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Tigers of Riverbanks: Ecological Patterns of Riparian Tiger Beetles along the Habitat Gradient in a Tropical Alluvial Plain

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Abstract: Although insects in general and tiger beetles in particular make up a large part of the river's biodiversity, their diversity and ecology are poorly understood from the Ramganga River. Diversity and habitat preferences of riparian tiger beetles in the alluvial plains of the Ramganga River was surveyed. Total 17 tiger beetle species from eight genera in the area. Among these two species originating exclusively from muddy habitat, seven species originating exclusively from sandy habitat, and eight species originating from multiple habitats such as grasslands, gravel and rocks, and shrubs. Similarity test (Anosim) and permutational multivariate analysis of variance (Permanova), indicated significant differences between tiger beetle communities in different habitats. By analysing the indicator value index , two species can be used as an indicator for gravel and rock habitats, three species as an indicator for muddy habitat, ten species as an indicator for sandy habitat, and one species as an indicator for shrub habitat. Market basket analysis using the apriori algorithm, showed two species were positively associated with muddy habitat and seven species were positively associated with sandy habitat.

Keywords: Caraboidea, Cicindelidae, Coleoptera, Conservation, Ramganga River

With more than 385,000 described species, beetles (Order- Coleoptera) account for about 40% of all described arthropod species and it is estimated that there are about 1.5 million beetle species worldwide (Stork et al., 2015, Bouchard et al., 2017). Beetles' great diversity is believed to be due to their extreme adaptive radiation, as they are found in all types of terrestrial and aquatic habitats (McKenna et al., 2019). Among the Coleoptera, tiger beetles are well-studied, brightly coloured predatory insects that are often used as flagship taxa for insect conservation (Knisley and Gwiazdowski 2020). Because of their ecological niche specificity and sensitivity to environmental degradation, they are considered bioindicators of habitat quality (Smith et al., 2021). So far, 2897 tiger beetle species have been reported worldwide, of which 247 species are found in India, including 127 endemic species (Pearson and Wiesner 2022).

Various aspects of tiger beetle ecology and behaviour have been studied in different regions of India over the past three decades. This research includes habitat preference in the river ecosystem, the impact of differential feeding on reproduction, larval tower building behaviour, reproductive behaviour, altitudinal distribution in the Himalayas, foraging and feeding ecology, and habitat association and use as a bioindicator (Ganeshaiah and Belavadi 1986, Shivashankar and Veeresh 1987, Shivashankar et al., 1988, Shivashankar and Pearson 1994, Uniyal and Mathur 2000, Sinu et al., 2006, Bhargav et al., 2008).

The Ramganga River is an important tributary of the Ganga River, which has its source in the Himalayan mountains and flows through the alluvial region of the Ganges. It serves as a habitat for many animals in this riverway, including conservation-dependent animals such as golden mahseer, gharial, lesser flamingo and otters (Ali et al., 2018, Gupta et al., 2020, Gangaiamaran et al., 2021, Vashistha 2022). Several species of benthic macroinvertebrates and insects have also been reported from this river (Nautiyal and Mishra 2022), but the diversity and ecology of tiger beetles have not been previously reported. Because of their importance in the food web, their abundance in different habitats, and their sensitivity to habitat structure and microclimate, ground beetles play an important role in habitat-insect relationship studies (Lange et al., 2023). As an important bioindicator and ecosystem service provider of the riverine landscape, it is important to understand the diversity of tiger beetles in the Ramganga River. Therefore, study aimed to determine tiger beetle diversity, species composition and their association between species and their respective habitat along the Ramganga River alluvial plain.

MATERIAL AND METHODS

Study was conducted in Ramganga River, a major tributary of the Ganga River. Geographically, this 642 km long river having catchment area of about 23,758 km^2 flows through two separate regions namely Himalayan mountainous terrain which is covered by forest in the state of Uttarakhand and Gangetic alluvial plain which is mainly covered by agricultural lands in the state of Uttar Pradesh (Bhattacharjee et al., 2022, Khan et al., 2022). Eleven study sites was selected with an interval of ~ 50 km along the Ramganga River from Biharipur Ahatmali, Uttar Pradesh to Khamdoopur, Uttar Pradesh (at the confluence of Ganga and Ramganga River) (Table 1, Fig. 1). Fieldwork was conducted in winter (November-December 2022) and summer (May-June 2023). At each site, depending on accessibility, a 50 m by 100 m plot was selected alongside either on the left or right bank of the river, for tiger beetle collection. The tiger beetles were collected between 10:00 –15:00 from five type of habitats namely grassland, gravel and rocks, mud, sand and shrub using a standard insect net (Dangalle et al., 2012). The samples were preserved in 96% ethanol and identified with the help of literature (Pearson et al., 2020). The final data set was composed of 55 sampling units, 11 for each habitat for specimen collection.

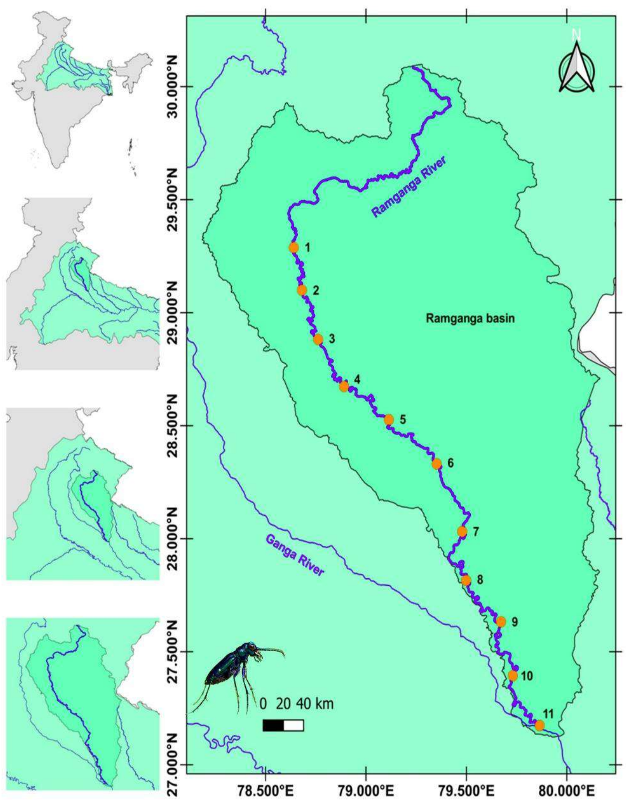

Fig. 1. Location of 11 study sites in the Ramganga River

Statistical analyses: For the analysis, summed species data (i.e., pooled over all seasons for all year) were used for each sampling site. For all statistical analyses, tiger beetle presence-absence data were used as they provide a natural basis for understanding relationships between multiple indicators of biodiversity at large geographic scales, lend themselves to the study of mobile species communities, and are worthy of describing ecological patterns (Arita et al., 2008, Dorazio et al., 2011, Dai et al., 2018, De et al., 2023).

Sample-based rarefaction curves (Gotelli & Colwell, 2001) were calculated to assess whether the sampling effort was sufficient to be representative of the tiger beetle diversity of the study area. To do this, the second-order Chao estimator (Chao2) (Colwell and Coddington 1994) and the first-order Jackknife estimator (Jackknife1) (Burnham and Overton 1978) were calculated using the 'BAT' package (Cardoso et al., 2014). For this Chao2 and Jackknife1 estimators were used because they are non-parametric, can use rare species frequencies for calculation, provide lower bound estimates for small sample fractions, can reduce bias, are more accurate and less sensitive to sample coverage, non-uniformity in species distributions and variability in capture probability, and are therefore reliable for studying invertebrate species richness (Smith and Pontius 2006, Hortal et al., 2006, Chao et al., 2009, Brito et al., 2021, Chiu 2023).

To find out whether the species composition of different habitats is similar or not, the nonparametric analysis of similarity (Anosim) test (Clarke 1993) and the nonparametric

Table 1. Study sites along the Ramganga river

Latitude	Longitude	Area
29°22'35.54"N	78°38'15.72"E	Mahpur, Afzalgarh, Uttar Pradesh
29° 9'32.60"N	78°40'35.95"E	Daryapur, Uttar Pradesh
28°56'6.59"N	78°44'42.54"E	Mohabaatpur, Moradabad, Uttar Pradesh
28°41'20.60"N	78°53'4.80"E	Tajpur Lakhan, Moradabad, Uttar Pradesh
28°31'8.40"N	79° 7'3.65"E	Bhopatpur, Uttar Pradesh
28°17'54.10"N	79°21'50.32"E	Fatehpur Thakuran, Bareilly, Uttar Pradesh
28° 2'51.24"N	79°29'6.43"E	Dandi, Dataganj, Badaun, Uttar Pradesh
27°49'0.38"N	79°29'32.57"E	Parour, Shahjahanpur, Uttar Pradesh
27°37'59.54"N	79°39'21.63"E	Manihaar, Uttar Pradesh
27°22'56.96"N	79°44'19.44"E	Sildaspur, Farrukhabad, Uttar Pradesh
27°10'31.45"N	79°51'45.35"E	Tera ghat, Farrukhabad, Uttar Pradesh

permutational multivariate analysis of variance (Permanova) (Anderson 2001) were performed in the 'vegan' package (Oksanen et al., 2019). To facilitate interpretation of the results from Anosim And Permanova, nonmetric multidimensional scaling (NMDS) was performed based on tiger beetles' composition. For bioindicator tiger beetles of specific habitats indicator value index (IndVal) (Dufrêne and Legendre 1997) were performed using 'labdsv' package (Roberts 2023). This index can assess a species' predictive value as an indicator of specific habitat which is beneficial for ecosystem conservation and management (Legendre 2024).

The Market basket analysis (MBA) is a data mining technique used to identify relationships between product groups, items, or categories (Aguinis et al., 2012). This analysis was performed with apriori algorithm (Agrawal et al., 1993) in the 'rule' package (Hahsler et al., 2005, 2011, 2023) to find out whether there is a connection between species and their respective habitats in the study area. The 'apriori algorithm' was used because it offers a good performance gain in data mining (Chee et al., 2018, Xie et al., 2019). The minimum support value was set at 0.038 and the confidence level at 0.95 to generate significant associations. The lift value was used as a measure of the association between species and habitat. If the lift value is greater than 1.0, the association is considered positive, and if the lift value is less than 1.0, the association is considered negative (Leote et al., 2020). All statistical analysis were performed in the R language and environment for statistical computing (R Core Team 2022).

RESULTS AND DISCUSSION

A total of 17 species of tiger beetles under eight genera were recorded from the study area. Among these species we found two species exclusively from muddy habitat, seven species exclusively from sandy habitat and eight species from multiple habitats like grassland, gravel and rocks and shrub (Fig. 2). The sample-based rarefaction curve of observed species richness based on the sampling data and the implemented non-parametric species richness estimators (Chao2 and Jackknife1) reached the asymptote for a species richness of 17, thus suggesting that the recorded species richness is likely representative of the tiger beetle diversity occurring in the study area (Fig. 3). The non-parametric Anosim test indicated significant differences exist between tiger beetle communities in different habitats (Anosim statistic R = 0.667) and the non-parametric Permanova test showed significant differences between tiger beetle communities in different habitats (Adonis, F = 19.087, R^2 = 0.604,). The Nmds plot (Fig. 4) illustrated that the habitats that had the similar species composition were clustered together. Two species (*Calomera chloris* and *Cylindera bigemina*) were identified as indicator of gravel and rocks habitat, three species (*Cylindera minuta*, *Lophyra striolata striolata* and *L. parvimaculata*) can be used as indicator of muddy habitat, ten species (*Calomera angulata*, *Calomera plumigera*, *Chaetodera vigintiguttata*, *Cicindela albopunctata*, *Cosmodela juxtata*, *Cylindera anelia*, *Cylindera cognata*, *Cylindera grammophora*, *Cylindera venosa* and *Myriochila dubia*) can be used as indicator of sandy habitat and one species (*Cicindela aurulenta*) can be used as indicator of shrub (Table 2, Fig. 5). No species were identified as indicator of grassland habitat. Two species (*Lophyra parvimaculata* and *Lophyra striolata striolata*) were positively associated (as lift value was 6.5 for both) with muddy habitat and seven species (*Calomera angulata*, *Calomera plumigera*, *Chaetodera vigintiguttata*, *Cosmodela*

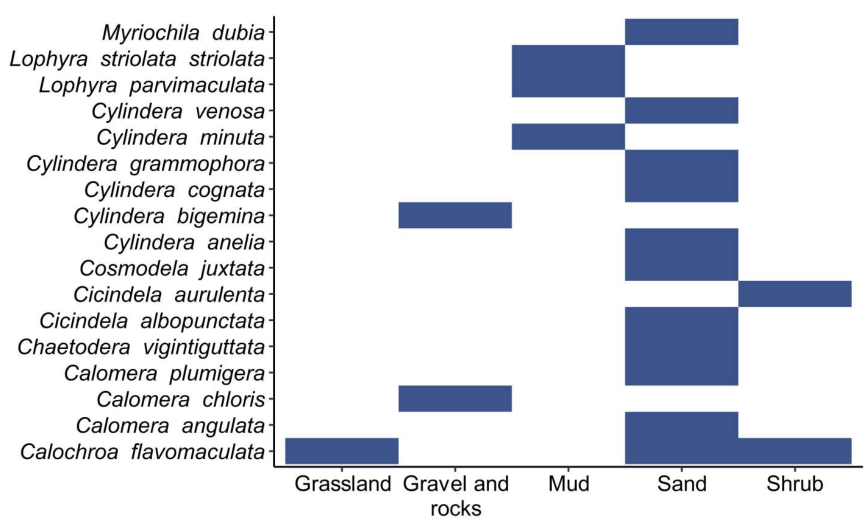

Fig. 2. Distribution of 17 species of tiger beetles in 5 habitat types

juxtata, *Cylindera anelia*, *Cylindera cognata* and *Cylindera venosa*) were positively associated (as lift value was 2.0 for all) with sandy habitat (Table 3).

The tiger beetles live in the transition area between terrestrial and aquatic ecosystems and can use both dry and wet habitats (Bobrek 2023). Thus, these species are among the few organisms that can be used for conservation monitoring in both terrestrial and aquatic ecosystems. The occurrence of 17 species (6.88% of all Indian species) of tiger beetles in the study area highlighted the important role of the Ramganga River in maintaining rich biodiversity. The eight tiger beetle species from multiple habitats which suggested the species-specific habitat utilizations of the tiger beetles where it is evident that within the same habitat, the tiger beetle population can coexist and escape competition for resources through niche partitioning (Brosius and Higley 2013, Vacher et al., 2016, Jaskuła and Płóciennik 2020). Furthermore, study found seven tiger beetle species from sandy habitats only and two tiger beetle species from muddy habitats only. This suggests that sandy substrates may provide more favorable ecological conditions such as suitable microclimate, easier burrowing for larval development, and greater prey availability compared to muddy habitats, which appear to support fewer specialized species (Pearson et al., 2020). Such differences highlight the importance of habitat type in shaping tiger beetle distribution and diversity patterns.

Among the six species of tiger beetles identified by Bhargav et al. (2008) as indicators of riverine or river-associated habitats in the Shivalik landscape of north-west India, the present study re-identified five species (*Calomera angulata*, *Calomera chloris*, *Chaetodera vigintiguttata*, *Cylindera bigemina* and *Cylindera venosa*) as indicators of specific habitats within the broader riverine riparian ecosystem. Their consistent reappearance as key habitat indicators highlighted the ecological significance of tiger beetles in monitoring habitat quality and heterogeneity within river systems. Notably, *Calochroa flavomaculata* did not emerge as an indicator of any particular habitat type in the present study, a pattern consistent with the earlier observations of Acciavatti and Pearson (1989) and Jaskuła (2011). However, evidence from previous research also suggested that this species may be shifting its distribution

Table 3. Species positively associated with sandy and muddy habitats

Species	Associated habitat	Lift
Lophyra striolata	Mud	6.5
Lophyra parvimaculata	Mud	6.5
Cylindera venosa	Sand	2.0
Calomera angulata	Sand	2.0
Chaetodera vigintiguttata	Sand	2.0
Cosmodela juxtata	Sand	2.0
Cylindera anelia	Sand	2.0
Cylindera cognata	Sand	2.0
Calomera plumigera	Sand	2.0

Table 2. Indicator species of tiger beetles for different habitats

Species	Habitat	Indicator value index (IndVal)	p value
Calomera chloris	Gravel and rocks	0.416	0.002
Cylindera bigemina	Gravel and rocks	0.298	0.02
Cylindera minuta	Mud	0.669	0.001
Lophyra striolata	Mud	0.636	0.001
Lophyra parvimaculata	Mud	0.273	0.036
Cylindera venosa	Sand	0.636	0.001
Calomera angulata	Sand	0.545	0.001
Chaetodera vigintiguttata	Sand	0.545	0.001
Cosmodela juxtata	Sand	0.545	0.001
Cylindera anelia	Sand	0.545	0.001
Cylindera cognata	Sand	0.545	0.001
Calomera plumigera	Sand	0.364	0.003
Myriochila dubia	Sand	0.364	0.003
Cicindela albopunctata	Sand	0.343	0.007
Cylindera grammophora	Sand	0.343	0.004
Cicindela aurulenta	Shrub	0.388	0.005

toward higher elevations, where it can potentially serve as a key climatic indicator (Singh et al., 2019). This absence from study area may be attributed to the species' broader ecological tolerance or less specialized habitat requirements compared to other tiger beetles, making it less suitable as a habitat-specific indicator. In the Ramganga River, human activities over the past few decades have substantially altered bank land-use patterns, and the river is increasingly threatened by pollution (Khan et al., 2019; Sarah et al., 2019; Bhattacharjee et al., 2022). With rapid urban development, sand extraction from rivers and coastal areas has intensified worldwide resulting in severe riverbed alteration, bank erosion, and the consequent loss of vital ecosystem services (Pandey et al., 2022; Rangel-Buitrago et al., 2023). Ramganga River is no longer an exception, as sand quarrying continues at various sites along its course (Daityari and Khan 2017; Alexander Speed et al., 2019; Nautiyal and Mishra 2022). These anthropogenic pressures threaten not

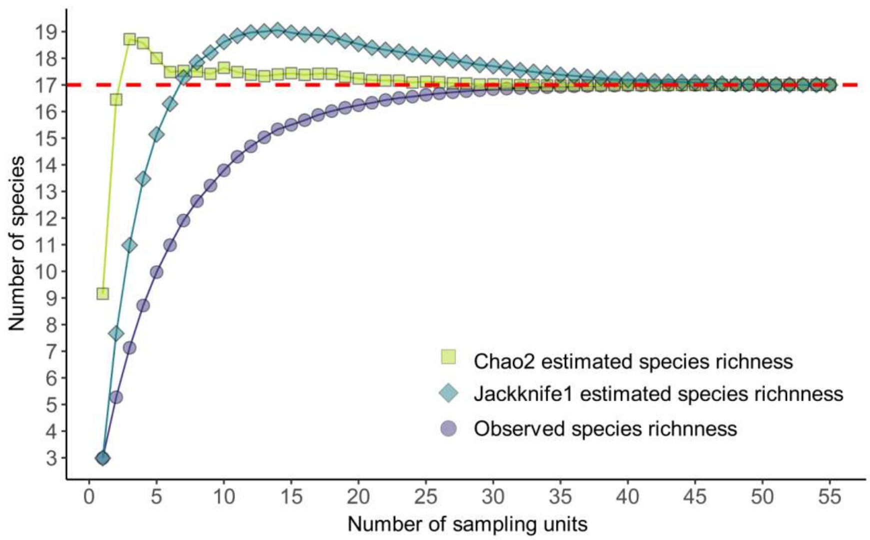

Fig. 3. Species accumulation curves for tiger beetles in Gangetic riparian zone at increasing sample size. The sampling effort yielded all the estimated species (17 species)

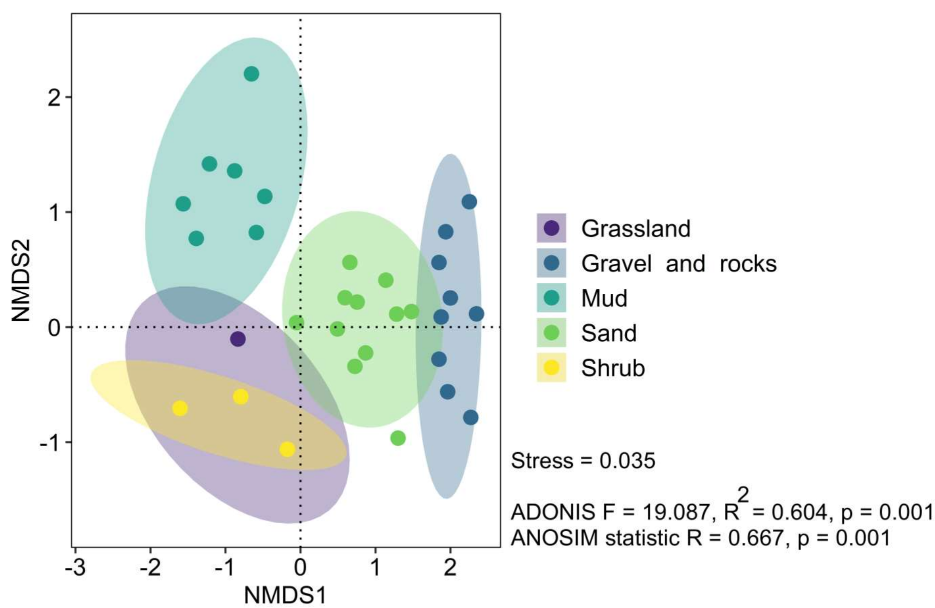

Fig. 4. Non-metric multidimensional scaling (NMDS) ordination plot illustrating differences among groups of habitats plotted in species space

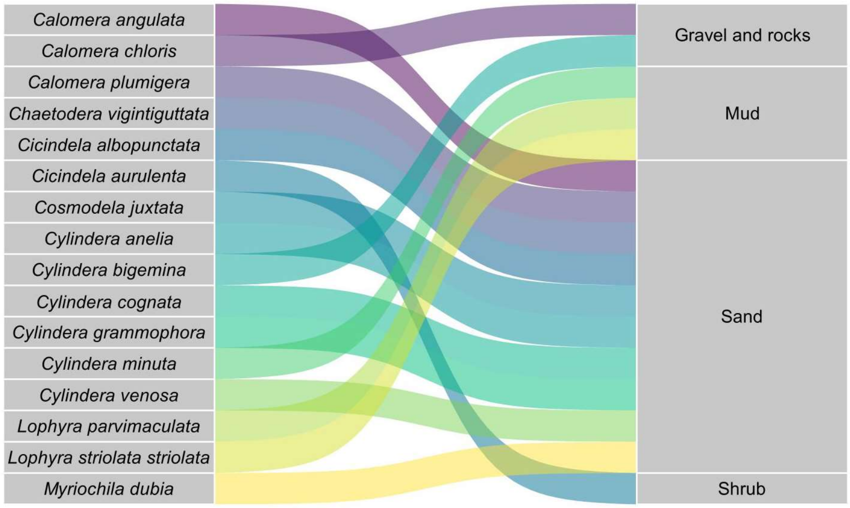

Fig. 5. Alluvial plot showing of 16 species of tiger beetles which are bioindicator of four habitat types. *Calochroa flavomaculata* is not shown was not significantly associated with any habitat and the grassland habitat is not shown was not significantly associated with any species

only riverine biodiversity but also the ecological functions that sustain local communities and biodiversity.

CONCLUSIONS

Present study provided the baseline information about the diversity of tiger beetles and species-specific habitat preferences in the Ramganga River. Moreover, study also concluded that tiger beetles are strongly associated with sandy habitats and riparian vegetation in riverbeds and riverbanks. Given the factors affecting their habitat, tiger beetles are highly habitat-specific and sensitive to environmental changes, the degradation of riparian zones directly risks their survival in the near future. Therefore, protecting riverbanks from uncontrolled sand mining, restoring natural substrates, and maintaining water quality are critical not only for the health of the river but also for conserving tiger beetle assemblages that serve as reliable bioindicators of ecosystem integrity. Integrating tiger beetle monitoring into river management plans can provide an early-warning system for ecological disturbances and help guide conservation actions. Ensuring the persistence of tiger beetle populations in the Ramganga River will thus play a vital role in conserving both biodiversity and the long-term resilience of riparian ecosystems.

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