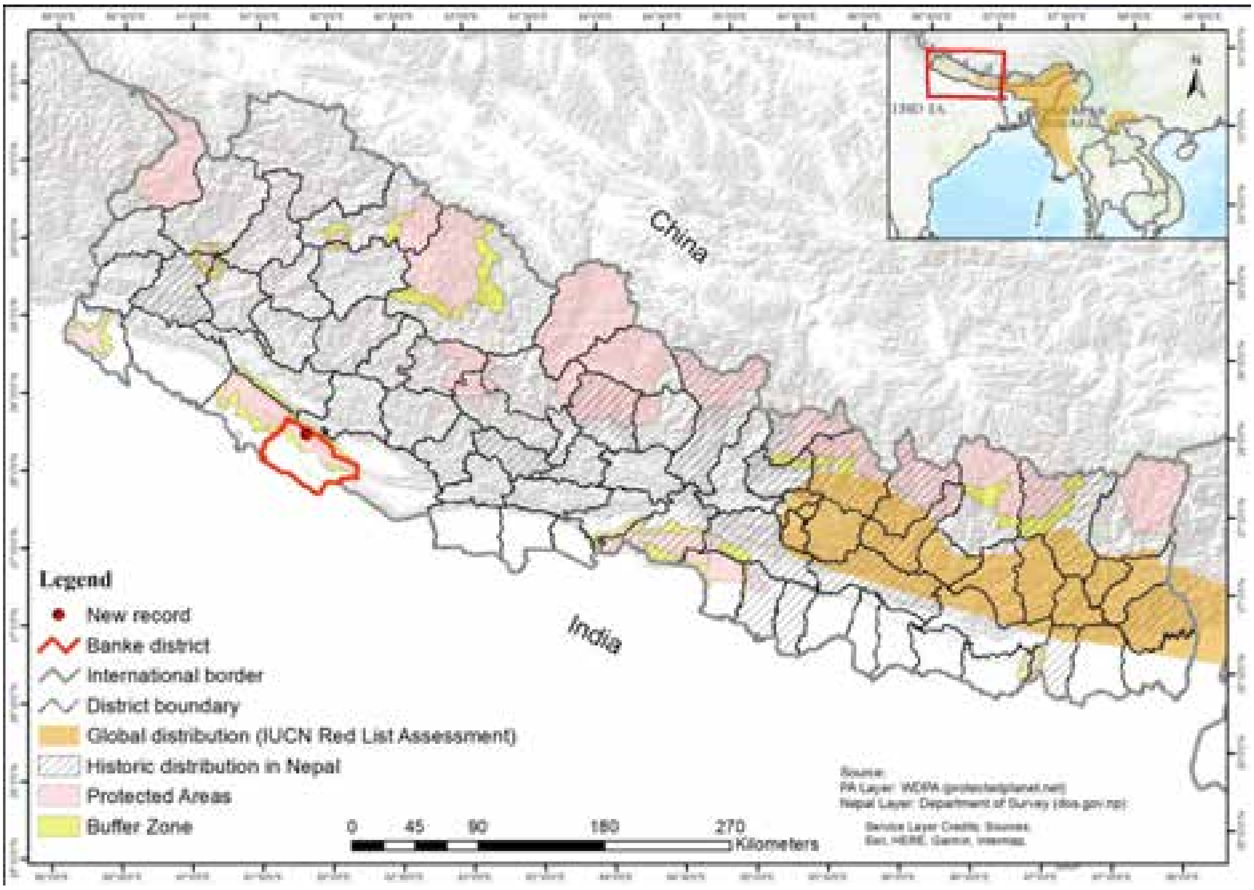

Figure 1. Past records of species in several districts of Nepal and comparison of present record with geographic range map of the IUCN Red List Assessment (Duckworth 2016).

of studies, anthropogenic pressure, habitat degradation, hunting, and pesticide usage are the major threats to the species (Shrestha 1997; Majpuria & Majupuria 2006; Baral & Shah 2008; Thapa et al. 2016). It is classified as a 'Least Concern' species globally as well as nationally by the IUCN Red List of Threatened Species (Jnawali et al. 2011; Duckworth 2016). The species has yet to be documented from the western part of the country.

Banke National Park (BaNP) established as the 10th national park of Nepal on 12 July 2010 is situated in the western part of the country. The core area of the park is entirely located in Banke District, Lumbini Province, while some portion of the buffer zone area also lies in Salyan District, Karnali Province. BaNP is linked with a trans-boundary landscape, joining Suhelwa Wildlife Sanctuary in India through Kamdi corridor including national and community forests towards the south and Bardiya National Park (BNP) towards the west, which further links with Katerniaghat Wildlife Sanctuary in India via the Khata corridor, national forest, and community forests. The park consists of eight vegetation types: Sal *Shorea robusta* forest, deciduous riverine forest, savannahs & grasslands, mixed hardwood forest, flood plain, Bhabar, and Chure Range foothills. These ecosystems harbour 34 species of mammals, 236 species of birds, nine species of amphibians, 24 species of reptiles, and 55 species of fish (BaNP 2018). About 90 percent of natural forest coverage is composed of mainly Sal *Shorea robusta*, Karma *Terminalia tomentosa*, Khair *Senegalia catechu*, and Sissoo *Dalbergia sissoo* species that support a wide variety of wildlife. Among rodents, only four species, viz., Northern Palm Squirrel *Funambulus pennantii*, Indian Crested Porcupine *Hystrix indica*, Red Giant Gliding Squirrel *Petaurista petaurista,* and House Rat *Rattus rattus have* been previously recorded in the park (BaNP 2018).

The Chure Hills cover the majority of Banke National Park, along with some flat areas. It is difficult to monitor wildlife crime and forest product smuggling in such locations with regular patrols. On 18 June 2023, a team of 10 persons from the BaNP and the Nepal Army were dispatched for a four-day camping operation. On the first day, the team walked from the Mahadeva area to Baghsal Sota (also known as Baghsal Khola), a perennial

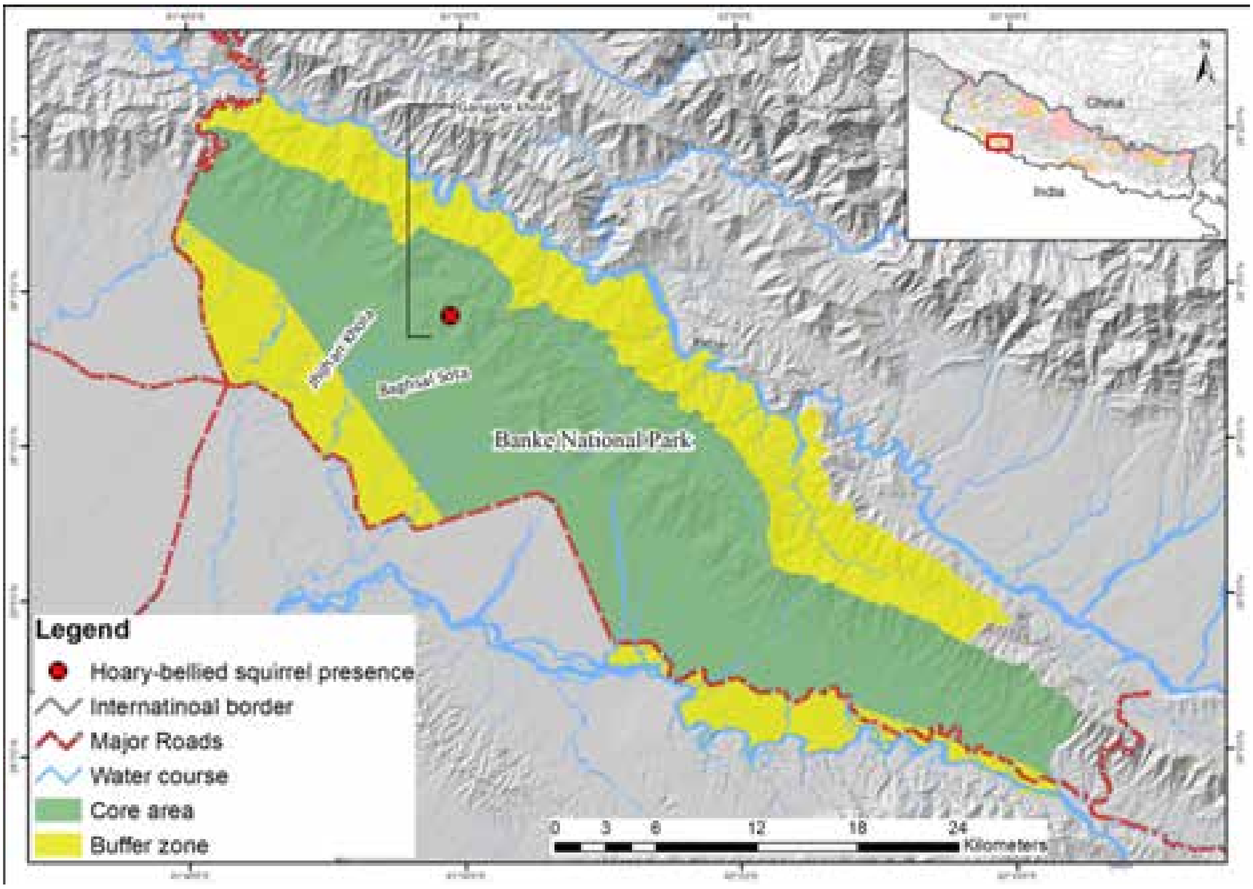

Figure 2. Map showing the sighted location of Hoary-bellied Squirrel *Callosciurus pygerythrus* in Banke National Park.

source of water. At 1540 h, while heading towards Chure Top along Gangate Khola (a tributary of Baghsal Sota), the first author noticed an animal climbing on a Jamun *Syzygium cumini* tree at 28.235701° N, 81.826066° E, at an elevation of 532 m (Figure 2). When the species was approached at close proximity, it leaped to the Bhorla *Bauhinia vahlii*, a climber and reached the canopy of the Jamun tree. The species was photographed with a Canon 2000D, and the location was marked with a Garmin 64s GPS. Binoculars (Olympus 8 x 42) were used to observe the species size, coloration, physical traits, and climbing and resting events in the field.

The animal has brown dorsal pelage but dark grey at limbs and in addition a yellowish hip patch, which occurs seasonally a blunt muzzle and comparatively larger tail, dirty white pelage, and alternating bands of black to blackish and yellowish to white appears in the tail. Based on the characteristics, the animal was identified as the juvenile Hoary-bellied Squirrel *Callosciurus* pygerythrus (Image 1 & 2).

The current photographic record provides the first photographic evidence and range extension of the

Image 1. Climbing event of Hoary-bellied Squirrel *Callosciurus pygerythrus*. © Yam Bahadur Rawat.

Image 2. Resting event of Hoary-bellied Squirrel *Callosciurus pygerythrus*. © Yam Bahadur Rawat.

Hoary-bellied Squirrel's distribution in the western part of the country. In addition, there is a lack of information regarding their population ecology, interactions with other sympatric rodents like the Orange-bellied Himalayan Squirrel *Dremomys lokriah,* and how the species react to an increase in anthropogenic interactions in human-dominated landscapes. However, an in-depth study of habitat characteristics, nutrition, distribution, movement, and activity patterns would further aid in the long-term survival of Hoary-bellied Squirrel in BaNP.

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NOTE

Cyperus babakan Steud. (Liliopsida: Poales: Cyperaceae), a new record for southern India

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Cyperus L. is a cosmopolitan genus of the family Cyperaceae and has remarkable species richness in India with about 947 species worldwide (Govearts et al. 2021). Prasad et al. (2020) treated the genus in strict sense and included 82 species in the checklist of flowering plants of India. While conducting field survey on 29 September 2022, for the taxonomic revision of the genus *Cyperus* L. in Kerala, an interesting specimen allied to *Cyperus pilosus* Vahl was collected. On critical examination with reliable literature (Steudel 1855; Kern 1952, 1974; Dai et al. 2010), it was identified as *Cyperus babakan* Steud. This species can be readily distinguished by its simple inflorescence, dense spikes, scabrous nature of glumes and the larger size of achenes.

Steudel (1855) recognized *Cyperus babakensis* based on the collection of Zollinger (H. 693) from the swamp near Babakan in the Tijikoya region, Java (Indonesian Archipelago). There is no description of *C. babakensis* in Zollinger's work (Zollinger, 1854) and it was validly published by Steudel (1855) as *C. babakan* in his monumental work, *Synopsis plantarum glumacerum*. During the same period, Miquel (1855) described and validly published Zollinger's collection (H. 693) as *C. babakensis* and noted that *Cyperus babakan* Steud. is "nomen rectius adjective more adhip" (the name is more correctly used as an adjective), hence, subsequent workers followed Miquel (Boeckeler 1868; Clarke 1893, 1909; Kuekenthal 1935). While revising Malaysian *Cyperus,* Kern (1952, 1974) treated *C. babakan* as a valid name and cited "the form C. babakensis, accepted by nearly all authors, was still a nomen nudum when C. babakan was already validly published therefore it cannot be upheld." The latest authors such as Dai et al. (2010), Govearts et al. (2021) and Prasad et al. (2020) accepted the treatment of Kern (1952, 1974).

Cyperus babakan Steud. is included under the section Proceri (Kern, 1952) of subgenus Cyperus; earlier this well-characterized species was placed under the subgenus Pycreus by Steudel (1855) and Miquel (1855). The species is native to Asia, extending from Southeastern parts of Tibet, the Malay Peninsula and the Malay Archipelago. In India, the species has been recorded from a few localities from the eastern and northeastern states (Kern 1974; Rao & Verma 1982; Karthikeyan et al. 1989; Prasad et al. 2020). Therefore, the collection represents a new record for southern India. A detailed description along with, photographs and relevant notes are provided for its easy identification.

Cyperus babakan Steud., Syn. Plant. Glum. 2: 6. 1855.

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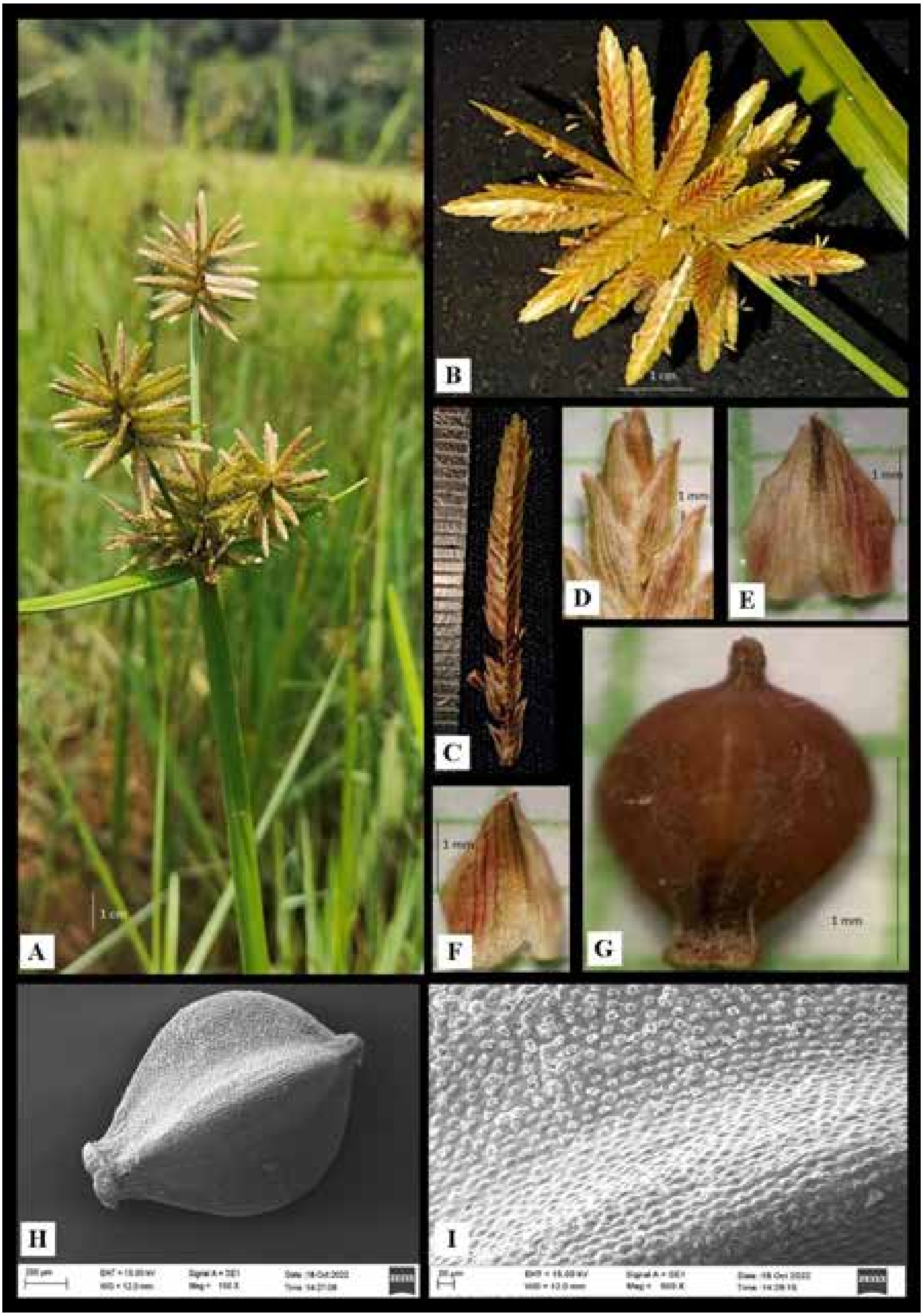

Image 1. ***Cyperus babakan*** **Steud: A— Habitat | B—Spike | C & D—Spikelet | E & F—Glume | G—Achene | H & I— SEM images of achene. © Anakha B.S. & Viji A.R.**

Type: Indonesia, Java *Zollinger, H.* 693. (G00191583, image!); (Iso L0042364, Image!)

Synonyms: *Cyperus babakensis* Steud. ex Miq., Fl. Ned. Ind. 3: 257. 1856. *Cyperus pilosus* var. *babakensis* (Steud. ex. Miq.) C.B. Clarke, J. Linn. Soc. Bot. 21: 151. 1884. *Duval-Jouvea babakensis* (Miq.) H. Pfeiff., Mitt. Inst. Allg. Bot. Hamburg 7: 167. 1928.

Perennials, rhizome emitting slender stolons clothed with brownish scales. Culm solitary, triquetrous, smooth, 60–90 × 0.4–0.6 cm. Leaves 2–3, shorter than or as long as the culm; flat, gradually acuminate, 35–85 × ca. 1 cm, scabrous on the margins towards the apex; basal sheaths often *bladeless*, leaf sheath and blades septate. Inflorescence simple, 3–10 × 4–10 cm. Involucral bracts 3–4, patent to reflexed; the lower two much longer than the inflorescence, 21–45 × 0.6–1 cm. Rays 2–5, unequal, erect, 2–10 cm long. Spikes ovoid or ovoid-oblong, very dense; rachis hispidulous. Spikelets patent to reflexed, compressed, 0.6–2 × 0.2–0.3 cm, 10–46 flowered; rachilla straight, wingless, persistent; internodes 0.5–0.7 mm long. Glumes membranous, obliquely erect, boat shaped, ovate, subacute at apex, minutely mucronulate, 2–3 × ca. 2 mm, 7–9 nerved, stramineous to reddish brown, keel antrorsely hispid-scabrous at least towards the top, margins hyaline. Stamens 3; anthers oblong-linear, 0.7–1 mm long, connective with apical reddish appendage. Stigmas 3. Achene triquetrous, broadly ellipsoid or obovoid, apiculate, broadly stipitate, 1.2–1.5 × 0.7–0.9 mm, black.

Note: The Scanning Electron Microscopic studies of achene revealed the presence of hexagonal *epidermal* cells having thin and inconspicuous periclinal wall and with a central dome shaped silica body.

Flowering and fruiting: June–November.

Distribution: Bangladesh, Borneo, Cambodia, China (Hainan, Tibet), Jawa, Malay Peninsula, New Guinea, Philippines, Sulavesi, Thailand, Vietnam, India: Arunachal Pradesh, Bihar, West Bengal, Kerala: Thiruvananthapuram

Habitat: In marshy areas along with *Cyperus tenuispica* Steud., *Eleocharis acutangula* (Roxb.) Schult., *E. retroflexa* (Poir.) Urb. etc.

Specimen collected: S. 5214 (TBGT), 29.ix.22, India, Kerala, Thiruvananthapuram District, Venjaramoodu, coll. Anakha B.S.

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