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ORIGINAL ARTICLE

Local and species contribution to the beta diversity and rarity of riparian spider community of the Ganga River, India

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Abstract

A modern approach to understanding biodiversity variation is to deconstruct beta diversity patterns into the local contribution to beta diversity (LCBD–uniqueness in species composition of a site) and species contribution to beta diversity (SCBD–influence of a species in the beta diversity within the region) which is a good approach to improving knowledge of the beta diversity. We carried out this work to understand the pattern and relationship of LCBD, SCBD and the rarity of the spider community in the riparian habitat of the Ganga River. We calculated the correlation between LCBD and species richness of both all the species and rare species. We used the first order and second order terms to find the relationship between SCBD and the number of sites occupied by species and to find the relationship between SCBD and the index of rarity for all the species and three ecological guilds of spiders. We found that the LCBD of the spider community had a significant relationship with total species richness but not with rare species richness. Spider species with intermediate occurrence across the study sites contributed more to SCBD values than species with high and low occurrence. We found that the index of rarity of spider species had a significant relationship with SCBD values. The non-parametric permutational multivariate analysis of variance (PERMANOVA) tests revealed no significant differences in the distribution of different ecological guilds of spiders between the study sites. The integrated LCBD and SCBD approach can be used to carry out effective conservation and restoration programmes that preserve the structural, functional, and ecological diversity of spiders, as well as other biological communities in riparian ecosystems.

Keywords LCBD · SCBD · Index of rarity · Riparian area · River ecosystem

Introduction

All over the world, freshwater habitats are facing various threats such as overexploitation of biotic resources, invasion of exotic species, water flow regulation through the construction of dams and reservoirs, uncontrolled extraction of water, organic and inorganic pollution from agricultural, industrial and domestic sources and climate change (Collen et al., 2014; Dudgeon et al., 2005; Strayer & Dudgeon, 2010; Vörösmarty et al., 2010). The freshwater ecosystem of the Ganga River is suffering from overexploitation of resources, pollution, riverbed mining, physical barriers, changes in land use patterns and climate change (Siddiqui & Pandey, 2019; Singh & Singh, 2019; Kamboj & Kamboj, 2019; Dey et al., 2019; Jain & Singh, 2020; Paudel & Koprowski, 2020; Santy et al., 2020; Verma et al., 2020). All these studies indicate that it is very important to have a thorough knowledge of the present status of the diversity and distribution of plants and animals that depend on the Ganga River. But so far no research has been done on the spatial pattern of biodiversity in the Ganga River.

A species may be common in a wide geographical range but it can be rare on a local scale such as in a conservation management unit (Flather & Sieg, 2007). Based on geographical range size, habitat specificity and local density Rabinowitz (1981) developed a typology of rarity that was largely applied in conservation studies of plants (Broennimann et al., 2005), birds (Kattan, 1992; Manne & Pimm,

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2001), mammals (Dobson & Yu, 1993) and vertebrates (Isaac et al., 2009). However, very few studies (Abellán et al., 2005; Fattorini, 2007 & 2010) were performed on the lesser-known taxa, such as invertebrates (Leroy et al., 2013). The process of setting conservation priorities for conservation at the species level is focused on the listing and ranking of species based on their level of threat or likelihood of extinction (Abellán et al., 2005).

The term beta diversity was coined by Whittaker (1960) and defined by him as 'the extent of change of community composition, or degree of community differentiation, in relation to a complex gradient of environment, or a pattern of environments'. This spatial variation in species composition among locations can be partitioned into two distinct components namely species turnover in which the replacement of species occurs among sites and may reflect species gained or lost due to historical events, competition and/or environmental sorting (Baselga, 2009; Legendre, 2014) and nestedness in which small biotas contain a non-random subset of the species in richer ones i.e. species loss or gain causes species-poor sites to resemble a strict subset of species-rich sites (Patterson & Atmar, 1986; Baselga, 2009). Legendre and De Cáceres (2013) partitioned the beta diversity into 'local contribution to beta diversity' (hereafter referred to as the LCBD) and 'species contribution to beta diversity' (hereafter referred to as the SCBD). The uniqueness in species composition of a site is indicated by the LCBD values (i.e. higher the LCBD values, more distinctive species combination in that site) and the influence of a species in the beta diversity within the studied region is indicated by the SCBD values (i.e. higher the SCBD values, more contribution to the beta diversity by that species) (da Silva et al., 2018; Heino & Grönroos, 2016; Legendre & De Cáceres, 2013; Pozzobom et al., 2020).

We carried out this study to understand the pattern of LCBD, SCBD and the rarity of spider community in the riparian habitat of the Ganga River. We chose spiders for this work because they are a remarkably diverse faunal group that has successfully colonised most of the world's ecosystems (Dimitrov & Hormiga, 2020) and are widely regarded as a successful bioindicator of habitat quality (De et al., 2021; Mader et al., 2016; Pearce & Venier, 2006; Schwerdt et al., 2018). The hypotheses for this work were – (1) the LCBD of the spider community would have a significant relationship with total species richness and with rare species richness (it was not hypothesized 'positive' or 'negative' relationship as according to Legendre & De Cáceres, 2013 the relationship between species richness and LCBD is not always positive or not always negative), (2) the spider species with intermediate occurrence across the river would have a higher contribution to SCBD values than the species with the high and low occurrence because the intermediate species show most variation in occupancy among sites (Gaston et al., 2006; Heino & Grönroos, 2016) and (3) the index of rarity of spider species would have a significant negative relationship with SCBD because the species rarity decreases beta diversity (Socolar et al., 2016). As ecological guilds are considered as basic structural units of ecological communities and ecosystems (Korňan & Kropil, 2014) and the beta diversity patterns should be associated with corresponding changes in guild composition (Jamoneau et al., 2017), the hypotheses two and three were tested separately for all species together as well as for different ecological guilds of the spiders.

Materials and methods

For this work we selected, 27 sites on the banks of the Ganga River between Bijnour in Uttar Pradesh and Batanagar in West Bengal. The approximate distance between two consecutive sites was about 75 km (Fig. 1). These sites were influenced by several anthropogenic disturbances such as agricultural activities, boats, effluent discharge, garbage dumping, presence of ghats (series of steps descending into the water body), grazing, human settlement, manmade embankment and sand mining (De et al., 2021). For a detailed description of the study sites refer to Ali et al., (2019).

We performed fieldwork during the summer (May and June) of 2018 and 2019 and the winter (November and December) of 2018 and 2019. At each site, we chose 50 m (width) × 100 m (length) plot along the river bank, either left or right bank, depending upon accessibility. Within each plot, we employed 15 quadrates of 4 × 4 m (5 across the length and 3 across the width) for spider collection. We collected spiders by pitfall trapping, vegetation beating, litter sampling, ground hand collection, aerial hand collection and sweep netting (Coddington et al., 1996). For pitfall trapping, we placed one plastic bottle of 10 cm in diameter and 11 cm in depth (Churchill & Arthur, 1999) filled with preservatives (69% water, 30% ethyl acetate, and 1% detergent) at the centre of each quadrate for overnight. For the other methods, we spent 30 min in the daytime collecting spiders in each quadrate for each technique. After collection, we preserved the specimens in 70% ethanol and identified with the help of the literature. For analysis, we used summed species data (i.e. pooled across all seasons) for each site.

We calculated the LCBD values for each site and SCBD values for each species after using Hellinger-transformation for presence-absence data (Legendre & De Cáceres, 2013) by the 'beta.div' function package 'adespatial' (Dray et al., 2020). We calculated the index of rarity value (Leroy et al., 2013) for each species with the 'rarity.weights' function of the 'Rarity' package (Leroy, 2016).

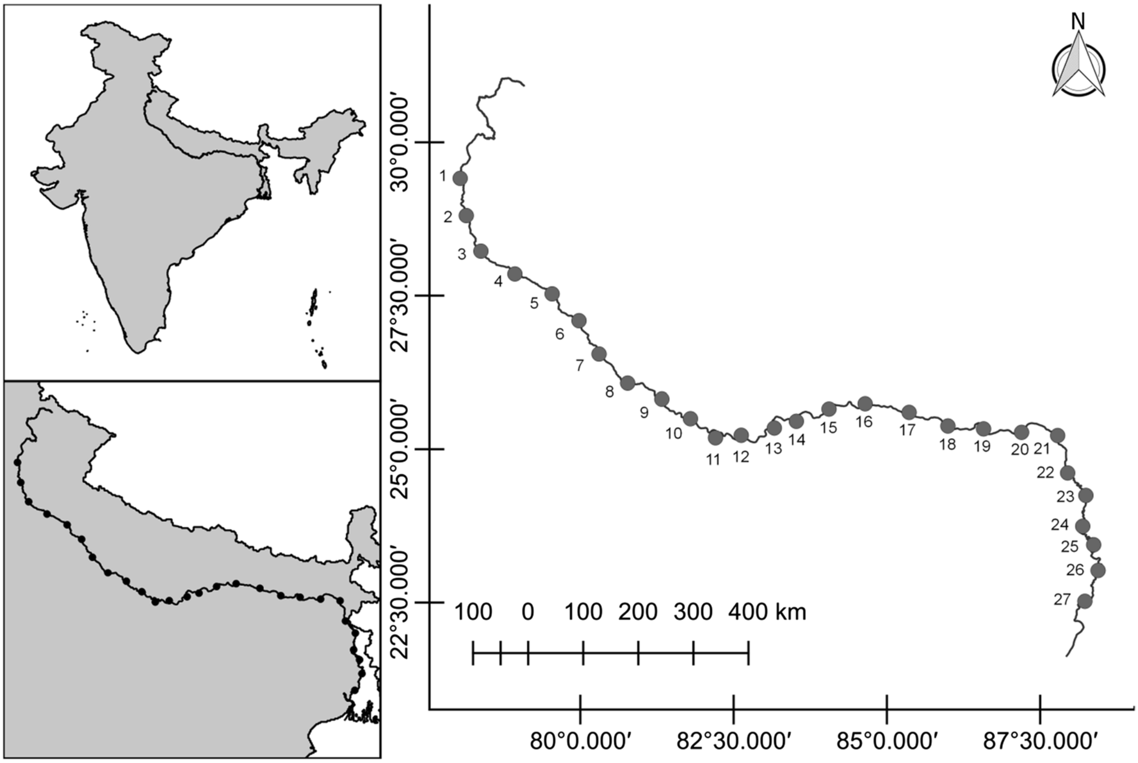


Fig. 1 Location of 27 sampling sites across the Ganga river

We calculated the Pearson's correlation between LCBD and species richness of both all the species and rare species. For this work, we considered only those species as rare which were found from one or two sites (Pozzobom et al., 2020).

We used both first order term (straight line response) and the second order term (curvilinear response) (Pozzobom et al., 2020) to find the relationship between SCBD and the number of sites occupied by species and to find the relationship between SCBD and index of rarity for all the species and three ecological guilds of spiders. We used the Akaike information criterion (AIC) values to determine which model fit best (Pozzobom et al., 2020). These three ecological guilds of spiders were 'orb web weavers' which include 35 species from 3 families namely Araneidae, Tetragnathidae and Uloboridae; 'ground hunters' which include 7 species from 4 families namely Corinnidae, Gnaphosidae, Lycosidae and Oonopidae and 'other hunters' which include 23 species from 4 families namely Oxyopidae, Philodromidae, Salticidae, Scytodidae and Sparassidae. Only three guilds were chosen because the numbers of species in those guilds were relatively higher than other guilds ('ambush hunters' which include 5 species from the family Thomisidae; 'sensing web weaver' which includes 1 species from the family Hersiliidae; 'sheet web weavers' which include 2 species from 2 families namely Agelenidae and Pisauridae; 'space web weavers' which include 5 species from the family Theridiidae and 'specialist' which includes 1 species from the family Zodariidae). For the identification of ecological guilds, we followed Cardoso et al., 2011.

We used the non-parametric permutational multivariate analysis of variance (PERMANOVA) (Anderson, 2001) to understand the difference in the distribution of spiders under five ecological guilds ('ambush hunters', 'ground hunters', 'orb web weavers', 'space web weavers' and 'other hunters') in the study sites by using 'adonis' functions respectively, of the 'vegan' package (Oksanen et al., 2019). To facilitate the interpretation of the results of PERMANOVA, we performed the non-metric multidimensional scaling (NMDS) based on the distribution of spiders under different ecological guilds in the study sites using 'metaMDS' function of the 'vegan' package (Oksanen et al., 2019).

We performed all the analyses in R (version 4.0.0) language and environment for statistical computing (R Core Team, 2020).

Results

The species richness varies from 17 to 58 species with a mean of 32.852 (SD 10.801) species per site (Fig. 2).

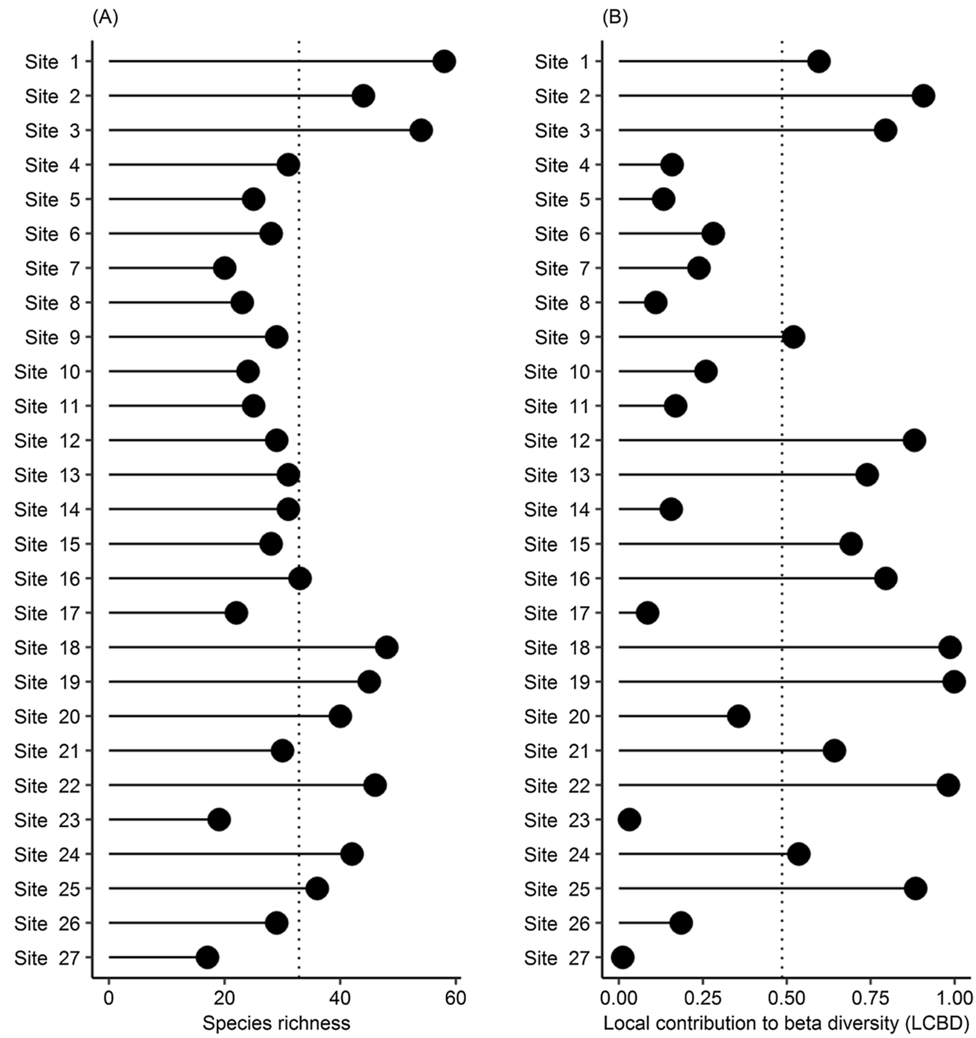


Fig. 2 Comparative account of **A** Species richness and **B** Local contribution to beta diversity (LCBD) in 27 sites of the Ganga river. The dotted vertical line represents mean value

The mean value of LCBD was 0.486 (SD 0.341) per site (Fig. 2). The LCBD of spider community was significantly and positively related with species richness (Pearson's correlation = 0.702, linear regression $R^2 = 0.493$, $p < 0.05$) but not significantly related to the richness of rare species (Pearsons correlation = 0.278, $p > 0.05$) (Fig. 3A and B).

The SCBD values range between 0.001 and 0.020 (Mean = 0.013, SD = 0.006). The spider species with high

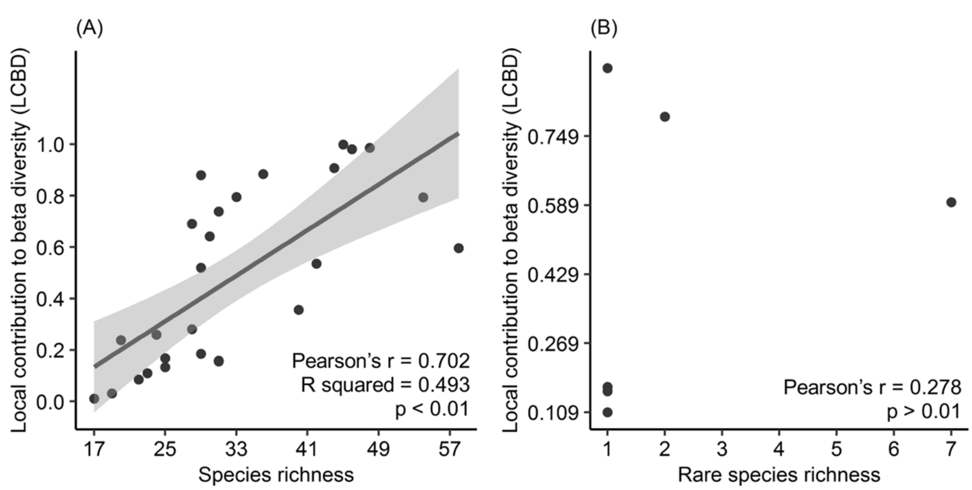


Fig. 3 Relationship between local contribution to beta diversity (LCBD) and species richness (**A**) and number of rare species richness **B** for spiders

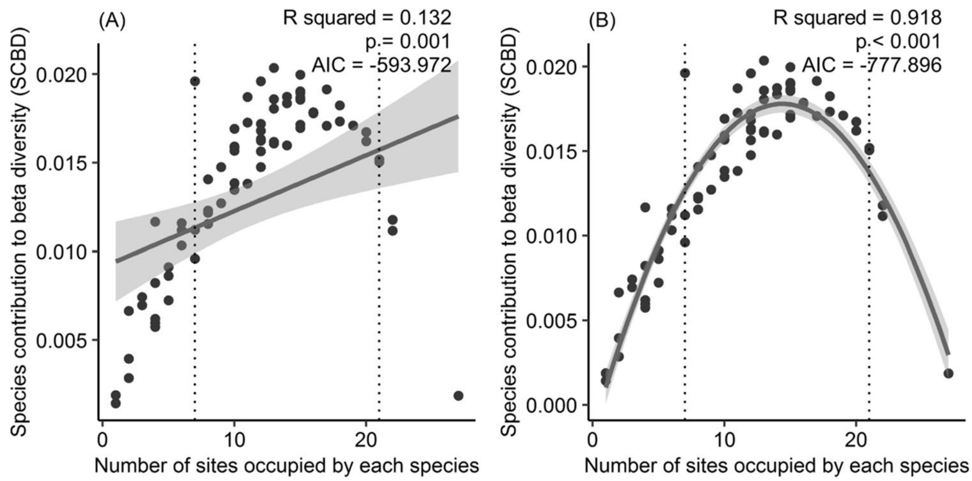


Fig. 4 **A** First order term (straight line response) and **B** Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by all species

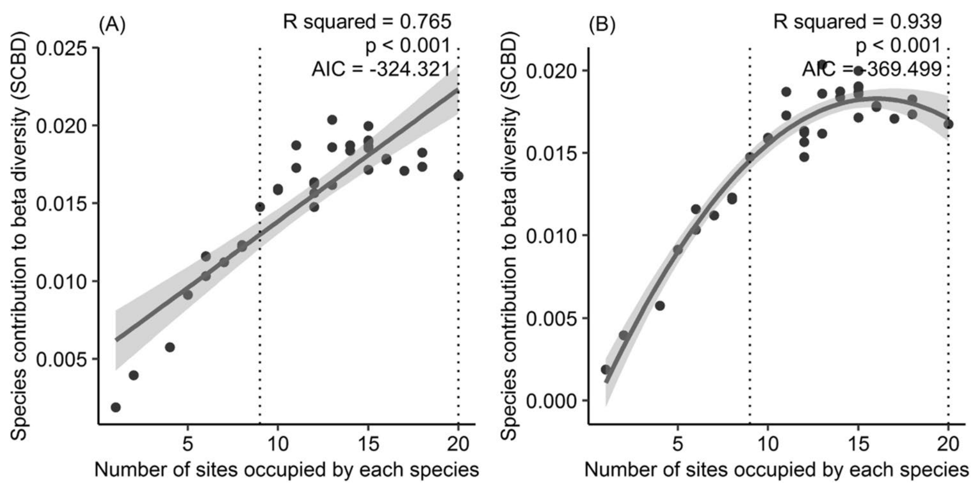


Fig. 5 **A** First order term (straight line response) and **B** Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by 'orb web weaver' spider species

SCBD values (values above 0.013) had intermediate occupancy between 7 and 21 sites for all species combined (Fig. 4A nd B), between 9 and 20 sites for only 'orb web weaver' species (Fig. 5A and B), between 10 and 21 sites for only 'ground hunters' species (Fig. 6) and between 7 and 21 sites for only 'other hunters' species (Fig. 7). We observed the highest SCBD value (0.020) for the orb weaver spider *Neoscona mukerjei* Tikader, 1980 which occupied 13 sites.

For all spider species, both of the first order term ($R^2 = 0.132$, $p = 0.001$) and the second order term ($R^2 = 0.918$, $p < 0.001$) between SCBD and number of sites occupied by each species were significant but the first order term had higher AIC value (-593.972) then the second order term model (AIC = – 777.896) (Fig. 4A nd B). For spider species under the orb web weaver guild, both the first order term ($R^2 = 0.765$, $p < 0.001$) and the second order term ($R^2 = 0.939$, $p < 0.001$) between SCBD and number of sites occupied by each species were significant but the first order term had higher AIC value (-324.321) then the second order term model (AIC = – 369.499) (Fig. 5A and B). For spider species under the ground hunter guild, the

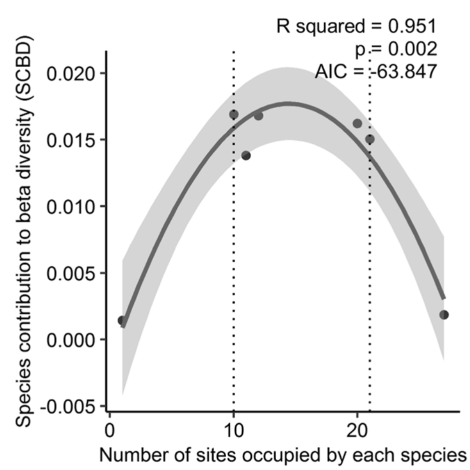


Fig. 6 Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by 'ground hunters' spider species

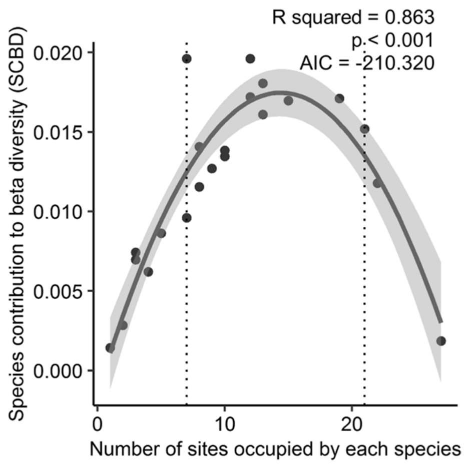


Fig. 7 Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by 'other hunters' spider species

first order term model between SCBD and the number of sites occupied by each species was not significant ($p = 0.914$) but the second order term between SCBD and number of sites occupied by each species was significant ($R^2 = 0.951$, $p = 0.002$, AIC = – 63.874) (Fig. 6). For spider species under the 'other hunters' guild, the first order term model between SCBD and the number of sites occupied by each species was not significant ($p = 0.084$) but the second order term between SCBD and number of sites occupied by each species was significant ($R^2 = 0.863$, $p < 0.001$, AIC = – 210.320) (Fig. 7).

For all spider species, both of the first order term ($R^2 = 0.495$, $p < 0.001$) and the second order term ($R^2 = 0.544$, $p < 0.001$) between SCBD and index of rarity were significant but the first order term had higher AIC value (– 636.802) then the second order term model (AIC = – 642.922) (Fig. 8A and B). For spider species under the orb web weaver guild, both of the first order term ($R^2 = 0.607$, $p < 0.001$) and the second order term ($R^2 = 0.745$, $p < 0.001$) between SCBD and index of rarity were significant but the first order term had higher AIC value (– 306.339) then the second order term model

Fig. 8 **A** First order term (straight line response) and (B) Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and index of rarity of all species

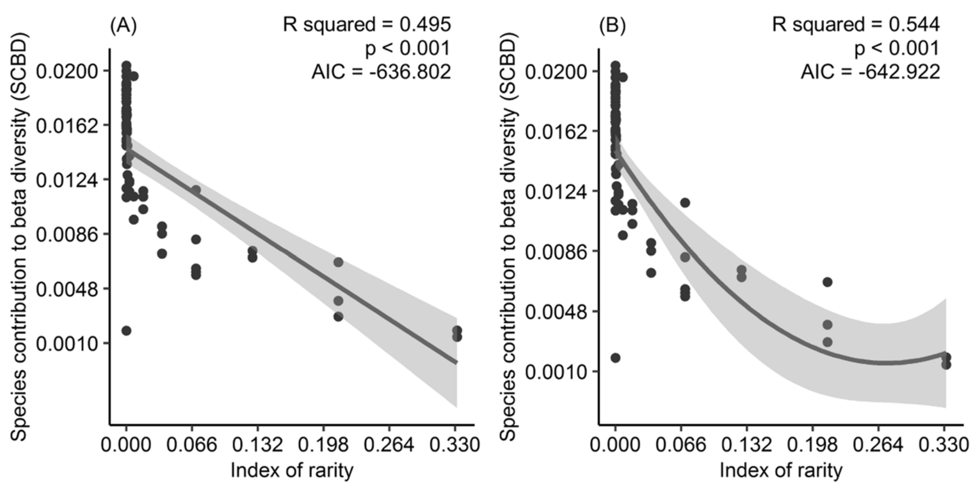
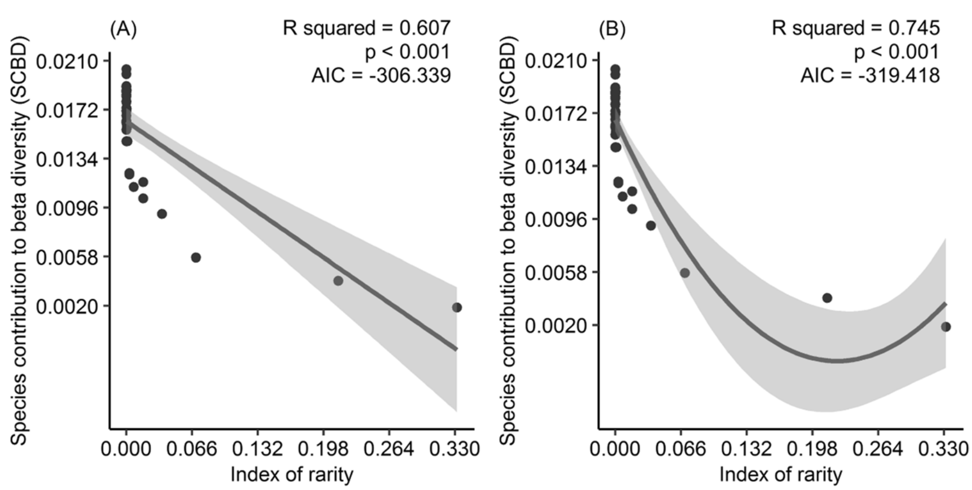


Fig. 9 **A** First order term (straight line response) and (B) Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and index of rarity of 'orb web weaver' spider species



(AIC = – 319.418) (Fig. 9A and B). For spider species under the ground hunter guild, both the first order term and the second order term between SCBD and index of rarity were not significant. For spider species under the 'other hunters' guild, both of the first order term ($R^2 = 0.540$, $p < 0.001$) and the second order term ($R^2 = 0.579$, $p = 0.0001$) between SCBD and index of rarity were significant but the first order term had higher AIC value (– 184.474) then the second order term model (AIC = – 184.503) (Fig. 10A nd B).

By PERMANOVA test we observed that there was no significant difference in the distribution of spiders under different ecological guilds in the study sites (ADONIS, F = 1.226, $R^2 = 0.065$, $p = 0.165$). With help of the NMDS plot, we found that the spiders of the same ecological guilds did not cluster together (Fig. 11).

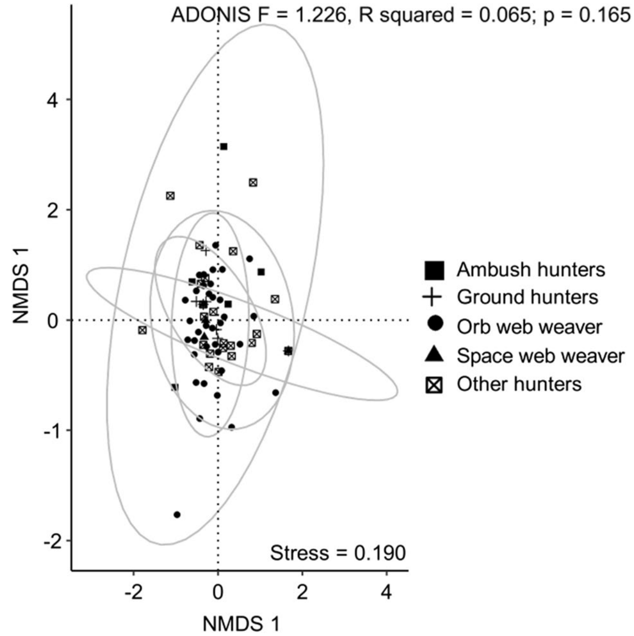


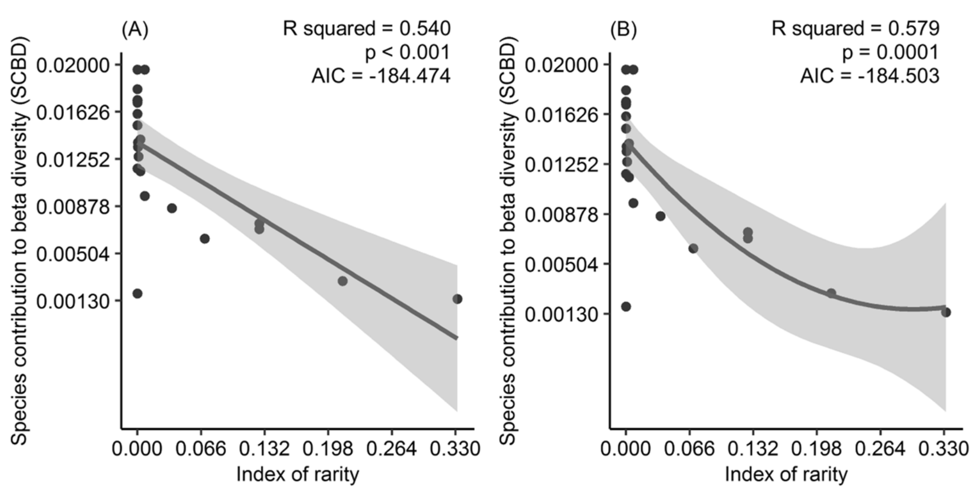
Fig. 11 Non-metric multidimensional scaling (NMDS) ordination plot illustrating that that the spiders of different ecological guilds did not clustered together in the sites

Discussion

Because a better understanding of diversity patterns is critical for managing and preserving aquatic ecosystems (Alahuhta et al., 2017), it is critical to understand beta diversity pattern and its components to manage freshwater ecosystems (Fernández-Aláez et al., 2020). Conservation biologists must strategically prioritise conservation efforts when resources are limited to maximise benefits (Dubois et al., 2020). The spatial variation in species compositions provides valuable information about some hotspots' unique contribution to biodiversity at the regional scale (Dubois et al., 2020; Socolar et al., 2016; Wiersma & Urban, 2005).

Different relationships can be observed between species richness and LCBD for different organisms because the relationship between them is not always positive or negative (Legendre & De Cáceres, 2013). Some studies found negative relationship (Dubois et al., 2020; Heino & Grönroos, 2016; Landeiro et al., 2018; Mimouni et al., 2015; Qiao et al., 2015; Vilmi et al., 2017) as well as some studies found positive relationship (Kong et al., (2017) and no relationship (Pozzobom et al., 2020) between species richness and LCBD. Only a few works (Dubois et al., 2020; Pozzobom et al., 2020; Qiao et al., 2015) mentioned negative relationships between rare species richness and LCBD. In this study, we found a significant positive relationship between species richness and LCBD values which indicates that the sites with unique species composition also harboured high species richness. Previous study had shown these sites are susceptible to habitat disturbance (De et al., 2021) that can disrupts the heterogeneity of the riverine landscape (Cao & Natuhara, 2020) and negatively affect biodiversity through the

Fig. 10 **A** First order term (straight line response) and **B** Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and index of rarity of 'other hunters' spider species



selection of homogenized disturbance-adapted traits resulting in local species loss (Gorczynski et al., 2021; McKinney & Lockwood, 1999). The remnant heterogeneous sites provide greater variety of micro-habitats that can promote predator species richness at local scale (Bellone et al., 2020; Karimzadeh & Sciarretta, 2022). Thus, the sites with unique species composition also harboured high spider species richness which results into positive relationship between species richness and LCBD values. We did not find any significant relationship between rare species richness and LCBD values probably because rare species with low occurrence have extremely low local contributions to β diversity (Brasil et al., 2020; Duarte et al., 2022; Legendre & de Cáceres, 2013).

When we analysed all the species together, we found that relationship between the SCBD and the number of sites occupied by each species was significant for both the first order term and the second order term but the value of the AIC was higher for the first order term then the second order term, and the value of R^2 is lower for the first order term then the second order term. In the case of orb web weaver spiders, we noticed a similar result. But the results of 'ground hunter' and 'other hunter' were different from these results. In the case of both 'ground hunter' and 'other hunter' spiders, we found that the first order term was not significant but the second order term was significant. As in all cases, the second order term explain better relationship, it was observed that the number of sites occupied by species and their SCBD values increased until intermediate occurrences were reached. This result indicates that the intermediate species contribute maximum to beta diversity because they show the greatest variation in occupancy among sites (Heino & Grönroos, 2016; Vilmi et al., 2017; Szabó et al., 2018). As spiders across different guilds had shown similar patterns we can conclude that biological traits and niche breadth of species had no influence on SCBD as reported in other studies (da Silva et al., 2018; Heino & Grönroos, 2016). As the influence of a species to the total regional beta diversity is proportional to the SCBD (Brito et al., 2020) and index of rarity is also based on species rarity weights across regional scale (Morel et al., 2019), we found that the first order term can illustrate a better relationship between SCBD and index of rarity across different ecological guild of the spiders.

Though the spiders are considered as common species, however, we need to keep in mind that keeping common species common is a challenging and complex process, especially in the case of spiders, the apex predator in the invertebrate world because the alternation of habitat may adversely affect the population of these species, particularly on the banks of the Ganga River, where anthropogenic pressure and consequent ecological damage are likely to be high. As the precipitation, vegetation cover, and land-use patterns change over time the hydrology and geomorphology of rivers also change which causes changes in assemblage patterns of riparian animals. Thus, depending on the nature and magnitude of changes in the habitat, species that were formerly common in a region may become rare, and vice versa. Thus, LCBD and SCBD may be remodelled over time in an area. But, the species which are adaptable to habitat changes may become ubiquitous and contribute less to assemblage patterns (Pozzobom et al., 2020).

Conclusion

Beta diversity, or spatial variation in species composition, is an important component of biodiversity. Sites with high diversity and differentiation from others should be given conservation priority to conserve as much biodiversity as possible. Because SCBD indicates which species contribute the most to beta diversity and LCBD indicates which sites have the most unique species assemblages, the SCBD and LCBD can be indicative of different scenarios for riparian environment conservation planning. The integrated LCBD and SCBD approach focusing on riparian spiders can thus be used to aid in the ecological assessment, restoration, and conservation planning of the Ganga River. However, because the natural environment is constantly changing and our ideas about the diversity and distribution patterns of plants and animals are limited but evolving, particularly in the case of invertebrates, a change in conservation strategy occurs with the increase of information and knowledge about any species (Abellán et al., 2005). This work on spider communities should be regarded as the first step in the process of understanding the spatial variation of the riparian spiders of any Indian river, which should be iterated with the help of new information generated through further research.

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Author's contribution KD: conceptualization, data curation, formal analysis, methodology, software, validation, visualization, writing—original draft; APS: data curation; AS: data curation; KS: data curation; MS: supervision, validation, writing – review and editing; VPU: project administration, resources, supervision, validation, writing – review and editing; SAH: funding acquisition, project administration, resources, supervision, validation, writing – review and editing. All authors read and approved the final manuscript.

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Data availability The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

Consent for publication All authors read and approved the final manuscript.

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