STUDIES ON ASSEMBLAGE OF SPIDERS (ARACHNIDA: ARANEAE) IN DIFFERENT RIPARIAN ZONES OF THE RIVER GANGA

THESIS

SUBMITTED TO THE

FOREST RESEARCH INSTITUTE DEEMED TO BE UNIVERSITY
DEHRA DUN, UTTARAKHAND

FOR

THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY IN FORESTRY
(WILDLIFE SCIENCE)

BY

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2021

DECLARATION

I hereby declare that the thesis entitled "**Studies on Assemblage of Spiders (Arachnida: Araneae) in Different Riparian Zones of the River Ganga**" submitted by me, **Kritish De** (Enrolment no.**16PhD416**) to Forest Research Institute Deemed to be University, Dehradun, for the award of the degree of Doctor of Philosophy in Forestry (Wildlife Science), embodies research work carried out by myself under supervision of Dr. V. P. Uniyal and Dr. Manju Siliwal. The thesis has been duly checked through URKUND a plagiarism detection tool approved by F.R.I. Deemed to be University and the thesis has plagiarism to the acceptable limits. No part of this thesis has been submitted for any other degree/diploma of the same Institution where the work was carried out, or to any other Institution and it fulfils the requirements of the ordinance governing award of Ph.D. Degree of F.R.I. Deemed to be University.

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Kritish De

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List of abbreviations

WWF	World Wide Fund for Nature
PBC	Polychlorinated biphenyl
TCA	Tarai Conservation Area
GRB	Ganga river basin
GRV	Ganga river valley
IUCN	International Union for Conservation of Nature
NGRBA	National Ganga River Basin Authority
TAL	Terai-Arc Landscape
UNESCO	United Nations Educational, Scientific and Cultural Organization
msl	Mean Sea Level
WSC	World Spider Catalog
CBD	Convention on Biological Diversity
UNCED	United Nations Conference on Environment and Development
FD	Functional diversity
FEve	Functional evenness
FDiv	FDiv Functional divergence
FDis	FDis functional dispersion
RaoQ	Rao’s quadratic entropy
ANOSIM	Analysis of similarities
PERMANOVA	Permutational multivariate analysis of variance
NMDS	Non-metric multidimensional scaling
KW	Kruskal–Wallis
D	Jaccard dissimilarity
RichDiff	Richness difference
Repl	Species replacement
S	Similarity
LCBD	Local contribution to beta diversity
SCBD	Species contribution to beta diversity
AIC	Akaike information criterion
RDA	Redundancy analysis

Summary

The junction of any aquatic ecosystem and the surrounding terrestrial ecosystem is considered the as the riparian ecosystem. The importance of the riparian ecosystem is far greater than its area as it supports a large biodiversity, both aquatic and terrestrial. Recent research has shown that biodiversity in the riparian region continues to decline all over the globe. The riparian ecosystem of the Ganga river, the largest river basin in India in terms of the catchment area is not an exception. 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 are considered as the major threats to the freshwater ecosystems, including the Ganga river. By reviewing recent and past research works, it was found that we have serious knowledge gap about the diversity and distribution of invertebrates, in general and of spiders, in particular of the Gangetic riparian areas. Therefore, knowledge about invertebrate animals living in Gangetic riparian areas is very important for the actual conservation management of the area.

With this background, this study was conducted (i) to understand overall spider diversity in riparian areas of the Ganga river, (ii) to compare spider diversity and richness in the different habitat of riparian zone of upper, middle and lower segments of the Ganga river and (iii) to identify habitat specific / indicator spider taxa for riparian zone of the Ganga river.

The study was conducted in the year 2018 and 2019, from Bijnour, Uttar Pradesh to Batanagar, West Bengal, 1955 km of the river Ganga which passes through four Indian states namely Uttar Pradesh, Bihar, Jharkhand and West Bengal. Total of 27 sampling sites were selected with an interval of about 75 km across the river. Among these sites site 1 to site 10 fell between Haridwar and Prayagraj (in the upper zone of the Gangetic plain), sites 11 to site 21 fell between Prayagraj and Farakka, West Bengal (in the middle zone of the Gangetic plain) and site 22 to site 27 fell between Farakka and Batanagar, West Bengal (in the lower zone of the Gangetic plain). Depending on the accessibility, the spiders were recorded from either left or right bank of the river during the month of May and June in summers and November and December in winter.

In this study 79 species belonging to 50 genus and 18 families were found from the study area. Maximum number of species from the upper zone (79 species, 50 genera and 18 families) followed by the middle zone (69 species, 42 genera and 18 families) and lower zone (64 species, 40 genera and 16 families). By analysis of similarities (ANOSIM) test it was found that there was no significant mean of ranked dissimilarities between the spider communities in upper, middle and lower zone. By permutational multivariate analysis of variance (PERMANOVA) test it was found that there was no significant difference of species composition between the upper, middle and lower zone. By non-parametric Kruskal–Wallis rank sum test it was found that the upper, middle and lower zones did not differ in terms of species richness, index of taxonomic diversity, index of variation in taxonomic distinctness, functional evenness, functional divergence and functional dispersion. The significant Pearson's correlation and linear relationship was observed between species richness and the functional evenness, species richness and the functional divergence, index of taxonomic diversity and the index of variation in taxonomic distinctness, index of taxonomic diversity and the functional dispersion, the index of variation in taxonomic distinctness and functional evenness, the index of variation in taxonomic distinctness and functional dispersion.

From result of SDR simplex analysis, it was found that the mean species replacement was higher than the mean similarity and mean richness difference across the study sites. The maximum variation occurred in the richness difference than species replacement and similarity across the entire stretch. The local contribution to beta diversity of spider community was significantly and positively related with species richness. It was found that the spider species with higher species contribution to beta diversity (SCBD) values had intermediate occupancy between 9 and 18 sites for all species, between 11 and 18 sites for 'orb web weaver' species, between 10 and 20 sites for 'ground hunters' species and between 7 and 19 sites for 'other hunters' species. For all spider species, both of the first order term (straight line response) and the second order term (curvilinear response) between SCBD and number of sites occupied by each species were significant.

By the analysis of similarities (ANOSIM) test it was found that there was significant difference in mean of ranked dissimilarities between the spider communities in different disturbed sites. By non-parametric permutational multivariate analysis of variance (PERMANOVA) test it was found that there was significant difference in species composition between the spider communities in different disturbed sites. From the study, it was found that the agriculture, human settlement and sand mining had significant negative impact on the species richness of the spiders. It was found that the agriculture, human settlement, manmade embankment and sand mining were the best disturbance combination that affected the species richness of the spider community. By IndVal analysis 14 species were found as indicator of very low disturbed sites; and one species was found as indicator of low disturbed sites.

Ganga river flows through six ecoregions which supports rich biodiversity of aquatic as well as riparian ecosystem and many of them are declared as threatened by IUCN. This biodiversity of the Ganga river is our national resource and for maintenance and improvement of this asset, we should acquire knowledge by multidisciplinary approach. This is the first work where functional, taxonomic, and beta diversity of spider community, as well as their potential to be used as bioindicator species in the riverine riparian ecosystem in India, were studied. However, research on a single biota is not enough for any ecosystem. Multidimentional studies should be conducted on the flora and fauna living in the Ganga river as well as other rivers of India as the results of these studies will directly help in the restoration, conservation, and management of the riverine ecosystem in India.

CHAPTER 1

INTRODUCTION

1.1 Definition of riparian zone

The word ‘riparian’ is originated from the Latin word riparius, which means the land near to the body of water (Naiman and Decamps, 1997). The British Standards Institution (2004) defined the riparian zone as areas adjacent to rivers, including riverbanks, are capable of directly affecting the aquatic ecosystem of the river. It is the part of the terrestrial landscape which is situated on the river channel banks and where the vegetation is affected by flood or elevated water table and soil water holding capacity (Naiman et al., 1993). It is an ecotone that is both hybrid and open in nature (Dufour et al., 2019). According to (Dufour et al., 2019) the riparian ecosystem is an ecotone which is hybrid (as both natural and anthropogenic process co-constructed it) as well as open (as adjacent terrestrial ecosystem interacts with aquatic ecosystem) in nature. Kauffman and Pyke (2001) considered riparian regions are hot spots of biodiversity, particularly in arid and semiarid areas where the riparian areas are the only ecosystem in the landscape dominated by the trees. The features of this region are that due to natural and human influence the changing bioclimatic, geo-morphological, and land use conditions trigger high spatial and temporal variability (Riis et al., 2020).

1.2 Importance of riparian zone

Because of their presence in the boundary between the terrestrial ecosystem and aquatic ecosystem, the importance of riparian zones is more significant than their proportion to land area (Gregory et al., 1991; Leroux and Loreau, 2008). In large managed landscapes, the river and its riparian zones form low-altered habitats that function as an informal ‘protected area’ (Mainstone et al., 2016). The three attributes viz hydrogeomorphic, vegetational, and trophic web elements) which are characterized by spatial and temporal variation (Gregory et al., 1991; Power and Rainey, 2000; Marcarelli, 2020), makes them important habitats for maintenance of biodiversity and provide multiple ecosystem services (Naiman, 1993; Hanna et al., 2019).

The riparian ecosystem provides (i) provisioning ecosystem service (such as standing crop of woody biomass for fuel), (ii) regulating and maintenance ecosystem service (such as damage mitigation of extreme flows by regulating hydrological cycles and water flow, pollination, protection of human lives and infrastructure by controlling mass flows, reduction in carbon dioxide by carbon sequestration, reduction in fire damage costs, reduction in transports of sediment and toxic particles in the streams, decreasing erosion and sediment pressure in streams, reduction of pollution and nutrient runoff, seed dispersal, sustaining populations of several species by providing habitats and controlling the temperature of the air and stream) and (iii) cultural ecosystem service by cultural ecosystem services by directly interacting with living systems, both in situ and outdoor (Riis et al., 2020).

1.3 Threats to the freshwater ecosystem and riparian zones

Qadri and Bhat (2020) estimated that among all water of the earth, only 2.5% is freshwater, of which 0.40% is surface and atmospheric water (0.01% of total freshwater). Among the surface and atmospheric moisture, freshwater lakes constitute 67.4% (i.e., 0.00674% of total global freshwater), wetlands constitute 8.50% (i.e., 0.00085% of total global freshwater) and, rivers constitute 1.60% (0.00016% of total global freshwater) (Qadri and Bhat, 2020). Though this tiny amount of freshwater covers only 2.3% of the worldwide land surface area, at least 9.5% of the described animal species of the Earth are supported by freshwater ecosystem (Reid et al., 2019). 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 are considered as the major threats to the freshwater ecosystems (Dudgeon et al., 2006, Collen et al., 2014, Strayer and Dudgeon, 2010, Vörösmarty et al., 2010, WWF, 2018). Using the Living Planet Index (World Wide Fund for Nature), it was found that between 1970 and 2014; the freshwater population declines by 83% and continue to surpass simultaneous declines in terrestrial or marine systems (Reid et al., 2019). Since 2006, there are twelve threats to the biodiversity of freshwater ecosystems are documented which are either entirely new or have since intensified, these are - climate change, declining calcium, e-commerce and invasions, emerging contaminants, engineered nonmaterial, expanding hydropower, freshwater salinization, harmful algal blooms, infectious diseases, light and noise, microplastic pollution and cumulative stressors (Reid et al., 2019).

Through some recent studies, scientists have seen that the freshwater ecosystem of the Ganga river is intimidated by overexploitation of resources, pollution, riverbed mining, physical barriers, change of land use pattern, and climate change (Siddiqui and Pandey, 2019; Singh and Singh, 2019, Kamboj and Kamboj, 2019; Dey et al., 2020, Jain and Singh, 2020, Paudel and Koprowski, 2020, Sah et al., 2020, Santy et al., 2020, Verma et al., 2020).

1.4 Studies on spiders of riparian ecosystem

There have been some important studies around the world in recent times about spiders of riparian areas regarding their diversity, ecology, and effectiveness as bioindicator taxa. Work by Avila et al. (2017) in Brazil found that species substitution and habitat structure shape riparian spider communities in ponds. Kraus et al. (2017) recommended using riparian spiders as indicator of Polychlorinated biphenyl (PBC) contamination across heterogeneous aquatic ecosystems in Manistique River Great Lakes Area, USA. Reyes-Maldonado et al. (2017) found that the riparian spider communities can be utilized as indicators for stream ecosystems disturbances in Piedras watershed, Puerto Rico. In Puerto Rico, Sanchez-Ruiz et al. (2017) found that structure of webs and body condition of riparian spiders are associated with diversity and quality of prey insect species. Work by Ferretti et al. (2018) at La Plata River Basin, South America found that the temperature seasonality, isothermality, and seasonal precipitation variation had the most impact on the spider distribution. Jackson and Sullivan (2018) found that the trophic dynamics of riparian spiders in the Sierra Nevada, USA, is driven by the ecosystem size and flooding. Laborda et al. (2018) studied the diversity of spiders of Uruguay river islands and reported the presence of 145 species under 33 families. Stańska et al. (2018) found that the complexity of habitats is a determinant factor in the distribution of body size in spider assemblages of riparian grasslands in Bug river Valley, Poland. In Ashtabula river, USA, Walters et al. (2018) found that the Araneidae and Tetragnathidae spiders can indicate the source and magnitude of Polychlorinated biphenyl (PBC) contamination.

Abdullah et al. (2019) studied the diversity of spiders in the Riparian Firefly Sanctuary in Malaysia and reported the presence of 26 species under seven families. In Romania, Graf et al. (2019) observed that land use, local environmental conditions, in-stream pesticide toxicity, and shading influence the composition of riparian spider community. The study by Kelly et al. (2019) in Puerto Rico found that urbanization can alter diets of riparian spiders. de Ávila et al. (2020) studied the beta diversity pattern of spider assemblages in temporary wetlands assemblages in Brazil. In central Romania, Graf et al. (2020) found that complex gradients of the habitat quality, stream, and catchment land use affect the diet of riparian spiders. Hunt et al. (2020) worked in the riparian ecosystem in south-western Australia and found that the spider communities are affected by the degradation of riparian zones.

In the recent past, research has also been done in India on the diversity of spiders in the riparian regions. From the riparian zone of the River Vishwamitri, Baroda, Gujarat, 17 families, 50 genera, and 92 species of spider were reported (Siliwal et al., 2003). They found that at the family level maximum diversity was seen in family Araneidae, but at the species level, ultimate diversity was found in non-weavers. At Tarai Conservation Area (TCA) at Uttarakhand, India, Hore and Uniyal (2008a, b) found that in the riparian sites orb web weaver spider families Araneidae and Tetragnathidae are predominant. From the surrounding area of Narmada river at Rajghat (Barwani) (Madhya Pradesh), Sharma et al. (2010) reported 44 species belonging to 12 families. From the Ousteri Lake riparian habitat of Puducherry, Alexandar (2013) documented ten species of Arachnida belonging to 9 families, of which three species were spiders. From the riparian zone of Periyar river, Kerala Noble and Joseph (2015) reported 68 species, 49 genera and, 13 families of spiders. From the riparian ecosystem of the Kavvayi River Basin, Kerala, Jose et al. (2018) reported 112 species, 81 genera and 21 families of spiders. Abhilash and Kumar (2018) reported 39 species, and17 families of spiders from the bank of river Pampa at Poovathoor, Pathanamthitta district, Kerala. Deshmukh and Tekade (2019) reported 48 species belonging to 12 families from the Charghad river basin of Morshi, Amravati. In India, most of the works on the riparian spiders were done in western and southern India. Knowledge of riparian spider diversity in northern India and eastern India is still limited, leading to opportunities for research in these areas.

1.5 Threats to the spider community

The main reason for the loss of wildlife and biodiversity around the world is anthropogenic activity, and spiders are no exception. Habitat destruction by land reclamation, eutrophication, and intensive agricultural management (Hajdamowicz and Jastrzębski, 2007), conversion of forests to agricultural lands (Potapov, 2020), and disturbance of forest ecosystems (Baldissera, 2020) are the major causes of loss of spider diversity throughout the world. Spiders are directly and indirectly harmed (by the lack of prey insects) due to the widespread use of synthetic pesticides to kill insect pests in agro-ecosystems (Bonte et al., 2000; Gibson et al., 1992; Warui et al., 2005). In recent times a reduction of spider population was occurred due to the decline of flying insect prey and this prey decline was resulted from the bottom-up trophic cascade (Nyffeler and Bonte, 2020). Damages to the local vegetation, particularly in natural grasslands, for grazing in an area, change the character of the population structure of spiders in that area (Bonte et al., 2000; Gibson et al., 1992; Warui et al., 2005). Due to increase of the invasive predators, the local spiders face stiff competition for food and self-defence, resulting in a decrease in the number of local spider populations (Hogg et al., 2011a and 2011b). Invasion of invasive plants in an area damages the diversity of local native plants and causes damage to the spider community (Schirmel and Buchholz, 2013). Some people's hobby is to bring wild animals into their home illegally as the pet and wildlife has to pay its price. Several species of spiders, especially Tarantula spiders, are victims of this illegal trade. As a result, spiders are collected from their local habitat, and wildlife is greatly lost (Fukushima et al., 2019; Gluszek et al., 2020; Kolby and thousand live bullfrogs from China, 2020).

1.6 Objectives, key research questions and hypothesis of the study

In view of all the issues mentioned above, this study was conducted with the following objectives –

1. To understand overall spider diversity in riparian areas of the Ganga river.
2. To compare spider diversity and richness in the different habitat of riparian zone of upper, middle and lower segments of the Ganga river.

3. To identify habitat specific / indicator spider taxa for riparian zone of the Ganga river.

The key research questions for the proposed study are —

1. What is the diversity of spiders in the riparian zones of the Ganga river?
2. Is there any significant difference present in diversity and assemblage of spiders between upper, middle and lower segments of the Ganga river?
3. Arc there any spider taxa specific to riparian habitat or can be used as indicator taxa for the assessment of the health of the riparian ecosystem of the Ganga river?

The central hypothesis for this study is "There is no significant difference present in diversity and assemblage of spiders in the riparian zones of the upper, middle and lower segments of the Ganga river."

CHAPTER 2

STUDY AREA AND SAMPLING METHODS

2.1 Description of the study area

2.1.1 Course of the Ganga river

At the confluence of the Alaknanda and Bhagirathi rivers at Devprayag, Uttarakhand the Ganga river begins. Although the Alaknanda is a longer river, the Bhagirathi river is thought to be the real source of the Ganga river. The Alaknanda originates from the foot of the Satopanth and Bhagirath Kharak glaciers in Uttarakhand, and in its course up to Devprayag, four tributaries namely, Dhauliganga, Nandakini, Pindar, and Mandakini join with her. The Bhagirathi river originates at the Gaumukh cave, Gangotri Glacier, Uttarakhand, and in its course up to Devprayag, seven tributaries namely Kedar Ganga, Jadh Ganga, Kakora Gad, Jalandhari Gad, Siyan Gad, Asi Ganga and Bhilangna River join with it. After flowing through the Himalaya, the Ganga falls into the Gangetic plain at Haridwar. From Haridwar, the Ganga flows towards the south-east direction through the states of Uttar Pradesh, Bihar, and Jharkhand. In its course, the Ramganga river, Gomti river, Ghaghara river, Gandak river, Koshi river and Fulhar river join from the North and Yamuna river, Tamasa (Tons) river and Sone river join from the South. At the border between Jharkhand and West Bengal, the Ganga swing around the Rajmahal hill range and enters West Bengal. At West Bengal, the Ganga river splits into two streams – the main stream flows towards East and enters Bangladesh and renamed as the Padma river and, another course flows towards South and renamed as the Bhagirathi/Hooghly river. At West Bengal, the Mayurakshi river, Ajay river and Rupnarayan river join from the West and Jalangi river and Churni river join from the East. Near Sagar Island, West Bengal, the Hooghly river falls into the Bay of Bengal. The total length of the Ganga river is about 2525 km.

2.2.2 Geology and hydrology

The Ganga River basin (GRB) spread over 1.086 ×106 km^2 area (Singh et al., 2007) which includes eleven states of India (Bihar, Chhattisgarh, Delhi, Haryana, Himachal Pradesh, Jharkhand, Madhya Pradesh, Rajasthan, Uttar Pradesh, Uttarakhand and West Bengal) of India (Rudra, 2018). The Ganga basin is the most populated river basin in the world, with a population of over 500 milion (Misra, 2011).

Based on the river morphology and characteristics of river channel, the Ganga river valley (GRV) is classified into seven segments, namely GRV-0 (between Gaumukh and Haridwar), GRV-I (between Haridwar and Garhmuktesar), GRV-II (between Garhmuktesar and Allahabad), GRV-III (between Allahabad and Buxar, GRV-IV (between Buxar and Barh, GRV-V (between Barh and Farraka) and GRV-VI (between Farraka and the Bay of Bengal) (Singh and Singh, 1992; Singh, 1996a,b, 2001). The annual hydrography of the Ganga river is characterised by very high flows during the monsoon season but low flows during the post-monsoon and pre-monsoon seasons (Singh et al., 2007). At Haridwar, annually 21,393×106 m^3 of water is discharged by the Ganga river, which is gradually increased towards downstream due to the contribution by its tributaries (Singh et al., 2007), which are classified into three types, namely Himalayan-source rivers (originating from the central Himalaya orogenic belt region, perennial in nature and have L-shaped longitudinal profiles with large discharge of sediments), Ganga alluvial plain-source rivers (originating from the interfluvial area of Himalayan rivers, have a smooth longitudinal profile and moderate sediment supply) and northern Indian craton-source rivers (perennial in nature and have smooth longitudinal profiles) (Singh, 1996a, 2004, Singh et al., 2007). The drainage network of the Ganga river basin discharges large amount of sediments (originated by erosion of the Himalaya orogenic belt, northern Indian craton regions, Himalayan foothills, and Ganga alluvial region) and water to the Ganga–Brahmaputra delta and the Bay of Bengal making the Bay of Bengal as one of the highest terrigenous input sites of the world (Singh et al., 2007). The largest Indian fluvial system is constituted by the Ganga river along with the tributaries and distributaries (Rudra, 2018).

Over the time, anthropogenic changes of land use land cover patterns, over-extraction of river water for industrial and agricultural purposes, construction of dams and barrages, over exploitation of ground water, and climate change cause changes in the hydrological cycle of the Ganga river both quantitatively and qualitatively (Misra, 2011).

2.1.3 Biodiversity

The Ganga river flows through six ecoregions, namely Himalayan subtropical pine forests (at Himalayan stretch), Terai-Duars savanna and grasslands (at the boundary between the Himalayas and the Indo-Gangetic plain), Upper Gangetic Plains moist deciduous forests (at the state of Uttar Pradesh and Bihar), Lower Gangetic plains moist deciduous forests (at the state of Bihar, Jharkhand and West Bengal), Sundarbans freshwater swamp forests (near the estuary at West Bengal) and Sundarbans Mangroves (near the estuary at West Bengal).

As the Ganga river flows through the vast variety of ecoregions, the river Ganga and its surrounding areas are rich in biodiversity. The Ganga river is home to about 200 fish species, 49 amphibian species, 13 turtle species, four species of Crocodylidae, 177 migratory and resident birds species, and four mammalian species (WII-GACMAC, 2018). Many of them are declared as threatened by IUCN. These includes Ganges shark (*Glyphis gangeticus*), Golden mahaseer (*Tor putitora*), Indian narrow-headed softshell turtle (*Chitra indica*), Indian peacock softshell turtle (*Nilssonia hurum*), Indian softshell turtle (*Nilssonia gangetica*), Indian spotted turtle (*Geoclemys hamiltonii*), Northern river terrapin (*Batagur baska*), Three-striped roofed turtle (*Batagur dhongoka*), Mugger crocodile (*Crocodylus palustris*), Gharial (*Gavialis gangeticus*), Black-bellied tern (*Sterna acuticauda*), Sarus crane (*Antigone antigone*), Greater adjutant (*Leptoptilos dubius*), Indian skimmer (*Rynchops albicollis*), Smooth-coated otter (*Lutrogale perspicillata*), Oriental small-clawed otter (*Aonyx cinerea*), and Ganges river dolphin (*Platanista gangetica gangetica*). On 5 October 2009 the Ganges river dolphin was declared as National Aquatic Animal by National Ganga River Basin Authority (NGRBA).

It has been observed that dolphin, birds and fishes have been able to draw more attention to the researchers for biodiversity study of the Ganga river and other animals could not gain more importance than that. In particular, the macro arthropods of the Ganga river have not gained much importance. Rao (2001) reported presence of five species of mayfly (Ephemeroptera), six species of dragonflies and damselflies

(Odonata), one species of aquatic beetles (Coleoptera), 22 species of aquatic bugs (Hemiptera), four species of Diptera, three species of stoneflies (Plecoptera) and six species of caddisflies (Trichoptera) betwwen Rishikesh and Kanpur. Nautiyal et al. (2014) reported presence of 11 families of diptera, three families of stoneflies (Plecoptera), five families of mayfly (Ephemeroptera), five families of aquatic bugs (Hemiptera), five families of dragonflies and damselflies (Odonata), seven families of aquatic beetles (Coleoptera) and seven families of caddisflies (Trichoptera) between Hardwar and Varanasi. De et al. (2019) reported presence of 37 species of odonates in the Ganga river. So far no work has been done to know the spider diversity of the Ganga river. So this is a large knowledge gap area where researchers should pay attention.

2.1.4 Protected areas

In the course of the Ganga river, one Biosphere Reserve, one National Park, one Ramsar site and three Wildlife Sanctuaries are located. The brief description of all these important areas are given below –

The Rajaji National Park: It is situated along the north-western extreme of the Terai-Arc Landscape (TAL) and was established in 1983 (Harihar et al., 2008). Total area of this national park is about 820 km^2 and it is very important protected area for the conservation of Asian elephant (*Elephas maximus*), Bengal tiger (*Panthera tigris tigris*), leopard (Panthera pardus), Himalayan black bear (*Ursus thibetanus laniger*) and sloth bear (*Melursus ursinus*).

Upper Ganga River Ramsar site: In the year 2005, the river stretch between Brijghat to Narora was designated as Ramsar wetland of international importance. This shallow river stretch provides important habitat for the Gangetic dolphin, gharial, crocodile, turtles, otters, several species of fishes and medicinal plants.

Hastinapur Wildlife Sanctuary: This sanctuary was established in the year 1986 to conserve the fast vanishing, unique Ganga River grassland-wetland complex (Khan and Abbasi, 2015). It is spared over 2073 km^2 are in five districts of Uttar Pradesh namely Muzzaffarnagar, Bijnor, Meerut, Ghaziabad and Jyotibafuley Nagar (Yadav et al., 2013). It is an important protected area for the conservation of the swamp deer (*Rucervus duvaucelii*), smooth-coated otter and gharial.

Kachhua Wildlife Sanctuary: In Uttar Pradesh, for the protection of turtles, the 7 km stretch of river between Rajghat and Ramnagar was designated as sanctuary area in the year 1989. It is situated just opposite to the Varanasi city.

Vikramshila Gangetic Dolphin Sanctuary: For the protection of the Gangetic dolphins, the 60 km river stretch between Munger to Kahalgaon was designated as a sanctuary in the year 1991.

Sundarban Biosphere Reserve: The Sundarban is the largest mangrove forest and delta region in the world extending over the southern region of West Bengal, India and the southern region of Bangladesh. UNESCO has declared this area as World Heritage Site list in 1987 and Biosphere Reserve in 1989. The part of the Sundarbans that is located in West Bengal, India, has one National Park (Sunderban National Park) and four Wildlife Sanctuaries (Haliday Island Wildlife Sanctuary, Lothian Island Wildlife Sanctuary, Sajnakhali Wildlife Sanctuary and West Sundarban Wildlife Sanctuary). This region has two ecoregions (Sundarbans freshwater swamp forests and Sundarbans mangroves).The Sundarban is important habitat for the Bengal tiger, fishing cat (*Prionailurus viverrinus*), jungle cat (*Felis chaus*), leopard cat (*Prionailurus bengalensis*) and many other animals and plants.

2.1.5 Brief description of the sampling sites

For the study the stretch of the Ganga river from Bijnour, Uttar Pradesh to Batanagar, West Bengal was selected which is about 1955 km long and passes through four states namely Uttar Pradesh, Bihar, Jharkhand and West Bengal. In this region the river flows through the alluvial Gngatic plain which is classified into upper, middle and lower plain (Srivastava et al., 1994; Thomas et al., 2002; Singh et al., 2006). In the Gangetic plain, the upper stretch of Ganga river starts from Haridwar, Uttarakhand and ends in Prayagraj (Allahabad), Uttar Pradesh; the middle stretch of the Ganga river starts downstream of Prayagraj (Allahabad) and ends at Jharkhand state and the lower stretch of Ganga river covers the state of West Bengal

(Chakraborti et al., 2003, 2009; Saha and Sahu, 2015). A total 27 sampling sites with an interval of every 75 km across the river were selected. Among these sites site 1 to site 10 fell between Haidwar and Prayagraj (in the upper zone of the Gangetic plain), sites 11 to site 21 fell between Prayagraj and Farakka, West Bengal (in the middle zone of the Gangetic plain) and site 22 to site 27 fell between Farakka and Batanagar, West Bengal (in the lower zone of the Gangetic plain).

The brief description of each of the 27 sampling sites following Ali et al. (2019) and field observation are given bellow –

Sampling site 1: This site (29°24'32.77"N, 78°3'21.61"E, 222 m msl) is located in the state of Uttar Pradesh. The left bank lie on the Bijnour district and the right bank lie in the Muzaffarnagar district. It is situated about 4 km upstream of Bijnor Barrage. It is located near the Hastinapur Wildlife Sanctuary. Mean depth of river is about 1.40 m and width of the river is about 6700 m. This site is comprised of a large wetland which is the habitat of wide variety of fishes, turtles, birds, amphibians, reptiles and invertebrates. Water temperature is worm and the river is characterised by muddy water with gentle flow. Riverine forest patches, scrubs, grassland and agriculture are the major land uses in this area.

Sampling site 2: This site (28°48'0.75"N, 78°8'44.13"E, 202 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Amroha district and the right bank lie in the Hapur district. It is situated near Garhmukteshwar and Tigrighat. The Upper Ganga river Ramsar site starts from here. Mean depth of river is about 3.20 m and width of the river is about 900 m. The river is characterised with muddy water, gentle flow and presence of multiple sandbars. Grasslands and agriculture are the major land uses in this area.

Sampling site 3: This site (28°13'11.05"N, 78°22'39.53"E, 182 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Badaun district and the right bank lie in the Bulandsahar district. It is situated about 4 km upstream of Bijnor Barrage. It is situated near Narora town and Narora Atomic Power Station. Mean depth of river is about 3.30 m and width of the river is about 850 m. The river is characterised by muddy water, gentle flow and presence of large sandbar. Grassland and agriculture are the major land uses in this area.

Sampling site 4: This site (27°50'45.21"N, 78°56'6.14"E, 163 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Badaun district and the right bank lie in the Kasganj district. It is situated near Kachla town. Mean depth of river is about 1.10 m and width of the river is about 800 m. The river is characterised by meanders with braided channels. Agriculture is the major land use of the site.

Sampling site 5: This site (27°31'5.62"N, 79°32'28.41"E, 145 m msl) is located in the state of Uttar Pradesh. Both of the left bank and right bank lie in the Farukkhabad district. Mean depth of river is about 1.40 m and width of the river is about 800 m. The river is characterised by meanders with braided channels. Agriculture is the major land use at this site.

Sampling site 6: This site **(**27°5'5.49"N, 79°56'55.40"E, 127 m msl) is located in the state of Uttar Pradesh, about 16 km downstream of Ramganga confluence. The left bank lie in the Hardoi district and the right bank lie in the Kannauj district. Mean depth of river is about 1.10 m and width of the river is about 750 m. The river is characterised by meanders with braided channels and sandbars. Agriculture is the major land use in the area.

Sampling site 7: This site (26°32'19.23"N, 80°18'15.82"E, 116 m msl) is located in the state of Uttar Pradesh. The Kanpur Barrage is located about 3 km downstream of this site. The left bank lie in the Unnao district and the right bank lie in the Kanpur Nagar district. Mean depth of river is about 2.50 m and width of the river is about 2000 m. The river is characterised by muddy water with gentle flow. Agriculture, industrial activities and human settlement are the major land uses at this site.

Sampling site 8: This site (26°3'43.10"N, 80°46'28.56"E, 106 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Rae Bareli district and the right bank lie in the Fatehpur district. Mean depth of river is about 1.90 m and width of the river is about 1800 m. The river is characterised by high turbidity with gentle flow and presence of multiple mid river islands. Agriculture and human settlement are the major land uses at this site.

Sampling site 9: This site (25°48'22.24"N, 81°19'50.89"E, 95 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Rae Bareli district and the right bank lie in the Fatehpur district. Mean depth of river is about 1.80 m and width of the river is about 1350 m. The river is characterised by high turbidity, meanders, gentle water flow and presence of several sandbars. Agriculture and human settlement are the major land uses at this site.

Sampling site 10: This site (25°30'44.24"N, 81°47'39.40"E, 85 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Prayagraj district and the right bank lie in the Kaushambi district. Mean depth of river is about 2.10 m and width of the river is about 4000 m. The river is characterised by high turbidity, gentle flow, presence of meanders and several sandbars. Agriculture and human settlement are the major land uses at this site. The confluence of the Ganga river and the Yamuna river is about 18.5 km downstream from this site.

Sampling site 11: This site (25°10'55.19"N, 82°12'21.43"E, 82 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Sant Ravidas Nagar district and the right bank lie in the Prayagraj district. Mean depth of river is about 9.50 m and width of the river is about 1250 m. The river is characterised by high turbidity, moderate flow and presence of meanders. Agriculture is the major land use around this area. The confluence of the Ganga river and the Tamas (Tons) river is about 28 km upstream from this site.

Sampling site 12: This site (25°13'57.80"N, 82°37'56.15"E, 72 m msl) is located in the state of Uttar Pradesh. The left bank lie in the Sant Ravidas Nagar district and the right bank lie in the Mirzapur district. Mean depth of river is about 5.90 m and width of the river is about 1250 m. The river is characterised by high turbidity, moderate flow with sand deposited areas. Agriculture is the major land use around this area.

Sampling site 13: This site (25°20'54.10"N, 83°10'16.91"E, 62 m msl) is located in the state of Uttar Pradesh, The confluence of the Gomti river and the Ganga river is located about 22 km downstream of this site. The left bank lie in the Varanasi district and the right bank lie in the Chandauli district. Mean depth of river is about 4.10 m and width of the river is about 2500 m. The river is characterised by high turbidity gentle flow and presence of sandbars. Agriculture and scrubland are the major land use around this area.

Sampling site 14: This site (25°27'15.80"N, 83°30'46.45"E, 62 m msl) is located in the state of Uttar Pradesh. Both of the left bank and right bank lie in the Ghazipur district. Mean depth of river is about 2.80 m and width of the river is about 1800 m. The river is characterised by high turbidity gentle flow and presence of sandbars. Agriculture is the major land use around this area.

Sampling site 15: This site (25°38'44.75"N, 84°4'49.54"E, 62 m msl) is located in the state of Uttar Pradesh and Bihar. The left bank lies in the Ballia district, Uttar Pradesh and the right bank lies in the Buxar district, Bihar. Mean depth of river is about 3.10 m and width of the river is about 5100 m. The river is characterised by high turbidity gentle flow and presence of islands and sand deposition at river banks. Agriculture is the major land use around this area.

Sampling site 16: This site (25°44'25.99"N, 84°37'44.21"E, 54 m msl) is located in the state of Bihar, at the Ganga and Ghaghara river confluence, and about 23 km upstream of the Sone confluence. The left bank lie in the Saran district and the right bank lie in the Bhojpur district. Mean depth of river is about 2.90 m and width of the river is about 2300 m. The river is characterised by high turbidity, gentle flow and presence of islands and sand deposition at river banks. Agriculture and human settlement are the major land use around this area.

Sampling site 17: This site (25°30'27.53"N, 85°20'10.68"E, 54 m msl) is located in the state of Bihar. The confluence of the Gandak river and the Ganga river is located about 19 km upstream of this site. The left bank lie in the Vaishali district and the right bank lie in the Patna district. Mean depth of river is about 3.20 m and width of the river is about 11000 m (including river islands). The river is characterised by high turbidity and presence of large mid river islands between braided channels. Agriculture and human settlement are the major land use around this area.

Sampling site 18: This site (25°22'16.84"N, 85°59'36.73"E, 55 m msl) is located in the state of Bihar. The left bank lie in the Begusarai district and the right bank lie in the Patna district. Mean depth of river is about 3.40 m and width of the river is about 1600 m. The river is characterised by high turbidity and low water flow. The agriculture is the major land use around this area

Sampling site 19: This site (25°19'24.58"N, 86°33'59.23"E, 40 m msl) is located in the state of Bihar. Both of the left bank and right bank lie in the Munger district. Mean depth of river is about 6.20 m and width of the river is about 2500 m. The river is characterised by high turbidity and moderate water flow. Agriculture is the main land use pattern around this area.

Sampling site 20: This site (25°'15'10.27"N, 87°12'41.46"E, 36 m msl) is located in the state of Bihar. Both of the left bank and right bank lie in the Bhagalpur district. Mean depth of river is about 3.30 m and width of the river is about 3700 m. The river is characterised by high turbidity and moderate water flow. Agriculture is the main land use pattern around this area. The confluence of the Koshi river and the Ganga river is located about 20 km downstream of this site.

Sampling site 21: This site (25°11'11.64"N, 87°45'35.03"E, 30 m msl) is located in the state of Bihar and Jharkhand. The left bank lies in the Katihar district, Bihar and the right bank lies in the Sahibganj district, Jharkhand. Mean depth of river is about 2.90 m and width of the river is about 10300 m including river islands. The river is characterised by high turbidity, moderate water flow and presence of large mid river islands between braided channels. Agriculture is the main land use pattern around this area. The confluence of the Fulhar river and the Ganga river is located about 18 km downstream of this site.

Sampling site 22: This site (24°26'41.98"N, 87°57'11.51"E, 24 m msl) is located in the state of West Bengal. Both of the left bank and right bank lie in the Murshidabad district. Mean depth is about 9.80 m and width of the canal is about 200 m. The river is characterised by high turbidity, moderate water flow. Agriculture is the main land use pattern around this area. This site is located at the feeder canal and about 23 km downstream of Farakka barrage.

Sampling site 23: This site (24°14'32.79"N, 88°14'55.02"E, 22 m msl) is located in the state of West Bengal. Both of the left bank and right bank lie in the Murshidabad district. Mean depth of river is about 6 m and width of the river is about 220 m. The river is characterised by high turbidity and moderate water flow. Agriculture and human settlements are the main land use patterns around this area. At this site, the Jiaganj town and the Ajimganj town are located on the left and right bank, respectively.

Sampling site 24: This site (23°44'14.26"N, 88°11'51.97"E, 16 m msl) is located in the state of West Bengal. The left bank lie in the Nadia district and the right bank lie in the Purba Bardhaman district. Mean depth of river is about 6.10 m and width of the river is about 360 m. The river is characterised by high turbidity and moderate water flow. Agriculture is the main land use patterns around this area. The confluence of Ganga river and Mayurakshi river is located 2.5 km downstream of this site and the confluence of Ganga river and Ajay river is located 14 km downstream of this site.

Sampling site 25: This site (23°26' 21.08"N, 88°22'33.25"E, 14 m msl) is located in the state of West Bengal. Both of the left bank and right bank lie in the Nadia district. Mean depth of river is about 6.80 m and width of the river is about 370 m. The river is characterised by high turbidity and moderate water flow. Agriculture, human settlement and riverine vegetation patches are the main land use patterns around this area. The confluence of Ganga river and Jalangi river is located 4 km downstream of this site.

Sampling site 26: This site (23°1'5.20"N, 88°26'49.72"E, 8 m msl) is located in the state of West Bengal. The left bank lie in the Nadia district and the right bank lie in the Hooghly district. Mean depth of river is about 10.10 m and width of the river is about 1150 m. The river is characterised by predominant tidal effects, high turbidity, moderate water flow and presence of mid river islands. Agriculture and human settlements are the main land use pattern in this area.

Sampling site 27: This site (22°30'56.68"N, 88°13'55.93"E, 4 m msl) is located in the state of West Bengal. The left bank lie in the South 24 Pargana district and the right bank lie in the Howrah district. Mean depth of river is about 12.50 m. and width of the river is about 880 m. The river is characterised by predominant tidal effects, high turbidity and moderate water flow. It is a part of Kolkata Port river transport route. The human settlements are the main land use patterns around this area. The port of Kolkata is located about 11 upstream of this site.

2.2 Spider collection and preservation

The samples were collected during summer (May and June) and winter (November and December) of 2018 and 2019. At each site, 50 m (width) × 100 m (length) plot along the river bank, either left or right bank, depending upon accessibility was chosen for sampling. Within each plot, 15 quadrates of 4 m × 4 m (5 across the length and 3 across the width and) were employed for spider collection. Within each quadrate, as spiders inhibit different stratum of vegetation and have different behaviours, different sampling methods produce a sampling bias across taxa (Uetz and Unzicker, 1976; Canard, 1982; Churchill, 1993; Edwards, 1993; Coddington et. al., 1996), the spiders were collected by six different methods namely aerial hand collection, cryptic searching, ground hand collection, pitfall trapping, sweep netting and vegetation beating (Sørensen et al., 2002) to avoid such bias. In each quadrate total 15 minutes were spent for performing each sampling method except for the pitfall trapping. Brief description of each method is given bellow –

Aerial hand collection: With this method, the spiders were collected from vegetation from level of the knee to the arm length level height. It is especially effective for web builder spiders and wandering spiders.

Cryptic Searching: In this method, the spiders living in the cryptic environment, holes in trees or fallen logs, bark crevices in tree brakes, under the stones and fallen logs were collected.

Ground hand collection: In this method, the spiders were hand-picked from the leaf litters, grounds and bellow knee level vegetation. This method is especially effective for ground dwelling and wandering spiders.

Pitfall trapping: Pitfall trap is a significant technique for spider collection (Churchill and Arthur, 1999). This method is effective for the ground dwelling spiders. For pitfall trapping, one plastic bottle of 10 cm depth and 9 cm diameter (Sørensen et al., 2002) filled with preservative (1% detergent, 30% ethyl acetate and 69% water) was placed at the centre of each quadrate for overnight.

Sweep netting: Sweep net is a significant technique for spider collection (Churchill and Arthur, 1999). In this method spiders are collected from low and medium height shrubs and vegetation. This method is affected by some factors such as type and age of the vegetation, weather condition, weight of the net, mess types and personal skill (Marshall et al., 2000). In this method a sweep net with 40 cm in ring diameter and 90 cm long handle was used to collected spiders from the plants (up to 2 m in height).

Vegetation beating: In this method, a white cloth (1 m × 1 m size) was put under the tree canopy and then the plants were grabbed and shaken and hit with sticks. As a result, the spiders living in those trees were falling off the white cloth were collected.

The collected spiders were preserved in 70% ethanol in plastic vial for identification in the laboratory using published literatures.

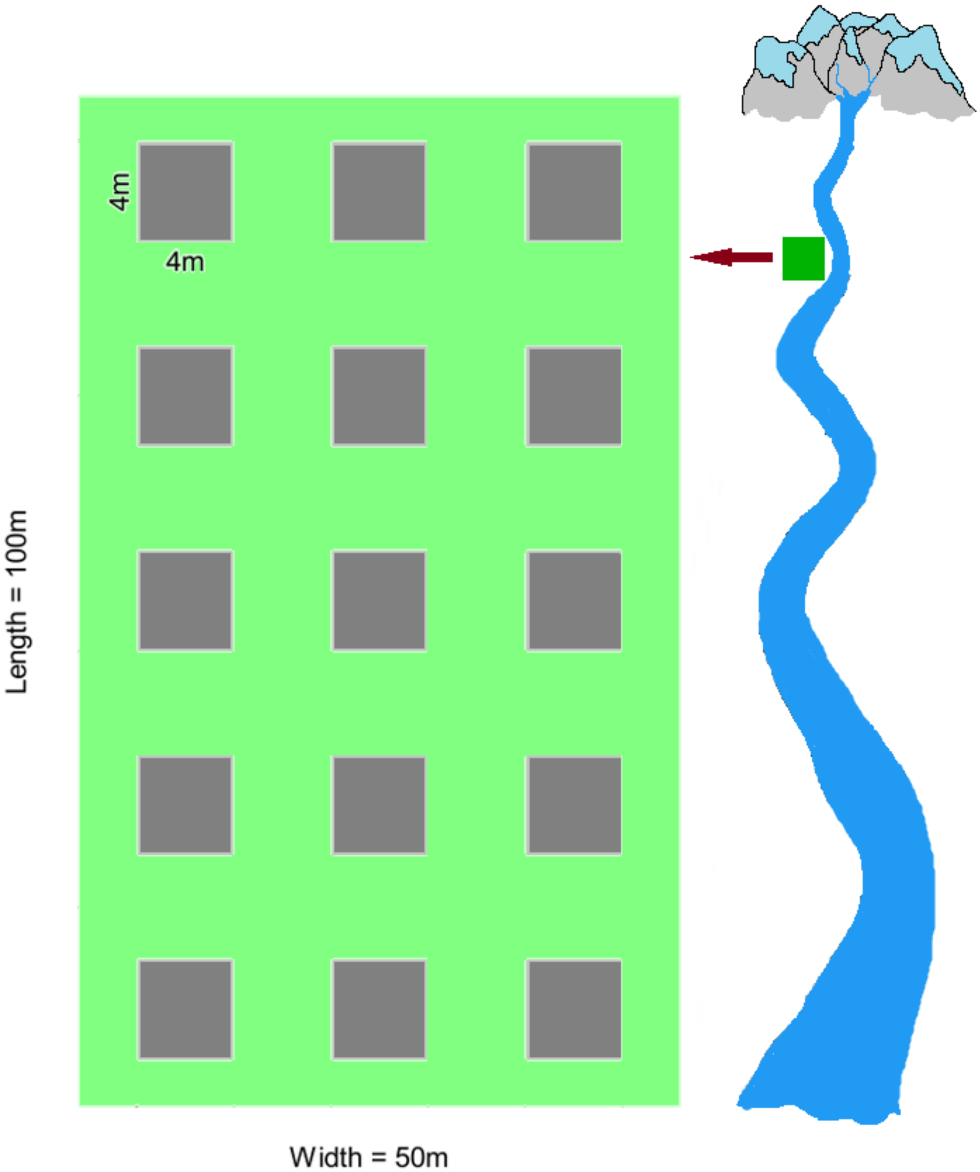
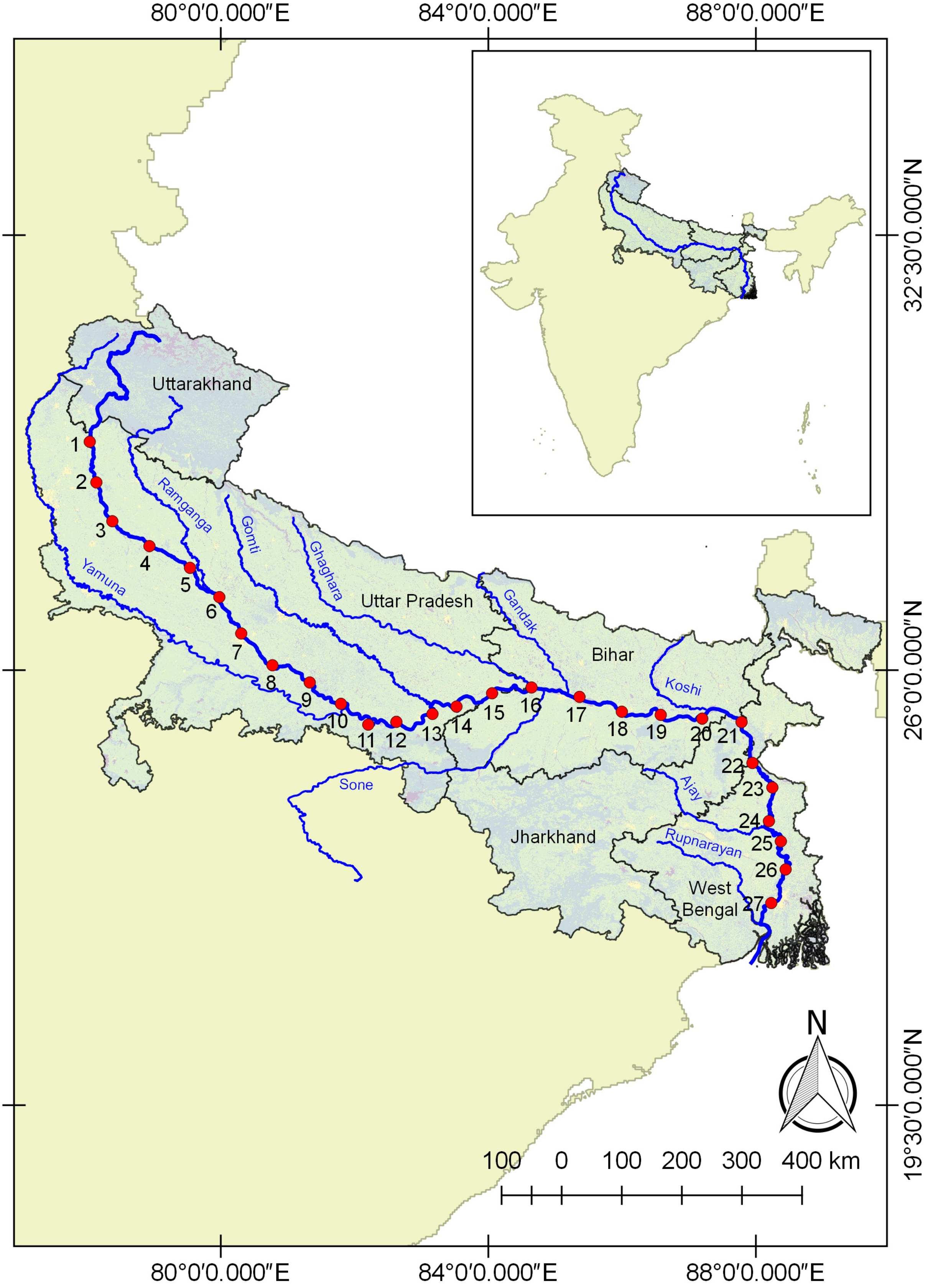


Figure 2.1: Schematic representation of quadrate sampling in river bank



Location of 27 study sites in the Ganga river

- Plate 1 -

Bijnour barrage

Narora barrage

Kanpur barrage

Farakka barrage

Clayey bank without vegetation

Eroded bank

Major barrages and various habitats in the Ganga river

- Plate 2 -

Ravine bank

Sandy bank

Sloppy bank

Meander with sand bar

River bank grassland

River bank vegetation dominated by *Polygonum* sp.

Various habitats in the Ganga river

- Plate 3 -

River bank vegetation dominated by *Saccharum* sp.

River bank vegetation dominated by *Typha* sp.

River feed wetland

Northern Indian craton basement rocks are exposed to form riverine hill

Various habitats in the Ganga river

- Plate 4 -

CHAPTER 3

FAUNISTIC INVENTORY OF SPIDERS

3.1 Introduction

The spiders, belong to the order Araneae and with 49116 species under 4206 genera and 128 families (World Spider Catalog, 2021) the order Araneae is the 6th largest order of Animals in terms of species richness only left behind Coleoptera, Lepidoptera, Diptera, Hymenoptera and Hemiptera (Zhang, 2011) and scientists estimated that total numbers of spider species on the Earth are likely roughly around 122000 (Agnarsson et al., 2013) so more than 70000 species are still to be discovered. Within the order Araneae, the family Salticidae (659 genera, 6329 species), family Linyphiidae (620 genera, 4672 species) and family Araneidae (177 genera, 3059 species) occupy first, second and third positions respectively, in terms of species richness (W.S.C., 2021).

Over time, the list of spider species that Indian scientists have been publishing shows a steady increase in the number of species. In 1987, Tikader listed 1067 species; in 2005, Siliwal et al. listed 1442 species; in 2007, Siliwal and Molur listed 1447 species; in 2009, Sebastian and Peter listed 1520 species and in 2012, Keswani et al. listed 1686 species of spiders from India. At present, 1855 species of spiders under 477 genera in 61 families are reported so far from India (Caleb and Sankaran, 2021). The highest number of species reported among these families is from the family Salticidae (275 species, 99 genera), then from the family Araneidae (185 species, 37 genera), and then from the family Thomisidae (179 species, 40 genera) (Caleb and Sankaran, 2021). There is no doubt that this number will continue to grow in the coming days.

3.2 Studies on spider taxonomy in India

The study of Arachnology in India began in the second half of the nineteenth century by the help of European scientists. During that time Blackwall (1864, 1867), Stolickza, 1869, Thorell (1877), Simon (1887, 1888, 1897) and Pickard-Cambridge

(1892, 1897) described different species of spiders from India and neighbouring countries. The lynx spider *Oxyopes lepidus* (Blackwall, 1864) (Family Oxyopidae) was the first spider species described from India by Blackwall (1864). At the starting of the twentieth century Pocock (1900a, 1900b, 1900c, 1901), Gravely (1915, 1921a, 1921b, 1922, 1931, 1935a, 1935b), Sheriffs (1919, 1927, 1928, 1929, 1931) and Reimoser (1934) did significant work in the field of Indian arachnology. Pocock (1900a) was the first to make a comprehensive list of spiders of India, Sri Lanka and Myanmar. Although the Indians were not particularly involved in arachnological study at that time, but the work by Narayan (1915) and Dayal (1935) can be specifically mentioned. Narayan (1915) provided taxonomic information on ant mimicking spiders under family Salticidae. From Lahor, Pakistan (then undivided India) Dyal (1935) described 45 new species and provided taxonomic information on 76 species. From the second half of the twentieth century, Indian scientists started working on spiders in the real sense. B. K. Tikader was the first Indian scientist to popularize research on spiders in India. Through his publications (Tikader, 1980; Tikader and Malhotra, 1980; Tikader, 1982a,b; Sethi and Tikader, 1988; Majumder and Tikader, 1991) he provided valuable taxonomic information about Araneidae, Clubionidae (now included in several other families as well as Clubionidae), Gnaphosidae, Heteropodidae (now Sparassidae), Lycosidae and Thomisidae family. In fact, the taxonomic keys provided in these publications are still used by arachnologists to identify Indian spiders. He also provided information on the spiders of Khasi and Jaintia Hills of North East India (Tikader, 1966 and 1968), Sikkim (1970) and Andaman and Nicobar Islands (Tikader, 1977) for the first time. The first comprehensive list of the spiders of India with 1067 species, 149 genera and 43 families was published by Tikader (1987). After Tikader, works by Gajbe (1983 - 1999) were important. He provided taxonomic information about spiders of central India (Madhya Pradesh and Chattishgarh).

Among the scientists currently studying, the names of Raychaudhuri (1995 - present), Saha (1995 - present), Sebastian (2001 - present), Sunil Jose (2001 - present), Sliwal (2005 - present), Dhali (2010 - present), Sen (2010 - present), Quasin (2012 - present), Uniyal (2012 - present), Caleb (2013 - present) and Das (2013 - present) are particularly noteworthy. Raychaudhuri, Saha, Dhali and Sen discussed in detail about the spiders of West Bengal, especially the Tarai Dooars region of North Bengal, and discovered several new species. Sebastian, Sunil Jose and Caleb shed light on the spiders of South India, especially the Western Ghats biodiversity hotspot. In 2009, Sebastian published his book, '*Spider of India*', where checklist of the 1,520 spiders was provided with morphological and ecological description of several common spiders of India. Sliwal had studied spider taxonomy in various parts of India, including western India, north-eastern India and the Himalayas and described several new species. In particular, her works on Mygalomorphae spiders make significant claims. Quasin and Uniyal shed light on Himalayan high altitude spiders and discover new species of spiders. Das has done significant research on spiders in different parts of India, particularly the Eastern Ghat hills of Odisha.

3.3 Phylogeny of spiders

The evolutionary variation of spiders, in contrast to order of insects, is not related to the food habits of spiders because all species of spiders are predatory (Blackledge et al., 2009) but relationships among major spider lineages remain mystery (Bond et al, 2014).

The spiders belong to the order Araneae under class Arachnida under phylum Arthropoda. Beside the the order Araneae, the class Arachnida includes 11 other orders namely Acari (mites and ticks), Amblypygi (whip spiders and tailless whip scorpions), Opiliones (harvestmen), Palpigradi (micro whip scorpions), Pseudoscorpiones (false scorpions), Ricinulei (hooded tickspiders), Schizomida (shorttailed whipscorpions), Scorpiones (true scorpions), Solifugae (camel spiders), Thelyphonida (whip scorpions) and Xiphosura (horseshoe crabs). Based on morphology, Shultz (1990) proposed that Order Araneae is closely related to Amblypygi, Schizomida and Thelyphonida.

At present, the order Araneae is classified into two suborders namely the Mesothelae and Opisthothelae, and the suborder Opisthothelae is classified into two infraorders namely Mygalomorphae and Araneomorphae (Dunlop et al., 2011; Bond et al, 2014).

The suborder Mesothelae is considered as most primitive and sister spider group and characterized by the presence of tergites (segments) on the abdominal ventral side and seven or eight spinnerets just behind the epigastric furrow (Jocqué et al., 2006). The suborder Mesothelae consists of single extant family Liphistiidae which includes 8 genera and 138 species (Dunlop et al., 2011; W.S.C., 2021).

The infraorder Mygalomorphae has characteristic two pairs of book lungs and paraxial chelicera (i.e. the chelicerae are projecting forward horizontally and the fang which is attached with the chelicerae can move parallel to the median plane of the body) (Tikader, 1982a). They are considered as primitive spiders. The infraorder Mygalomorphae consists of 15 families namely Actinopodidae (3 genera, 73 species), Antrodiaetidae (4 genera, 37 species), Atypidae (3 genera, 54 species), Barychelidae (42 genera, 294 species), Ctenizidae (2 genera, 5 species), Cyrtaucheniidae (8 genera, 107 species), Dipluridae (8 genera, 93 species), Hexathelidae (7 genera, 45 species), Idiopidae (22 genera, 407 species), Mecicobothriidae (1 genus, 2species), Microstigmatidae (12 genera, 41 species, Migidae (11 genera, 102 species), Nemesiidae (22 genera, 194 species), Paratropididae (5 genera, 17 species), and Theraphosidae (147 genera, 985 species) (Dunlop et al., 2011; W.S.C., 2021).

The infraorder Araneomorphae has characteristic one pair book lungs and diaxial chelicerae (i.e. the chelicerae are projecting downward and the fang articulated with chelicerae move to the transverse plane of the body) (Tikader, 1982a). They are considered as the modern spiders. This infraorder includes 112 families (W.S.C, 2020).

Based on the presence of the cribellum (flat plate like structure that bears numerous densely packed spigots that produce silk) infraorder Araneomorphae can be classified into two groups - cribellate and ecribellate (Coddington and Levi, 1991).

3.4 General morphological description of spiders

The body of spider is made up of two parts, the prosoma or cephalothorax (anterior part) and the opisthosoma or abdomen (posterior part), and these two parts are connected to each other by a narrow structure called the pedicel.

The dorsal portion of the cephalothorax is covered by a hard sclerotised shield called ‘carapace’ and the ventral portion of the cephalothorax is covered by another hard sclerotised shield called ‘sternum’. The carapace consists of two regions namely 'cephalic region' and 'thoracic region' and in the middle of these two regions, narrow grooves present called 'cervical furrows'. At the thoracic region a narrow groove is present which is called the ‘thoracic groove’ or ‘fovea’ and some striae radiate from this groove, which are called ‘thoracic radii’. The sternum is located in the ventral side of the cephalothorax. Generally it is heart shaped and posterior portion is narrow.

At the apex of the anterior region there are 6 to 8 simple eyes present and the shapes, sizes and arrangements of these eyes varies in different families, genera and species. These eyes are generally of two types, ‘white eyes’ and ‘black eyes’. The white eyes are called ‘nocturnal eyes’ and the black eyes are called ‘diurnal eyes’. It is called 'homogeneous' when it has one type of eyes and it is called 'heterogeneous' when it has both types of eyes. Generally the eyes are arranged in the 2 rows - anterior row and posterior row. The ‘anteromedian eyes’ and ‘anterolateral eyes’ are arranged on the anterior row and the ‘posteromedian eyes’ and ‘posterolateral eyes’ are arranged on the posterior row. These eye rows may be straight or curved. When these are curved, they are of two types namely ‘procurved’ (median eyes are further backward than the laterals) and ‘recurved’ (the median eyes are further forward than the laterals). The area which is occupied by the eyes is called ‘ocular region’ and the area which is margined by the 4 median eyes is called ‘ocular quad’. The region between the anterior edge of carapace and the anterior eyes is called ‘clypeus’.

Six pairs of appendages are attached with the cephalothoraxes which are a pair of ‘chelicerae’, a pair of ‘pedipalp’ and 4 pairs of ‘legs’.

The chelicerae are the first pair of appendages. They are attached just beneath the anterior margin of the carapace. Each chelicera has a large basal part and a curved 'fang' at apex. The inner surface of chelicera has a groove equipped with rows of teeth, into which the fang can be closed when not in use. The outer margin of this groove is called ‘promargin’ while the inner margin is called ‘retromargin’. Sometimes the promargin contains stout hairs to make a structure called ‘scopulae’.

Pedipalp is the second pair of appendages and it consists of 6 segments - coxa, trochanter, femur, patella, tibia, and tarsus. The coxa of pedipalp enlarged into a plate like structure called maxilla. In female, the tarsus is simple in structure and may be provided with a claw. In mature male, the tarsus of pedipalp is modified to the copulatory organ.

The spiders have four pair of legs which are numbered as I, II, III and IV from the front. Each leg consists of 6 parts - coxa, trochanter, femur, patella, tibia, metatarsus and tarsus. The legs may be ‘prograde’ (anterior 2 pairs of legs are positioned forward and the posterior 2 pairs are positioned backward) or ‘laterigrade’ (anterior 2 pairs of legs are directed more or less laterally). The distal end of tarsus is provided with 2 or 3 claws. The legs are covered by hairs. In some cases the legs bear very fine and smooth micro hairs called ‘trichobothria’ and spines.

The abdomen or ophisthosoma is the second body part. The dorsal side of the abdomen is variable in shape, colour, decoration and hairs in different species. At the abdominal ventral surface, 1 or 2 pairs of 'book lungs' present which are opened to the exterior by one or two pairs of 'spiracles' (opening of the book lung). The female genital organ is called 'epigyne' which is located at the abdominal ventral surface, anterior to a transverse fold called 'epigastric furrow'. At the posterior end of the abdomen, one pair 'anal tubercle' present. Bellow the anal tubercles, three pairs of spinnerets are present - anterior, median and posterior spinnerets. In some species, a flat plate like structure called 'cribellum' present that bears numerous densely packed spigots that produce silk. The spiders which do not have cribellum, a small tubercle called 'colulus' present at the base of anterior spinnerets.

3.5 Inventory of spiders from Gangetic riparian zones

In this study 79 species belonging to 50 genus and 18 families were found from the study area. The list of species recorded form the study area is given in the appendix 1. Keys to the families and genera of spiders recorded form the study area is given in the appendix 1. Distribution of the recorded spider species in 27 sites is given in the appendix 3. The general and taxonomic description about the families and genera of spiders recorded are described below. These description and details follow available published literatures (Agnarsson, 2004; Barrion and Litsinger, 1995; Biswas, 1984; Dhali et al., 2017; Jastrzębski, 1997; Malamel et al., 2015; Patel and Patel, 1972; Platnick et al., 2011; Prószyński, 2017; Rajoria, 2016; Ranasinghe and Benjamin, 2016; Roy et al., 2016; Roy et al., 2017; Sen et al., 2015; Sethi and Tikader, 1988; Sunil Jose, 2011; Sunil Jose et al., 2007; Tanikawa and Yamasaki, 2019; Tikader and Biswas, 1981; Tikader and Malhotra, 1980; Tikader and Patel, 1975; Tikader, 1960, 1962, 1973, 1977, 1980, 1982a, 1982b; Uniyal and Hore, 2009; Uniyal et al., 2011; and Zhu 1998) and field observations.

Family 1: Agelenidae C. L. Koch, 1837

This family is very common in grassland and low height vegetation lands. They build characteristic non adhesive funnel webs made up of flat, slightly concave silk sheet with a funnel shape retreat at one end close to the soil surface on grass or shrub or under logs. Body colours usually grey to brown and the abdomen is decorated with reddish brown folium and a series of spots or bands of yellow to white colour. Eight eyes are equal in size and arranged in two rows (4:4) Prosoma is oval, attenuated in front, narrow and long in the eye region. Opisthosoma is oval, narrow and tapering in posterior part. Sternum is heart shaped and wide. Legs are long, slender and with three claws. Spines are present in the legs. Anterior spinnerets are separated widely; posterior spinnerets are two segmented, long and slender with apical segment narrowing towards tip. So far 1342 species under 90 genera are reported worldwide (W.S.C., 2021) and 12 species under 4 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Agelena* Walckenaer, 1805 was found from the study area.

***Agelena* Walckenaer, 1805** They are commonly called the 'Funnel web weavers' as they build large, sheet-like web with a funnel like retreat in the vegetation close to the ground. They are characterized by the presence of long and narrow abdomen; clearly separated anterior spinnerets and much longer posterior spinnerets. Several clearly marked chevrons are present on the dorsal surface of the abdomen. Only one species *Agelena* sp. was found from the study area.

Family 2: Araneidae Clerck, 1757

This is a very common spider family. They make circular wheel shaped web (orb web) to capture prey. Body colour varies. The nocturnal species are greyish brown to dark brown in colour but diurnal species are usually brightly colourful. Eight eyes are arranged in two rows (4:4). Lateral eyes are widely seperated from median eyes. Prosoma often flat to swollen, the cephalic region separated from the thoracic region by oblique depression. Shape of the ophisthosoma varies species to species. Generally it is globose and overhanging carapace. Sternum is heart shaped or triangular. Legs are relatively stout, spined and with three claws. The third leg is always shorter than the others. Six spinnerets are sub-equal, simple, and short, form a compact cluster. Spinnerets have aggregate glands spigots which produce viscid silk. So far 3059 species under 177 genera are reported worldwide (W.S.C., 2021) and 185 species under 37 genera are reported from India (Caleb and Sankaran, 2021). A total of 12 genera were found from the study area. These are *Acusilas* Simon, 1895; *Anepsion* Strand, 1929; *Araneus* Clerck, 1757; *Argiope* Audouin, 1826; *Cyclosa* Menge, 1866; *Cyrtophora* Simon, 1864; *Eriovixia* Archer, 1951; *Gasteracantha* Sundevall, 1833; *Larinia* Simon, 1874; *Neoscona* Simon, 1864; *Nephila* Leach, 1815 and *Thelacantha* Hasselt, 1882

***Acusilas* Simon, 1895** They make medium sized orb web and placed a curled leaf at the hub of the web. The spider shelters inside this curled leaf. They are diurnal hunters. Only one species *Acusilas* sp. was found from the study area.

***Anepsion* Strand, 1929** They are medium sized spiders and build vertical orb webs in the bushes and grasses. They are characterized by presence of a pair of dorsal bulging on the abdomen. Only one species *Anepsion* sp. was found from the study area.

***Araneus* Clerck, 1757** They build small to median sized orb webs. During day time, they rest inside the silken nest constructed with leaves in the corner of the web. At this position, they contact tip of their front legs with a signal thread which is connected to the hub of the web. Only one species *Araneus mitificus* (Simon, 1886) was found from the study area.

***Argiope* Audouin, 1826** They are commonly called the ‘cross spider’. They are commonly recognized by the large size and brightly coloured and decorated abdomen of the female. They build medium to large sized vertical orb webs and rest at the hub of the web. They are diurnal hunters. They decorate their webs by a zigzag stabilimentum or two crossing stabilimenta by silk bands. Two species were found from the study area. These are *Argiope aemula* (Walckenaer, 1841) and *Argiope pulchella* Thorell, 1881

***Cyclosa* Menge, 1866** They are commonly called the 'trashline orbweavers' or 'garbage line spiders'. They build medium sized orb webs. They decorate their web by linear stabilimentum which is filled with prey remains and other debris, where they hide. Total seven species were found from the study area. These are *Cyclosa bifida* (Doleschall, 1859); *Cyclosa confraga* (Thorell, 1892); *Cyclosa hexatuberculata* Tikader, 1982; *Cyclosa insulana* (Costa, 1834); *Cyclosa simoni* Tikader, 1982; *Cyclosa spirifera* Simon, 1889 and *Cyclosa* sp.

***Cyrtophora* Simon, 1864** They are commonly called the 'tent web spiders' because of their characteristic webs. They do not build typical orb webs, instead, they build a tent like web which is horizontally aligned and supported by a complex network of threads. Often, they live in colonies. Some species has the ability to change the body colour rapidly. Only one species *Cyrtophora cicatrosa* (Stoliczka, 1869) was found from the study area.

***Eriovixia* Archer, 1951** They are commonly called 'bird dropping spiders'. They are characterized by the presence of a tail like extension from the end of the abdomen. They build small to medium sized orb webs. In most of the time, they are seen in the resting position on the upper side of leaf, pulling the legs arround the carapace and abdomen, forming a circular structure. Only one species *Eriovixia laglaizei* (Simon, 1877) was found from the study area.

***Gasteracantha* Sundevall, 1833** They build small to medium vertical orb webs. During resting position at the hub of the web, only abdomen and thoracic portion of cephalothorax is visible. They are closely related to the genus *Thelacantha* but differ visually by absence of two large white spots on the upper surface of the abdomen and presence of larger abdominal spines, particularly the longer lateral spines. Only two species were found from the study area. These are *Gasteracantha geminata* (Fabricius, 1798) and *Gasteracantha hasselti* C. L. Koch, 1837

***Larinia* Simon, 1874** They build small to medium orb webs. They are nocturnal hunters. During night, they sit at the hub of the web and wait for the prey, but during day time, they rest in the vegetation. Only one species *Larinia* sp. was found from the study area.

***Neoscona* Simon, 1864** They are closely related to the genus *Araneus* but distinguished by the presence of longitudinal thoracic groove. They are nocturnal hunters. They make medium sized orbs at sunset, sit in the web all night for prey capture, and roll up the web in the morning. In the morning, they hide in the bushes mainly in the retreat made of leaves. Different morphological variations are seen in the same species. Total seven species were found from the study area. These are *Neoscona mukerjei* Tikader, 1980; *Neoscona nautica* (L. Koch, 1875); *Neoscona subfusca* (C. L. Koch, 1837); *Neoscona theisi* (Walckenaer, 1841); *Neoscona vigilans* (Blackwall, 1865); *Neoscona* sp.1 and *Neoscona* sp.2.

***Nephila* Leach, 1815** They are commonly called the ‘giant wood spiders’. They are very common spiders. The notable feature is that they make extremely large sized orb webs. The size of female is much larger than the male. Some kleptoparasitic spiders such as *Argyrodes* (family Theridiidae) are often seen living in their webs. Only one species *Nephila pilipes* (Fabricius, 1793) was found from the study area.

***Thelacantha* Hasselt, 1882** They build small to medium vertical orb webs. During resting position at the hub of the web, only abdomen and thoracic portion of cephalothorax is visible.They are closely related to the genus *Gasteracantha* but differ visually by presence of two large white spots on the upper surface of the abdomen and presence of smaller abdominal spines. Only one species *Thelacantha brevispina* (Doleschall, 1857) was found from the study area.

Family 3: Corinnidae Karsch, 1880

Members of this family are living ground dwellers. They live under rocks, in woody debris, litter, humus or on foliage. Some species mimic ants. Some species are dark to metallic and some species are dark to yellowish brown in colour. Eight eyes are present. Prosoma is generally oval in shape, but in ant mimicking species it become elongated and sometimes sclerotized heavily. Ophisthosoma is generally oval in shape, but in ant mimicking species it become elongated. Sometimes scuta or transverse hands or patches of white setae present. The sternum is oval in shape and has distinct margin. In legs, two claws are present in tarsi. In ant mimicking species the legs are slender and long. Sclerotized, triangular colulus present. The anterior spinnerets are contiguous and sturdy, posterior spinnerets are slightly apart than anterior pair. So far 795 species under 70 genera are reported worldwide (W.S.C., 2021) and 17 species under 7 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Castianeira* Keyserling, 1879 was found from the study area.

***Castianeira* Keyserling, 1879** They are commonly called the 'ant mimicking spiders' as exhibit Batesian mimicry by mimicking ants. The identifying features for this genus are - cephalothorax oval, longer than wide and narrow in the front; eyes round and white, anterior row of eyes slightly recurved, posterior row of eyes procurved; promargin of cheliceraewith 2 teeth; legs long, slender, tibia I and II with 2 or 3 pairs of ventral spines, trochanter IV ventrally notched; abdomen longer than wide, narrowing in front, clothed with pubescence; epigynum with convex sclerotised plate, copulatory opening distinct, well separated. Only one species *Castianeira* sp. was found from the study area.

Family 4: Gnaphosidae Pocock, 1898

These are nocturnal hunters and ground dwellers, but some species live on plants. During daytime they rest under the stone or loose bark, often in a silken retreat. Some species exclusively feeds on ants. They capture prey by tactile or chemotactic stimuli because of having poor eyesight. Body is usually uniformly black in colour, but some are brown and some have markings. Small, eight eyes are arranged in two rows (4:4). Anterior eyes round, posterior median eyes irregualr or flattened in shape. Except for the anterior median eyes, silvery soft lustres present on a surface of the eyes. Prosoma is pear shaped to oval, at side smoothly convex, fovea is distinct. Opisthosoma is elongated and cylindrical. Dorsal scutum present in the ophisthosoma of adult males. Sternum is flat, oval and anterior is pointed. Legs are prograde, short, stout and usually with two claws with claw tufts. Anterior lateral spinnerets are well separated, large, parallel and cylindrical. So far 2549 species under 162 genera are reported worldwide (W.S.C., 2021) and 154 species under 31 genera are reported from India (Caleb and Sankaran, 2021). Two genera were found from the study area. These are *Prodidomus* Hentz, 1847 and *Zelotes* Gistel, 1848

***Prodidomus* Hentz, 1847** Earlier this genus was placed in a separate family Prodidomidae but later studies found that it belongs to the family Gnaphosidae. Their body is covered with squamiform hairs, fovea absent in the carapace and the anterior spinnerets close to each other. Only one species *Prodidomus* sp. was found from the study area.

***Zelotes* Gistel, 1848** They are nocturnal hunters and generally live in association with ants in leaf litter, near water bodies, under stones and grasses. Their body is not covered with squamiform hair and fovea present in the carapace. Only one species *Zelotes* sp. was found from the study area.

Family 5: Hersiliidae Thorell, 1870

They are commonly called the ‘tree trunk spider’. They produce very thin sensing web around the tree trunk, old walls or under stones. Their body colour varies widely within species from blackish brown to pale white but in most cases body colour is consistent with the surrounding environment. They have eight eyes which are arranged in two recurved rows. Generally, anterior median eyes are larger than the posterior median eyes. Prosoma is oval and flat, fovea narrow and longitudinal, covered with dense plumose setae. Opisthosoma is flat and densely covered with plumose setae. Sternum is heart shaped. Legs are prograde, very long and slender, legs III shortest, tarsi three clawed. Spinnerets are cylindrical and tapering distally. Posterior spinnerets are very long (as long as abdomen). The inner surface of the spinnererts is with a series of long tubules providing thin silk threads. Colulus present. So far 182 species under 16 genera are reported worldwide (W.S.C., 2021) and 12 species under 3 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Hersilia* Audouin, 1826 was found from the study area.

***Hersilia* Audouin, 1826** They are found on the tree bark where they camouflage with the background. Their head is fiat and angular laterally; ocular quadrangle parallel sided; clypeus high and prominent; protarsi of leg I, II and IV are bi-segmented. Only one species *Hersilia savignyi* Lucas, 1836 was found from the study area.

Family 6: Lycosidae Sundevall, 1833

They are ground dwelling spiders, commonly called wolf spiders. The female carries the egg sac along with them attached to the spinnerets and the and newly hatched young spiders on the dorsal side of ophisthosoma. Body colour varies widely within species from yellowish brown to grey or black but in most cases body colour is consistent with the surrounding environment. Eight eyes are dark and arranged in three rows (4:2:2) Eyes are unequal in size; eyes of the anterior eyes are smaller than the other eyes. Prosoma is longer than wide. In cephalic region prosoma is narrow and high. Fovea is elongated. Carapace is covered with dense setae. Ophisthosoma is oval in shape and covered by dense setae. Sternum is oval or scutiform. Legs are long, strong and stout, spines and scopula usually present, tarsi bearing 3 claws. Six spinnerets are present. The colulus is absent. So far 2425 species under 124 genera are reported worldwide (W.S.C., 2021) and 130 species under 19 genera are reported from India (Caleb and Sankaran, 2021). Two genera were found from the study area. These are *Hippasa* Simon, 1885 and *Lycosa* Latreille, 1804.

***Hippasa* Simon, 1885** They differ from other genera of wolf spiders in the structure of the spinnerets as the posterior spinnerets are distinctly longer than the anterior, with apical segment conical and as long as the basal. They are commonly found in the slopes, vegetation of sandy river bank. They generally make sheet like webs with funnel retreat like family Agelenidae. Only one species *Hippasa lycosina* Pocock, 1900 was found from the study area.

***Lycosa* Latreille, 1804** They are commnly known as the 'burrowing wolf spiders'. They build open, vertical burrows, preferably in the open areas. The female carries the cocoon by attaching with the spinnerets. The female carry the newly hatched young ones on the back. Their third pair of legs are shorter than the first pair. Only two species *Lycosa* sp.1 *and Lycosa* sp.2 were found from the study area.

Family 7: Oonopidae Simon, 1890

They are very small in size and commonly called the ‘goblin spiders’ and found in the leaf litter. Body is often brightly coloured, orange, yellow, pink, reddish-brown or greenish. Six eyes present. Eyes are close together and median eyes are large. Some species, particularly the species which inhabit termite nest do not have eyes. The prosoma is convex to flat, fovea absent, anterior part is narrow. Ophisthosoma is oval in shape, either enclosed in shield or soft bodied. Sternum is oval, broad and apex is blunt. Legs are short and strong. Tarsi are provided with two biserially dentate claws. Length of anterior and posterior spinnerets is same. So far 1872 species under 114 genera are reported worldwide (W.S.C., 2021) and 46 species under 13 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Brignolia* Dumitrescu and Georgescu, 1983 was found from the study area.

***Brignolia* Dumitrescu and Georgescu, 1983** They are free free hunting spiders live in the leaf litter or the canopy. They are characterized by the presence of spineless legs and having large dorsal scutum that covers the abdomen. Only one species *Brignolia* sp. was found from the study area.

Family 8: Oxyopidae Thorell, 1870

They are commonly called the 'lynx spiders'. They are free living spiders hunting for prey on the leaf and branches of plants. Body colour is variable, from green to yellow to brown. Body size is small to medium. Eight eyes are arranged in a hexagonal structure. Clypeus is high and with stripes and spots. The prosoma is longer than wide, convex and high at the anterior portion. The ophisthosoma is slender and pointed at the posterior end. The sternum is scutiform. Legs bear numerous long spines on tibiae and metatarsi. Spinnerets are not modified and median spinnerets are smaller. The colulus is present. So far 438 species under 9 genera are reported worldwide (W.S.C., 2021) and 83 species under 4 genera are reported from India (Caleb and Sankaran, 2021). Three genera were found from the study area. These are *Hamataliwa* Keyserling, 1887; *Oxyopes* Latreille, 1804 and *Peucetia* Thorell, 1869

***Hamataliwa* Keyserling, 1887** They are medium sized spiders found searching for prey on the leafs and branches of the tree. Characteristic features are Carapace rectangular, front face shorter than rear, nearly parallel sided; front face narrower, rear face receding; clypeus vertical; anterior median eyes closed, separated by less than their diameter; abdomen at most 1/5th longer than carapace and rarely with geometric colour patterns. Only one species *Hamataliwa incompta* (Thorell, 1895) was found from the study area.

***Oxyopes* Latreille, 1804** They are diurnal hunters. They are very fast and active. They search for prey in the grasses and weeds. Their body colour varies from yellow-green to dull brown. The female lay eggs on grass stalks or under curled leaves and guard it until the young emerge. Three species were from the study area. These were *Oxyopes* sp.1, *Oxyopes* sp.2 and *Oxyopes* sp.3.

***Peucetia* Thorell, 1869** They are the green lynx spiders. They are diurnal hunters. They are very fast and active. They search for prey in the grasses and plant leaves. The cephalothorax and abdomen has white and brown decoration. Only one species *Peucetia viridana* (Stoliczka, 1869) was found from the study area.

Family 9: Philodromidae Thorell, 1870

They are commonly called the ‘running crab spiders’. They are very active and catch their prey very rapidity. Generally they live on the plants. Body colour is variable, from greyish brown to reddish brown to white to pale cream. Eight equal sized eyes are arranged in two rows (4:4). Shape of the prosoma is variable, from elongated to as long as wide. Generally, fovea is not present. The prosoma is covered by soft setae. Shape of the ophisthosoma is variable. It may be heart shaped or oval or elongated. The ophisthosoma is covered by soft setae. The legs are slender, latetigrade, leg II longer than others, two claws are present in tarsi, metatarsus dorsally with unilobate rigid structure. The colulus is absent. So far 536 species under 31 genera are reported worldwide (W.S.C., 2021) and 45 species under 8 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Tibellus* Simon, 1875 was found from the study area.

***Tibellus* Simon, 1875** They are medium sized spiders. Body colour is light brown to pale yellow. The abdomen has brown stripe on the dorsal surface. They are commonly found on low vegetation and foliage where they search of prey. Only one species *Tibellus* sp. was found from the study area.

Family 10: Pisauridae Simon, 1890

They are commonly called the 'nursery web spiders'. The female carry the egg sacs with their pedipalps and jaws. When the eggs comes to hatch, the female make a tent like structure called 'nursery', puts her eggs inside the tent and guard outside. Some species are able to walk on water. Body colour is cryptic, oftren the prosoma and ophisthosoma are decorated with longitudinal bands. Eight eyes are of same size and arranged in 2 or 3 or 4 rows and at least one pair of eyes are located on shallow tubercles. The prosoma is longer than the wide. The ophisthosoma is elongated and tapering on the posterior end. The sternum is longer than the wide and anterior end is blunt. Legs are long, slender and provided with spines. Both anterior and posterior spinnerets are same in size. So far 353 species under 51 genera are reported worldwide (W.S.C., 2021) and 18 species under 9 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Perenethis* L. Koch, 1878 was found from the study area.

***Perenethis* L. Koch, 1878** They are found in ground vegetation, especially near the water bodies. They have distinct broad continuous longitudinal band present on each side of both cephalothorax and abdomen. Anterior median eye procurved and posterior lateral eye recurved; 2 teeth on the retromargin and 3 teeth on the promargin of chelicerae. Only one species *Perenethis venusta* L. Koch, 1878 was found from the study area.

Family 11: Salticidae Blackwall, 1841

They are commonly called the ‘jumping spiders’. Morphologically, this family has huge variation from species to species. Some species mimic ants. The body colour varies from species to species. The length of prosoma varies from short to long. Front part of prosoma is square shaped. The shape of ophisthosoma is variable; it may be short or elongated. Sometimes, front of the sternum is narrow. Tarsi are provided with two claws. Eyes usually in three rows (4, 2, 2); anterior median eyes very large, second row of eyes very small, often minute; third row of two eyes of medium size. They are largest family of spiders. So far 6329 species under 659 genera are reported worldwide (W.S.C., 2021) and 275 species under 99 genera are reported from India (Caleb and Sankaran, 2021). Total 10 genera were found from the study area. These were *Carrhotus* Thorell, 1891; *Epeus* Peckham and Peckham, 1886; *Epocilla* Thorell, 1887; *Hasarius* Simon, 1871; *Hyllus* C. L. Koch, 1846; *Myrmarachne* MacLeay, 1839; *Phintella* Strand, 1906; *Plexippus* C. L. Koch, 1846; *Rhene* Thorell, 1869 and *Telamonia* Thorell, 1887

***Carrhotus* Thorell, 1891** They are small to medium sized spiders. Body colour is black to blakish brown. They have characteristic pair of longitudinal bands on cephalothorax and abodomen. Only two species were found from the study area. These were *Carrhotus viduus* (C. L. Koch, 1846) and *Carrhotus* sp.

***Epeus* Peckham and Peckham, 1886** They are small sized spiders having colourful decoration on cephalothorax and abdomen. They are hunting for prey on shrubs and broad leaved plants. Only one species *Epeus indicus* Prószyński, 1992 was found from the study area.

***Epocilla* Thorell, 1887** They are commonly called the 'orange jumping spiders'. They are often found on the opposite side of plant leaves in search of prey. On the abdomen of female, a series of characteristic chevron marks are present. Only two species were found from the study area. These were *Epocilla aurantiaca* (Simon, 1885) and *Epocilla* sp.

***Hasarius* Simon, 1871** They are medium size jumping spiders found in low vegetations and grasses. Body colour is blackish brown. They are characterized by presence of crescent-shaped white line along posterior end of the cephalothorax and anterior edge of the abdomen. Only one species *Hasarius adansoni* (Audouin, 1826) was found from the study area.

***Hyllus* C. L. Koch, 1846** They are medium sized jumping spiders having dull coloured, stout and hairy body. Some species have characteristic tufts of long bristles on the both sides of the eye area. Only one species *Hyllus* sp. was found from the study area.

***Myrmarachne* MacLeay, 1839** Thay are unique spiders that exhibit Batesian mimicry by mimicking ants. They live in close association with ants but do not feed on ants, instead they receiv protection, particularly from Sphecid wasps. Two species were found from the study area. These were *Myrmarachne* sp.1, *Myrmarachne* sp.2 and *Myrmarachne* sp.3

***Phintella* Strand, 1906** They are small, slender spiders with metallic body shades. They are often found wandering on the leaf of the plats in search of prey. Only one species *Phintella vittata* (C. L. Koch, 1846) was found from the study area.

***Plexippus* C. L. Koch, 1846** They are medium sized jumping spiders, generally found roming on the tree bark and crevices of the tree trunk. They are characterized by the presence of white bands on the abdomen. They build structurally complex dense nests on the tree trunk and on rocks and walls. Two species were found from the study area. These were *Plexippus paykulli* (Audouin, 1826) and *Plexippus petersi* (Karsch, 1878)

***Rhene* Thorell, 1869** They are medium sized, black coloured jumping spiders. First pair of legs are robust than the others. They are found on the plant foleage and low grasses and vegetation. Only one species *Rhene flavicomans* Simon, 1902 was found from the study area.

***Telamonia* Thorell, 1887** Thay are very common spider, characterised by the presence of two longitudinal stripes along the abdomen. Male are darker than female. They are commonly found on the plant leaves and grasses hunting preys. Only one species *Telamonia dimidiata* (Simon, 1899) was found from the study area.

Family 12: Scytodidae Blackwall, 1864

They are commonly called the ‘spitting spiders’. They catch their prey by a specialised technique. They spit a venomous fluid on the prey to immobilize it. Body colour is pale yellow to pale brown. Female carry the egg sac by chelicera. Six small eyes are present which are arranged in three diads which are widely spaced. Prosoma is oval and domed towards thoracic region. Fovea is absent. Dark stripes are present on the dorsal surface. Ophisthosoma is oval and broad, sometimes decorated. The female epigastric region has anchoring holes. Sternum is sclerotized and oval in shape. Legs are long and slender, three claws are present in tarsus, and spines are not present. Colulus is present which is large, pointed and provided with setae. So far 246 species under 5 genera are reported worldwide (W.S.C., 2021) and 12 species under 2 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Scytodes* Latreille, 1804 was found from the study area.

Scytodes **Latreille, 1804** They are nocturnal hunters. Generally, they are found on the ground in the leaf litter and debris. They are unable to move fast, instead they move very slowly for prey capturing. The female carry egg cocoons in its chelicerae. Only one species *Scytodes pallida* Doleschall, 1859 was found from the study area.

Family 13: Sparassidae Bertkau, 1872

They are commonly called the ‘huntsman spider’. Male of some species make sounds by vibrations of the abdomen to attract female. Body size ranges from medium to very large. Body colour is variable, ranges from white, green, cream, grey or dark brown. Eight eyes are arranged in two rows. Prosoma is oval and narrow at the eye area, fovea not present and covered with dense setae. Ophisthosoma is round or oval, but sometimes elongated and covered with dense setae. Sternum is circular or longer than wide. Legs are long, robust and laterigrade, distal metatarsus dorsally with trilobate soft membrane. The colulus is not present. So far 1256 species under 87 genera are reported worldwide (W.S.C., 2021) and 84 species under 13 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Olios* Walckenaer, 1837 was found from the study area.

Olios **Walckenaer, 1837** They are dull brownish to green-brown spiders which are identified by the markings on the ventral side of the abdomen. They build an oval shaped sac like retreat which is firmly attached to the underside of stones or between leaves by silk. Only one species *Olios milleti* (Pocock, 1901) was found from the study area.

Family 14: Tetragnathidae Menge, 1866

They are commonly called the 'long-jawed orb weavers' due to presence of robust chelicerae. They make small to medium orb webs to capture prey. Body size is medium to large. Body colour is dull brown or grey. Sometimes silvery markings are present on body. Eight eyes are arranged in two rows. The prosoma is longer than wide. The shape of ophisthosoma is variable. It may be elongated or rounded or oval. The sternum is longer than wide and posterior end is pointed. Legs are slender, long and have 3 claws on tarsi, tarsi without ventral comb of serrated hairs. Anterior and posterior spinnerets are of same size. So far 989 species under 50 genera are reported worldwide (W.S.C., 2021) and 55 species under 12 genera are reported from India (Caleb and Sankaran, 2021). Four genera were found from the study area. These were *Guizygiella* Zhu, Kim and Song, 1997; *Leucauge* White, 1841; *Opadometa* Archer, 1951 and *Tetragnatha* Latreille, 1804

***Guizygiella* Zhu, Kim and Song, 1997** They are nocturnal hunters. They build vertical orb webs, which have a vacant portion in the upper part. They hide in a curled leaf retreat. They are found on plant foliage, tree trunks and shrubs. Two species were found from the study area. These were *Guizygiella melanocrania* (Thorell, 1887) and *Guizygiella indica* (Tikader and Bal, 1980)

***Leucauge* White, 1841** They are characterized by silver colour abdomen with red, green and golden decoration. They build horizontal orb webs in the low vegetations. Two species were found from the study area. These were *Leucauge decorata* (Blackwall, 1864) and *Leucauge* sp.

***Opadometa* Archer, 1951** They are characterized by white colour abdomen with orange, black, yellow decoration. They build small horizontal orb webs in the low vegetations. Only one species *Opadometa fastigata* (Simon, 1877) was found from the study area.

***Tetragnatha* Latreille, 1804** They are moderately large sized, elongated spiders. They build vertical, sometimes horizontal orb webs in trees, shrubs, and tall grass. Some build their webs in the vegetation above water bodies to capture emerging aquatic insects. Four species were found from the study area. These were *Tetragnatha* sp.1, *Tetragnatha* sp.2, *Tetragnatha* sp.3 and *Tetragnatha* sp.4

Family 15: Theridiidae Sundevall, 1833

They are commonly known as the 'cob web spider'. They exhibit a large diversity in their lifestyle. Some species make three dimensional space webs and some species live as kleptoparasite on webs of other spider species. Body colour is variable. Some species are black, some are yellow to brown. Eight eyes are arranged in two rows. The shape of prosoma is variable. It may be flat to high. Ophisthosoma is oval or round; in some species it is elongated. The sternum is triangular to scutiform, posterior end is attenuated. Tarsi IV is provided with ventral comb of serrated hairs. So far 2516 species under 124 genera are reported worldwide (W.S.C., 2021) and 85 species under 32 genera are reported from India (Caleb and Sankaran, 2021). Four genera were found from the study area. These were *Faiditus* Keyserling, 1884; *Nihonhimea* Yoshida, 201; *Steatoda* Sundevall, 1833 and *Thwaitesia* O. Pickard-Cambridge, 1881

***Faiditus* Keyserling, 1884** They are small sized spiders. All species are kleptoparasitic i.e. lives on webs of other spiders. Generally, male are larger than the female. Only one species *Faiditus* sp. was found from the study area.

***Nihonhimea* Yoshida, 2016** They are small to medium sized spiders. They build irregular tangle webs on crevasse of tree trunks or rocks. Two species were found from the study area. These were *Nihonhimea indica* (Tikader, 1977) and *Nihonhimea mundula* (L. Koch, 1872).

***Steatoda* Sundevall, 1833** They are moderately large sized spiders. They build irregular tangle webs. In some species the male have stridulating organ on abdomen which produce sounds by vibration during courtship and agonistic encounters. Only one species *Steatoda* sp. was found from the study area.

***Thwaitesia* O. Pickard-Cambridge, 1881** They are small sized spiders. Their abdomen is covered by small silvery plates which give a shiny appearance. Only one species *Thwaitesia* sp. was found from the study area.

Family 16: Thomisidae Sundevall, 1833

They are commonly called crab spiders because of crab appearance of the legs. They are ambush hunters, do not make webs, sit and wait for prey on the flower petals, leafs, foliage etc. Body colour is very varied. It is either bright pink or yellow or green or gray or brown or white. Eight eyes are present which are arranged in two rows. Generally, the lateral eyes are larger than other eyes and placed on tubercles. Prosoma is semi-circular or elongated or oval in shape. Ophisthosoma is round or oval or elongated in shape. Sternum is heart shaped. Legs III and IV are shorter than legs I and II, tarsi with two claws. Anterior spinnerets are shorter than the rest. So far 2153 species under 169 genera are reported worldwide (W.S.C., 2021) and 179 species under 40 genera are reported from India (Caleb and Sankaran, 2021). Three genera were found from the study area. These were *Camaricus* Thorell, 1887; *Runcinia* Simon, 1875 and *Thomisus* Walckenaer, 1805

***Camaricus* Thorell, 1887** They can be easily identified by brown coloured abdomen and black abdomen which is highly decorated by yellow or black colour. They are mostly found on the opposite side of plant leafs or tree barks where they hunts the prey. Only one species *Camaricus formosus* Thorell, 1887 was found from the study area.

***Runcinia* Simon, 1875** They are commonly found on the grasses and sedges, concealing them self with the background. They are polyphagous predator and feed on a wide variety of arthropods but mostly prefer small moths. Female construct irregular shaped egg sacs which are camofladged with the surroundings. Only one species *Runcinia ghorpadei* Tikader, 1980 was found from the study area.

***Thomisus* Walckenaer, 1805** They are commonly called the ‘flower crab spiders’ because they are found to sit and wait for preys such as bees, flies and other flying insects on the flower petals. They hunt by ambushing. They are able to conceal themselves with the background by changing their body colour. Sexual dimorphism is very prominent in this genus, male are darker than the female. Three species were found from the study area. These were *Thomisus lobosus* Tikader, 1965; *Thomisus pugilis* Stoliczka, 1869 and *Thomisus* sp.

Family 17: Uloboridae Thorell, 1869

They are commonly called cribellate orb weavers or hackled orb weavers. They do not have any poison gland. Instead, they produce a feathery silk called cribellate silk or hackled silk to make orb webs. If the prey trapped in the web, they wrap it by the silk. Body colour is usually light brown or light grey. They have eight or four eyes. Prosoma has shapes such as narrow and long, triangular or pear shaped. Ophisthosoma is narrow or has one or two humps on it. Sternum is long or oval or triangular. In some species it is made up by two separate sternites. Legs I and IV are longer than leg II and leg III. Three claws are present in the tarsi. Dorsal trichobothria present in the femora of legs. Anterior spinnerets have three segments of which the second segment is thin and the third segment is dome shaped. So far 287 species under 19 genera are reported worldwide (W.S.C., 2021) and 25 species under 5 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Zosis* Walckenaer, 1841 was found from the study area.

***Zosis* Walckenaer, 1841** They are commonly called the 'feather legged spiders'. They catch the prey by making horizontal orb webs by extremely fine mesh of cribellate silk. They are characterized by the presence of 8 eyes in two rows, posterolateral eyes not on tubercles; abdomen oval; sternum not divided and legs elongated with prominent bands. Only one species *Zosis geniculata* (Olivier, 1789) was found from the study area.

Family 18: Zodariidae Thorell, 1881

They are commonly called ‘ant spiders’ because some species of this family are specialised to hunt ants and termites. They are typically small, ground dwelling and mostly burrowing spiders. They live under stones, logs and litter, some species live in burrow. They do not construct any web to catch prey**.** Body colour varies among species, from pale to dark brown. Sometime ophisthosoma is decorated with patters or with metallic lustre. Numbers of eyes are six or eight. The arrangement of eyes varies, either in two or three rows. The size of eyes is also varies. Although the shape of prosoma varies from species to species, it is usually oval and narrow in anterior portion. Fovea is either absent or poorly developed or highly developed. Ophisthosoma is usually ovoid; in many cases it is twice longer than its width, in some species scutum present. Sternum is shield shaped or oval. In the legs, the tarsus is three clawed. The species specialists for digging the soil have stiff spines on the hind leg. Anterior spinnerets are long but median and posterior spinnerets are reduced or absent. So far 1184 species under 87 genera are reported worldwide (W.S.C., 2021) and 30 species under 11 genera are reported from India (Caleb and Sankaran, 2021). Only one genus *Tropizodium* Jocqué and Churchill, 2005 was found from the study area.

***Tropizodium* Jocqué and Churchill, 2005** They are blackish brown ant mimicking spiders. Identifying characters are – Cephalothorax longer than wide, cephalic region slightly higher with rounded margin and provided with light brown patches; anterior row of eyes straight or slightly procurved, anterior median eyes larger than others and encircled by deep brown patches, posterior row of eyes strongly procurved and posterior medians widely separated and closer to adjacent laterals; legs long and strong, covered with fine hairs; sternum heart shaped, pointed behind, covered with hairs; abdomen globular, slightly pointed behind, overlaps cephalothorax in front;

anterior pair of spinnerets long and other two pairs not developed. Only one species *Tropizodium* sp. was found from the study area.

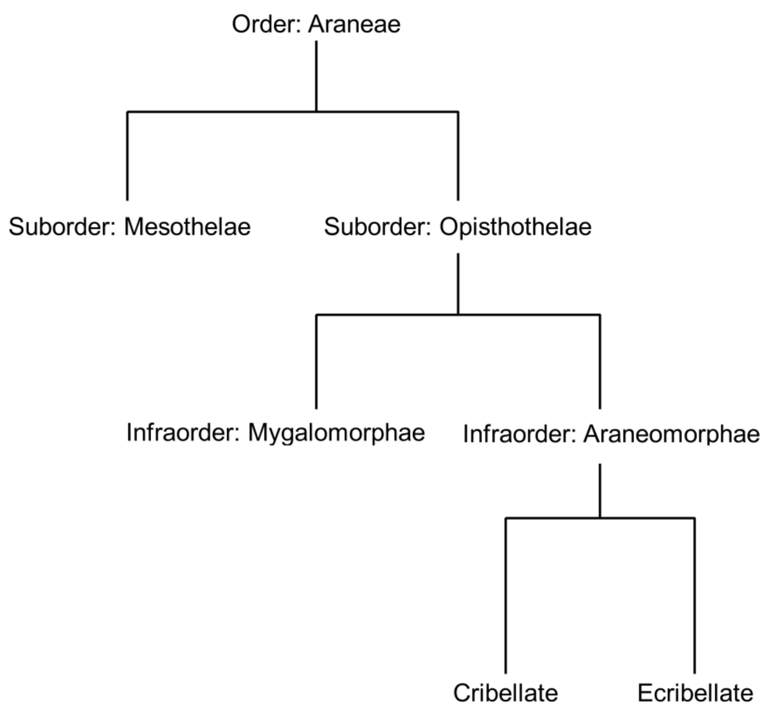


Figure 3.1: Classification of the order Araneae

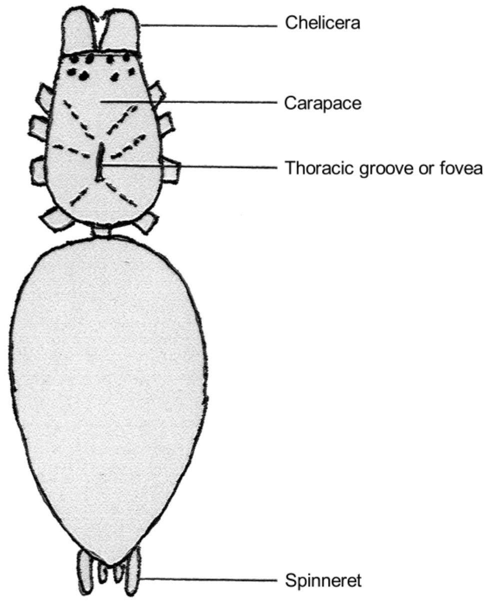


Figure 3.2: Dorsal morphology of spider

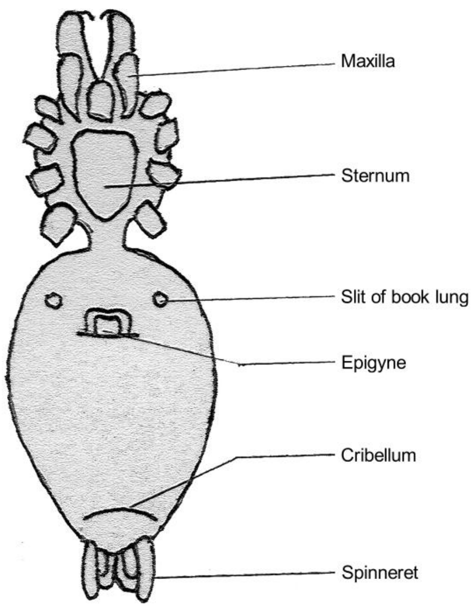


Figure 3.3: Ventral morphology of spider

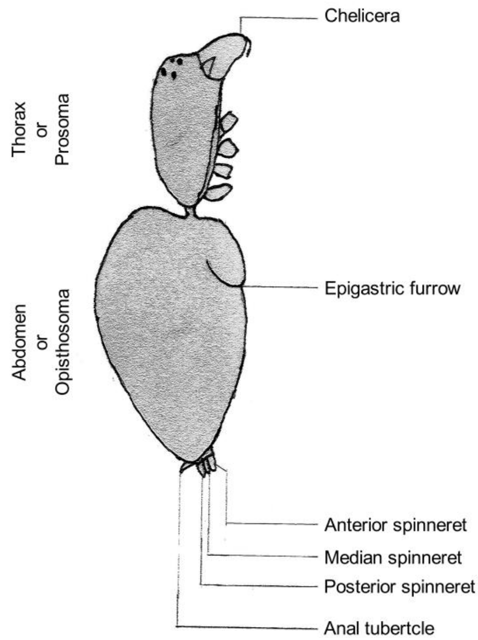


Figure 3.4: Lateral morphology of spider

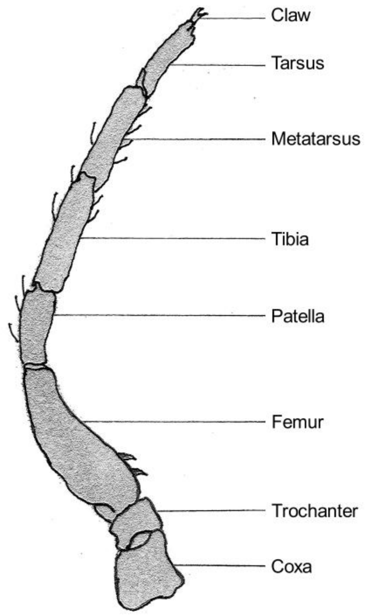


Figure 3.5: Parts of the leg of spider

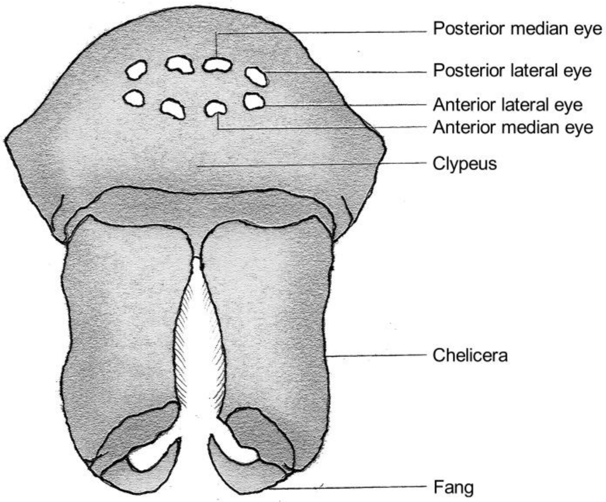


Figure 3.6: Frontal morphological view of spider

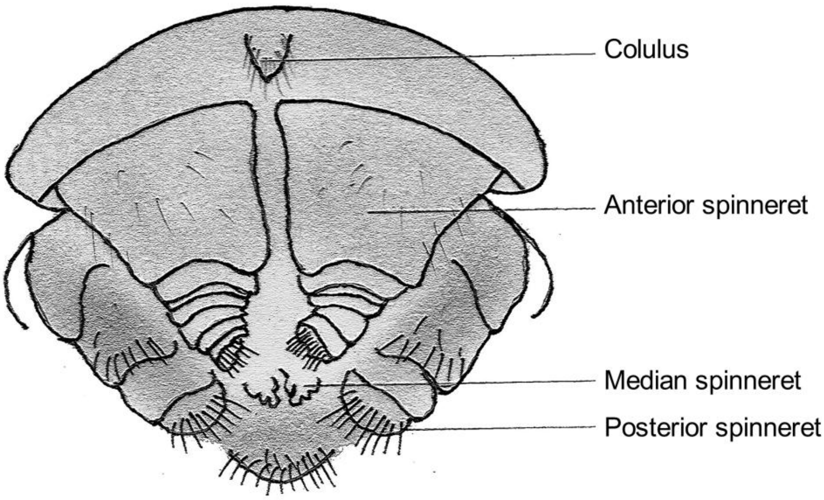


Figure 3.7: Various parts of the spinnerets of the spider

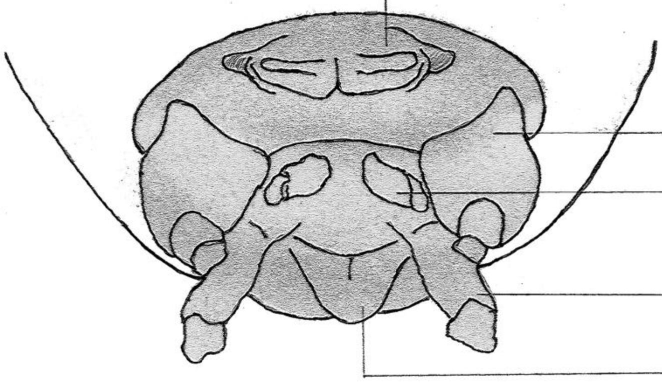


Figure 3.8: Ventral view of cribellum of cribellate spider

Species account of spiders across the study area


Agelena sp. ♀


Acusilas sp. ♀


Anepsion sp. ♀


Araneus mitificus ♀


Argiope aemula ♀


Argiope pulchella ♀

Cyclosa bifida ♀

Cyclosa confraga ♀

Cyclosa hexatuberculata ♀

Cyclosa insulana ♀

Cyclosa simoni ♀

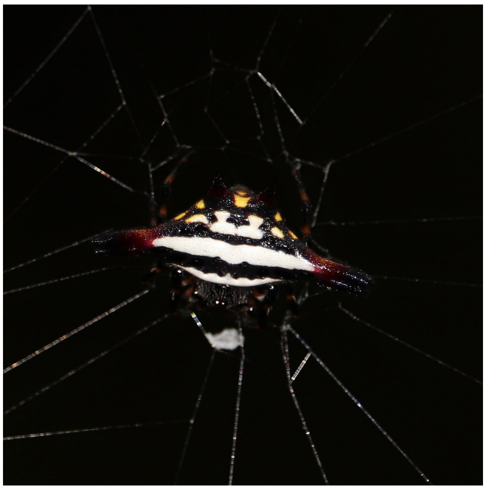
Cyclosa spirifera ♀

Species account of spiders across the study area

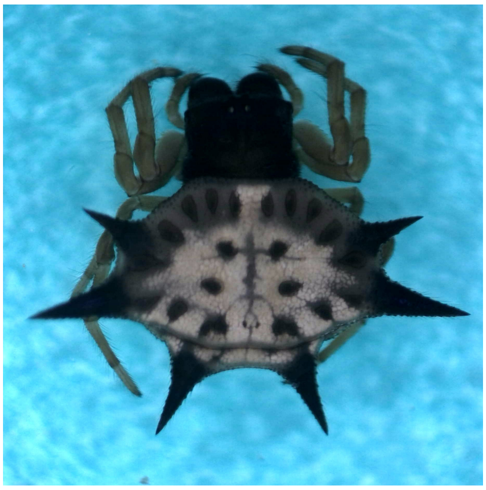
Cyclosa sp. ♀

Cyrtophora cicatrosa ♀

Eriovixia laglaizei ♀



Gasteracantha geminata ♀



Gasteracantha hasselti ♀

Larinia sp. ♀

Neoscona mukerjei ♀

Neoscona nautica ♀

Neoscona theisi ♀

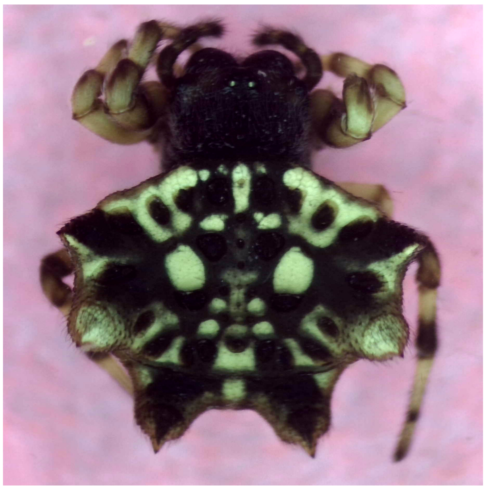
Neoscona vigilans ♀

Neoscona sp.1 ♀

Neoscona sp.2 ♀

Species account of spiders across the study area

Nephila pilipes ♀



Thelacantha brevispina ♀

Castianeira zetes ♀

Prodidomus sp. ♀

Zelotes sp. ♀

Hersilia savignyi ♀

Species account of spiders across the study area

Hippasa lycosina ♀

Lycosa sp.1 ♀

Lycosa sp.2 ♀

Brignolia sp. ♀

Hamataliwa incompta ♀

Oxyopes sp.1 ♀


Oxyopes sp.2 ♀


Oxyopes sp.2 ♀


Peucetia viridana ♀


Tibellus sp. ♀


Perenethis venusta ♀


Carrhotus viduus ♀

Species account of spiders across the study area

Carrhotus sp. ♀

Epeus indicus ♀

Epocilla aurantiaca ♀

Epocilla sp. ♀

Hasarius adansoni ♀

Hyllus sp. ♀

Myrmarachne sp.1 ♀

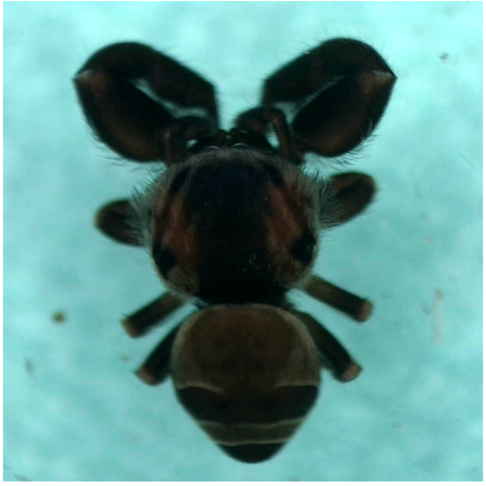
Myrmarachne sp.2 ♀

Myrmarachne sp.3 ♀

Phintella vittata ♀

Plexippus paykulli ♀

Plexippus petersi ♀



Rhene flavicomans ♀

Telamonia dimidiata ♀

Scytodes pallida ♀

Olios milleti ♀

Guizygiella indica ♀

Guizygiella melanocrania ♀

Species account of spiders across the study area

Leucauge decorata ♀

Leucauge sp. ♀

Opadometa fastigata ♀

Tetragnatha sp.1 ♀

Tetragnatha sp.2 ♀

Tetragnatha sp.3 ♀

Tetragnatha sp.4 ♀

Faiditus sp. ♀

Nihonhimea indica ♀

Nihonhimea mundula ♀

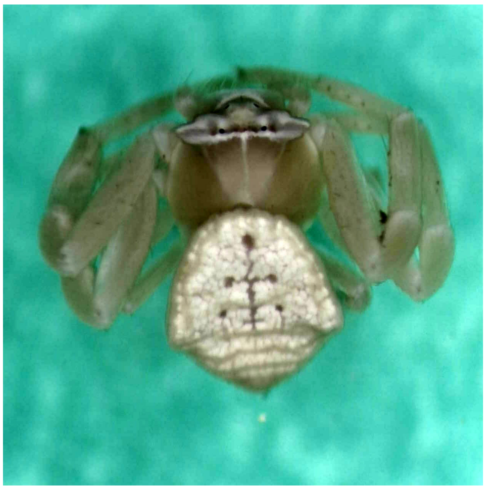
Steatoda sp. ♀

Thwaitesia sp. ♂

Camaricus formosus ♀

Runcinia ghorpadei ♀

Thomisus lobosus ♀



Thomisus pugilis ♀

Thomisus sp. ♀

Zosis geniculata ♂

Tropizodium sp. ♀

CHAPTER 4

PATTERN OF TAXONOMIC AND FUNCTIONAL DIVERSITY OF SPIDER COMMUNITY

4.1 Introduction

The Convention on Biological Diversity (CBD) drafted in the United Nations Conference on Environment and Development (UNCED) in the year 1992 defined biodiversity as "*The variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems*". The biodiversity encompasses three main components namely (i) the taxonomic diversity (accounts for species richness and abundance), (ii) phylogenetic diversity (accounts for evolutionary lineages of species) and (iii) functional diversity (accounts for the resource use strategies and ecological traits of species) (Tribot et al., 2016; Le Bagousse-Pinguet et al., 2019). These biodiversity components complement ecosystem services and complement ecosystem functioning (Tribot et al., 2016). These components may have contrasting effects on ecosystem functioning and need not to be relate each other. (Le Bagousse-Pinguet et al., 2019). The biodiversity is declining worldwide, but the rate at which biodiversity components namely taxonomic diversity, phylogenetic diversity and functional diversity are declining varies (Le Bagousse-Pinguet et al., 2019). For this reason, scientists have recently sought detailed knowledge about biodiversity components.

The rank of species occupies the most important place in most of the biodiversity studies (Gaston, 2000). But in recent years, scientists have not come to believe that the biodiversity of a region depends solely on the number of species and using taxonomic surrogacy method which is based on the fact that the species and higher taxonomic ranks, such as genera and families have predictable relationships (Campbell et al., 2011). In this method, the number of species is not assessed directly, but indirectly estimated by higher ranked taxa, for example, genus, family, order, class etc. (Campbell et al., 2011). The index of taxonomic diversity (Δ^+) and the index of variation in taxonomic distinctness (λ^+) proposed by Warwick and Clarke (1995) and Clarke and Warwick (1998, 2001) are such taxonomic surrogate measures which utilized information obtained from the hierarchical taxonomic tree (for example, Linnaean classification or phylogenetic distances matrix) (Campbell et al., 2011) and these indices are not vulnerable to the sample size like other diversity indices (Warwick and Clarke, 1995).

The component of biodiversity that influences the dynamics, productivity, stability and other aspects of ecosystem functioning by organismal traits is called the functional diversity (FD) (Tilman, 2001). The aim of the measurements of the functional diversity (FD) is to quantify the diversity of functional traits within species assemblages (Mason and Mouillot, 2013). There are several methods proposed by scientists to quantify the functional diversity such as functional richness (FRic) – the amount of functional trait space filled, functional evenness (FEve) – the evenness of abundance distribution in filled trait space, functional divergence (FDiv) - the degree to which abundance is distributed toward the extremities of filled trait space (Laliberté and Legendre, 2010; Mason and Mouillot, 2013), functional dispersion (FDis) – the mean distance in multidimensional trait space of individual species to the centroid of all species in the community (Laliberté and Legendre, 2010) and Rao's quadratic entropy (RaoQ) (Botta-Dukát, 2005).

There have been several studies on taxonomic and functional diversity of spiders worldwide in the recent past. Cardoso et al. (2011) studied on the guild composition pattern and functional diversity of spiders in global scale and proposed presence of eight ecological guilds in the spider community. Schirmel et al. (2012) found that the functional dispersion (FDis) and Functional evenness (FEve) differs but functional divergence (FDiv) did not differ in different life stages in spiders. Researches revealed that the age of forests (Morel et al., 2019), agricultural managements (Gallé et al., 2018; Picchi et al., 2020), grazing (Leroy et al., 2014; Kaltsas et al., 2019), invasive plant species (Schirmel and Buchholz, 2012; Leroy et al., 2014, Gomes et al.; 2017), landscape structure (Schirmel et al., 2016; Joseph et al., 2017; Gallé et al., 2018; Delgado de la flor et al., 2020), seasonal changes (Baldissera et al., 2020) and vegetation structure (Corcuera et al., 2015; Melliger et al., 2018) are the main driving forces controlling the taxonomic and functional diversity of spiders. But so far no research has been done on the taxonomic and functional diversity of spiders particularly in riparian ecosystems in India.

With this background the study was performed to understand the pattern of taxonomic and functional diversity of spider community in Gangetic riparian zones.

4.2 Statistical analysis

For estimation of site species richness two non parametric species richness estimators viz. second order Chao estimator (Chao2) of species richness (Chao, 1984, 1987; Chao et al., 2009; Gotelli and Colwell, 2011) and second order Jackknife estimator (Jackknife2) of species richness (Smith and van Belle 1984) were used. The non-parametric estimators were used because these estimators used rare species data in assemblages to adjust the number undetected species. (Gotelli and Colwell, 2011) and both Chao2 and Jackknife2 are least biased for sample size (Colwell and Coddington, 1994).

The non-parametric analysis of similarities (ANOSIM) test (Clarke, 1993) was used to compare the mean of ranked dissimilarities (with Jaccard distance) of species compositions between upper, middle and lower zone. The non-parametric permutational multivariate analysis of variance (PERMANOVA) (Anderson, 2001) test was used to compare species compositions between upper, middle and lower zone. To facilitate interpretation of the results of ANOSIM and PERMANOVA, the non-metric multidimensional scaling (NMDS) based on spider species composition (with Jaccard distances) of the sites was performed.

To test whether species richness and indices of taxonomic and functional diversity differ between upper, middle and lower zones, the non-parametric Kruskal–Wallis rank sum test was used.

For taxonomic diversity analysis, the systematic of spiders (Appendix 4) from class to species was used. For estimating taxonomic diversity two indices namely Index of taxonomic diversity (Δ^+) and the index of variation in taxonomic distinctness (λ^+) as proposed by Clarke and Warwick (1998, 2001) were used.

For functional diversity analysis the spiders were classified (Appendix 4) by their ecological guild (Cardoso et al., 2011) and their stratum of hunting (Gallé et al., 2018). For estimating diversity three indices namely functional evenness (FEve) functional divergence (FDiv) and functional dispersion (FDis) (Laliberté and Legendre, 2010; Mason and Mouillot, 2013) were used.

For estimation of (after 100 randomization) Chao2 and Jackknife2 the EstimateS Version 9 (Colwell, 2013) was used. For analysis of similarities (ANOSIM), permutational multivariate analysis of variance (PERMANOVA), non-metric multi-dimensional scaling (NMDS) and calculation of indices taxonomic diversity the R package '*vegan*' (Oksanen et al., 2019) was used. For calculation of indices of functional diversity the R package '*FD*' (Laliberté and Legendre, 2010; Laliberté et al., 2014) was used. The *R language and environment for statistical computing* (R Core Team, 2020) was used for the statistical analysis.

4.3 Results

The species accumulation curve (pooled for each site) reached an asymptote for both Chao2 and Jacknife2 estimators which indicated that the sampling efforts were adequate to capture most of the species in the study sites (Figure 4.1).

From the study area, a total of 79 species of spiders under 50 genera and 18 families were recorded. Among them, highest number of species was found under family Araneidae (25 species under 12 genera), followed by the family Salticidae (15 species under 10 genera) and Tetragnathidae (9 species under 4 genera). Total 5 species were found each under family Theridiidae (4 genera), Oxyopidae (3 species) and Thomisidae (3 genera). Three species under two genera were found from the family Lycosidae and 2 species under 2 genera from family Gnaphosidae. One species each was found from the families Agelenidae, Corinnidae, Hersiliidae, Oonopidae, Philodromidae, Pisauridae, Scytodidae, Sparassidae, Uloboridae and Zodariidae. Comparative account of numbers of genera and species under 18 families is given in the figure 4.2 and comparative account of species richness in 27 study sites is given in the figure 4.3 (A).

Maximum number of species from the upper zone (79 species, 50 genera and 18 families) (site 1, 3 and 7 were most species rich and site 7, 8 were 10 least species rich); followed by the middle zone (69 species, 42 genera and 18 families) (site 18, 19 and 20 were most species rich and site 17, 11 and 15 were least species rich) and lower zone (64 species, 40 genera and 16 families) (site 22, 24 and 25 were maximum species rich and site 17 and 23 were least species rich).

By non-parametric analysis of similarities (ANOSIM) test it was found that there was no significant mean of ranked dissimilarities between the spider communities in upper, middle and lower zone (ANOSIM statistic R = 0.003, p = 0.442). By non-parametric permutational multivariate analysis of variance (PERMANOVA) test it was found that there was no significant difference of species composition between the upper, middle and lower zone (ADONIS, F = 0.870, R^2 = 0.068, p = 0.7). By NMDS plot (Figure 4.4) it was found that all the zones that had the similar species composition were clustered together and the upper, middle and lower zones overlap with each other which indicate that these zones did not differ in species composition.

Among the sampling sites, the index of taxonomic diversity (Δ^+) was maximum in the site 27 and minimum in the site 6 (Figure 4.3 B) and the index of variation in taxonomic distinctness (λ^+) was maximum in the site 10 and minimum in the site 8 (Figure 4.3 C).

Among the sampling sites, the functional evenness (FEve) was maximum in the site 23 and minimum in the site 22 (Figure 4.3 D), the functional divergence (FDiv) was maximum in the site 24 and minimum in the site 5 (Figure 4.3 E), the functional dispersion (FDis) was maximum in the site 11 and minimum in the site 10 (Figure 4.3 F).

By non-parametric Kruskal–Wallis (KW) rank sum test it was found that the upper, middle and lower zones did not differ in terms of species richness (KW χ^2 = 0.299, p > 0.05) (Figure 4.5), index of taxonomic diversity (Δ^+) (KW χ^2 = 2.799, p > 0.05) (Figure 4.6 A), index of variation in taxonomic distinctness (λ^+) (KW χ^2 = 3.084, p > 0.05) (Figure 4.6 B), functional evenness (FEve) (KW χ^2 = 0.528, p > 0.05) (Figure 4.7 A), functional divergence (FDiv) (KW χ^2 = 2.569, p > 0.05) (Figure 4.7 B) and functional dispersion (FDis) (KW χ^2 = 1.709, p > 0.05) (Figure 4.7 C).

The significant ($p < 0.05$) Pearson's correlation and linear relationship was observed between between species richness and the functional evenness (FEve), species richness and the functional divergence (FDiv), index of taxonomic diversity (Δ^+) and the index of variation in taxonomic distinctness (λ^+), index of taxonomic diversity (Δ^+) and the functional dispersion (FDis), the index of variation in taxonomic distinctness (λ^+) and functional evenness (FEve), the index of variation in taxonomic distinctness (λ^+) and functional dispersion (FDis) (Table 4.3, Figure 4.8).

4.4 Discussion

Information on the diversity and distribution patterns of species in the riparian region is very important because the conservation management of the respective region is determined based on this baseline information. This study quantified the taxonomic and functional diversity of the riparian spider community of the Ganga river. A total of 79 species of spiders under 50 genera and 18 families were documented from the study area, and all were reported for the first time from the Gangetic riparian zones.

The maximum species richness was observed in the site 1, 2 and 3. Due to the fact that these regions are located at the junction of the Gangetic plain and the Himalayan hills, the edge effect is effective in this region which supports higher biodiversity. In addition, protected areas such as Hastinapur Wildlife Sanctuary and Upper Ganga Ramsar Site are located in the region which provides protection to the wildlife of the region. For all these reasons, the biodiversity in this region is much higher than in other regions. The species richness in some sites were comparatively low due to the proximity of these sites to the densely populated urban areas and the fact that spider habitat had shrunk for several reasons including anthropogenic disturbance, resulting in reduced diversity.

As the biodiversity conservation management strategies become integrated with the taxonomic and functional diversity (Jetz et al., 2014; Wiens et al., 2008), the relation between biological diversity and ecosystem functions has become a main research topic in ecology in recent time (Le Bagousse-Pinguet et al., 2019). There has been some research on relationship between taxonomic diversity and functional diversity over the past decade (Baraloto and Hérault, 2012; Devictor et al., 2010; Seymour et al., 2015; Villéger et al., 2012).

Farias and Jaksic (2009) noticed a negative association between species richness and functional evenness (FEve) and in this study it was also noticed a significant negative relationship (- 1) between them. Mouchet et al. (2010) found that functional evenness (FEve) and functional divergence (FDiv) are relatively independent of other indices. This study also found that these two indices had no significant relationship with each other. Mason et al. (2005) expected that there would be no relationship between functional divergence (FDiv) and species richness, but in this study significant positive relationship between them was observed.

Studies by Tribot et al. (2016) found that the aesthetic value of ecosystem is increased by the taxonomic and functional diversity. As aesthetic experience increase the social motivation to the conservation of ecosystem, the taxonomic and functional diversity act as important factors for biodiversity conservation (Tribot et al., 2016).

This study was first work in the river ecosystem in India because in the past there has not been any work on the taxonomic and functional diversity of spider community in the riparian region of the Ganga river as well as other rivers in India. In the future, there should be research on the taxonomic and functional diversity of the flora and fauna of the riparian region of India's rivers on both spatial and temporal scale and the knowledge gained from those works will enable us for proper management and implementation of conservation plans in the riparian regions.

Table 4.1: Values of species richness, taxonomic and functional diversity indices for 27 study sites.

Sites	Species richness	Taxonomic diversity indices		Functional diversity indices		
		Δ+	λ+	FEve	FDiv	FDis
Site 1	58	74.329	262.858	0.125	0.851	0.318
Site 2	44	74.009	323.477	0.143	0.808	0.333
Site 3	54	73.633	261.452	0.135	0.852	0.313
Site 4	31	71.284	369.919	0.138	0.821	0.273
Site 5	25	74.331	285.918	0.217	0.754	0.351
Site 6	28	70.530	299.234	0.192	0.801	0.234
Site 7	20	71.735	255.578	0.222	0.798	0.299
Site 8	23	74.457	178.526	0.286	0.826	0.337
Site 9	29	75.465	222.815	0.185	0.769	0.342
Site 10	24	71.607	391.286	0.227	0.809	0.218
Site 11	25	73.619	350.450	0.217	0.839	0.362
Site 12	29	72.666	231.657	0.185	0.764	0.341
Site 13	31	71.705	364.391	0.172	0.778	0.273
Site 14	31	72.698	333.996	0.172	0.783	0.267
Site 15	28	72.190	345.361	0.192	0.787	0.251
Site 16	33	72.802	313.262	0.161	0.776	0.283
Site 17	22	73.594	241.183	0.250	0.799	0.274
Site 18	48	73.732	324.222	0.130	0.818	0.297
Site 19	45	72.999	350.098	0.116	0.767	0.310
Site 20	40	73.138	286.263	0.132	0.777	0.305
Site 21	30	72.793	322.656	0.179	0.768	0.303
Site 22	46	73.799	311.785	0.114	0.839	0.329
Site 23	19	74.324	185.151	0.294	0.783	0.291
Site 24	42	72.754	281.255	0.150	0.879	0.331
Site 25	36	74.506	321.362	0.147	0.762	0.315
Site 26	29	72.577	321.416	0.185	0.756	0.316
Site 27	17	76.557	256.285	0.260	0.782	0.307
Mean	32.852	73.253	295.995	0.182	0.798	0.303
SD	10.801	1.322	54.634	0.051	0.033	0.0352
Median	30	73.138	311.785	0.179	0.787	0.307

Table 4.2: Comparative account of species richness, taxonomic and functional diversity indices for upper, middle and lower zones.

		Species richness	Taxonomic diversity indices		Functional diversity indices		
			Δ+	λ+	FEve	FDiv	FDis
Upper	Mean	33.6	73.138	285.106	0.187	0.809	0.302
	SD	13.509	1.685	64.382	0.052	0.031	0.046
	Median	28.5	73.821	274.388	0.189	0.809	0.316
Middle	Mean	32.909	72.903	314.867	0.173	0.787	0.297
	SD	8.129	0.617	44.247	0.039	0.023	0.033
	Median	31	72.802	324.222	0.172	0.778	0.297
Lower	Mean	31.5	74.086	279.542	0.192	0.8	0.315
	SD	11.946	1.447	52.906	0.071	0.048	0.015
	Median	32.5	74.062	296.52	0.168	0.783	0.316

Table 4.3: Pearson's correlation coefficient (r) between species richness, indices of taxonomic and functional diversity. The significant ($p < 0.05$) values are in boldface.

	Species richness	Δ^+	λ^+	FEve	FDiv
Δ^+	0.046				
λ^+	0.191	**-0.517***			
FEve	**-0.855***	0.201	**-0.494***		
FDiv	**0.449***	-0.033	-0.037	-0.186	
FDis	0.205	**0.609***	**-0.394***	-0.088	0.094

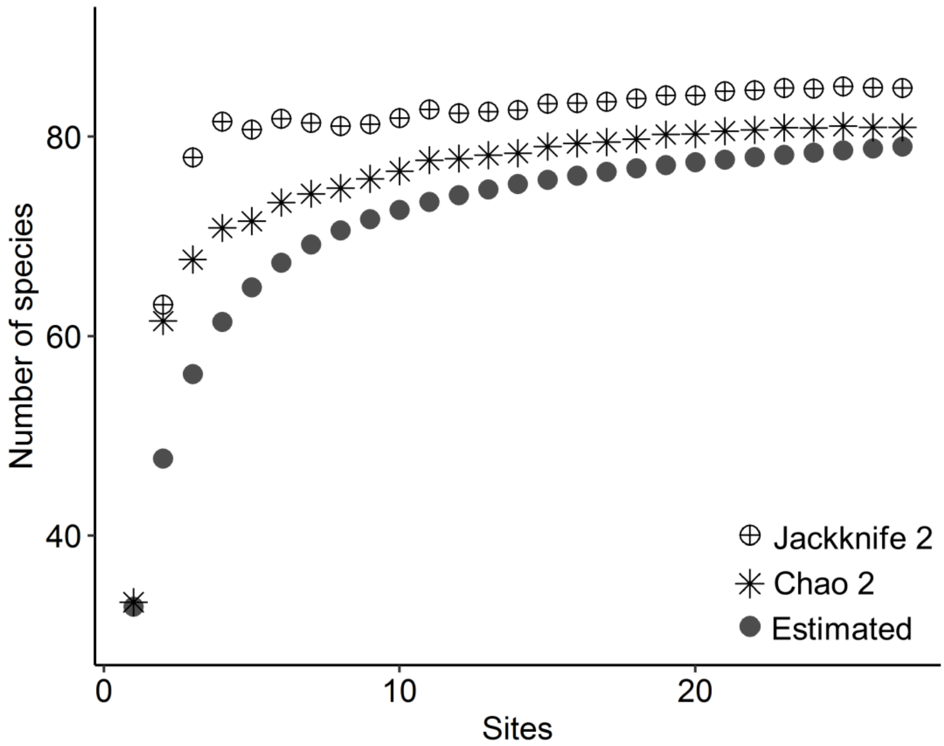


Figure 4.1: Species accumulation curve

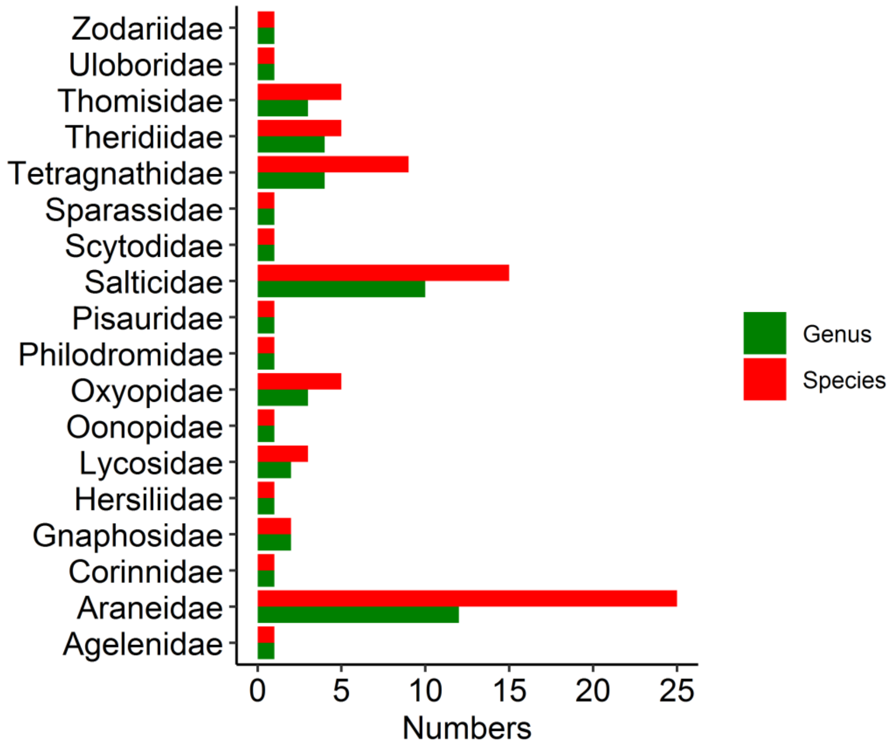


Figure 4.2: Comparative account of numbers of genera and species under 18 families of spiders recorded from the study area.

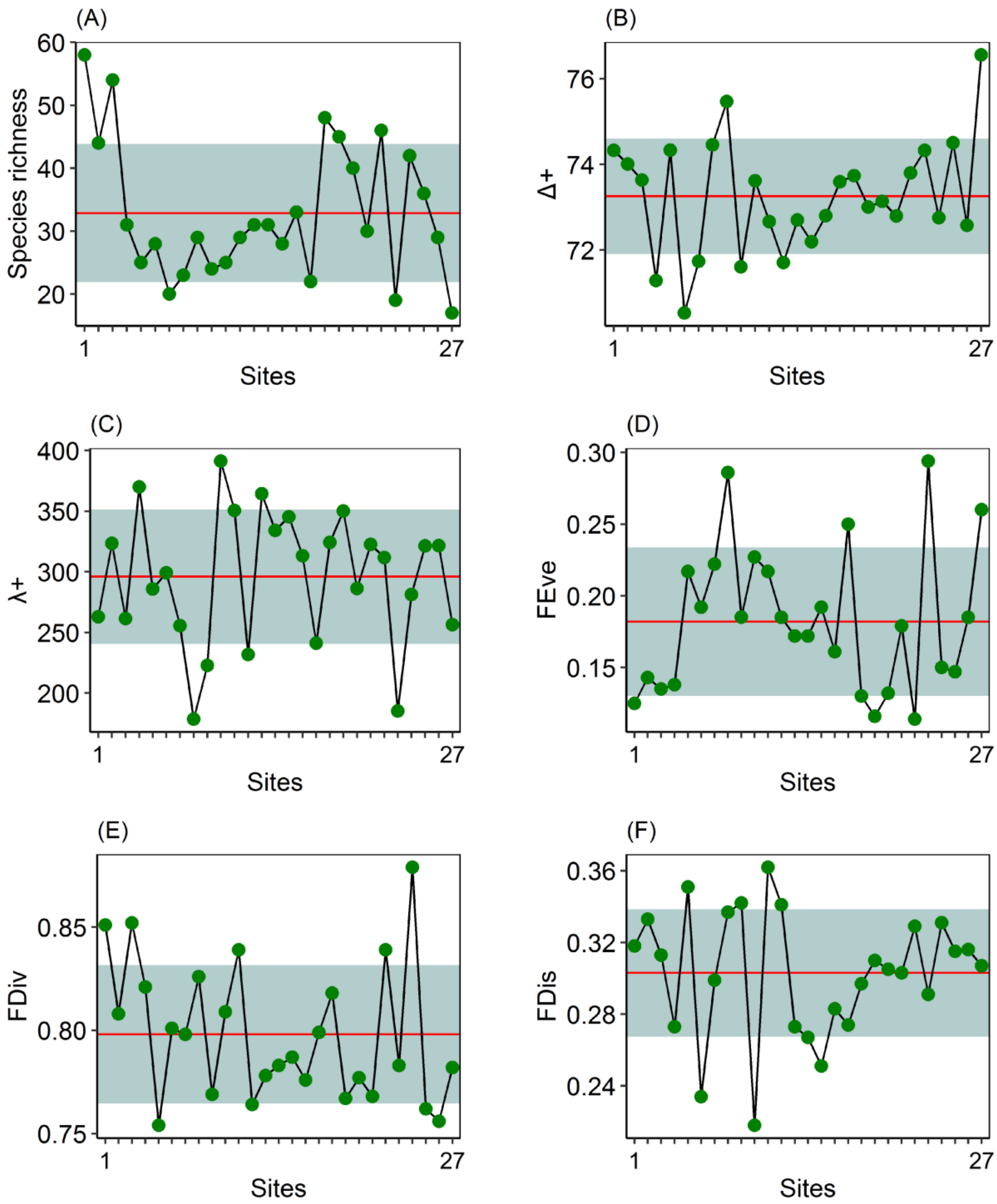


Figure 4.3: Comparative account of the (A) species richness, (B) index of taxonomic diversity (Δ^+), (C) index of variation in taxonomic distinctness (λ^+), (D) functional evenness (FEve), (E) functional divergence (FDiv) and (F) functional dispersion (FDis) of spiders across 27 sites. In each figure the red horizontal line represents the mean value and the shaded area represents values within the mean ± standard deviation.

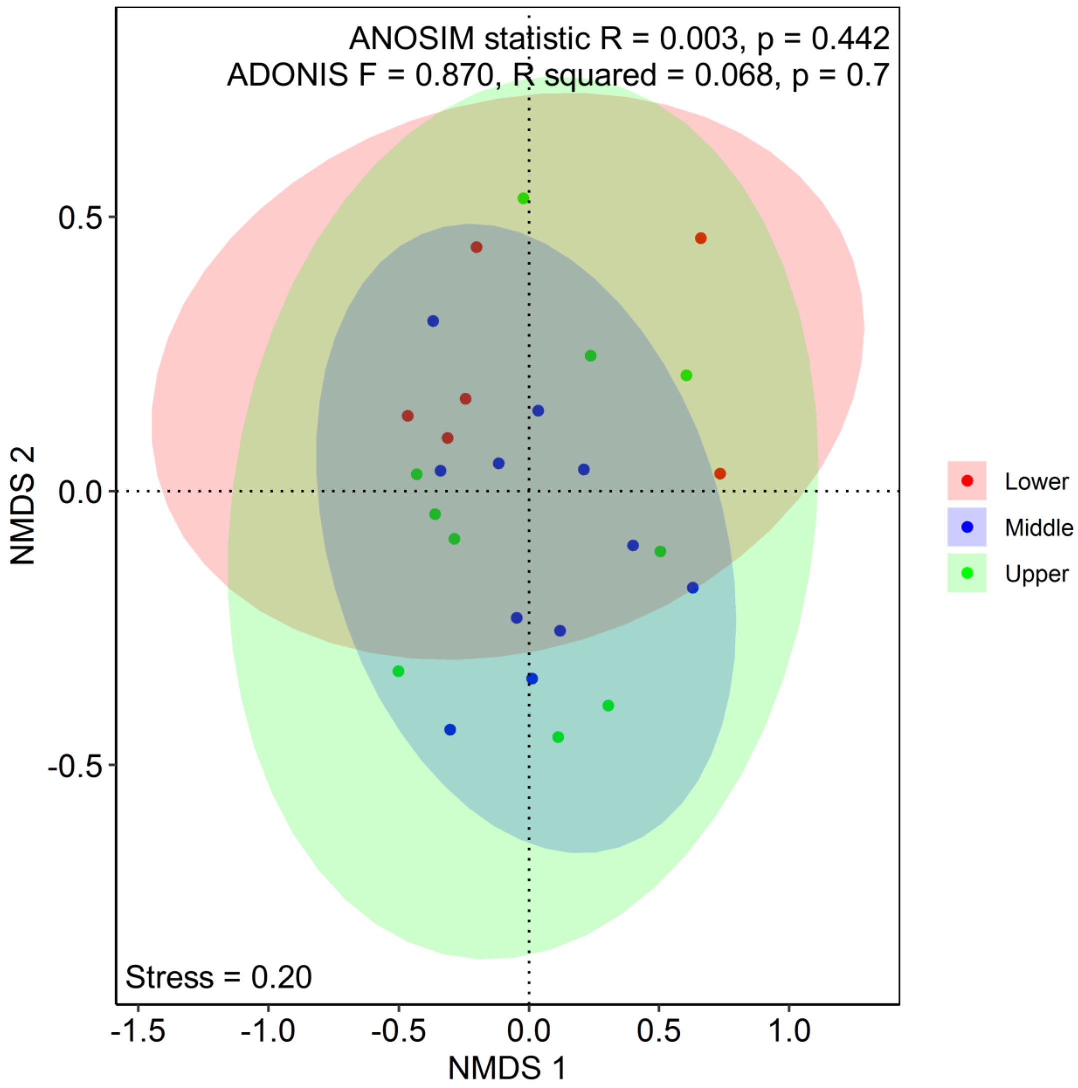


Figure 4.4: Non-metric multidimensional scaling (NMDS) ordination plot illustrating differences among upper, middle and lower zone. The ellipses represent standard deviations of the weighted average of NMDS scores for each zone.

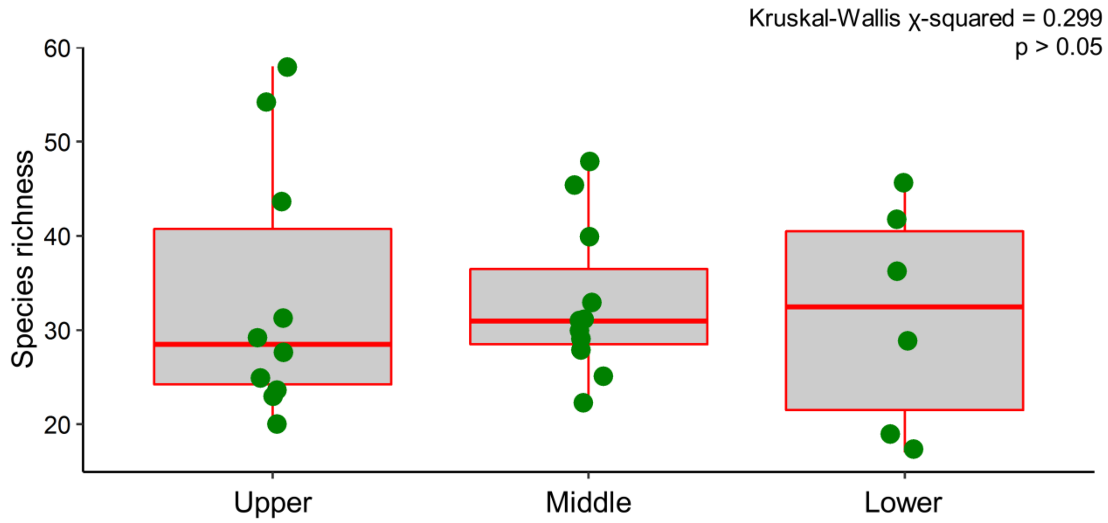


Figure 4.5: Comparative account of species richness between the upper, middle and lower zones.

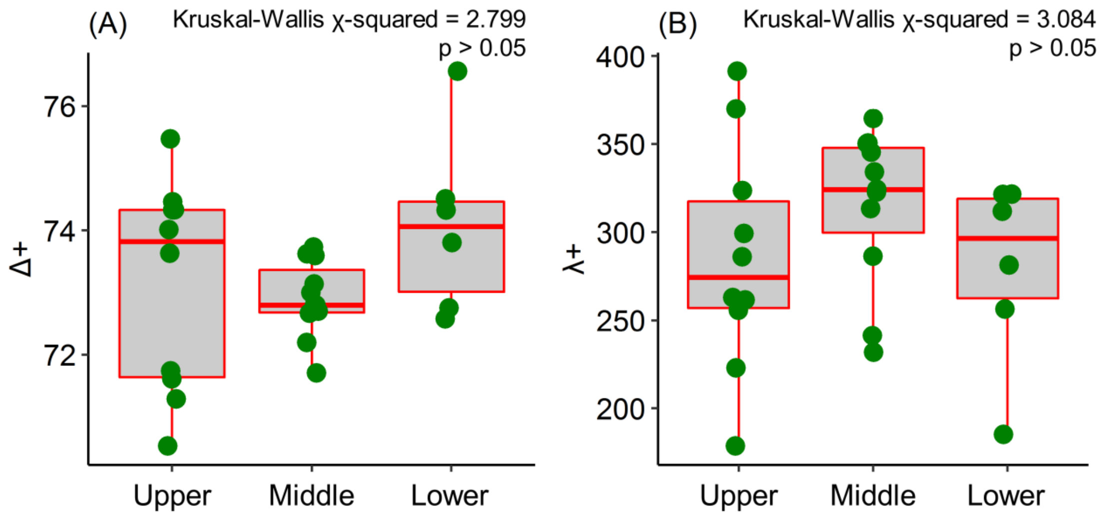


Figure 4.6: Comparative account of (A) index of taxonomic diversity (Δ^{+}) and (B) index of variation in taxonomic distinctness (λ^{+}) richness between the upper, middle and lower zones.

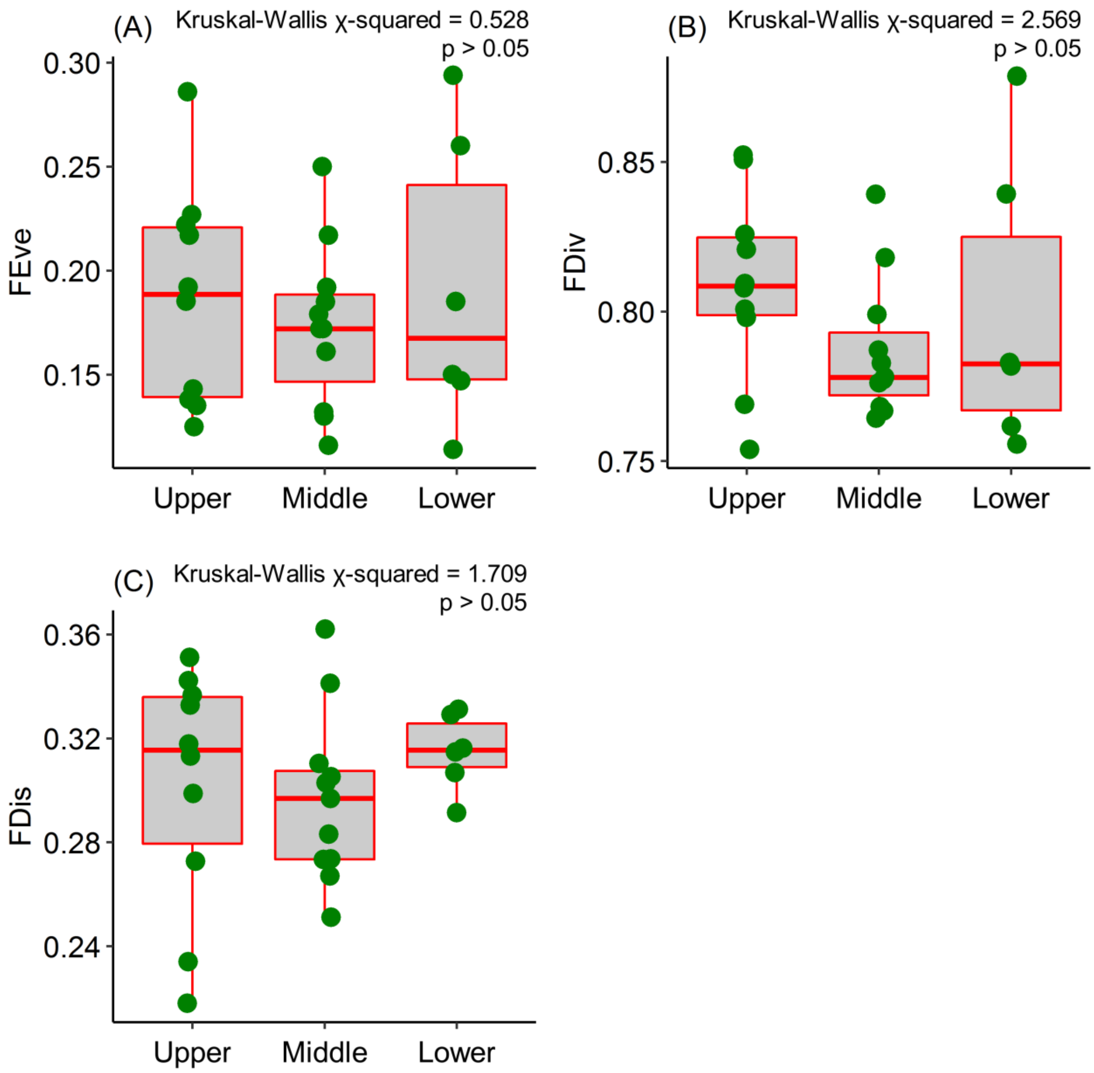


Figure 4.7: Comparative account of (A) functional evenness (FEve), (B) functional divergence (FDiv) and (C) functional dispersion (FDis) between the upper, middle and lower zones.

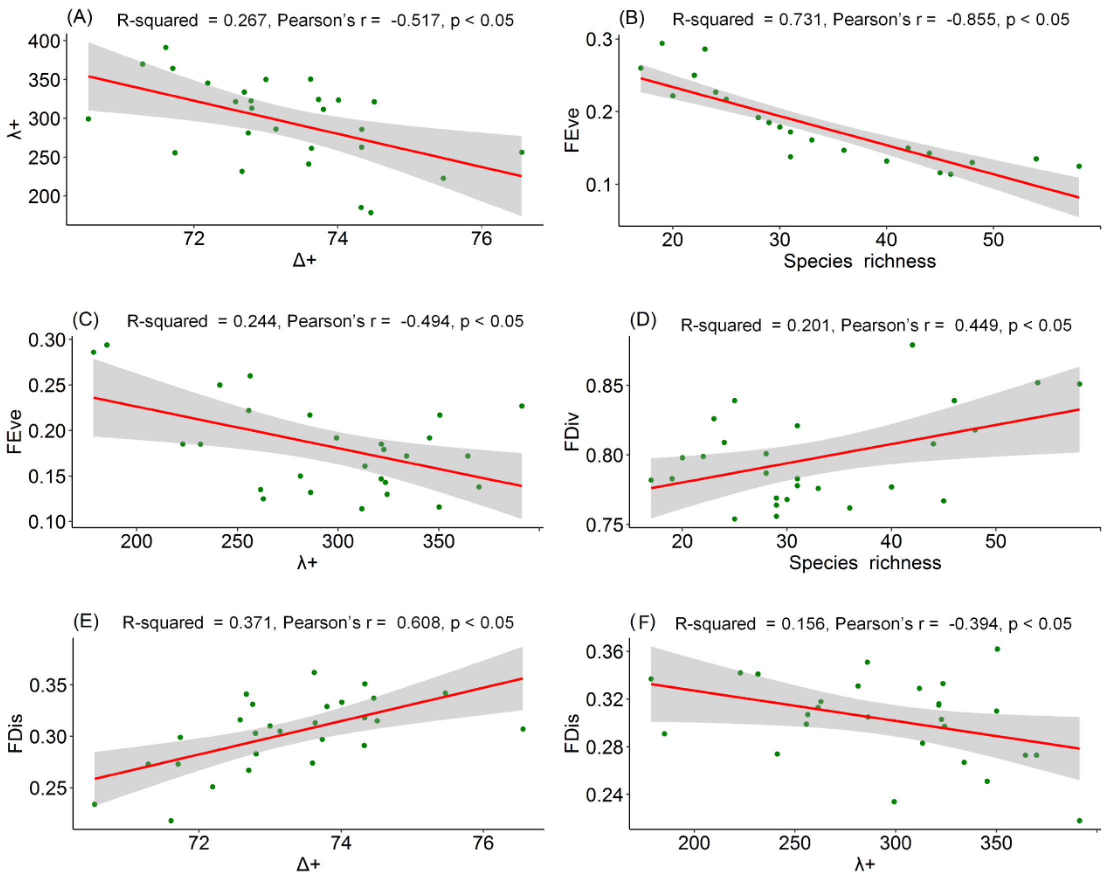


Figure 4.8: Linear relationship between (A) index of variation in taxonomic distinctness (λ^+) and index of taxonomic diversity (Δ^+), (B) between functional evenness (FEve) and species richness, (C) between functional evenness (FEve) and index of variation in taxonomic distinctness (λ^+), (D) between functional divergence (FDiv) and species richness, (E) between functional dispersion (FDis) and index of taxonomic diversity (Δ^+) and (F) between functional dispersion (FDis) and index of variation in taxonomic distinctness (λ^+).

CHAPTER 5

STRUCTURE OF BETA DIVERSITY OF SPIDER COMMUNITY

5.1 Introduction

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*". But, as a single value calculated for a given area, Whittaker's (1960, 1972) beta diversity (β_W) does not allow statistical comparisons of beta diversity between two or more areas (Anderson et al., 2006). For beta diversity studies, the dissimilarity (Jaccard) (D) of species composition can be decomposed into two components namely richness difference (RichDiff) and species replacement (Repl) (Podani and Schmera, 2011; Baselga, 2012; Podani et al., 2013). Species replacement (Repl, also called species turnover) refers to the fact that species tend to replace each other along ecological gradients that are sufficiently long and the replacement rate is also a function of the ecological tolerance, or niche breadth, of the species where richness difference (RichDiff) refers to the fact that one community may include a larger number of species than another which reflects the diversity of niches available at different locations along the sampling axis or throughout the study area (Legendre, 2014). Podani and Schmera (2011) and Podani et al. (2013) noted that the sum of similarity (S) and dissimilarity (D) is 1.

In summary, the relationship between dissimilarity (D), similarity (S), species replacement (Repl) and richness difference (RichDiff) are following –

Repl + RichDiff = D

1 – S = D

S + Repl + RichDiff = 1

Legendre and De Cáceres (2013) partitioned the beta diversity into local contribution to beta diversity (hereafter referred as LCBD) and species contribution to beta diversity (hereafter referred as SCBD). The LCBD is the uniqueness of the sampling units in terms of community composition and SCBD is the variation of individual species across the study area (Legendre and De Cáceres, 2013). The uniqueness in species composition of a site is indicated by the LCBD values and the influence of a species in the beta diversity within the studied region is indicated by the SCBD values (Legendre and De Cáceres 2013; Heino and Grönroos 2017; da Silva et al. 2018, Pozzobom et al., 2020).

A species may be common at global scale but it can be rare on a local scale (Flather and Sieg, 2007). Based on geographical range size, habitat specificity and local density (Rabinowitz, 1981) developed a typology of rarity and that was largely applied in conservation studies of plants (Broennimann et al., 2005), birds (Kattan, 1992; Manne and Pimm, 2001), mammals (Dobson and Yu, 1993) and vertebrates (Isaac et al., 2009). However, very few studies (Abellán et al., 2005, Fattorini, 2007 and 2010) were performed for the lesser-known taxa, such as invertebrates because of lack of data on the abundance and habitat specificity or difficulties in obtaining such data (Leroy et al., 2013). The process of setting conservation priorities for conservation at 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).

As a result of the studies over the past years, we have been able to gain some idea about the pattern of beta diversity of spider communities in several ecosystems. Foord and Dippenaar-Schoeman (2016) observed that the regional turnover of mountain spider community comes from the result of niche processes which suggests localized adaptation of taxa. Rodriguez-Artigas et al. (2016) found that the similarity between grassland spider communities declines with the increasing geographic distance between the sites. They also found that the spider community structure at a regional scale is influenced by the abiotic factors, stochastic events and differential dispersal capacity of different spider groups. Ávila et al. (2017, 2019) found that spider beta diversity has significant correlations with habitat structures in highland ponds and temporary wetlands. On subtropical land-bridge islands, beta diversity of spider community is determined by the dispersal difference (Wu et al., 2017). Zhang et al. (2018) found that in temperate forests the beta diversity structure of spider community is determined by niche specialization, along the environmental gradients and dispersal limitations. Carvalho et al. (2019) observed that in the forest spider communities the species assemblage variation was mainly determined by the species replacement. Gusmão et al. (2019) found that spider beta diversity is driven more by the inter-specific plant functional variation than the intra-specific variation. The geographical distance, size of the karst area and mean annual temperature are the factors which regulate the beta diversity pattern of European cave-dwelling spiders (Mammola et al., 2019). Pitta et al. (2019) found that across different Mediterranean habitat types, the climatic factors play significant role to shape beta diversity of spider community.

All over the world, the freshwater habitats are facing various threats such as overexploitation of biotic resources, invasion of exotic species, water flow regulation through construction of dams and reservoirs, , uncontrolled extraction of water, organic and inorganic pollution from agricultural, industrial and domestic sources and climate change (Dudgeon et al., 2006, Collen et al., 2014, Strayer and Dudgeon, 2010, Vörösmarty et al., 2010). Through some recent studies scientists have seen that the fresh water ecosystem of the Ganga river is intimidated by overexploitation of resouces, pollution, riverbed mining, physical barriers, change of land use pattern and climate change (Siddiqui and Pandey, 2019; Singh and Singh, 2019, Kamboj and Kamboj, 2019; Dey et al., 2020, Jain and Singh, 2020, Paudel and Koprowski, 2020, Sah et al., 2020, Santy et al., 2020, Verma et al., 2020). All these studies indicate that it is very important to have a thorough knowledge of 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 beta diversity pattern of plants and animals in the Ganga river.

With this background, the study was performed to understand the pattern and relationship of beta diversity and rarity of spider community of the riparian habitat of the Ganga river.

5.2 Statistical analysis

The Jaccard dissimilarity (D), species replacement (Repl) and richness difference (RichDiff) between each pair of sites were calculated using the R package ‘*adespatial*’ (Dray et al., 2019). The triangular diagram called SDR-simplex plot (Podani and Schmera, 2011 and Podani et al., 2013) was prepared to graphically represent the similarity (S), richness difference (RichDiff) and species replacement (Repl) using the R package ‘*ggtern*’ (Hamilton and Ferry, 2018).

The LCBD values for each site and SCBD values for each species (Appendix 5) were calculated after using Hellinger-transformation (Legendre and De Cáceres, 2013) by the R package ‘*adespatial*’ (Dray et al., 2019). The index of rarity values (Leroy et al., 2013) for each species were calculated with the R package ‘*Rarity*’ (Leroy, 2016).

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

Both first order term (straight line response) and the second order term (curvilinear response) (Pozzobom et al., 2020) were used to find the relationship between SCBD and 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 and used 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 includes 35 species from 3 families namely Araneidae, Tetragnathidae and Uloboridae; ‘ground hunters’ which includes 7 species from 4 families namely Corinnidae, Gnaphosidae, Lycosidae and Oonopidae and ‘other hunters’ which includes 23 species from 4 families namely Oxyopidae, Philodromidae, Salticidae, Scytodidae and Sparassidae. Only three guilds were chosen because number of species in those guilds was relatively higher than the rests. For identification of ecological guilds, work by Cardoso et al. (2011) was followed.

The *R language and environment for statistical computing* (R Core Team, 2020) was used for all statistical and ecological analysis.

5.3 Results

From result of SDR simplex plot (Figure 5.1), it was found that the mean species replacement (Repl = 0.381) was higher than the mean similarity (S = 0.372) and mean richness difference (RichDiff = 0.242). The maximum variation occurred in the richness difference (RichDiff) (SD = 0.158) than species replacement (Repl) (SD = 0.141) and similarity (S) (SD = 0.092) across the entire stretch.

Low levels of species richness and LCBD in the middle segment of the Ganga river (Figure 5.2) was noticed.

The mean value of LCBD was 0.486 (SD 0.341) per site (Figure 5.3). The local contribution to beta diversity (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, $p > 0.05$) (Figure 5.4, A and B).

It was found that the spider species with higher SCBD values had intermediate occupancy between 9 and 18 sites for all species (Figure 5.5, A and B), between 11 and 18 sites for 'orb web weaver' species (Figure 5.6A and 5.6B), between 10 and 20 sites for 'ground hunters' species (Figure 5.7) and between 7 and 19 sites for 'other hunters' species (Figure 5.8).

For all spider species, both of the first order term (straight line response) (R^2 = 0.132) and the second order term (curvilinear response) (R^2 = 0.918) between SCBD and number of sites occupied by each species were significant but the first order term (straight line response) had lower AIC value (-593.97) then the second order term (curvilinear response) model (AIC = -777.89) (Table 5.1, Figure 5A and 5B).

For spider species under the orb web weaver guild, both of the first order term (straight line response) (R^2 = 0.765) and the second order term (curvilinear response) (R^2 = 0.939) between SCBD and number of sites occupied by each species were significant but the first order term (straight line response) had lower AIC value (-324.32) then the second order term (curvilinear response) model (AIC = -369.49) (Table 5.1, Figure 6A and 6B). For spider species under the ground hunter guild, the first order term (straight line response) model between SCBD and number of sites occupied by each species was not significant but the second order term (curvilinear response) between SCBD and number of sites occupied by each species was significant (R^2 = 0.951) (Table 5.1, Figure 5.7). For spider species under the 'other hunters' guild, the first order term (straight line response) model between SCBD and number of sites occupied by each species was not significant but the second order term (curvilinear response) between SCBD and number of sites occupied by each species was significant (R^2 = 0.863) (Table 5.1, Figure 5.8).

For all spider species, both of the first order term (straight line response) (R^2 = 0.495) and the second order term (curvilinear response) (R^2 = 0.544) between SCBD and index of rarity were significant but the first order term (straight line response) had lower AIC value (-636.80) then the second order term (curvilinear response) model (AIC = -642.92) (Table 5.2, Figure 5.9A and 5.9B). For spider species under the orb web weaver guild, both of the first order term (straight line response) (R^2 = 0.607) and the second order term (curvilinear response) (R^2 = 0.745) between SCBD and index of rarity were significant but the first order term (straight line response) had lower AIC value (-306.339) then the second order term (curvilinear response) model (AIC = -319.418) (Table 5.2, Figure 5.10A and 5.10B). For spider species under the ground hunter guild, both of the first order term (straight line response) and the second order term (curvilinear response) between SCBD and index of rarity were not significant. For spider species under the 'other hunters' guild, both of the first order term (straight line response) (R^2 = 0.540) and the second order term (curvilinear response) (R^2 = 0.579) between SCBD and index of rarity were significant but the first order term (straight line response) had lower AIC value (-184.47) then the second order term (curvilinear response) model (AIC = -184.50) (Table 5.2, Figure 5.11A and 5.11B).

5.4 Discussion

To manage freshwater ecosystems, understanding of components and patterns of beta diversity is very important (Fernández-Aláez et al., 2020). When available resources are limited, scientists should prioritize the conservation efforts strategically to get most of the benefits (Dubois et al., 2020). The valuable information about the unique contribution of some hotspots to the biodiversity at regional scale is provided by the spatial variation of species compositions (Wiersma and Urban, 2005; Socolar et al., 2016; Dubois et al., 2020).

The SDR simplex method indicated that the spider community was structured with 37.6% similarity (S) and 62.4% dissimilarity (D). This dissimilarity included 38.1% species replacement (Repl) and 24.2% richness difference (RichDiff). This higher value of dissimilarity (D) than similarity (S) indicated that the spider species composition in different sites of the Ganga river had a less common portion. The species replacement (Repl) component of beta diversity is more influential in shaping spider community of Ganga river than the richness difference (RichDiff) and similarity (S) because of its higher value then the rest two components.

Legendre and De Cáceres, 2013 said that, the relationship between species richness and local contribution to beta diversity (LCBD) is never necessarily positive or negative. Some researches mentioned a negative relationship between species richness and local contribution to beta diversity (LCBD) such as work by Mimouni et al., 2015 (for zooplankton communities), Qiao et al., 2015 (for plant species in subtropical forest), Landeiro et al., 2018 (for multiple taxonomic groups including both plants and animals), Heino and Grönroos, 2017 (for aquatic insects), Vilmi et al. 2017 (for diatoms) and Dubois et al., 2020 (for plant communities of lake edge wetlands). The positive relationship between species richness and local contribution to beta diversity (LCBD) was mentioned by Kong et al. (2017) for fish and no relationship was found by Pozzobom et al. (2020) for aquatic macrophytes. In this study, significant positive relationship was found between species richness and local contribution to beta diversity (LCBD) values. In very few works mentioned negative relationships between rare species richness and local contribution to beta diversity (LCBD) such as work by Qiao et al. (2015) for plant species in subtropical forest, Dubois et al. (2020) for plant communities of lake edge wetlands and Pozzobom et al. (2020) for aquatic macrophytes. In this study, any significant relationship between rare species richness and local contribution to beta diversity (LCBD) values was not observed.

Mixed results were observed in determining the relationship between the SCBD and number of sites occupied by each species. When all the species were analyzed together, it was found that this relationship was significant for both the first order term (straight line response) and the second order term (curvilinear response) but the value of the AIC was less for the first order term (straight line response) then the second order term (curvilinear response), although the value of R^2 is lower for the first order term (straight line response) then the second order term (curvilinear response). In the case of orb web weaver spiders, similar result was noticed. 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, it was noticed that the first order term (straight line response) was not significant but the second order term (curvilinear response) was significant.

In the case of relationship between SCBD and index of rarity, the similar phenomenon was noticed in all cases except ‘ground hunter’ spiders. For ‘ground hunter’ spiders both of the first order term (straight line response) and the second order term (curvilinear response) were not significant. But for ‘orb web weaver’ spiders, ‘other hunter’ spiders and for all the species of spiders, the relationship between SCBD and index of rarity were significant. For all of these cases the value of R^2 is lower for the first order term (straight line response) then the second order term (curvilinear response) but AIC value was higher for second order term (curvilinear response) then the order term (straight line response).

This is the first work in any Indian river where the beta diversity of spider community is studied. Since the natural environment is always changing and our ideas about diversity and distribution pattern of plants and animals are limited but always evolving, particularly the case of invertebrates, with the increase of information and knowledge about any species, the change in conservation category takes place (Abellán et al., 2005). This work on spider community should be considered as the first step in the process of understanding the spatial variation of riparian biota of the Ganga river which should be iterated with the help of new information, not only in the case of spiders but also in all other species of plants and animals.

Table 5.1: Model statistics evaluating the relationships between species contributions to beta diversity (SCBD) and number of sites occupied by each species

SITES	R^2	p	AIC
All spider species			
First order term (straight line response)	0.132	0.00102	-593.97
Second order term (curvilinear response)	0.918	2.2×10^{-16}	-777.89
'Orb web weaver' spiders			
First order term (straight line response)	0.765	6.57×10^{-12}	-324.32
Second order term (curvilinear response)	0.939	2.2×10^{-16}	-369.49
'Ground hunters' spiders			
First order term (straight line response)	0.002	0.913	-44.75
Second order term (curvilinear response)	0.951	0.002	-63.85
'Other hunters' spiders			
First order term (straight line response)	0.135	0.084	-169.94
Second order term (curvilinear response)	0.863	2.327×10^{-9}	-210.32

Table 5.2: Model statistics evaluating the relationships between species contributions to beta diversity (SCBD) and index of rarity for each species

RARITY	R^2	p	AIC
All spider species			
First order term (straight line response)	0.495	4.81×10^{-13}	-636.80
Second order term (curvilinear response)	0.544	1.07×10^{-13}	-642.92
'Orb web weaver' spiders			
First order term (straight line response)	0.607	3.508×10^{-8}	-306.34
Second order term (curvilinear response)	0.745	3.267×10^{-10}	-319.42
'Ground hunters' spiders			
First order term (straight line response)	0.424	0.113	-48.59
Second order term (curvilinear response)	0.492	0.258	-47.47
'Other hunters' spiders			
First order term (straight line response)	0.540	6.467×10^{-5}	-184.47
Second order term (curvilinear response)	0.579	0.0002	-184.50

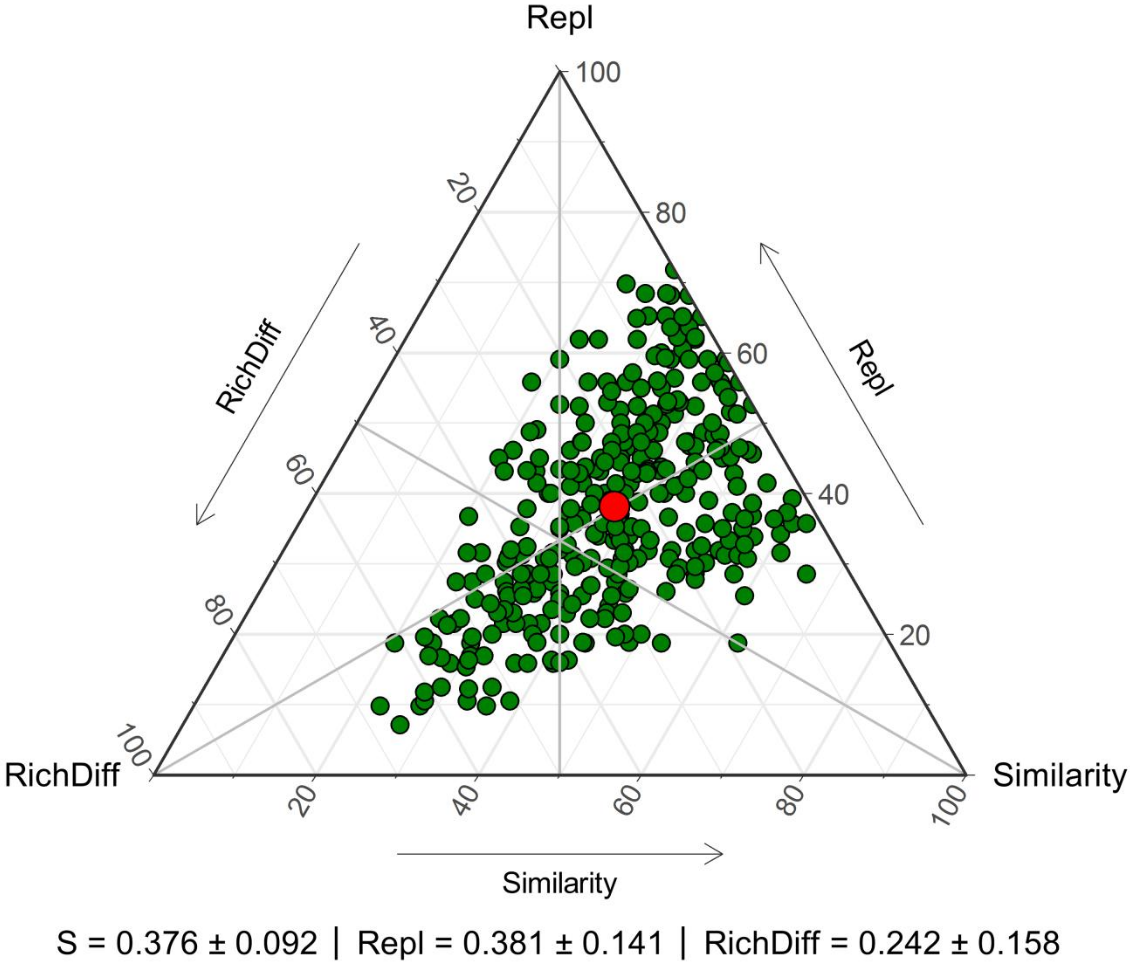


Figure 5.1: SDR simplex plots for beta-diversity using Jaccard dissimilarity (D) index. Green dots represent site pairs for the stretch. Big dot in red colour depicts position of mean values of Similarity (S), richness difference (RichDiff) and species replacement (Repl).

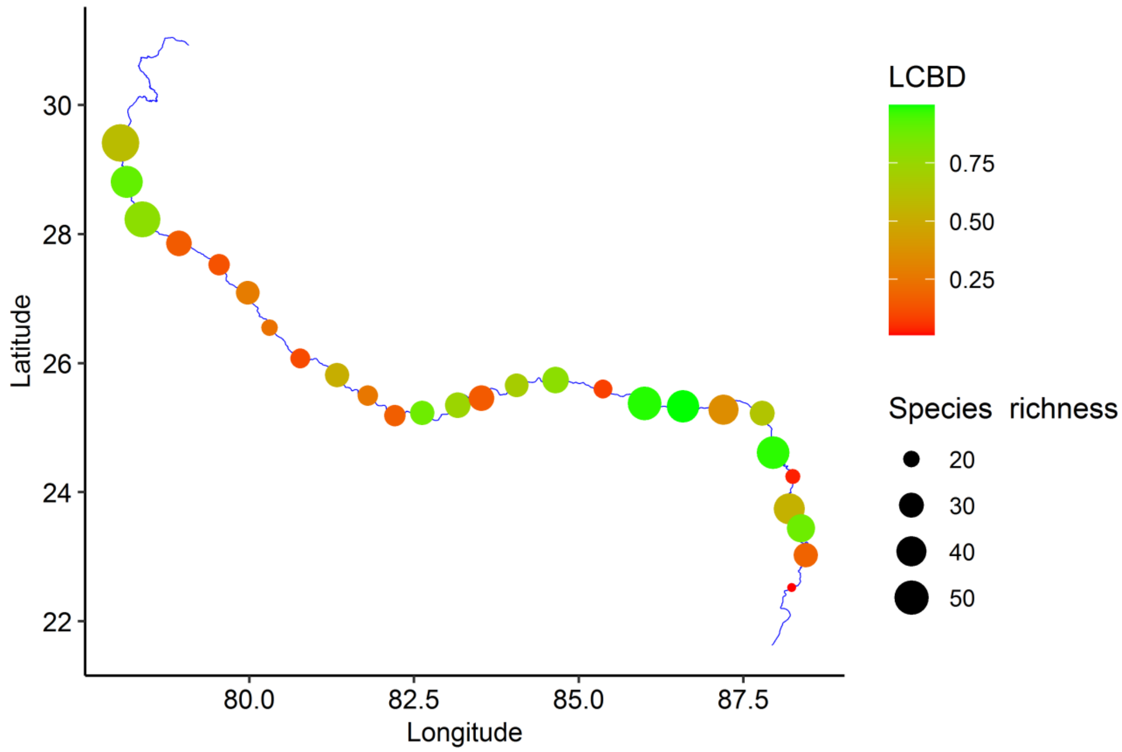


Figure 5.2: The map showing species richness and local contribution to beta diversity (LCBD) in 27 sites (represented by the bubbles) across the Ganga river. The size and shade of each bubble is proportional to the species richness and local contribution to beta diversity (LCBD), respectively.

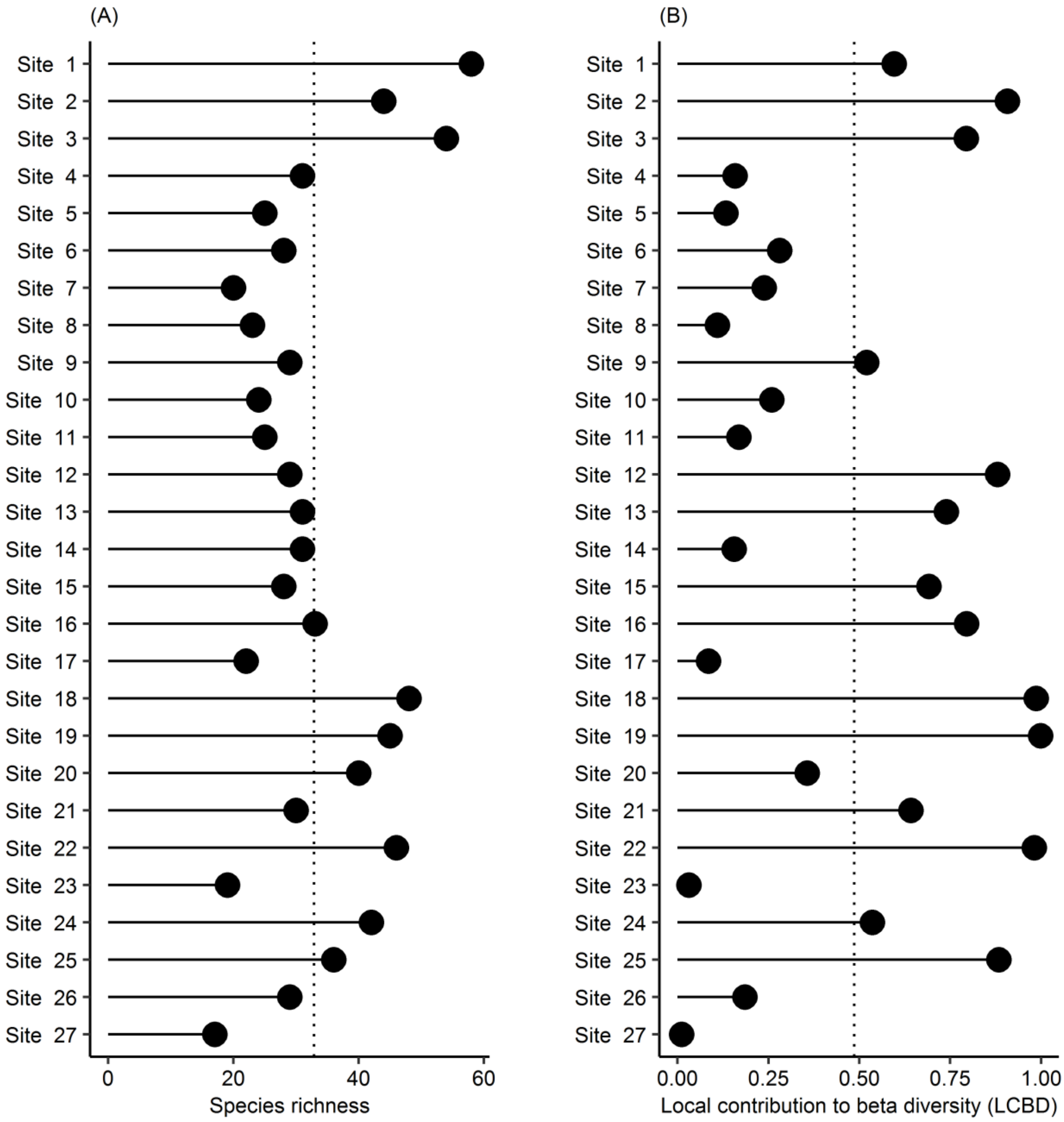


Figure 5.3: Comparative account of (A) species richness and (B) local contribution to beta diversity (LCBD) in 27 sites of the Ganga river. The dotted vertical line represents mean value.

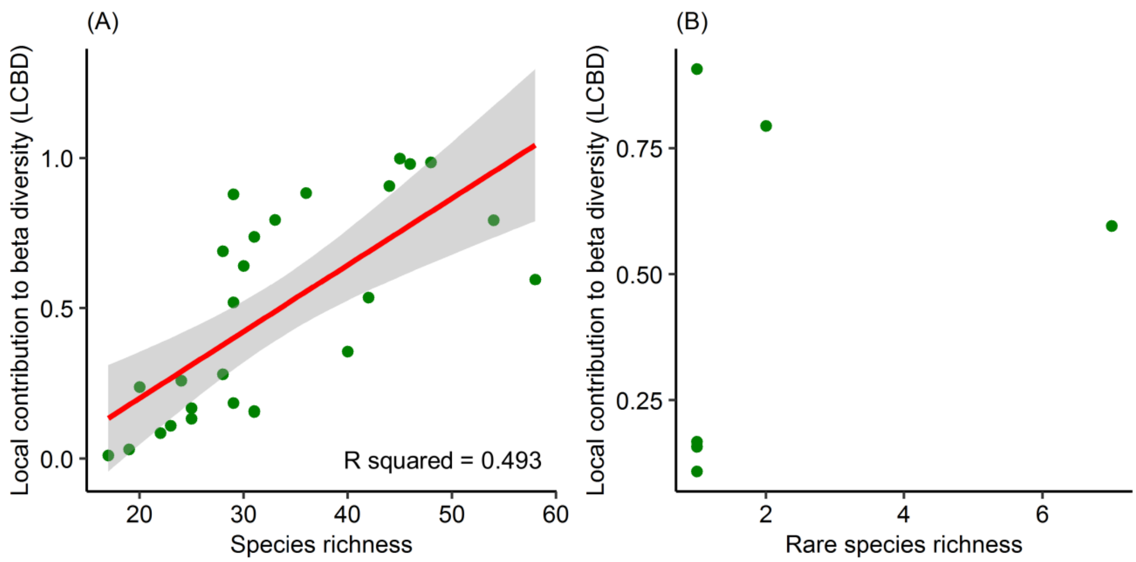


Figure 5.4: Relationship between local contribution to beta diversity (LCBD) and species richness (A) and number of rare species richness (B) for spiders.

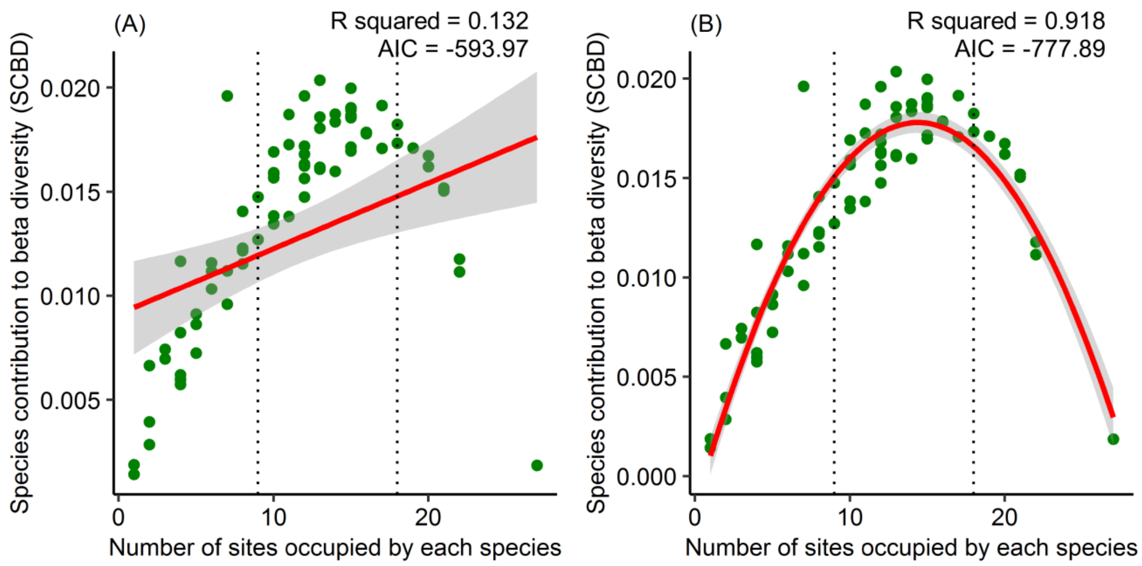


Figure 5.5: (A) First order term (straight line response) and (B) second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by all species.

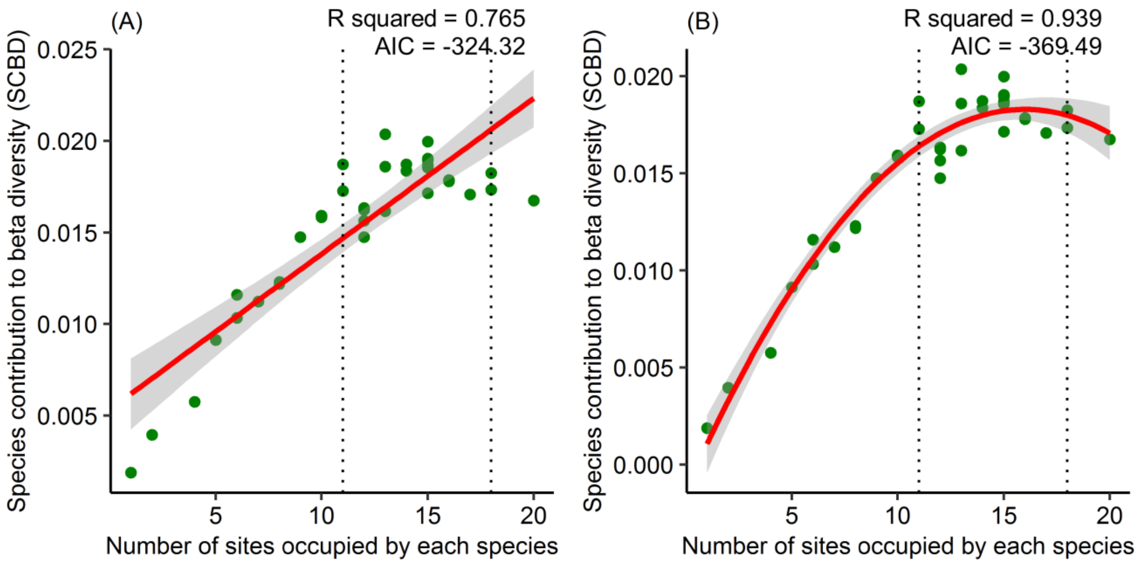


Figure 5.6: (A) First order term (straight line response) and (B) second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by 'orb web weaver' spider species.

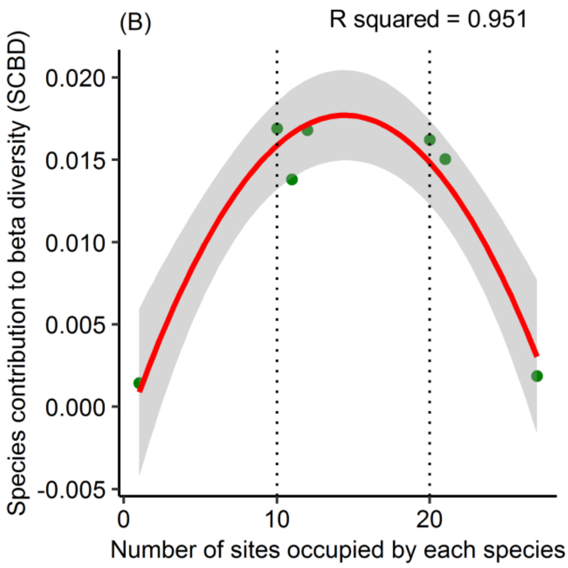


Figure 5.7: Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by 'ground hunters' spider species.

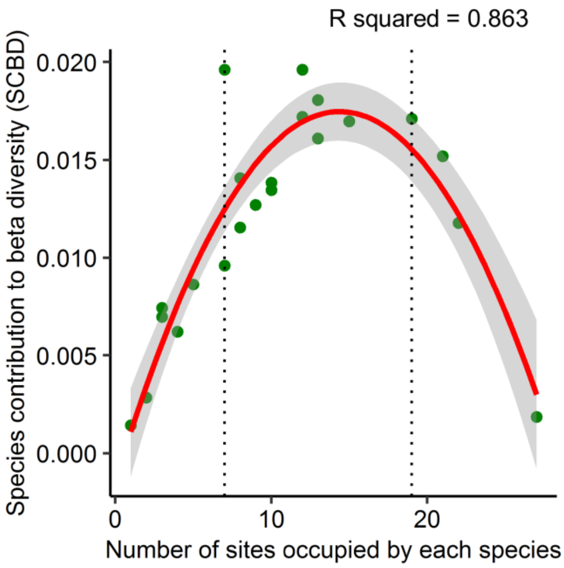


Figure 5.8: Second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and number of sites occupied by 'other hunters' spider species.

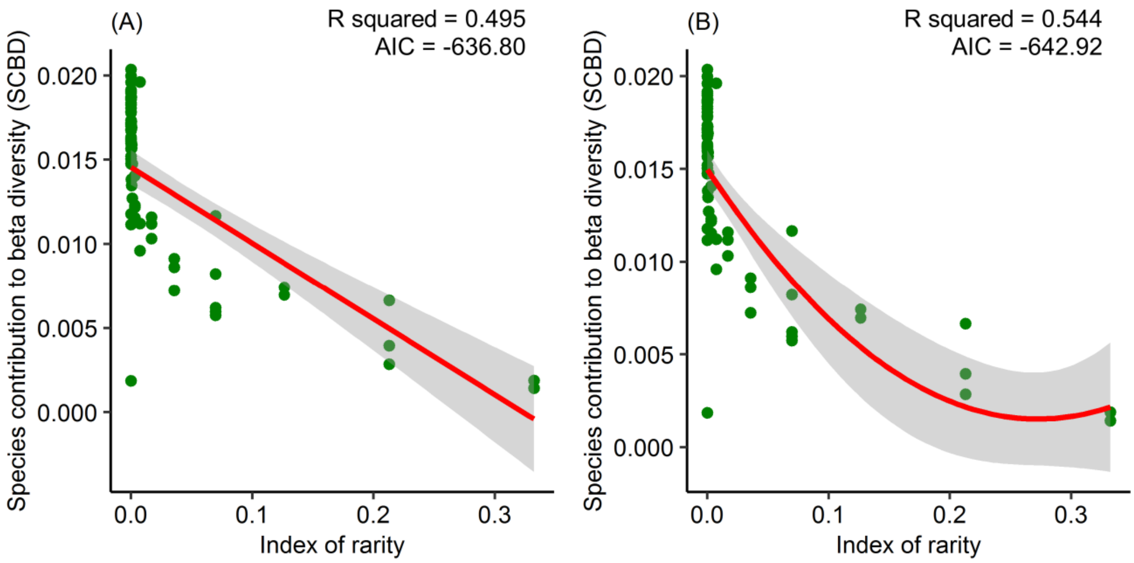


Figure 5.9: (A) First order term (straight line response) and (B) second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and index of rarity of all species.

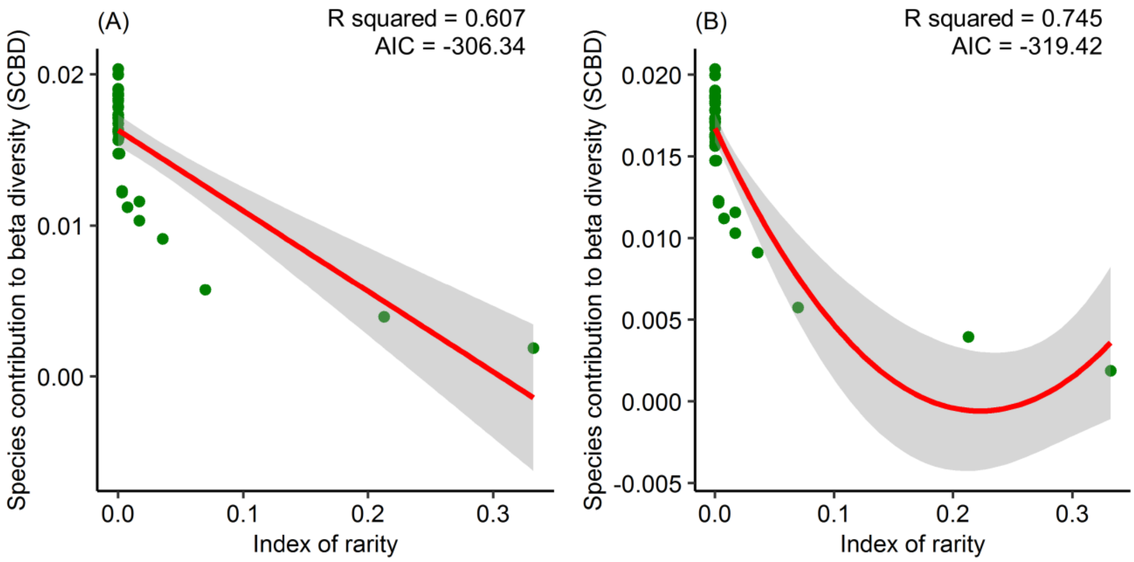


Figure 5.10: (A) First order term (straight line response) and (B) second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and index of rarity of 'orb web weaver' spider species.

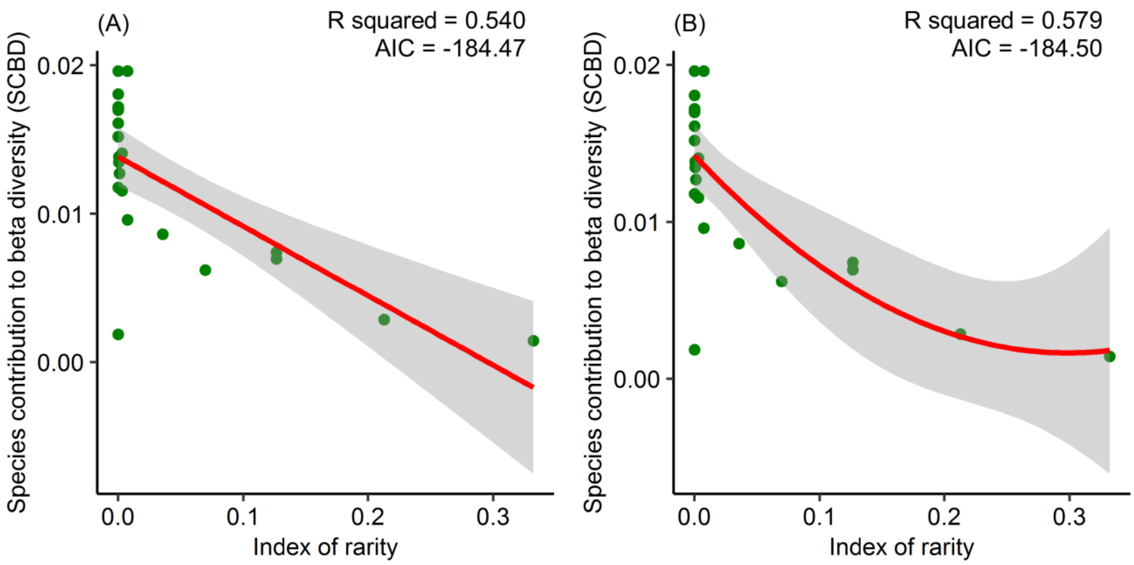


Figure 5.11: (A) First order term (straight line response) and (B) second order term (curvilinear response) relationship between species contribution to beta diversity (SCBD) and index of rarity of 'other hunters' spider species.

CHAPTER 6

SPIDERS AS BIO-INDICATORS OF HABITAT DISTURBANCE

6.1 Introduction

Bioindicators are functional groups or taxa that mirror the state of the habitat (Lencinas et al. 2015) as environmental indicators (by indicating any local environmental changes) or as ecological indicators (by the response to the specific ecosystem stress) or biodiversity indicators (by indicating the taxonomic diversity levels of a site) (McGeoch 1998; 2007). Jenkins (1971) and Spellerberg (1991) divided bioindicators in to detectors (decrease with increase in environmental stress), exploiters (increase with increase in environmental stress) and accumulators (they can be utilized to measure levels of toxins as they take up such chemicals). By using adapted, resident and widespread species, the biomonitoring programs represent simple yet basic contributions to environmental management and environmental risk assessment (Conti et al., 2018). For prioritization of conservation actions, the bioindicators are utilized for spatial comparisons between sites, or ecosystem recovery monitoring or to study their response to the decisions (Peri et al. 2016; Schwerdt et al, 2018).

Among the arthropods, spiders are one of the most well-known and diversified group, they have a cosmopolitan distribution and they occupy different ecological niches, they have the capacity of exploration and adaptation to various ecological conditions, they show quick responses to the disturbances, they are sensitive to the changes in environmental conditions, local management practices and landscape composition and in the quantity or quality of resources and are relatively easy to sample. For having all these features, Spiders worldwide are considered to be bio-indicators (Pearce and Venier 2006; Mader et al. 2016; Schwerdt et al., 2018). In recent years, the spiders are successfully used as bioindicators for air pollution (Rachwał et al., 2018; Rutkowski et al., 2018), different agricultural practices, climatic conditions, or various cultivars grown (Radkova et al., 2019), disturbances of stream ecosystems (Reyes-Maldonado et al., 2017), effect of the canopy openness gradient on biodiversity conservation (Košulič et al., 2016), forest restoration (Borchard, 2014), grazing effects (Kaltsas et al., 2019), the ground of the central and peripheral area of olive agroecosystem (Benhadi-Marín et al., 2019), the health of natural grasslands (Schwerdt et al., 2018), heavy metal contamination (Yang et al., 2016; Conti et al., 2018, Hansson et al., 2019), low anthropogenic intervention (Rosa et al., 2019) and management strategies in fruit orchards (Mazzia et al., 2015).

The freshwater ecosystems are facing various adversities all over the world such as flow modifications by the construction of dams and reservoirs, overexploitation of biotic resources, unlimited extraction of water, invasion of exotic species, organic and inorganic pollution from agricultural, industrial and domestic sources and changes in climatic conditions (Dudgeon et al., 2006, Collen et al., 2014, Strayer and Dudgeon, 2010, Vörösmarty et al., 2010). Scientists have seen through some recent studies (Siddiqui and Pandey, 2019; Singh and Singh, 2019, Kamboj and Kamboj, 2019; Dey et al., 2020, Jain and Singh, 2020, Paudel and Koprowski, 2020, Sah et al., 2020, Santy et al., 2020, Verma et al., 2020), that the freshwater ecosystem of the Ganga river is intimidated by overexploitation, pollution, riverbed mining, physical barriers, change of land use pattern and climate change. But, as these types of works are labour intensive, time-consuming and costly, there is a great need for ecological indicators for the Ganga river to know the state of the ecosystem in a short time at low cost. But, so far no research has been done to find out any invertebrate taxa for bioindicator of habitat quality of riparian zones of the Ganga river.

With this background, I carried out the present work by integrating IndVal analysis (Dufrêne and Legendre, 1997) and rarity index analysis (Leroy et al., 2013) to find out least rare yet most significant bioindicator spider taxa for undisturbed habitat for Gnagetic riparian zones.

6.2 Statistical analysis

Total nine types of disturbances across 27 study sites were recognized. These were agriculture, boats, effluent discharge, garbage dump, ghats, grazing, human settlement, manmade embankment and sand mining. By following Gezie et al. (2017), score of 1 was assigned for any or minimum disturbance (if we got disturbances in 0 - 5 quadrates), 2 for moderate (if we got disturbances in 5 - 10 quadrates), and 3 for high disturbance (if we got disturbances in 10 - 15 quadrates). The overall disturbance of each site was calculated by adding individual values (a total of nine different factors).

The overall disturbance score was ranged from 9 to 22. Based on this disturbance scores, the sites were classified into five groups, namely very low disturbed sites (disturbance score up to 11), low disturbed sites (disturbance score between 12 to 14), moderately disturbed sites (disturbance score between 15 to 17), highly disturbed sites (disturbance score between 18 to 20) and very highly disturbed sites (disturbance score more than 20) (Appendix 6).

The non-parametric analysis of similarities (ANOSIM) test (Clarke, 1993) was used to compare the mean of ranked dissimilarities (with Jaccard distance) of species compositions between five groups of disturbed sites. The non-parametric permutational multivariate analysis of variance (PERMANOVA) (Anderson, 2001) test was used to compare species compositions between five groups of disturbed sites. To facilitate interpretation of the results of ANOSIM and PERMANOVA, the non-metric multidimensional scaling (NMDS) based on spider species composition (with Jaccard distances) of the sites was performed.

To investigate the relationship between spider distribution matrix and habitat disturbance, the redundancy analysis (RDA) was performed. To assess the significance of constraints, permutation test (with 999 permutations) was performed using both direct model (which permutes community data) and reduced model (which permutes residuals of the community data). The automatic backward stepwise model with 999 permutations was used to know which disturbance affected spider distribution in RDA ordination space. Prior to analysis all data of habitat disturbance and species richness was normalized (mean = 0 and SD = 1) (Miyazono & Taylor 2013; Datry et al. 2016). Then, the significant ($p < 0.05$) indicator value (IndVal: Dufrêne and Legendre 1997) and and rarity index analysis (Leroy et al., 2013) for each species was calculated. The Spearman's rank correlation, which is a distribution free and nonparametric statistical measurement of the strength and the direction of the arbitrary monotonic association between two variables (Xiao et al., 2015) was used to find out relationship between IndVal and rarity index.

For analysis of similarities (ANOSIM), permutational multivariate analysis of variance (PERMANOVA) and non-metric multi-dimensional scaling (NMDS) the R package '*vegan*' (Oksanen et al., 2019) was used. To find out best disturbance combination that affected the species richness of the spider community, the R package

‘MuMIn’ (Barton 2020) was used. To find out indicator value for each species the R package ‘labdsv’ package (Roberts 2019) was used. To calculate rarity index for each species the R package ‘Rarity’ (Leroy, 2016) was used. The *R language and environment for statistical computing* (R Core Team, 2020) was used for the statistical analysis.

6.3 Results

Six sites (1, 2, 3, 18, 19 and 22) were found as very low disturbed, seven sites (4, 13, 14, 16, 20, 24 and 25) as low disturbed, four sites (9, 12, 21 and 26) as moderately disturbed, six sites as highly disturbed (5, 6, 8, 10, 11 and 15) and four sites (7, 17, 23 and 27) as very highly disturbed (Figure 6.1).

By non-parametric analysis of similarities (ANOSIM) test it was found that there was significant difference in mean of ranked dissimilarities between the spider communities in five groups of disturbed sites (ANOSIM statistic R = 0.3709, p = 0.001). By non-parametric permutational multivariate analysis of variance (PERMANOVA) test it was found that there was significant difference in species composition between the spider communities in five groups of disturbed sites (ADONIS, F = 2.219, R^2 = 0.287, p = 0.001). By NMDS plot (Figure 6.2) it was found that had the groups of disturbed sites with similar species composition overlap with each other, but very low disturbed sites and very highly disturbed sites did not overlap indicating differences in species composition between them.

It was found that the permutation test for RDA under direct model (F = 1.421, p = 0.002) and reduced model (F = 1.421, p = 0.004) were significant. The variance of the RDA biplot (Figure 6.3) of spider metrics and habitat disturbance based on the first two axes explained 55.10% of the variance. Axes 1 and 2 explained 40.94% and 14.16% of the variation in spider assemblages, respectively. This first axis was positively correlated with the entire habitat disturbances; the second axis was positively correlated with boats, manmade embankment, garbage dump, effluent discharge, ghats and human settlement but negatively correlated with grazing, agriculture and sand mining. The automatic backward stepwise model resulted in 8 steps and it was found that the human settlement and sand mining had significant ($p < 0.05$) affect on the spider distribution in RDA ordination space (Table 6.1).

From the multiple linear regression (Table 6.2), it was found that the agriculture, human settlement and sand mining had significant ($p < 0.05$) negative impact on the species richness of the spiders. It was found that the agriculture, human settlement, manmade embankment and sand mining were the best disturbance combination (Table 6.3) that affected the species richness of the spider community.

By IndVal analysis *Agelena* sp., *Brignolia* sp., *Carrhotus* sp., *Cyclosa insulana, Epeus indicus, Hasarius adansoni, Hippasa lycosina, Hyllus* sp., *Neoscona nautical, Perenethis venusta, Rhene flavicomans, Thwaitesia* sp., and *Zosis geniculata* were found as indicator of very low disturbed sites; and *Nihonhimea indica* was found as indicator of low disturbed sites (Table 6.4).

It was found that the IndVal and Rarity index had significant Spearman's rank correlation ($\sigma = 0.670$, $p = 0.008$).

6.4 Discussion

The spider communities of riparian ecosystem include varieties of taxa with a large variation in hunting techniques that respond differently to prey availability and spatial structure, which, in turn make them responsible to represent overall view of both both the riparian and aquatic habitats of the condition of riverine ecosystem (Reyes-Maldonado et al., 2017).

It was found that out of all the disturbances, the four most important factors were agriculture, human settlement, manmade embankment and sand mining which affected the species richness of spider species and two disturbances namely, human settlements and sand mining affected the distribution pattern of the spider community.

Through this work, a total of 14 species of spiders were identified as bioindicators, of these, 13 species were indicator of very low disturbed sites and one species was indicator of low disturbed sites. But there is a difference between the rarities of these spider species. The spider species with the low rarity value should be considered because an indicator species whose presence determines the status of the habitat should be available readily. Aisen et al., (2017) suggested that the species with IndVal values less than 0.70 should be considered as detector indicator species of any habitat condition.

Geographically any river is an ever-changing entity because the rainfall, temperature, amount of forest and the nature of the land-use affect the river hydrology and in many cases it is seasonal and this change is accompanied by changes in the river-dependent biota. Prolonged bio-monitoring on a long river like the Ganga is a daunting task for any scientific body. For this, we have to rely on the people living on the banks of the river and depend on the river for their livelihood. We should identify such animals and plants as bio-indicators which are readily available and can be easily identified by them so that they can present any visible change in an area to the scientists. This is an initial work on the bio-indicator spider identification for the Ganga river. As a single taxon cannot indicates overall biodiversity or environmental conditions (Lehmitz et al., 2020), It is expected that river researchers will study the bio-indicator capacity of all types of plants and animals living in the water and on the banks of the Ganga river and present new information for effective conservation, restoration and management of this freshwater ecosystem.

Table 6.1: Result of automatic backward stepwise model

Variables	Model statistics		
Step1	AIC	F	p value
Ghats	75.813	0.7058	0.866
Garbage dump	75.909	0.7692	0.787
Manmade embankment	76.087	0.8867	0.602
Agriculture	76.196	0.9589	0.502
Effluent discharge	76.175	0.9449	0.494
Grazing	76.217	0.9728	0.475
Human settlement	76.381	1.0825	0.307
Boats	76.715	1.3077	0.137
Sand mining	77.053	1.5383	**0.049**
Step 2	AIC	F	p value
Garbage dump	74.967	0.7862	0.786
Grazing	75.248	0.9827	0.453
Agriculture	75.305	1.0226	0.385
Effluent discharge	75.35	1.0548	0.338
Manmade embankment	75.558	1.2019	0.177
Boats	75.696	1.3004	0.133
Human settlement	75.883	1.4341	0.080
Sand mining	76.059	1.5618	**0.042**
Step 3	AIC	F	p value
Grazing	74.249	0.924	0.562
Agriculture	74.36	1.006	0.416
Effluent discharge	74.465	1.0836	0.32
Manmade embankment	74.625	1.2035	0.209
Boats	74.73	1.2821	0.136
Human settlement	75.06	1.5314	0.055
Sand mining	75.138	1.5908	**0.038**
Step 4	AIC	F	p value
Effluent discharge	73.674	1.0837	0.32
Manmade embankment	73.831	1.2067	0.196
Boats	73.908	1.2672	0.128
Agriculture	74.032	1.3653	0.085
Sand mining	74.323	1.597	**0.042**
Human settlement	74.564	1.7899	**0.018**
Step 5	AIC	F	p value
Manmade embankment	73.251	1.2634	0.164
Boats	73.238	1.2522	0.148
Agriculture	73.331	1.3296	0.102
Sand mining	73.638	1.5845	0.050
Human settlement	74.295	2.1405	**0.002**
Step 6	AIC	F	p value
Agriculture	72.762 1	0.2661	0.153

	Boats	72.801 1	0.3001	0.133
	Sand mining	73.105 1	0.5636	**0.031**
	Human settlement	75.129 3	0.3977	**0.001**
Step 7		AIC	F	p value
	Boats	72.229 1	0.2841	0.159
	Sand mining	72.364 1	0.4061	0.092
	Human settlement	74.141 3	0.066	**0.001**
Step 8		AIC	F	p value
	Sand mining	71.703 1	0.3468	0.100
	Human settlement	74.722 4	0.3456	**0.001**

Table 6.2: Effects of nine disturbance types on the species richness of spiders. β refers to the parameter estimate from the multiple regression; SE is the standard error of that estimate. Significant p values (< 0.05) are in boldface.

Multiple R squared	0.889		
Adjusted R squared	0.8303		
F statistic	15.13 $_{(df = 9,17)}$		
p value	0.000001834		
Coefficients			
	β	SE	p value
(Intercept)	0.000003	0.079	1
Agriculture	0.313	0.132	**0.029**
Effluent discharge	0.159	0.208	0.453
Garbage dump	0.139	0.207	0.510
Ghats	0.050	0.217	0.821
Grazing	0.163	0.129	0.225
Human settlement	0.661	0.243	**0.015**
Manmade embankment	0.155	0.213	0.475
Sand mining	0.181	0.082	**0.042**
Boats	0.194	0.167	0.261

Table 6.3: Effects of four disturbance types (best predictors) on the species richness of spiders. β refers to the parameter estimate from the multiple regression; SE is the standard error of that estimate.

Multiple R squared	0.8724		
Adjusted R squared	0.8491		
F statistic	$37.59_{(df = 4,22)}$		
p value	0.000000001553		
Coefficients			
	β	SE	p value
(Intercept)	0.000002	0.075	1.0000
Agriculture	0.447	0.083	0.00002
Human settlement	0.733	0.116	0.000002
Manmade embankment	0.262	0.121	0.042
Sand mining	0.185	0.078	0.026

Table 6.4: List of significant (IndVal p < 0.05) bioindicator spider species and their rarity index.

Species	Habitat disturbance	IndVal	p value	Rarity index
Zosis geniculata	Very low	0.667	0.004	0.069
Rhene flavicomans	Very low	0.621	0.004	0.007
Agelena sp.	Very low	0.549	0.003	0.036
Epeus indicus	Very low	0.540	0.008	0.003
Hippasa lycosina	Very low	0.519	0.001	0.0001
Carrhotus sp.	Very low	0.459	0.015	0.001
Brignolia sp.	Very low	0.454	0.008	0.00004
Hyllus sp.	Very low	0.394	0.038	0.0004
Hasarius adansoni	Very low	0.394	0.044	0.0004
Perenethis venusta	Very low	0.389	0.029	0.069
Neoscona nautica	Very low	0.349	0.031	0.0000002
Cyclosa insulana	Very low	0.335	0.029	0.00000003
Thwaitesia sp.	Very low	0.261	0.011	0
Nihonhimea indica	Low	0.462	0.001	0.000003

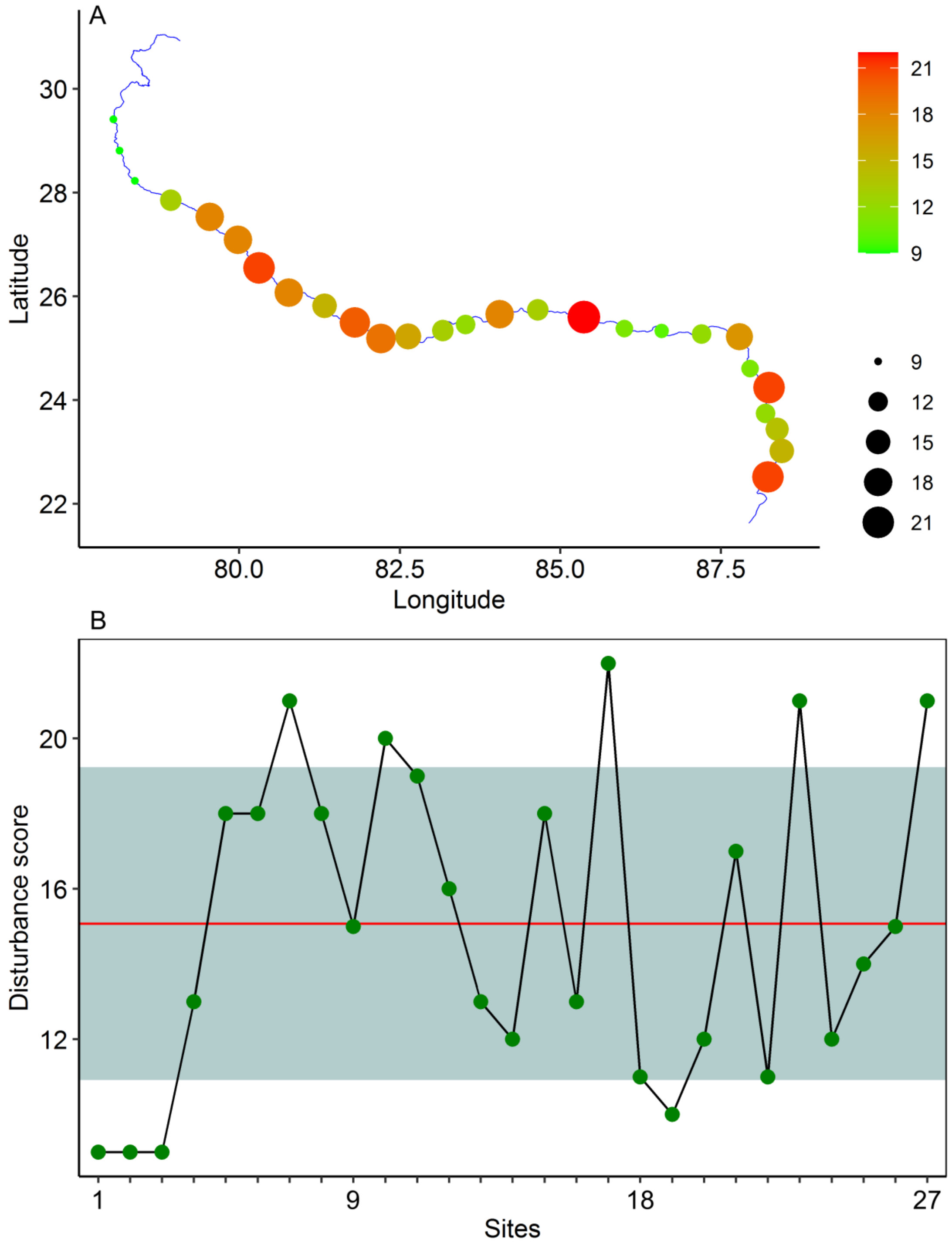


Figure 6.1: Comparative account of the disturbance score of 27 sites. In figure A, the size and shade of the bubbles (representing location of sampling sites) are proportional to the disturbance score. In figure B, the red horizontal line represents the mean value and the shaded area represents values within the mean ± standard deviation.

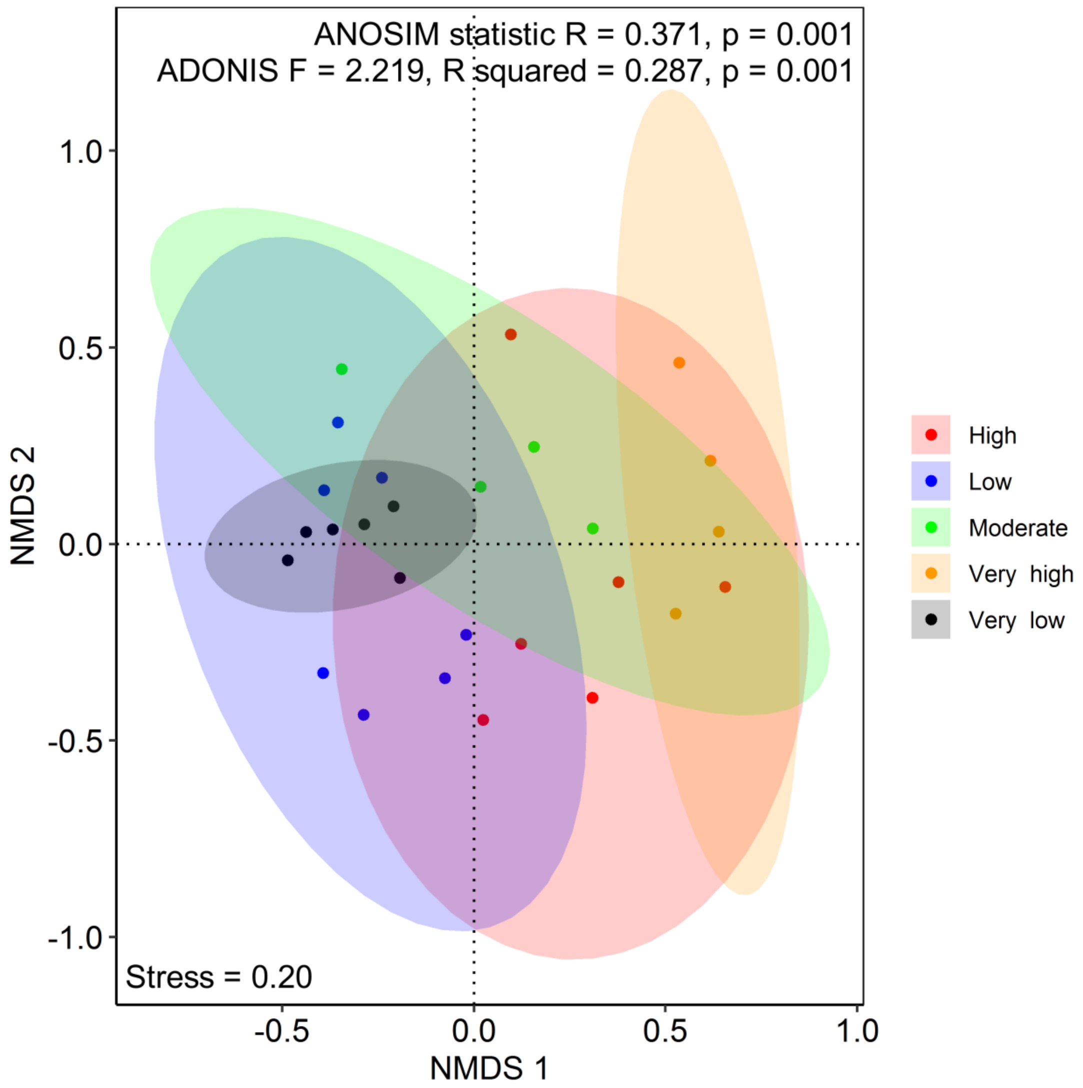


Figure 6.2: Non-metric multidimensional scaling (NMDS) ordination plot illustrating differences among groups of sites plotted in species space. The ellipses represent standard deviations of the weighted average of NMDS scores for each group.

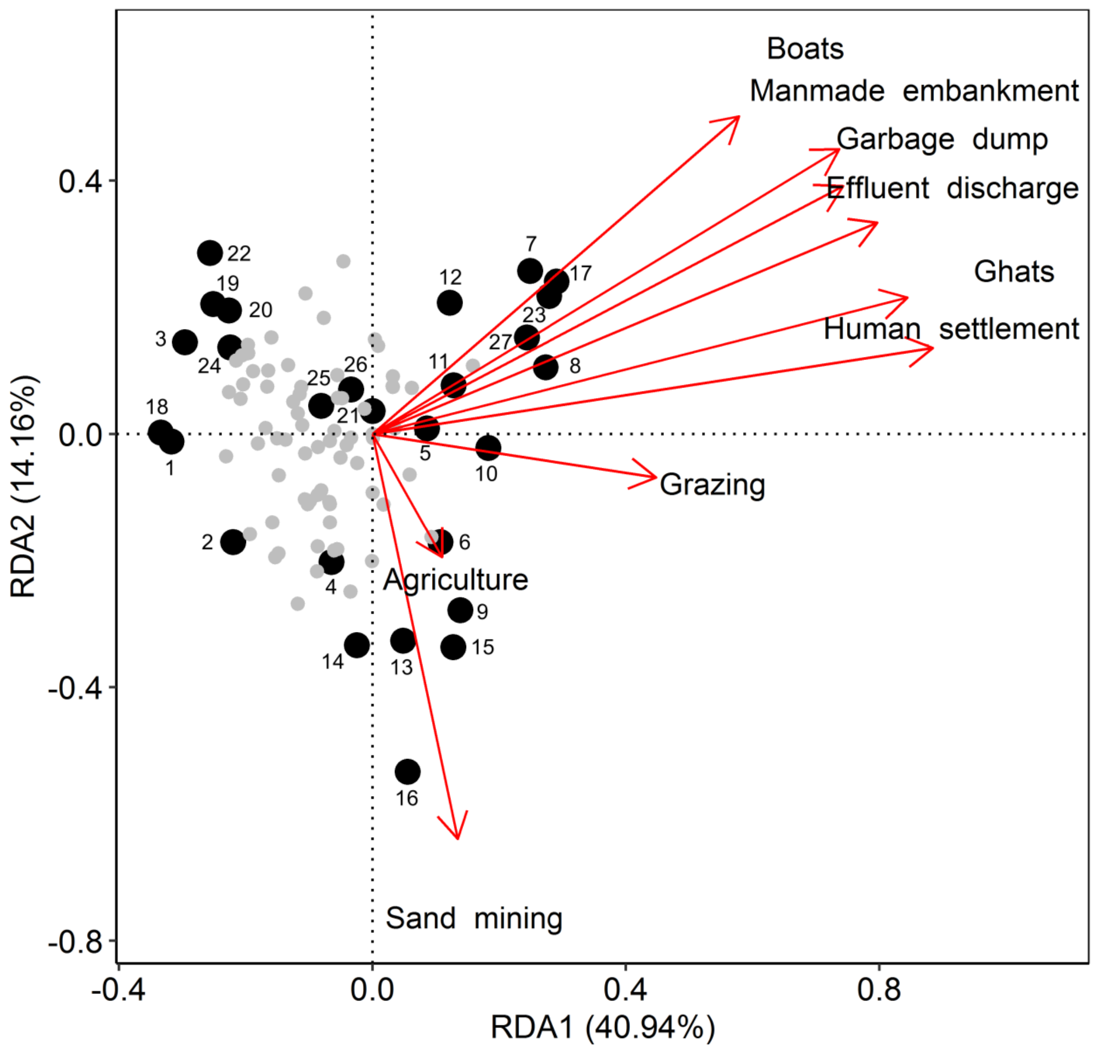


Figure 6.3: Ordination diagram of the redundancy analysis (RDA) of the spider community. Arrows represent the direction of change of the habitat disturbance. The length of the arrow indicates the variable's importance in explaining the spider community. Angles between variables indicate the correlation between the habitat disturbances. Sites locations (black dotes) and species locations (grey dotes) relative to each other indicate their similarity in ordination space.

River bank agriculture

Boats

Effluent discharge

Garbage dump

Ghats

River bank grazing

Various habitat disturbances

- Plate 19 -

Human settlement

Manmade embankment

Sand mining activity

Various habitat disturbances

- Plate 20 -

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSION

Humans depend on biodiversity in an uninterrupted way, yet species are rapidly disappearing due to human activity (Gascon et al., 2015). In order to conserve riparian biodiversity, it is important to understand the diversity pattern of flora and fauna of this ecosystem. Maintaining biodiversity in the riparian ecosystem is essential because it plays a major role in ecosystem services provision (Pompozzi et al., 2020). The biodiversity and characteristics of the spider community directly determine the ecosystem services quality (Hu et al., 2020). The spiders are considered to be the largest terrestrial predator in the world because with over 48,000 species and over 25 million tons standing biomass globally, the spiders prey on 400–800 million metric tons of insects per year, which is equal to approximately 1‰ of the global terrestrial net primary production and no other animal on earth can live up to this statistic (Nyffeler and Birkhofer, 2017). Being the generalist predators, most of the spiders can significantly decline insect pest population (Sunderland et al., 1997; Pekár, 2012). Spiders have useful value and have been used as model organisms for the study of ecology, behaviour, and communication (Gillespie and Spagna, 2009.) Although invertebrate animals play an essential part in the food chain of all types of ecosystems in the world, it has been observed that invertebrates do not play a significant role in the study of biodiversity in any region; particularly spiders are of little importance in the study of biodiversity, especially in the riparian area. This study was aimed to fill the information gap about the diversity of spiders in the riverine riparian ecosystem.

In this study, an inventory of the spider community of the Gangetic riparian zone was prepared. Total 79 species of spiders under 50 genera and 18 families were documented for the first time from the Gangetic riparian zones. High species richness was observed in the regions that were located at the junction of the Gangetic plain and the Himalayan hills due to edge effect. In contrast, low species richness was observed in the sites which were located near the densely populated urban areas.

As recent biodiversity conservation strategies do not depend only on the species richness but integrate both taxonomic diversity and functional diversity of target animal or plant group, the taxonomic and functional diversity of spider community of the study area are also studied in this work. For taxonomic diversity, two indices, namely the index of taxonomic diversity and the index of variation in taxonomic distinctness were used. For functional diversity, three indices, namely functional evenness, functional divergence and functional dispersion were used. The negative relationship was found between species richness and functional evenness, index of taxonomic diversity and the index of variation in taxonomic distinctness, functional evenness and index of variation in taxonomic distinctness, functional dispersion and index of variation in taxonomic distinctness; but positive relationship was found between species richness and functional divergence and between index of taxonomic diversity and functional dispersion.

The pattern of beta diversity was studied to find out the spatial variation in the diversity of spider communities of the different sites on the banks of the river Ganga. To do this, first SDR simplex method was used and then the local contribution and species contribution to beta diversity were calculated. The SDR simplex method showed that species replacement plays the most important role in determining the beta diversity of the spider community of the Gangetic riparian zones. A significant positive relationship between species richness and local contribution to beta diversity was noticed but any significant relationship between rare species richness and local contribution to beta diversity was not noticed. Ii was found that the species contribution to beta diversity and number of sites occupied by each species had a significant first-order term and the second-order term relationship.

The spider community exhibits different types of hunting strategies in different vegetation structures (so that verities of ecological guilds), and as they response differentially to various biological and biological factors, they are considered as environmental indicators for the assessment of human distress on ecosystems. The importance of the ecological indicators in globally vulnerable ecosystems like the freshwater riparian ecosystem is immense, because by the ecological indicators, we can very easily determine the real state of the ecosystem almost accurately at a low cost in minimum time. Out of 79 species of spiders reported in this study, 14 species can be considered as bio-indicators, of which 13 species were indicators of very low disturbed sites and one species were indicators of very low disturbed sites. However, there was difference in the reality index between these 14 species.

This is the first work where functional, taxonomic, and beta diversity of spider community, as well as their potential to be used as bioindicator species in the riverine riparian ecosystem in India, were studied. However, research on a single group of plants or animals is not enough for any ecosystem. Diverse studies should be conducted on the flora and fauna living in the rivers of India as the results of these studies will directly help in the restoration, conservation, and management of the riverine ecosystem in India.

Any natural ecosystem is a dynamic and ever-changing entity, and particularly the river ecosystem is the best example of this. In the course of time, the geomorphology of the river ecosystem is being changed because the water flow, pattern of land use, amount of forest cover, and morphological changes within the river are occurred both by natural and anthropogenic activities. These changes also lead to changes in the composition of the flora and fauna which depend on the riverine ecosystem. So information about the biodiversity of the riverine ecosystem is also changed with time. So, the conservation priorities and management plans for any ecosystem are also modified with time.

The actual conservation of an ecosystem is not just the work of any scientific community, as they can only determine the current state of the ecosystem and predict the state of the ecosystem in the future. The work of conserving the ecosystem depends on the people who are socially and economically dependent on the ecosystem, regardless of the villages and towns. Government and non-government organizations can play a leading role in this regard not only by providing financial assistance but also by making people aware of the dire consequences of the destruction of the ecosystem.

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Appendix 1: List of species of spiders recorded from the study area. The species which are endemic in India are in red colour.

Family	Genus	Species
Agelenidae C. L. Koch, 1837	*Agelena* Walckenaer, 1805	*Agelena* sp.
Araneidae Clerck, 1757	*Acusilas* Simon, 1895	*Acusilas* sp.
	Anepsion Strand, 1929	*Anepsion* sp.
	Araneus Clerck, 1757	*Araneus mitificus* (Simon, 1886)
	Argiope Audouin, 1826	*Argiope aemula* (Walckenaer, 1841)
		Argiope pulchella Thorell, 1881
	Cyclosa Menge, 1866	*Cyclosa bifida* (Doleschall, 1859)
		Cyclosa confraga (Thorell, 1892)
		Cyclosa hexatuberculata Tikader, 1982
		Cyclosa insulana (Costa, 1834)
		Cyclosa simoni Tikader, 1982
		Cyclosa spirifera Simon, 1889
		Cyclosa sp.
	Cyrtophora Simon, 1864	*Cyrtophora cicatrosa* (Stoliczka, 1869)
	Eriovixia Archer, 1951	*Eriovixia laglaizei* (Simon, 1877)
	Gasteracantha Sundevall, 1833	*Gasteracantha geminata* (Fabricius, 1798)
		Gasteracantha hasselti C. L. Koch, 1837
	Larinia Simon, 1874	*Larinia* sp.
	Neoscona Simon, 1864	*Neoscona mukerjei* Tikader, 1980
		Neoscona nautica (L. Koch, 1875)
		Neoscona theisi (Walckenaer, 1841)
		Neoscona vigilans (Blackwall, 1865)
		Neoscona sp.1
		Neoscona sp.2
	Nephila Leach, 1815)	*Nephila pilipes* (Fabricius, 1793)
	Thelacantha Hasselt, 1882	*Thelacantha brevispina* (Doleschall, 1857)
Corinnidae Karsch, 1880	*Castianeira* Keyserling, 1879	*Castianeira zetes* Simon, 1897
Gnaphosidae Pocock,1898	*Prodidomus* Hentz, 1847	*Prodidomus* sp.
	Zelotes Gistel, 1848	*Zelotes* sp.
Hersiliidae Thorell, 1870	*Hersilia* Audouin, 1826	*Hersilia savignyi* Lucas, 1836
Lycosidae Sundevall,1833	*Hippasa* Simon, 1885	*Hippasa lycosina* Pocock, 1900
	Lycosa Latreille, 1804	*Lycosa* sp.1
		Lycosa sp.2

Oonopidae Simon,1890	*Brignolia* Dumitrescu and Georgescu, 1983	*Brignolia* sp.
Oxyopidae Thorell,1870	*Hamataliwa* Keyserling, 1887	*Hamataliwa incompta* (Thorell, 1895)
	Oxyopes Latreille, 1804	*Oxyopes* sp.1
		Oxyopes sp.2
		Oxyopes sp.3
	Peucetia Thorell, 1869	*Peucetia viridana* (Stoliczka, 1869)
Philodromidae Thorell, 1870	*Tibellus* Simon, 1875	*Tibellus* sp.
Pisauridae Simon, 1890	*Perenethis* L. Koch, 1878	*Perenethis venusta* L. Koch, 1878
Salticidae Blackwall, 1841	*Carrhotus* Thorell, 1891	*Carrhotus viduus* (C. L. Koch, 1846)
		Carrhotus sp.
	Epeus Peckham and Peckham, 1886	*Epeus indicus* Prószyński, 1992
	Epocilla Thorell, 1887	*Epocilla aurantiaca* (Simon, 1885)
		Epocilla sp.
	Hasarius Simon, 1871	*Hasarius adansoni* (Audouin, 1826)
	Hyllus C. L. Koch, 1846	*Hyllus* sp.
	Myrmarachne MacLeay, 1839	*Myrmarachne* sp.1
		Myrmarachne sp.2
		Myrmarachne sp.3
	Phintella Strand, 1906	*Phintella vittata* (C. L. Koch, 1846)
	Plexippus C. L. Koch, 1846	*Plexippus paykulli* (Audouin, 1826)
		Plexippus petersi (Karsch, 1878)
	Rhene Thorell, 1869	*Rhene flavicomans* Simon, 1902
	Telamonia Thorell, 1887	*Telamonia dimidiata* (Simon, 1899)
Scytodidae Blackwall,1864	*Scytodes* Latreille, 1804	*Scytodes pallida* Doleschall, 1859
Sparassidae Bertkau, 1872	*Olios* Walckenaer, 1837	*Olios milleti* (Pocock, 1901)
Tetragnathidae Menge,1866	*Guizygiella* Zhu, Kim and Song, 1997	*Guizygiella melanocrania* (Thorell, 1887)
		Guizygiella indica (Tikader and Bal, 1980)
	Leucauge White, 1841	*Leucauge decorata* (Blackwall, 1864)
		Leucauge sp.
	Opadometa Archer, 1951	*Opadometa fastigata* (Simon, 1877)
	Tetragnatha Latreille, 1804	*Tetragnatha* sp.1

		Tetragnatha sp.2
		Tetragnatha sp.3
		Tetragnatha sp.4
Theridiidae Sundevall, 1833	*Faiditus* Keyserling, 1884	*Faiditus* sp.
	Nihonhimea Yoshida, 2016	*Nihonhimea indica* (Tikader, 1977)
		Nihonhimea mundula (L. Koch, 1872)
	Steatoda Sundevall, 1833	*Steatoda* sp.
	Thwaitesia O. Pickard-Cambridge, 1881	*Thwaitesia* sp.
Thomisidae Sundevall, 1833	*Camaricus* Thorell, 1887	*Camaricus formosus* Thorell, 1887
	Runcinia Simon, 1875	*Runcinia ghorpadei* Tikader, 1980
	Thomisus Walckenaer, 1805	*Thomisus lobosus* Tikader, 1965
		Thomisus pugilis Stoliczka, 1869
		Thomisus sp.
Uloboridae Thorell,1869	*Zosis* Walckenaer, 1841	*Zosis geniculata* (Olivier, 1789)
Zodariidae Thorell, 1881	*Tropizodium* Jocqué and Churchill, 2005	*Tropizodium* sp.

Appendix 2: Keys to the spider families and genera recorded from the study area

The keys were prepared following Agnarsson, 2004; Barrion and Litsinger, 1995; Biswas, 1984; Dhali et al., 2017;Jastrzębski, 1997; Malamel et al., 2015; Patel and Patel, 1972; Platnick et al., 2011; Prószyński, 2017; Rajoria, 2016; Ranasinghe and Benjamin, 2016; Roy et al., 2016; Roy et al., 2017; Sen et al., 2015; Sethi and Tikader, 1988; Sunil Jose, 2011; Sunil Jose et al., 2007; Tanikawa and Yamasaki, 2019; Tikader and Biswas, 1981; Tikader and Malhotra, 1980; Tikader and Patel, 1975; Tikader, 1960, 1962, 1973, 1977, 1980, 1982a, 1982b; Uniyal and Hore, 2009; Uniyal et al., 2011, and Zhu 1998

Keys to the spider families

	Cribellum present --	**1**
	Cribellum absent ---	**2**
1	Eight eyes, homogeneous, dark, both rows recurved. metatarsus IV compressed and concave at dorsal portion, trichobothria absent at tarsi --	**Uloboridae**
2	Less than 8 eyes present --	**3**
	8 eyes present --	**5**
3	Carapace domed towards thoracic region, femele epigastric region with anchoring holes --	**Scytodidae**
	Shape of the carapace different --------------------------------------	**4**
4	Tracheal spiracles distinct, anteriorly positioned, just behind the epigastric groove, book lung present, female palp clawless, abdomen either with scuta or uniformly soft, endites converging, tarsal claws less well developed, without spatulated claw tufts ---	**Oonopidae**
	Tracheal spiracle single, inconspicuous, positioned just in front of spinnerets, abdomen without setose shield, claw teeth implanted on side facing opposite claw, serrula absent, eyes 2.2.4, fangs at base almost as thick as long, trochanters not notched --	**Zodariidae**

5	Tarsi with two claws --	**6**
	Tarsi with three claws --	**7**
6	Eyes usually in three rows (4, 2, 2); anterior median eyes very large, second row of eyes very small, often minute; third row of two eyes of medium size --	**Salticidae**
	Eyes arranged differently --	**8**
8	Legs laterigrade, directed towards side or forwards -------------	**9**
	Legs prograde, directed forwards and backwards ---------------	**10**
9	Tarsi and metatarsi without scopulae, legs I and II usually much longer than legs III and IV -----------------------------------	**Thomisidae**
	Tarsi and sometimes metatarsi with scopulae, legs different ---	**11**
11	Distal metatarsus dorsally with unilobate rigid structure --------	**Philodromidae**
	Distal metatarsus dorsally with trilobate soft membrane --------	**Sparassidae**
10	Posterior median eyes flat and round, without dome shaped lens, maxillae obliquely depressed, anterior spinnerets conical, not widely separated, without setae on spigots, anterior lateral spinnerets one segment with enlarged pyriform gland spigots, sometimes spinnerets long and cylindrical, far apart ------------	**Gnaphosidae**
	Posterior median eyes with dome-shaped lens, maxillae usually not obliquely depressed, tarsi without auxiliary claws, sternum mostly longer than wide, eyes in two rows, opisthosoma with scutum; posterior spinnerets with two large cylindrical gland spigots ---	**Corinnidae**
7	Posterior spinnerets strongly elongated ---------------------------	**12**
	Posterior spinnerets not strongly elongated ----------------------	**13**
12	Spinnerets not in a single transversal row, tibia I with 2-3 pairs of ventral spines ---	**Agelenidae**
	Spinnerets not in a single transversal row, tibia I without ventral spines --	**Hersiliidae**
13	Eyes either in three or four rows or in three groups -------------	**14**
	Eyes in two rows, posterior spinnerets not particularly long or with one segment only, trochanters often notched ---------------	**15**

14	Eyes in three groups 4:2:2; carapace broad, raised towards the back ---	**Pisauridae**
	Eyes in three rows or four rows 2:2:2:2, 4:2:2 or 2:4:2; posterior eyes not much larger than anterior ones, trochanters notched ---	**16**
16	Clypeus high, posterior eyes and anterior lateral eyes forming a hexagonal group in front of small anterior median eyes, numerous long spines on tibiae and metatarsi ---------------------	**Oxyopidae**
	Clypeus not as high as in Oxyopidae, eye position and setae on legs different ---	**17**
17	Eyes sessile, not on tubercles, opisthosoma oval, smoothly rounded posteriorly, male palpal tibiae without retrolateral apophysis, cocoon attached to spinnerets, anal tubercle with one segment --	**Lycosidae**
	At least one pair of eyes on shallow tubercles, opisthosoma almost always elongated, tapered to back, male palpal tibia with retro lateral apophysis, anal tubercle biarticulate, labium hardly longer than wide anterior lateral eyes normal -------------	**Pisauridae**
15	Paracymbium fused to cymbium or rudimentary, chelicerae without stridulating files, Tarsi IV with ventral comb of serrated hairs ---	**Theridiidae**
	Paracymbium fused to cymbium or rudimentary, chelicerae without stridulating files, Tarsi without ventral comb of serrated hairs ---	**18**
18	Chelicerae divergent from base, usually long and strong --------	**Tetragnathidae**
	Chelicerae not divergent from base, tarsus and metatarsus together longer than patella and tibia -------------------------------	**Araneidae**

Key to the Genera under family Agelenidae

1	Abdomen is long and narrow; anterior spinnerets and much longer posterior spinnerets clearly separated, clearly marked chevrons are present on the dorsal surface of the abdomen --- ---	***Agelena***

Key to the Genera under family Araneidae

	Spinnerets are situated on an elevated circular space surrounded by a thick flange in the form of a ring, abdomen hard flattened dorsally and provided with conical humps and spines ---	**1**
	Spinnerets are not surrounded by thick flange in the form of a ring and abdomen is not hard ---------------------------------	**2**
1	Cephalic region provided with a median bulge; abdominal spines very short ---	***Thelacantha***
	Abdominal spines longer, lateral spines are longer then the rests --	**Gasteracantha**
2	Tarsus and metatarsus together longer than patella and tibia. Labium longer than wide; abdomen two and one-half to three times as long as wide; tarsus IV not Iprovided with sustentaculumCarapace with cephalic region convex and elevated; abdomen elongated or oval, non-lobate -----------	***Nephila***
	Tarsus and metatarsus together not longer than patella and tibia --	**3**
3	Posterior row of eyes strongly procurbed; anterior lateral eyes smaller than posterior laterals. Labium wider than long; abdomen not longer than two and one-half times of its width; tarsus IV provided with sustentaculum. Eyes of anterior row not evenly spaced or medians closer to each other than to laterals adult female larger than 9 mm.; tibia I of male straight and unmodified -------------------------------	***Argiope***
	Posterior row of eyes nearly straight or recurved; lateral eyes subequal --	**4**
4	Cephalothorax convex, cephalic region strongly elevated, abdomen without posterior tubercle or tail like projection, cephalothorax anteriorly narrowing; abdomen without any tubercles but with pairs of moderately small, spherical sigillae in 2 longitudinal rows ---------------------------------	***Acusilas***
	Cephalothorax may or may not be convex, cephalic region not elevated --	**5**
5	Cephalothorax flat with distinct thoracic furrow; abdomen anteriorly very high with at least 1 pair of shoulder humps -	***Cyrtophora***
	Cephalothorax not flat, thoracic furrow may or may not be distinct; abdomen anteriorly not high, with or without shoulder humps ---	**6**

6	Posteromedian eyes closely apposed, carapace provided with a 'U' shaped mark between cephalic and thoracic regions --	***Cyclosa***
	Posteromedian eyes separate, carapace without any such mark --	**7**
7	Opisthosoma flattish, with a tail like extension to the rear --	***Eriovixia***
	Opisthosoma without a tail like extension at the rear --------	**8**
8	Abdomen more than twice longer than wide. Abdomen a little pointed mid-longitudinally over the carapace and no caudal projection; ventral side of abdomen with a white median longitudinal band framed by black colour -----------	***Larinia***
	Abdomen less than twice longer than wide -------------------	**9**
9	Cephalic region high with a pair of dorsal bulging -----------	***Anepsion***
	Cephalic region without a pair of dorsal bulging ------------	**10**
10	Thoracic groove transverse epigyne with distinct scape, often wrinkled, not provided with any lateral lobes ----------	***Araneus***
	Thoracic groove longitudinal epigyne with unwrinkled scape and provided with one or two pairs of lateral lobes ---	***Neoscona***

Key to the genus under family Corinnidae

1	Cephalothorax oval, longer than wide and narrow in the front; eyes round and white, anterior row of eyes slightly recurved, posterior row of eyes procurved; promargin of cheliceraewith 2 teeth; legs long, slender, tibia I and II with 2 or 3 pairs of ventral spines, trochanter IV ventrally notched; abdomen longer than wide, narrowing in front, clothed with pubescence; epigynum with convex sclerotised plate, copulatory opening distinct, well separated ------------	***Castianeira***

Key to the genera under family Gnaphosidae

1	Body covered with squamiform hairs; carapace without fovea; anterior spinnerets close to each other ------------------	***Prodidomus***

2 Body not covered with squamiform hairs; carapace with fovea; anterior spinnerets apart to each other; chelicera broad; eyes are equidistant; posterior row of eyes straight or slightly procurved; median eyes are small or slightly larger than the laterals --- ***Zelotes***

Key to the genus under family Hersiliidae

1 Head fiat and angular laterally; ocular quadrangle parallel sided; clypeus high and prominent; protarsi of leg I, II and IV are bisegmented --- ***Hersilia***

Key to the genera under family Lycosidae

Posterior spinnerets distinctly longer than the anterior, with apical segment conical and as long as the basal, anterior row of eyes little wider than the second row, sternum generally provided with mid-longitudinal dark marking ---------------- ***Hippasa***

Posterior spinnerets at most only slightly longer than the anterior and apical segment hemispherical and very short, Anterior row of eyes shorter than the second row, sternum without longitudinal marking ----------------------------------- **1**

1 Clypeus from front slanting, fourth metatarsus shorter than tibia and patella IV together, third pair of legs are shorter than the first pair, labium longer than wide, anterior lateral and posterior median eyes not pearly white, tibia IV with the two equally stout dorsal spines, anterior row of eyes straight or slightly procurved, anterior median eyes are not smaller than the anterior laterals -------------------------------- ***Lycosa***

Key to the genus under family Oonopidae

1 Legs without spines; dorsal scutum large and covers the abdomen; posterior genitalic tube simple or twisted ---------- ***Brignolia***

Key to the genera under family Oxyopeidae

Carapace dorsally flat and straight in lateral view ------------- **1**

Carapace not dorsally flat and not straight in lateral view----- **2**

1 Carapace rectangular, front face shorter than rear, nearly parallel sided; front face narrower, rear face receding; clypeus vertical; anterior median eyes closed, separated by less than their diameter; abdomen at most 1/5th longer than carapace and rarely with geometric colour patterns ----------- ***Hamataliwa***

2 Posterior row of eyes strongly procurved and equidistant from each other, ocular quadrangle longer than wide and limited by the posterior median eyes and the anterior lateral eyes -- ***Oxyopes***

Anterior median eyes smallest; posterior lateral eyes forming a slightly procurved row (not so procurved as in Oxyopes), cephalothorax not so high or convex as that of Oxyopes ----- --- ***Peucetia***

Key to the genus under family Philodromidae

1 Cephalothorax longer thln wide; posterior eyes strongly recurved, anterior lateral eyes nearer to the posterior median eyes than to the anterior median eyes; upper margin of the furrow of the chelicerae with one or two teeth; second pair of legs longer than the others, scopulae present in the tarsi of leg I and II --- ***Tibellus***

Key to the genus under family Pisauridae

1 Anterior median eye procurved and posterior lateral eye recurved; 2 teeth on the retromargin and 3 teeth on the promargin of chelicerae; distinct broad continuous longitudinal band present on each side of both cephalothorax and abdomen ------------------------------------ ***Perenethis***

Key to the genera under family Salticidae

Retromargin of chelicerae with more than a tooth Ant mimicking; cephalothorax long and narrow; sternum lanceolate and about three times as long as broad, apical end truncate and posterior end sharply pointed cephalic - thoracic region distinctly marked by a constriction; pedicel

	long, conspicuous, visible from above ------------------------	***Myrmarachne***
	Retromargin of chelicerae with a single tooth, not ant mimicking --	**1**
1	Sternum not strongly attenuated in front; epigynal plate semicircular; internal genitalia with long transparent tubules arranged in complex loops ----------------------------	***Epeus***
	Sternum strongly attenuated in front; epigynal plate otherwise; internal genitalia with short sclerotized tubules arranged in simple loops ---------------------------------------	**2**
2	Beetle like; cephalothorax somewhat rounded with thick mouse like hairs, posteriorly wider; 1st pair of legs in males robust with tibia broad and flat ---------------------------------	***Rhene***
	Not beetle like; cephalothorax and 1st pair of legs in male otherwise ---	**3**
3	Cephalothorax circular or U shaped ---------------------------	**4**
	Cephalothorax neither circular nor U shaped ----------------	**5**
4	Both 1st and 2nd pairs of legs a little more robust than 3rd and 4th pair, tibia not flat and not fringed with stiff hairs alongside dorsal and ventral face -------------------------------	***Hasarius***
5	Cephalothorax swollen or spherical, with horn like tuft of long, stiff, slightly curved bristles lateral to anterolateral eyes ---	**6**
	Cephalothorax otherwise, without any hornlike tuft of long, stiff, curved bristles --	**7**
6	Abdomen of female pale with a pair of longitudinal dark lines, male slender with mid dorsal white band on abdomen	***Telamonia***
	Abdomen with different pattern --------------------------------	**8**
8	Embolus long, often with pars pendula; tibial apophysis sometimes with a few spur like projection at the flat tip ----	***Hyllus***
7	Cephalothoracic length always more than 1.2 x its width ---	**9**
	Cephalothoracic length less than always more than 1.2 x its width --	**10**
9	Cephalothorax convex with cephalic margins nearly parallel; abdomen of female pale with series of chevron	

	marks and white bands, in male such bands extending throughout the body ---	***Plexippus***
	Cephalothorax slopping posteriorly; males usually black with 2 longitudinal white bands extending from thoracic region to tip of abdomen, females brownish, with pale yellow chevron pattern on abdomen -------------------------	***Carrhotus***
10	Chelicerae slender, with fangs long, sometimes larger than chelicerae, curved at tip; abdomen often with gray, indistinct, linear pattern ---	***Phintella***
	Cheliceral fang never so; abdomen of female with a series of chevron marks --	***Epocilla***

Key to the genus under family Scytodidae

1	Cephalothorax high, subglobose behind and slopes forward; eyes 6, arranged in 3 widely separated pairs, anterior eye row strongly recurved; legs long, slender,coxa I contiguous, tarsal claw pectinate in double row; abdomen oval and decorated; epigynum simple -------------------------------------	***Scytodes***

Key to the genus under family Sparassidae

1	Anterior lateral eye smaller than anterior median eye, anterior median eye large, posterior row of eyes slightly procurved, lateral eyes not prominent and sessile; clypeus shorter than the diameter of an anterior median eye; anterior tibia with 2 pairs of ventral spines; spinnerets without any membranous stalk and without chitinous ring -----------------	***Olios***

Key to the genera under family Tetragnathidae

Body narrow and elongated; abdomen very elongated and sub cylindrical, dorsal side with or without any dull silvery markings; chelicerae very long and each margin provided with more than 4 teeth; lateral eyes not contiguous; maxillae parallel ---	***Tetragnatha***
Body not narrow and elongated; abdomen not very elongated, dorsal side with glossy silvery markings; chelicerae as long	

	as wide and each margin provided with 4 teeth; lateral eyes contiguous; maxillae variable --------------------------------------	**1**
1	Epigyne without scape having spiral openings on ventral side ---	***Guizygiella***
	Epigyne with scape having spiral openings on ventral side --	**2**
2	Abdomen postero-medially broad, anteriorly narrow, with blunt shoulder humps, caudal tubercle absent, anterior part overlaps cephalothorax; tibia of leg IV with a brush of hairs --	***Opadometa***
	Abdomen anteriorly broad, posteriorly narrow, with or without shoulder hump and caudal tubercle, anterior part does not overlap cephalothorax; tibia of leg IV without brush of hairs --	***Leucauge***

Key to the genera under family Theridiidae

	Colulus and paired setae absent. Anterior median eye diameter equal to or smaller than posterior median eye; posterior eye row commonly straight and lateral eye contiguous --	***Theridion***
	Colulus large to small or reduced to pair of seate only -------	**1**
1	Copulatory bursa anterior margin medially acute, a strongly hooked theridioid tegular apophysis distal tip, abdomen with paired (or multiple) humps ---------------------------------------	***Faiditus***
	Not like above ---	**2**
2	Posterior median eyes about their diameter or less apart, abdomen covered by silvery plates ------------------------------	***Thwaitesia***
	Not like above ---	**3**
3	Patella without any such tubercle; abdomen devoid of hump or posterior dorsal extension, but with distinct wavy cardiac pattern; male palp with circular embolus and laterally projecting tegular apophysis; epigynal opening distinct -------	***Nihonhimea***

Key to the genera under family Thomisidae

	Lateral eyes on strong conical protuberance --------------------	**1**

Lateral eyes not on conical protuberance ------------------------ **2**

1 Abdomen widened and truncated behind ------------------------ ***Thomisus***

Abdomen long, lateral sides with longitudinal muscular corrugation -- ***Runcinia***

2 Abdomen broadened, not truncated behind, integument not clothed with clavate setae, cephalic region as wide as thoracic region --- ***Camaricus***

Key to the genus under family Uloboridae

1 8 eyes arranged in 2 rows, posterolateral eyes not on tubercles; abdomen oval; sternum not divided; legs elongated with prominent bands ------------------------------- ***Zosis***

Key to the genus under family Zodariidae

1 Cephalothorax longer than wide, cephalic region slightly higher with rounded margin and provided with light brown patches; anterior row of eyes straight or slightly procurved, anterior median eyes larger than others and encircled by deep brown patches, posterior row of eyes strongly procurved and posterior medians widely separated and closer to adjacent laterals; legs long and strong, covered with fine hairs; sternum heart shaped, pointed behind, covered with hairs; abdomen globular, slightly pointed behind, overlaps cephalothorax in front; anterior pair of spinnerets long and other two pairs not developed ----------- ***Tropizodium***

Appendix 3: Distribution of spider species documented from 27 sites (+ indicates present and 0 indicates absence)

Species	Sites																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Agelena sp.	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	+	0	0	0
Acusilas sp.	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anepsion sp.	+	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Araneus mitificus	+	0	+	0	0	0	+	+	+	+	0	+	+	0	+	+	0	+	+	0	+	+	+	+	+	0	+
Argiope aemula	+	0	0	+	0	+	0	+	+	+	0	0	+	0	0	+	+	0	0	+	+	+	0	+	+	+	0
Argiope pulchella	+	0	+	0	+	+	+	0	0	+	0	+	+	0	+	0	+	0	+	+	0	+	0	+	0	0	+
Cyclosa bifida	+	0	+	0	+	0	+	0	0	+	0	0	0	+	0	0	0	+	+	+	+	+	+	0	+	+	0
Cyclosa confraga	+	+	+	0	0	+	0	+	0	0	+	+	+	0	0	0	0	+	0	+	0	+	0	+	0	+	+
Cyclosa hexatuberculata	0	+	0	0	0	+	+	0	0	+	+	+	0	+	+	+	0	+	+	+	+	0	0	+	+	0	0
Cyclosa insulana	+	+	+	+	0	+	0	+	0	0	+	+	+	+	+	+	+	+	+	0	+	+	0	0	0	0	0
Cyclosa simoni	0	+	+	+	0	0	0	0	+	+	0	0	+	0	0	0	0	+	+	+	0	+	0	+	+	+	0
Cyclosa sp.	+	0	+	+	+	0	0	0	0	0	+	0	+	+	0	0	0	+	+	0	+	+	0	+	0	0	0
Cyclosa spirifera	0	+	+	+	+	0	0	0	+	0	0	0	0	+	+	+	0	+	+	+	0	0	0	0	0	+	+
Cyrtophora cicatrosa	0	+	0	+	0	0	0	0	+	+	0	0	+	+	+	+	0	+	+	+	+	+	+	+	0	+	0
Eriovixia laglaizei	+	0	+	+	+	0	0	0	0	0	0	+	0	+	0	0	0	+	+	+	0	+	0	+	0	+	0
Gasteracantha geminata	+	+	+	+	0	0	0	0	0	0	0	0	0	+	0	+	0	+	0	+	+	+	0	+	+	0	0
Gasteracantha hasselti	+	+	0	0	+	+	+	0	+	0	0	+	+	+	+	+	0	+	+	+	0	0	0	+	+	+	+
Larinia sp.	+	0	0	0	+	0	+	0	+	0	0	0	0	0	+	0	0	+	0	+	0	+	+	0	+	+	0
Neoscona mukerjei	+	0	+	+	0	+	+	+	0	0	+	+	0	0	0	+	+	0	+	0	0	+	+	0	0	0	0
Neoscona nautica	+	+	+	0	0	+	0	+	0	+	+	+	+	0	+	0	+	+	+	0	+	+	0	0	+	0	0
Neoscona theisi	+	+	+	0	0	+	+	0	0	+	0	0	+	0	+	0	+	+	+	+	0	0	0	+	+	0	+

Neoscona vigilans	0	+	+	+	0	+	0	0	0	+	+	0	0	0	0	+	+	0	+	0	+	+	+	+	+	+	0
Nephila pilipes	0	0	+	0	0	+	0	0	0	0	+	0	0	+	0	0	0	0	+	0	+	+	0	+	+	+	0
Neoscona sp 1	+	+	+	+	+	0	0	0	0	+	0	0	+	0	0	+	0	+	+	0	0	0	0	+	0	+	0
Neoscona sp 2	+	+	+	+	+	0	0	0	+	0	+	0	+	+	+	+	0	+	0	0	+	+	0	0	+	0	0
Thelacantha brevispina	+	+	0	0	0	+	0	+	+	0	0	+	0	+	+	+	0	0	0	+	0	0	0	+	0	0	0
Castianeira zetes	0	+	+	0	0	0	0	+	0	0	0	+	0	0	0	0	+	+	+	0	0	+	+	+	0	0	0
Prodidomus sp.	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zelotes sp	0	0	+	0	+	0	+	+	+	0	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Hersilia savignyi	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Hippasa lycosina	+	+	+	0	0	0	0	0	+	0	0	+	0	0	0	0	0	+	+	+	0	+	0	+	+	0	0
Lycosa sp 1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Lycosa sp 2	+	+	+	0	+	0	+	+	+	0	+	+	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+
Hamataliwa incompta	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxyopes sp 1	+	+	+	+	+	+	0	0	+	0	0	0	0	0	0	+	0	+	+	0	+	0	0	0	+	0	+
Oxyopes sp 2	+	+	0	0	0	0	+	0	0	0	+	+	+	+	0	0	0	+	+	+	0	+	0	0	0	+	0
Oxyopes sp 3	0	0	+	+	0	0	0	+	0	+	0	+	0	0	+	0	+	0	0	+	0	+	+	+	+	0	0
Peucetia viridana	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	+	0	0	0
Tibellus sp	0	0	0	0	+	0	+	+	+	0	0	+	0	0	0	0	+	0	0	0	0	0	0	0	0	0	+
Perenethis venusta	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	+	0	0	0
Carrhotus viduus	+	+	0	+	+	0	0	0	0	0	0	+	0	0	0	0	0	+	+	+	+	+	0	+	+	+	0
Carrhotus sp.	+	+	0	+	0	0	0	0	0	0	0	+	0	0	0	0	0	+	+	+	0	+	0	+	0	0	0
Epeus indicus	+	0	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	0	+	0	+	0	0	0
Epocilla aurantiaca	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Epocilla sp.	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hasarius adansoni	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	0	+	+	+	0
Hyllus sp.	+	0	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	+	0	0	+	+	0

Myrmarachne sp 1	+	+	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0
Myrmarachne sp 2	0	0	+	0	0	0	0	0	0	0	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myrmarachne sp 3	0	0	0	0	0	0	0	0	+	0	0	0	0	+	0	+	0	0	0	0	0	0	0	0	0	0	0
Phintella vittata	+	+	+	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	+	+	0	0	0
Plexippus paykulli	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Plexippus petersi	+	+	+	+	+	+	+	+	+	0	+	+	+	+	+	+	0	+	+	+	+	+	0	0	+	+	0
Rhene flavicomans	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	+	0	0	0	+	0	0	0
Telamonia dimidiata	+	+	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+	0	0	0	+	+	0	+	0	+
Olios milleti	+	0	+	0	0	+	0	0	+	0	+	0	+	0	0	+	0	0	0	0	0	+	0	0	0	0	0
Guizygiella indica	+	0	+	0	0	+	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0	+	0	0
Guizygiella melanocrania	+	0	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	+	+	+	0
Leucauge decorata	+	+	+	+	+	0	+	+	+	+	+	+	+	0	0	+	+	0	+	0	+	+	+	+	0	0	+
Leucauge sp.	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	+	0	0	+	+	0
Opadometa fastigata	0	0	+	0	0	+	0	0	0	0	0	0	0	+	0	0	0	+	+	+	0	+	0	+	0	0	0
Tetragnatha sp 1	0	0	+	+	0	0	0	0	0	+	0	0	+	+	0	+	0	+	+	0	+	0	0	0	+	0	0
Tetragnatha sp 2	0	+	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	+	+	+	0	+	0	+	0	0	0
Tetragnatha sp 3	+	0	0	0	0	+	0	0	0	0	0	0	+	+	+	0	0	+	0	+	0	+	0	0	0	+	0
Tetragnatha sp 4	+	+	0	+	0	0	0	0	0	0	0	0	+	+	+	0	0	0	0	0	0	0	0	0	0	0	0
Faiditus sp	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nihonhimea indica	0	+	+	+	0	+	0	0	0	0	0	0	+	+	+	+	0	+	+	+	0	+	0	+	+	0	0
Nihonhimea mundula	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Steatoda sp.	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thwaitesia sp.	+	+	+	+	+	+	0	0	+	+	+	+	+	+	+	+	0	+	+	+	+	+	0	+	+	+	0
Camaricus formosus	+	+	+	0	0	+	0	0	+	0	0	0	0	+	0	0	+	+	0	+	+	0	0	0	0	0	0
Runcinia ghorpadei	+	0	+	0	0	0	0	+	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0
Thomisus lobosus	+	+	0	0	+	+	0	+	+	+	0	+	+	0	+	+	+	0	+	0	+	0	+	0	+	+	0

Thomisus pugilis	0	0	+	0	0	0	0	0	0	+	0	0	0	0	0	0	+	0	0	0	0	0	+	0	0	0	0
Thomisus sp.	0	+	0	0	0	0	0	0	+	0	0	0	0	0	0	+	0	+	0	+	+	0	0	0	0	0	0
Zosis geniculata	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	+	0	0	0	0	0
Tropizodium sp.	0	0	0	0	0	0	0	+	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scytodes pallida	+	+	0	+	+	0	0	0	0	+	0	0	+	+	+	+	0	+	+	0	0	+	0	+	+	+	0
Brignolia sp.	+	+	+	0	0	0	0	0	+	0	+	0	0	0	0	0	0	+	+	+	+	+	0	0	+	0	+

Appendix 4: Systematic position and guild composition of spiders documented from the study sites

SYATEMATIC POSITION						GUILD	STRATUM
ORDER	INFRAORDER		FAMILY	GENUS	SPECIES		
Araneae	Araneomorphae	Entelegynae	Agelenidae	*Agelena*	*Agelena sp.*	Sheet web weavers	Ground
Araneae	Araneomorphae	Entelegynae	Araneidae	*Acusilas*	*Acusilas sp.*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Anepsion*	*Anepsion sp.*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Araneus*	*Araneus mitificus*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Argiope*	*Argiope aemula*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Argiope*	*Argiope pulchella*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyclosa*	*Cyclosa bifida*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyclosa*	*Cyclosa confraga*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyclosa*	*Cyclosa hexatuberculata*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyclosa*	*Cyclosa insulana*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyclosa*	*Cyclosa simoni*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyclosa*	*Cyclosa spirifera*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyclosa*	*Cyclosa sp.*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Cyrtophora*	*Cyrtophora cicatrosa*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Eriovixia*	*Eriovixia laglaizei*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Gasteracantha*	*Gasteracantha geminata*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Gasteracantha*	*Gasteracantha hasselti*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Larinia*	*Larinia sp.*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Neoscona*	*Neoscona mukerjei*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Neoscona*	*Neoscona nautica*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Araneidae	*Neoscona*	*Neoscona theisi*	Orb web weavers	Vegetation

Araneae	**Araneomorphae**	**Entelegynae**	**Araneidae**	***Neoscona***	***Neoscona vigilans***	**Orb web weavers**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Araneidae**	***Neoscona***	***Neoscona sp 1***	**Orb web weavers**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Araneidae**	***Neoscona***	***Neoscona sp 2***	**Orb web weavers**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Araneidae**	***Nephila***	***Nephila pilipes***	**Orb web weavers**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Araneidae**	***Thelacantha***	***Thelacantha brevispina***	**Orb web weavers**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Corinnidae**	***Castianeira***	***Castianeira zetes***	**Ground hunters**	**Ground**
Araneae	**Araneomorphae**	**Entelegynae**	**Gnaphosidae**	***Prodidomus***	***Prodidomus sp.***	**Ground hunters**	**Ground**
Araneae	**Araneomorphae**	**Entelegynae**	**Gnaphosidae**	***Zelotes***	***Zelotes sp.***	**Ground hunters**	**Ground**
Araneae	**Araneomorphae**	**Entelegynae**	**Hersiliidae**	***Hersilia***	***Hersilia savignyi***	**Sensing web weavers**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Lycosidae**	***Hippasa***	***Hippasa lycosina***	**Ground hunters**	**Ground**
Araneae	**Araneomorphae**	**Entelegynae**	**Lycosidae**	***Lycosa***	***Lycosa sp 1***	**Ground hunters**	**Ground**
Araneae	**Araneomorphae**	**Entelegynae**	**Lycosidae**	***Lycosa***	***Lycosa sp 2***	**Ground hunters**	**Ground**
Araneae	**Araneomorphae**	**Entelegynae**	**Oxyopidae**	***Hamataliwa***	***Hamataliwa incompta***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Oxyopidae**	***Oxyopes***	***Oxyopes sp 1***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Oxyopidae**	***Oxyopes***	***Oxyopes sp 2***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Oxyopidae**	***Oxyopes***	***Oxyopes sp 3***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Oxyopidae**	***Peucetia***	***Peucetia viridana***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Philodromidae**	***Tibellus***	***Tibellus sp***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Pisauridae**	***Perenethis***	***Perenethis venusta***	**Sheet web weavers**	**Both**
Araneae	**Araneomorphae**	**Entelegynae**	**Salticidae**	***Carrhotus***	***Carrhotus viduus***	**Other hunters**	**Both**
Araneae	**Araneomorphae**	**Entelegynae**	**Salticidae**	***Carrhotus***	***Carrhotus sp.***	**Other hunters**	**Both**
Araneae	**Araneomorphae**	**Entelegynae**	**Salticidae**	***Epeus***	***Epeus indicus***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Salticidae**	***Epocilla***	***Epocilla aurantiaca***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Salticidae**	***Epocilla***	***Epocilla sp.***	**Other hunters**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Salticidae**	***Hasarius***	***Hasarius adansoni***	**Other hunters**	**Both**
Araneae	**Araneomorphae**	**Entelegynae**	**Salticidae**	***Hyllus***	***Hyllus sp.***	**Other hunters**	**Vegetation**

Araneae	Araneomorphae	Entelegynae	Salticidae	*Myrmarachne*	*Myrmarachne sp 1*	Other hunters	Both
Araneae	Araneomorphae	Entelegynae	Salticidae	*Myrmarachne*	*Myrmarachne sp 2*	Other hunters	Both
Araneae	Araneomorphae	Entelegynae	Salticidae	*Myrmarachne*	*Myrmarachne sp 3*	Other hunters	Both
Araneae	Araneomorphae	Entelegynae	Salticidae	*Phintella*	*Phintella vittata*	Other hunters	Vegetation
Araneae	Araneomorphae	Entelegynae	Salticidae	*Plexippus*	*Plexippus paykulli*	Other hunters	Both
Araneae	Araneomorphae	Entelegynae	Salticidae	*Plexippus*	*Plexippus petersi*	Other hunters	Both
Araneae	Araneomorphae	Entelegynae	Salticidae	*Rhene*	*Rhene flavicomans*	Other hunters	Vegetation
Araneae	Araneomorphae	Entelegynae	Salticidae	*Telamonia*	*Telamonia dimidiata*	Other hunters	Vegetation
Araneae	Araneomorphae	Entelegynae	Sparassidae	*Olios*	*Olios milleti*	Other hunters	Both
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Guizygiella*	*Guizygiella indica*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Guizygiella*	*Guizygiella melanocrania*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Leucauge*	*Leucauge decorata*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Leucauge*	*Leucauge sp.*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Opadometa*	*Opadometa fastigata*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Tetragnatha*	*Tetragnatha sp 1*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Tetragnatha*	*Tetragnatha sp 2*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Tetragnatha*	*Tetragnatha sp 3*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Tetragnathidae	*Tetragnatha*	*Tetragnatha sp 4*	Orb web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Theridiidae	*Faiditus*	*Faiditus sp.*	Space web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Theridiidae	*Nihonhimea*	*Nihonhimea indica*	Space web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Theridiidae	*Nihonhimea*	*Nihonhimea mundula*	Space web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Theridiidae	*Steatoda*	*Steatoda sp.*	Space web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Theridiidae	*Thwaitesia*	*Thwaitesia sp.*	Space web weavers	Vegetation
Araneae	Araneomorphae	Entelegynae	Thomisidae	*Camaricus*	*Camaricus formosus*	Ambush	Vegetation
Araneae	Araneomorphae	Entelegynae	Thomisidae	*Runcinia*	*Runcinia ghorpadei*	Ambush	Vegetation
Araneae	Araneomorphae	Entelegynae	Thomisidae	*Thomisus*	*Thomisus lobosus*	Ambush	Vegetation

Araneae	**Araneomorphae**	**Entelegynae**	**Thomisidae**	***Thomisus***	***Thomisus pugilis***	**Ambush**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Thomisidae**	***Thomisus***	***Thomisus sp.***	**Ambush**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Uloboridae**	***Zosis***	***Zosis geniculata***	**Orb web weavers**	**Vegetation**
Araneae	**Araneomorphae**	**Entelegynae**	**Zodariidae**	***Tropizodium***	***Tropizodium sp.***	**Specialist**	**Ground**
Araneae	**Araneomorphae**	**Haplogynae**	**Scytodidae**	***Scytodes***	***Scytodes pallida***	**Other hunters**	**Both**
Araneae	**Araneomorphae**	**Haplogynae**	**Oonopidae**	***Brignolia***	***Brignolia sp.***	**Ground hunters**	**Ground**

Appendix 5: Values of LCBD, Leroy rarity index and LCBD

Species	Number of sites occupied	SCBD	Leroy rarity index
Agelena sp.	5	0.007238452	0.035640381
Acusilas sp.	1	0.001883654	0.332039945
Anepsion sp.	2	0.003952198	0.212771598
Araneus mitificus	18	0.018241874	6.20E-09
Argiope aemula	15	0.018673304	6.93E-07
Argiope pulchella	15	0.01997083	6.93E-07
Cyclosa bifida	14	0.018724614	2.88E-06
Cyclosa confraga	14	0.018366326	2.88E-06
Cyclosa hexatuberculata	15	0.018554128	6.93E-07
Cyclosa insulana	17	0.017079296	3.21E-08
Cyclosa simoni	13	0.016174305	1.11E-05
Cyclosa spirifera	13	0.018591527	1.11E-05
Cyclosa sp.	12	0.016240622	3.96E-05
Cyrtophora cicatrosa	16	0.017791745	1.55E-07
Eriovixia laglaizei	12	0.015649884	3.96E-05
Gasteracantha geminata	12	0.014752942	3.96E-05
Gasteracantha hasselti	18	0.017339893	6.20E-09
Larinia sp.	11	0.018714581	0.000131028
Neoscona mukerjei	13	0.020358354	1.11E-05
Neoscona nautica	16	0.017856812	1.55E-07
Neoscona theisi	15	0.019042961	6.93E-07
Neoscona vigilans	15	0.018951062	6.93E-07
Neoscona sp 1	12	0.01633606	3.96E-05
Neoscona sp 2	15	0.017147231	6.93E-07
Nephila pilipes	10	0.015838424	0.00040258
Thelacantha brevispina	11	0.0172703	0.000131028
Castianeira zetes	10	0.016910498	0.00040258
Prodidomus sp.	1	0.001428979	0.332039945
Zelotes sp.	21	0.015041427	0
Hersilia savignyi	27	0.00185732	0
Hippasa lycosina	11	0.013822752	0.000131028
Lycosa sp 1	27	0.00185732	0
Lycosa sp 2	20	0.016212517	2.00E-10
Hamataliwa incompta	2	0.002849888	0.212771598
Oxyopes sp 1	13	0.018054987	1.11E-05
Oxyopes sp 2	12	0.017199142	3.96E-05
Oxyopes sp 3	12	0.01960487	3.96E-05
Peucetia viridana	4	0.006207128	0.069709129
Tibellus sp.	7	0.019611134	0.007433221

Sites	LCBD
1	0.596
2	0.907
3	0.794
4	0.158
5	0.133
6	0.281
7	0.238
8	0.109
9	0.52
10	0.259
11	0.168
12	0.88
13	0.739
14	0.155
15	0.691
16	0.795
17	0.085
18	0.986
19	0.999
20	0.356
21	0.642
22	0.981
23	0.031
24	0.536
25	0.884
26	0.185
27	0.011

Perenethis venusta	4	0.005965556	0.069709129
Carrhotus viduus	13	0.016094355	1.11E-05
Carrhotus sp.	9	0.0127085	0.001147231
Epeus indicus	8	0.011548565	0.003032209
Epocilla aurantiaca	2	0.002849888	0.212771598
Epocilla sp.	1	0.001428979	0.332039945
Hasarius adansoni	10	0.013468513	0.00040258
Hyllus sp.	10	0.013843466	0.00040258
Myrmarachne sp 1	5	0.008623854	0.035640381
Myrmarachne sp 2	3	0.006965279	0.126458132
Myrmarachne sp 3	3	0.007425017	0.126458132
Phintella vittata	19	0.017104343	1.10E-09
Plexippus paykulli	27	0.00185732	0
Plexippus petersi	22	0.011779812	0
Rhene flavicomans	7	0.009598212	0.007433221
Telamonia dimidiata	21	0.015187511	0
Olios milleti	8	0.014066714	0.003032209
Guizygiella melanocrania	7	0.011212104	0.007433221
Guizygiella indica	5	0.009125144	0.035640381
Leucauge decorata	20	0.01674127	2.00E-10
Leucauge.sp.	6	0.010326154	0.016900704
Opadometa fastigata	8	0.012177602	0.003032209
Tetragnatha sp 1	10	0.015916348	0.00040258
Tetragnatha sp 2	8	0.012297966	0.003032209
Tetragnatha sp 3	9	0.014756881	0.001147231
Tetragnatha sp 4	6	0.011592229	0.016900704
Faiditus sp.	1	0.001428979	0.332039945
Nihonhimea indica	14	0.015975261	2.88E-06
Nihonhimea mundula	27	0.00185732	0
Steatoda sp.	1	0.001428979	0.332039945
Thwaitesia sp.	22	0.011159566	0
Camaricus formosus	10	0.015680815	0.00040258
Runcinia ghorpadei	4	0.008226573	0.069709129
Thomisus lobosus	17	0.019144101	3.21E-08
Thomisus pugilis	4	0.011668697	0.069709129
Thomisus sp.	6	0.011186431	0.016900704
Zosis geniculata	4	0.005745244	0.069709129
Tropizodium sp.	2	0.006652868	0.212771598
Scytodes pallida	15	0.016970526	6.93E-07
Brignolia sp.	12	0.016813719	3.96E-05

Appendix 6: Different habitat disturbances scores across 27 sites

Sites	Disturbances									Sum	Class
	Agriculture	Effluent discharge	Garbage dump	Ghats	Grazing	Human settlement	Manmade embankment	Sand mining	Boats		
1	1	1	1	1	1	1	1	1	1	9	Very low
2	1	1	1	1	1	1	1	1	1	9	Very low
3	1	1	1	1	1	1	1	1	1	9	Very low
4	3	1	1	1	3	1	1	1	1	13	Low
5	3	2	2	2	3	2	1	1	2	18	High
6	3	2	2	2	3	2	1	1	2	18	High
7	2	3	3	2	2	2	3	1	3	21	Very high
8	3	2	1	2	3	2	2	1	2	18	High
9	3	1	1	2	3	2	1	1	1	15	Moderate
10	1	2	3	3	2	3	2	1	3	20	High
11	3	1	3	2	3	2	1	1	3	19	High
12	1	2	2	2	2	2	2	1	2	16	Moderate
13	2	2	1	1	2	2	1	1	1	13	Low
14	1	1	1	2	1	2	1	1	2	12	Low
15	1	2	2	2	2	2	2	3	2	18	High
16	2	1	1	1	1	1	1	3	2	13	Low
17	1	3	3	3	2	3	3	1	3	22	Very high
18	2	1	1	1	1	1	1	1	2	11	Very low
19	1	1	1	1	1	1	1	1	2	10	Very low
20	2	1	1	1	2	1	1	1	2	12	Low

21	2	1	2	2	2	2	2	1	3	17	Moderate
22	1	1	1	1	2	1	1	1	2	11	Very low
23	1	3	3	3	1	3	3	1	3	21	Very high
24	3	1	1	1	1	1	1	1	2	12	Low
25	3	1	1	2	2	1	1	1	2	14	Low
26	2	2	2	1	2	2	1	1	2	15	Moderate
27	1	3	3	3	1	3	3	1	3	21	Very high

NOTES ON THE DIVERSITY OF SPIDERS IN RIPARIAN ECOSYSTEM IN INDIA

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ABSTRACT: Riparian zones are one of the most biodiversity rich areas of the world. Flora and fauna of the riparian ecosystem, located at the boundary of the aquatic and terrestrial ecosystems, provide a variety of ecosystem services. But it has been found that despite being extremely important, our knowledge of the flora and fauna of riparian region is extremely limited, particularly about the invertebrates. In this paper, we are providing a brief idea about spider diversity of the riparian ecosystem in India. We hope that in the future there will be more research on the flora and fauna of the riparian regions in India, which will benefit biodiversity conservation management.

KEYWORDS: Diversity, Spiders, Riparian area, India

I. INTRODUCTION TO THE RIPARIAN ZONE AND ITS IMPORTANCE

The word 'riparian' is originated from the Latin word riparius which means the land near to the body of water [1]. It is basically the part of the terrestrial landscape that is located on the banks of the river channel and where the vegetation is affected by flood or elevated water table and soil water holding capacity [2]. It is hybrid as it results from co-construction by anthropogenic and natural processes, and it is open because the land located beside the fluvial systems interacts with the river and corresponding processes [3]. The features of this region are that, due to natural and human influences the changing bioclimatic, geo-morphological and land use conditions trigger high spatial and temporal variability [4]. The importance of riaparian zones is greater than their proportion to land area, because of their location in the boundary between aquatic and terrestrial ecosystems [5]. The three attributes viz. hydrogeomorphic, vegetational, and trophic web elements) which are characterized by spatial and temporal variation [6] makes them important habitats for maintenance of biodiversity and provide multiple ecosystem services [2, 7]. The riparian ecosystem provides provisioning ecosystem service (such as standing crop of woody biomass for fuel), regulating and maintenance ecosystem service (such as damage mitigation of extreme flows by regulating hydrological cycles and water flow, pollination, protection of human lives and infrastructure by buffering and attenuation of mass flows, reduction in carbon dioxide by carbon sequestration, reduction in fire damage costs , reduction in sediment and toxic particles transport in streams by filtering or storage of particles, reduction of erosion and sediment loads in streams by stabilization and control of erosion, reduction of pollution and damage costs of nutrient runoff, seed and propagule dispersal, sustaining populations of several species by providing habitats, temperature control in stream and air) and cultural ecosystem service by direct in situ and outdoor interactions with living systems, that depend on presence in the environmental setting [4].

II. THREATS TO THE FRESHWATER ECOSYSTEM AND RIPARIAN ZONES

It is estimated that among all water of the earth, only 2.5% is freshwater of which 0.40% is surface and atmospheric water (0.01% of total freshwater) [8]. Among the surface and atmospheric water, freshwater lakes constitute 67.4% (i.e. 0.00674% of total global freshwater), wetlands constitute 8.50% (i.e. 0.00085% of total global freshwater) and rivers constitute 1.60% (0.00016% of total global freshwater) [8]. Though this tiny amount of freshwater covers only 2.3% of the global land surface area, but it supports at least 9.5% of the described animal species of the Earth [9]. Overexploitation of biotic resources, invasion of exotic species, water flow regulation through construction of dams and reservoirs, uncontrolled extraction of water, organic and inorganic pollution from agricultural, industrial and domestic sources and climate change are considered as the major threats to the freshwater ecosystems [10, 11, 12, 13 and 14].

III. STUDIES ON SPIDERS OF RIPARIAN ECOSYSTEM IN INDIA

There have been some important studies around the world in recent times about spiders of riaparian areas regarding their diversity and ecology such as in Australia [15], Malaysia [16], Poland [17], Puerto Rico [18], Romania [19], South America [20], Uruguay [21] and USA [22]. In the recent past, research has also been done

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in India on the diversity of spiders in the riparian regions. From the riparian zone of the River Vishwamitri, Baroda, Gujarat 17 families, 50 genera and 92 species of spider were reported and it was found that at family level maximum diversity was seen in family Araneidae but at species level maximum diversity was found in non-weavers [23]. In a comparative study at Tarai Conservation Area (TCA) at Uttarakhand between pure sal woodland, mixed sal woodland, plantation, grassland and riparian swamp forest it was found that family Araneidae and Tetragnathidae, mostly constructs delicate orb web are predominant in riparian sites [24, 25]. From surrounding area of Narmada river at Rajghat (Barwani) (Madhya Pradesh) 44 species belonging to 12 families were reported [26]. From Ousteri Lake riparian habitat of Puducherry documented 10 species of Arachnida belonging to 9 families of which 3 species are spiders were reported [27]. From riparian zone of Periyar river, Kerala 68 species, 49 genera and 13 families of spiders were reported [28]. From Kavvayi River Basin, Kerala 112 species of spiders belonging to 81 genera and 21 families were reported [29]. From the bank of river Pampa at Poovathoor, Pathanamthitta district, Kerala. 39 species of spiders belonging to 17 families were reported [30]. From Charghad river basin of Morshi, Amravati 48 species belonging to 12 families were reported [31]. Knowledge of riparian spider diversity in northern India and eastern India is still limited, leading to opportunities for research in these areas.

IV. DISCUSSION

The main reason for the loss of wildlife and biodiversity around the world is anthropogenic activity and spiders are no exception. Habitat destruction by land reclamation, eutrophication and intensive agricultural management [32], conversion of forests to agricultural lands [33] and disturbance of forest ecosystems [34] are major cause of loss of spider diversity throughout the world. Spiders are directly and indirectly harmed (by the lack of prey insects) due to the widespread use of synthetic pesticides [35]. Damages to the local vegetation, particularly in natural grasslands, for grazing in an area changes the character of population structure of spiders in that area [35]. In order to increase the number of invasive predators in an area, the local spiders face stiff competition for food and self-defence, resulting in a decrease in the number of local spider population [36, 37]. Invasion of invasive plants in an area damages diversity local native plants and causes damage to spider community [38]. Some people's hobby is to bring wild animals into their home illegally as pet and the wildlife has to pay its price. Several species of spiders, especially Tarantula spiders, are victims of this illegal trade. As a result, spiders are collected from their local habit at and wildlife is greatly lost [39, 40]. In such a situation, researches should be conducted on diversity, distribution and ecology of riparian plants and animals in India so that we can gain knowledge for proper conservation and management of the riparian ecosystem.

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