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Diversity and Microhabitat Association of Spider Fauna in Manas National Park, Assam, India

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ABSTRACT

Spiders act as a useful indicator of the health of an ecosystem and it is also one of the most diverse arthropod groups. The present study was intended to investigate the diversity of spider fauna in Manas National Park (MNP) of Assam in northeast India. The study was carried out in the parts of Bhuyapara, Bansbari, Panbari, and Kuklung Forest Range of MNP from September 2018 to August 2021. Three different habitat types namely woodland, grassland, and riparian habitats were sampled using 50 m×10 m transects and a semi-quantitative sampling method as a sampling technique. From MNP, a total of 73 species of spiders were recorded belonging to 47 genera and 16 families. Family Araneidae was the most abundant family supporting 21 species and 28.77% of the total species recorded. The majority of the spider species were found in woodland habitats with 54.17% of the total recorded species. Again, orb waver was the most abundant guild structure which comprised 45.21% of the total recorded guild. The surface of a leaf or among leaves was the most abundant microhabitat, comprised 42.47% of all recorded microhabitat. Thus, the result of the present study opined that MNP harbors a great diversity of spider species and subsequently calls for conservation priority areas in the region.

Keywords Arthropod, Araneidae, Guild structure, Manas National Park, Microhabitat.

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INTRODUCTION

Spiders are carnivorous creatures, well-known macro-invertebrate predators, and play an important role in almost every terrestrial and semi-terrestrial habitat. They play an important role in the food chain by regulating the populations of terrestrial arthropods and thus are an integral part of global biodiversity. A significant portion of terrestrial arthropod diversity is spiders as they occupy the seventh position in the world on the basis of total species diversity (Sebastian and Peter 2009, Polchaninova *et al.* 2023). In spite of their high diversity and ecological role in many ecosystems, spiders are generally poorly studied arthropod groups and received little attention from the conservation community. India, although recognized as a mega-diverse country of the world up till now there exists extremely fragmentary knowledge about the diversity and distribution of spider fauna (Punjoo 2015). India harbors 1,685 species of spider belonging to 438 genera under 60 families (Keswani *et al.* 2012). Out of these 1053 species of spiders are endemic to India (Siliwal and Molur 2007). The pioneering work on Indian spiders has been initiated by several European workers (Padayatty 2011). They described many species from India, Burma, and Sri Lanka. Tikader was considered the father of Indian Arachnology who extensively studied the spiders of the Indian subcontinent and introduced a large number of new species through his studies (Tikader 1987). In recent times many research articles have been published from various parts of the country on the subject of taxonomic descriptions of new species of spiders belonging to various families (Caleb 2020).

Various worker's attempts to study the diversity of spiders have been carried out in different states of India by various authors (Shivarama *et al.* 2013, Ankhade and Manwar 2013, Deshmukh and Raut 2014, Sethy and Ahi 2022). A number of works on the seasonal diversity and composition of spiders in different vegetation types have been carried out by Rajeevan *et al.* (2019). The diversity and distribution of spiders in different vegetation types along altitudinal gradients have been carried out by Quasin and Uniyal (2011). However, the information regarding the diversity, habitat ecology, and data on the life cycles of Indian spiders is far from complete.

Rajkhowa *et al*. (2014) have suggested that the northeastern region of India is the bio-geographical gateway of greater India and that can be considered as one of the richest biodiversity hot-spot zones of Assam. Until now, there are records about the spiders from Northeastern states like Tripura, Meghalaya, Sikkim, Manipur, Arunachal Pradesh, and Mizoram. Assam, a part of the Northeast India region falls under the east Himalayan biodiversity hotspot. Singh *et al.* (2012) have published articles on the diversity of spider fauna in the Barpeta district of Assam. The diversity of spiders in agricultural fields of the Sanitpur district of Assam has been carried out by Ahmed (2015). In recent years, many research articles were published from the state of Assam on the subject of the taxonomic description of new species of spiders Ahmed *et al.* (2014a, 2014b), Basumatary *et al.* (2018) and Basumatary and Brahma (2019a, 2019b, 2021). Studies were also conducted in protected areas of Assam that include the diversity of spiders in the Gibbon Wildlife Sanctuary (Chetia and Kalita 2012), Chakrashila Wildlife Sanctuary (Basumatary and Brahma 2017) and a handbook of spiders from selected protected areas of upper Assam such as Gupta *et al.* (2015). Manas National Park of Assam, a UNESCO World Heritage site located in the foothills of the Eastern Himalayas is a site of outstanding natural value (Saikia 2012). However, study on spider diversity in the Manas National Park is still lacking. It is well established that to carry out meaningful conservation-based studies first we have to know about the fauna of a particular region. Thus, there exists a serious need to explore the diversity and distribution of spiders in the National Park. Keeping in view the necessity, the goal of the present study is to study the spider diversity found in the Manas National Park. The present study provides reliable information on the poorly studied spider fauna of the National Park and serves as a base for future research.

MATERIALS AND METHODS

Study site

The Manas National Park (MNP) located in the state of Assam, India is the core area of Manas Tiger Reserve (MTR) Assam with an area of 950 km^2 extending from 26°28'N to 26°49'N latitudes and from 90°15'E to 90°49'E longitudes (Fig. 1). The National Park is bounded by Royal Manas National Park of Bhutan on the north and on the south by areas of North Kamrup. The southern boundary of the park is mostly dominated by agricultural areas. The eastern and western boundary of the park is surrounded by forest reserves. It is divided into four ranges viz., Bhuyanpara (Eastern Range), Bansbari (Central Range), Panbari (Western Range), and Kuklung. The Kuklung Range established in the year 2016 with an area of 350 km^2 is the first addition to Manas National Park. The different streams and rivers, which originated

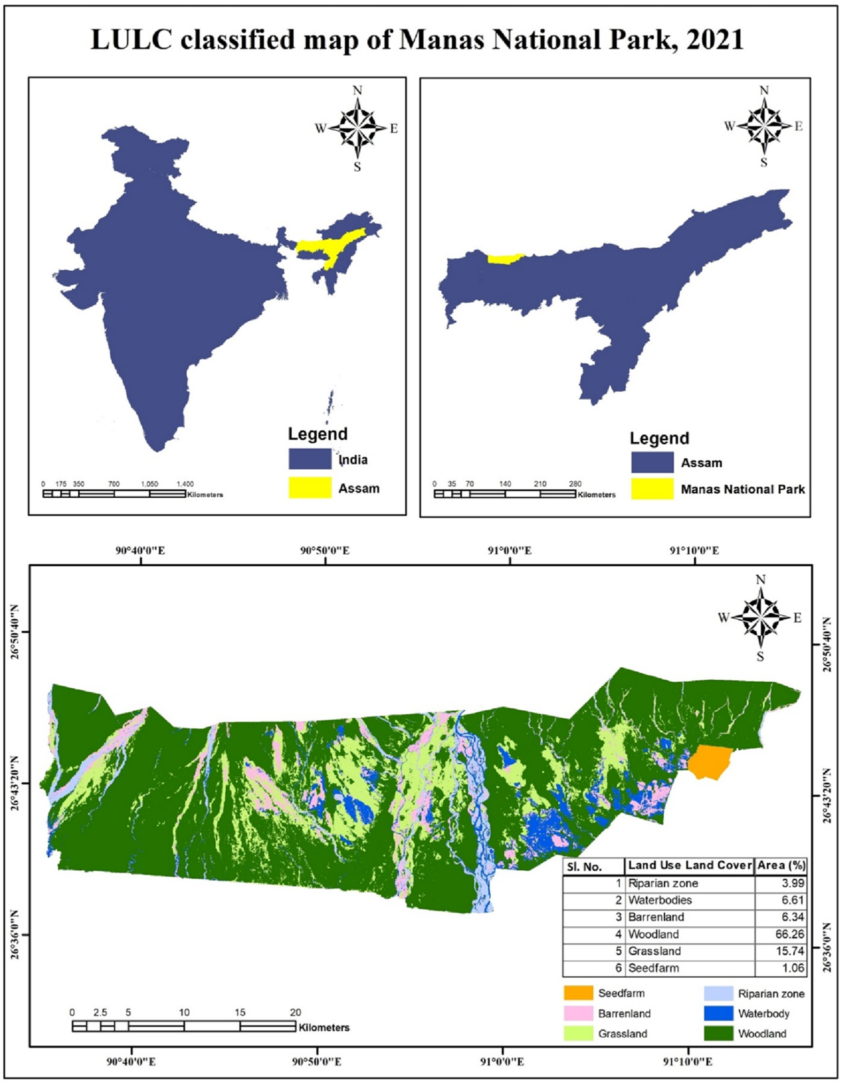

Fig. 1. LULC classified map of Manas National Park.

from Bhutan hills split into a distribution network in the plains of the park. The vegetation of the study area includes (a) tropical semi-evergreen forests, with common trees including *Aphammixis pofystachya, Anthocephalus chinemis, Syzygium cumini, Syzygium formosum, Syzygium oblatum, Bauhinia purpurea, Mallotus philippemis, Actinodaphne obvata,* (b) tropical moist and dry deciduous forests, characterized by trees such as *Bombax ceiba, Sterpvlfavillosa, Dillenia indica, Dillenia pentagyna, Careya arborea, Lagerstroemia parviflora, Lagerstroemia speciosa, Terminalia bellirica, Terminalia chebula,Trewia polycrapa, Gmelina arborea, Oroxylum indicum, Bridelia retusa* and (c) extensive alluvial grasslands, comprising many different grass species together with a variety of tree and shrub species. The climate of the study area is moist tropical with an annual rainfall between 3000 mm to 4000 mm. Rainfall in the region starts in mid-March and lasts till October. The months from November to February remain relatively dry and dry up most of the water. The climate can be divided into four distinct seasons namely pre-monsoon (March-May), monsoon (June-September), retreating monsoon (October-November), and winter (December-February) based on the variation in the rainfall, temperature and winds.

Methods of study

The study was carried out from September 2018 to August 2019 in Bhuyapara, Bansbari, Panbari, and Kuklung Forest Range of Manas National Park. Spiders were sampled in three different habitats viz., Woodland, Grassland, and Riparian (Table 1). For data collection habitats were stratified based on noticeable differences in vegetation types. To study the spider diversity, the transect method was used as per Eberhardt (1978). Line transects of 100 m × 1 m (length and breadth respectively) were placed randomly within the stratified habitats for spider data collection. Altogether 90 line transects of equal sizes were placed in all the habitats of the study sites with 30 transects per habitat type of the study area (Table 1). All the line transects were separated by a distance of 200 m between two transects were taken. To investigate the habitat ecology of spider habitat variables such as tree canopy cover, litter cover, litter depth, temperature, and humidity were measured. Vegetation data were collected using 10 x 10 m size quadrants adjacent to each transect used for spider sampling as per Weaver (1918) and Hao *et al.* (2020). To study the spider diversity in terms of guild structure the foraging guild structure of the spider species was divided into seven major types

Table 1. Major habitats characteristics, sampling sites and transect details of the study area.

Habitat	Sub type	Characteristics	No. of transect	Sampling sites	Area (%)
Woodland	Tropical semi evergreen forest	Semi-evergreen parches occur chiefly along the northern part of the sanctuary, on the India-Bhutan international boundary. The common trees in these forests are *Aphanumixis porlystnchyn, Antfiocephalus chinensis, Syzygium ctrmini, S. forrnosum, S. oblaturn, Bauhinia* sp.	15	c, u, k, l, r, v s, o, t, u, j, p, *n, q*	66.26
	East Himalaya mixed moist deciduous forest	Forest occurred in successional stage between the grassland and the semi-evergreen forest. Dominant species include *Terminilia bellirica, Sterculia villosa, Lagerstroemia parviflora, Dillenia pentagyna, Michelia champaca, Strospermum personatum, Bombax ceiba* and *Fagara budrunga*	15		
Grassland	Short grassland	Dominant grass species include *Imperata cylindrica*, *Imperata arundinacea, Saccharum spontaneum* and *Saccharum procerum.*	15	a, b, c, f, g, h i, j, k, l, m, n	15.74
	Tall grassland	Grassland located at well drained high land. Dominant grass species include *Imperata cylidrica, Themeda arundinacea, Themeda caudate* and *Arundo donax*	15		
Riparian habitat	Riparian fringing forests	Forest occured along the banks of the streams. The principal species were *Simul, Khoir* and *Sissoo*	30	c, o, l, p, n, q, r	3.99

Abbreviations: a= Lwkhibazar, b= Sewali Camp, c = Teklai Camp, f= Rupohi Camp, g= Makhibaha Camp, h= Plot.No.07 Gwnpuri, i= Matigaltab Grassland, j= Kodom Pukhuri Anti-Poaching Camp, k=Corphuli Camp, l= 5^{th} Mile Road, m=Pohufield, n= Bura Buri Jharnala, o= Koklabari, p= 3^{rd} Mile Road, q= Kuribeel, r= Panbari Jhar, s= Kalamati River, t= Agragnala, u= Bansbari-Mothanguri Road, v= Roisingla Tiniali.

namely Orb weavers, Ground hunters, Sensing web, Sheet web, other hunters, Ambush hunters, and Space web (Cardoso *et al.* 2011).

Survey and data collection

Data collection was made on foot along the transects using the active searching method (Coddington *et al.*1996), that includes aerial sampling, ground collection, beating sampling, and litter sampling. Aerial sampling involves searching the leaves, branches, and tree trunks from knee height up to maximum overhead arm's reach. The ground collection involves searching the logs, rocks, and plants below low knee level. Beating sampling includes striking vegetation with a 1 m long stick and catching the falling spiders on an inverted umbrella. Litter sampling includes searching the leaf litter. The survey was conducted from 07:00 hrs to 11:00 hrs. Spiders were searched for 2 hrs in each transect without any interruption. On encounter with each individual of a species, photographs were taken and the locality, date, time, their GPS location were recorded in the field notebook. GPS locations were taken using Garmin etrex 64 and photographs were taken using Canon 3000D. The foraging guild structure of each spider species was also recorded. The collected spiders were killed by transferring them into a bottle containing a small cotton swab with a few drops of chloroform or ether and preserved in 70% ethyl alcohol. The canopy cover was estimated by using a densitometer. The percentage litter cover was estimated visually within each quadrate. Litter depth was measured by inserting a measurement ruler into the leaf litter until the harder soil layer was encountered. Temperature and humidity were measured by using a Thermo hygrometer.

Identification

Spiders were identified using photographs to their designated order to family level, then genus and its species if possible. The collected specimens were observed and studied under a stereo zoom microscope (Leica EZ4), and taxonomic identification of the specimens was done with the help of existing literature and descriptions (Tikader 1987, Sebastian and Peter 2009).

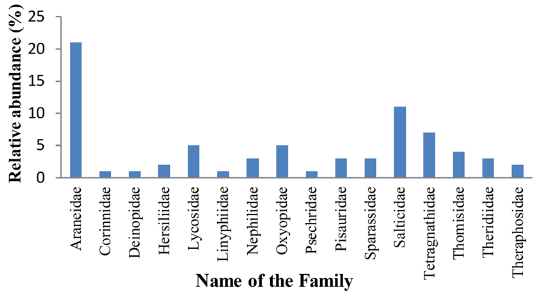

Fig. 2. Chart showing relative abundance of species recorded in each family.

Data analysis

All statistical analyses were done using Species Diversity and Richness IV (SDR-IV) software (version 4.1.2), PAST (version 3.0), and SPSS (version 16.0) software, and the bootstrap method was used to calculate a 95% confidence interval. Shannon-Weiner Diversity Index (H′) was used to determine species diversity in each habitat (Shannon and Weiner (1963), Konopiński (2020)). The proportional abundance of spiders in woodland, grassland, and riparian habitat was calculated using the formula of Prop-WL= (WL)/ (WL+GL+RP), Prop-GL= (GL)/ (GL+RP+WL) and Prop-RP= (RP)/ (RP+WL+GL) as per Saikia (2011). One Way Analysis of Variance (ANOVA) was used to assess the means differences in spider species abundance across various habitats (Zar 1996, Kim 2017). Principal Component Analysis (PCA) was used to determine the correlation of species assemblage with various environmental parameters (Ian and Jorge (2016).

RESULTS

Species assemblages and abundance

The study revealed altogether 73 species of spiders belonging to 47 genera and 16 families (Fig. 2. Table 2, See Plate- 1A-1G). The study found that the family Araneidae was the most dominant family (21 species, 28.77%) in terms of number of species, followed by Salticidae (11 species, 15.06%), Tetragnathidae (7 species, 9.59%) and Oxyopidae (5 species, 6.85%). In terms of the number of individuals, Lycosidae (143

Table 2.. Proportional abundance of spider fauna in three different habitats of the study area.

Family	Scientific name	Woodland	Grassland	Riparian	Guild structure
Araneidae	*Agriope pulchella*	1.57	0	0	ORW
	Argiope catenulata	0	1.57	0	ORW
	Argiope anasuja	1.57	0	0	ORW
	Argiope aemula	0.52	0.52	0	ORW
	Cyrtarachne bengalensis	1.57	0	0	ORW
	Cyrtophora moluccensis	0	0	1.57	ORW
	Cyclosa bifida	0.73	0.34	0	ORW
	Cyclosa insulana	0.85	0.25	0	ORW
	Cyrtophora citricola	1.57	0	0	ORW
	Cyrtophora inequiles	0	0	1.57	ORW
	Eriovixia laglaizei	1.57	0	0	ORW
	Gasteracantha diadesmia	1.57	0	0	ORW
	Gasteracantha hasselti	1.57	0	0	ORW
	Gasteracantha kuhli	1.57	0	0	ORW
	Neoscona odites	0	0	1.57	ORW
	Neoscona nautica	0	0	1.57	ORW
	Neoscona bengalensis	0	0	1.57	ORW
	Neoscona vigilans	1.57	0	0	ORW
	Neoscona mukerjei	0	0	1.57	ORW
	Nephiligyns malabarensis	0	0	1.57	ORW
	Parawixia dehaani	1.57	0	0	ORW
Corinnidae	*Castianeira zetes*	1.57	0	0	GRH
Deinopidae	*Deinopis* sp.	0	0	1.57	AMH
Hersiliidae	*Hersilia savignyi*	0.85	0	0.25	SEW
	Hersilia longivulva	1.57	0	0	SEW
Lycosidae	*Hippasa agelenoides*	0	0.39	0.67	GRH
	Hogna sp.	0	0	1.57	GRH
	Lycosa tista	0.25	0.85	0	GRH
	Pardosa pseudoannulata	0.52	0.2	0.31	GRH
	Pardosa sumatrana	0.28	0.22	0.53	GRH
Linyphiidae	*Linyphia striata*	1.57	0	0	SHW
Nephilidae	*Herennia multipuncta*	1.57	0	0	ORW
	Nephila pilipes	0.93	0	0.2	ORW
	Nephila kuhlii	1.57	0	0	ORW
Oxyopidae	*Oxyopes birmanicus*	0.52	0.31	0.19	OTH
	Oxyopes javanus	0.52	0.17	0.34	OTH
	Oxyopes shewta	0.34	0.73	0	OTH
	Oxyopes linearis	0.61	0.44	0	OTH
	Oxyopes sikkimensis	1.57	0	0	OTH
Psechridae	*Psechrus torvus*	0.8	0	0.29	SHW
Pisauridae	*Perenethis venusta*	0	0	1.57	SHW
	Thalassius albocinctus	0	1.57	0	SHW
	Dolomedes sp.	0	0	1.57	SHW
Sparassidae	*Olios milleti*	0.85	0	0.25	OTH
	Heteropoda venatoria	1.57	0	0	OTH
	Heteropoda nilgirina	1.57	0	0	OTH
Salticidae	*Carrhotus viduus*	1.57	0	0	OTH
	Epeus tener	1.57	0	0	OTH
	Epeus indicus	1.57	0	0	OTH
	Hyllus semicupreus	0.34	0.73	0	OTH
	Bianor angulosus	1.57	0	0	OTH
	Plexippus paykulli	1.57	0	0	OTH
	Myrmarachne kuwagata	0	0	1.57	OTH
	Phintella vittata	0.52	0	0.52	OTH
	Portia fimbriata	1.57	0	0	OTH

Table 2. Continued.

Family	Scientific name	Woodland	Grassland	Riparian	Guild structure
	Telamonia dimidiata	1.57	0.00	0.00	OTH
	Plexippus petersi	1.57	0.00	0.00	OTH
Tetragnathidae	*Tetragnatha mandibulata*	0.85	0.25	0	ORW
	Tetragnatha cochinensis	0	1.57	0	ORW
	Leucauge decorata	0.57	0.18	0.29	ORW
	Opadometa fastigata	1.57	0	0	ORW
	Leucauge tessellata	1.57	0	0	ORW
	Tylorida striata	0.34	0	0.73	ORW
	Leucauge sp.	0	0	1.57	ORW
Thomisidae	*Camaricus formosus*	1.57	0	0	AMH
	Oxytate virens	1.57	0	0	AMH
	Phrynarachne sp.	1.57	0	0	AMH
	Thomisus pugilis	1.57	0	0	AMH
Theridiidae	*Argyrodes flavescens*	0.97	0	0.18	SPW
	Argyrodes sp.	1.57	0	0	SPW
	Theridion sp.	1.57	0	0	SPW
Theraphosidae	*Lyrognathus saltator*	1.57	0	0	SEW
	Misumena sp.	0	0	1.57	SEW

ORB-Orb weavers, GRH- Ground hunters, SEW- Sensing web, OTH- Other hunters, SHW- Sheet web, AMH- Ambush hunters, SPW-Space web.

individuals) was the most dominant family, followed by Araneidae (79 individuals), Tetragnathidae (59 individuals), and Oxyopidae (49 individuals). The woodland habitat (52 species, 54.17%) harbors the highest number of species, followed by riparian habitat (30 species, 31.25%) and grassland (14 species, 14.58%). The rank abundance curve for woodland habitat showed a gradual slope but the curves for grassland and riparian habitat presented a steeper slope (Fig. 3).

Diversity indices

Analysis of the Shannon Wiener index of diversity in different habitats of the study area showed that the diversity of spider was highest in woodland habitat (H'=3.48) and lowest in grassland (H'=2.36) during the study period (Fig. 3). Pielou's evenness index among spiders showed the highest values in grassland (J'= 0.75) and lowest in woodland (J'= 0.62). Again, analysis of One-Way ANOVA to compare the mean

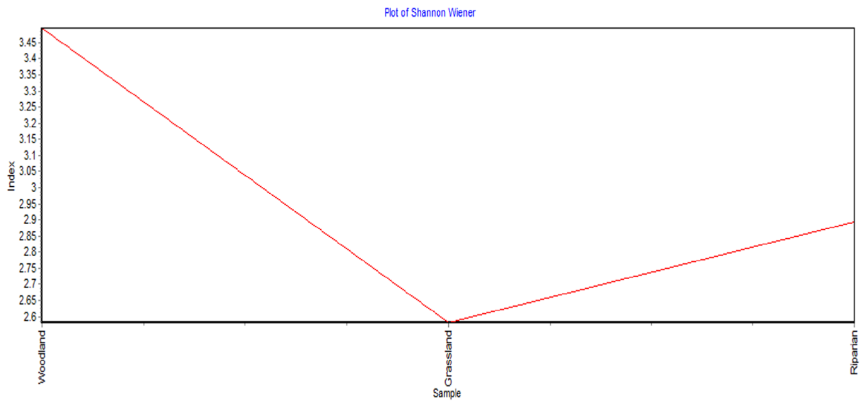

Fig. 3. Species diversity of spider fauna sampled in three different habitat of the study area.

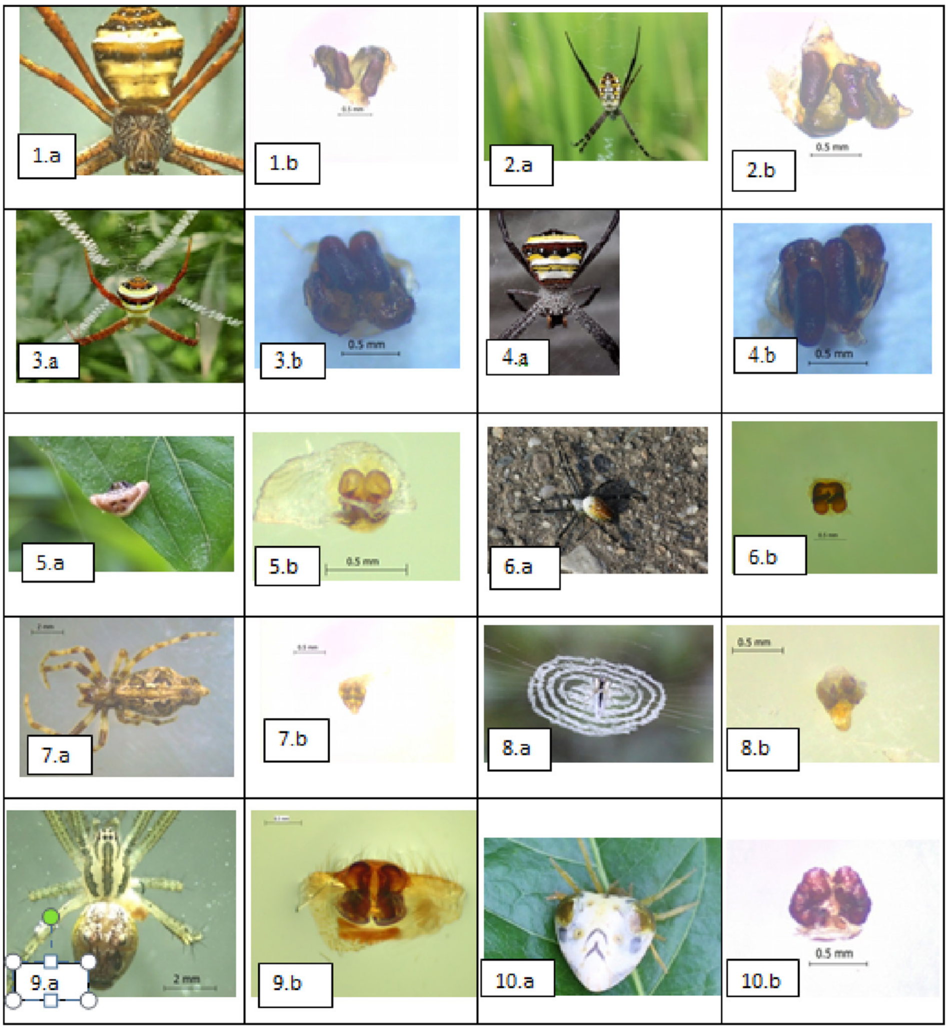

Plate 1A. Plates showing the spider diversity of the study area of Manas National Park: (1.a) *Agriope pulchella,* (1.b) Epigyne of *Agriope pulchella,* (2.a) *Argiope catenulata,* (2.b) Epigyne of *Argiope catenulata*, (3.a) *Argiope anasuja,* (3.b) Epigyne of *Argiope anasuja,* (4.a) *Argiope aemula*, (4.b) Epigyne of *Argiope aemula,* (5.a) *Cyrtarachne bengalensis,* (5.b) Epigyne of *Cyrtarachne bengalensis,* (6.a) *Cyrtophora moluccensis,* (6.b) Epigyne of *Cyrtophora moluccensis*, (7.a) *Cyclosa bifida,* (7.b) Epigyne of *Cyclosa bifida*, (8.a) *Cyclosa insulana,* (8.b) Epigyne of *Cyclosa insulana*, (9.a) *Cyrtophora citricola*, (9.b) Epigyne of *Cyrtophora citricola*, (10.a) *Cyrtarachne inequiles,* (10.b) Epigyne of *Cyrtarachne inequiles.*

differences of spider species abundance scores in three different habitats of MNP was significantly different at the <0.05 level (F=5.79, P= 0.001). Post hoc comparisons using the LSD test indicated that there was a significant difference between the mean abundance score in woodland habitat (M= 3.72, SD=5.646) and grassland habitat (Mean= 1.22, SD=2.992), P=0.002 and grassland habitat (M= 1.22, SD=2.992) and riparian habitat (M=3.35, SD= 6.269), P=0.006.

Feeding guild and habitats

The majority of the spider species belonged to orb waver with 45.21% of the total recorded spider species, followed by other hunters (26.03%), ground hunters (8.22%), ambush hunters (5.48%), and space waver (4.11%). Orb weavers were the most abundant guild structure in the entire three habitats (Woodland- 38.46%, Grassland- 28.57%, and Riparian- 46.67%). The other hunter was the second most abundant guild

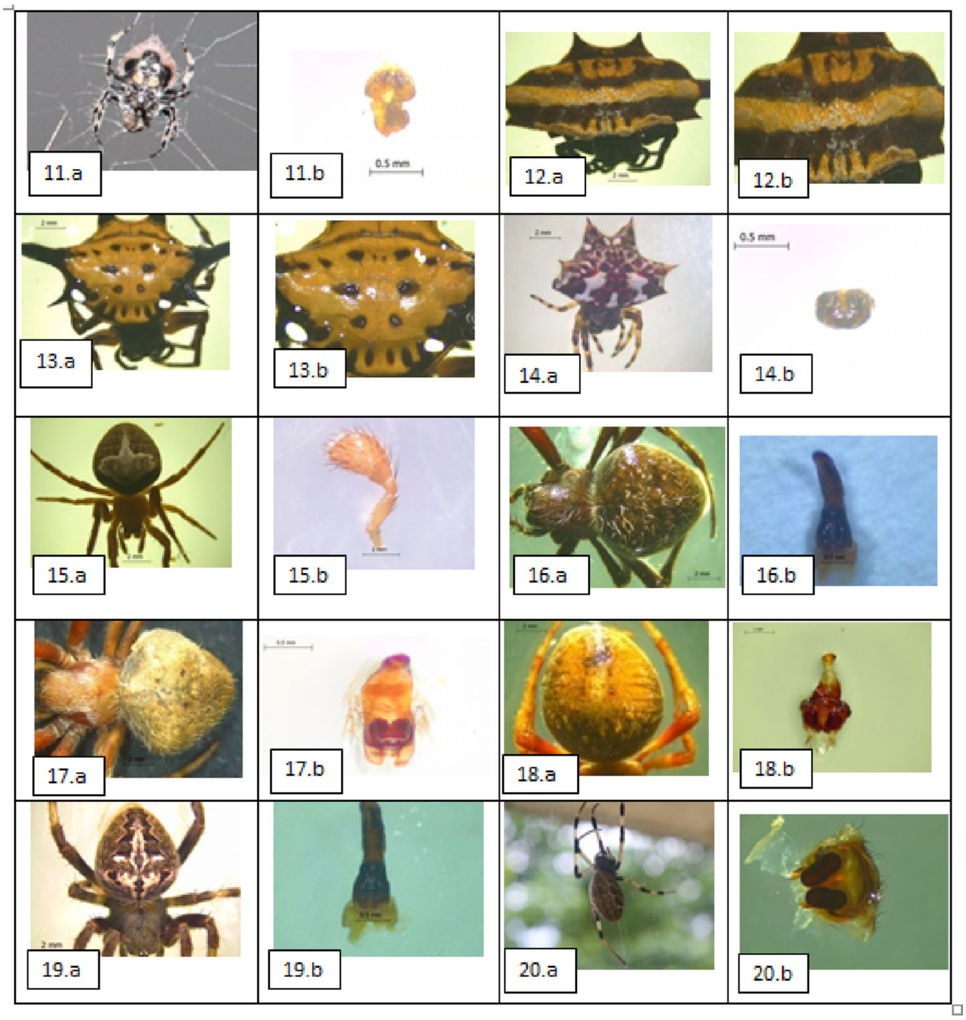

Plate 1B. Plates showing spider diversity of the study area. (11.a) *Eriovixia laglaizei,* (11.b) Epigyne of *Eriovixia laglaizei*, (12.a) *Gasteracantha diadesmia,* (12.b) Dorsal view of *Gasteracantha diadesmia,* (13.a) *Gasteracantha hasselti,* (13.b) Dorsal view of *Gasteracantha hasselti,* (14.a) *Gasteracantha kuhli,* (14.b) Epigyne of *Gasteracantha kuhli,* (15.a) *Neoscona odites,* (15.b) Pedipalp of *Neoscona odites,* (16.a) *Neoscona nautica,* (16.b) Epigyne of *Neoscona nautica,* (17.a) *Neoscona bengalensis*, (17.b) Epigyne of *Neoscona bengalensis,* (18.a) *Neoscona vigilans,* (18.b) Epigyne of *Neoscona vigilans,* (19.a) *Neoscona mukerjei,* (19.b) Epigyne of *Neoscona mukerjei,* (20.a) *Nephiligyns malabarensis*, (20.b) Epigyne of *Nephiligyns malabarensis.*

in the woodland (34.62%) and grassland (35.71%) habitat. In the case of riparian habitat, the second most abundant guild was ground hunters (16.67%). However, sensing web, ambush hunters, and space web guild types were not recorded in the grassland (Fig. 4).

Habitat microhabitat variations

The present study has documented five major types of microhabitats namely between trees or branches (BTB), under stones or tree holes (UST), tree bark (TB), soil or ground zone (SL), and surface of a leaf or among leaves (LUS). Overall, the LUS microhabitat was the most abundant microhabitat comprising 42.47% of all recorded microhabitats, followed by BTB (34.25%), SL (9.59%), TB (8.22%), and UST (5.48%). The BTB microhabitat type had the highest relative abundance in the woodland (36.54%) hab-

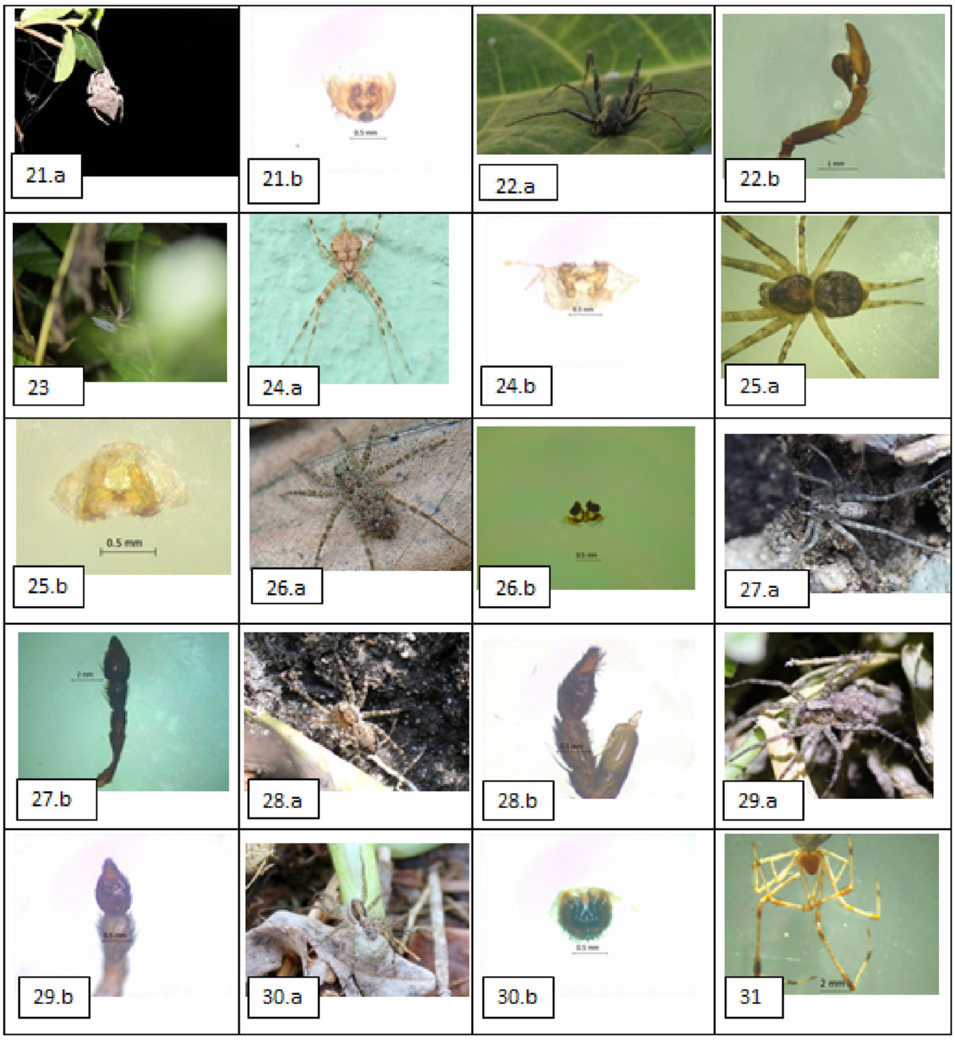

Plate 1C. Plates showing spider diversity of the study area: (21.a) *Parawixia dehaani,* (21.b) Epigyne of *Parawixia dehaani,* (22.a) *Castianeira zetes*, (22.b) Pedipalp of *Castianeira zetes,* (23) *Deinopis* sp., (24.a) *Hersilia savignyi,* (24.b) Epigyne of *Hersilia savignyi,* (25.a) *Hersilia longivulva,* (25.b) Epigyne of *Hersilia longivulva,* (26.a) *Hippasa agelenoides,* (26.b) Epigyne of *Hippasa agelenoides,* (27.a) *Hogna* sp., (27.b) Pedipalp of *Hogna* sp., (28.a) *Lycosa tista*, (28.b) Pedipalp of *Lycosa tista*, (29.a) *Pardosa pseudoannulata*, (29.b) Pedipalp of *Pardosa pseudoannulata,* (30.a) *Pardosa sumatrana,* (30.b) Epigyne of *Pardosa sumatrana,* (31) *Linyphia striata.*

itat. In the case of grassland and riparian habitats, the LUS (50%) microhabitat type had the highest relative abundance. The highest relative abundance of SL (21.43%) and UST (7.14%) microhabitat was found in grassland habitat. The TB microhabitat type had the highest relative abundance in the woodland (11.54%) habitat and was not recorded in the grassland habitat (Fig. 5).

Environmental parameters

In different study sites of MNP, the temperature recorded was in the range of 20°C to 35.9°C with a mean average of 29.11±0.482SE degree Celsius. The humidity recorded during the study period ranged from 18% to 92% with a mean average of 58.21±3.011SE percentage. Again, the canopy cover

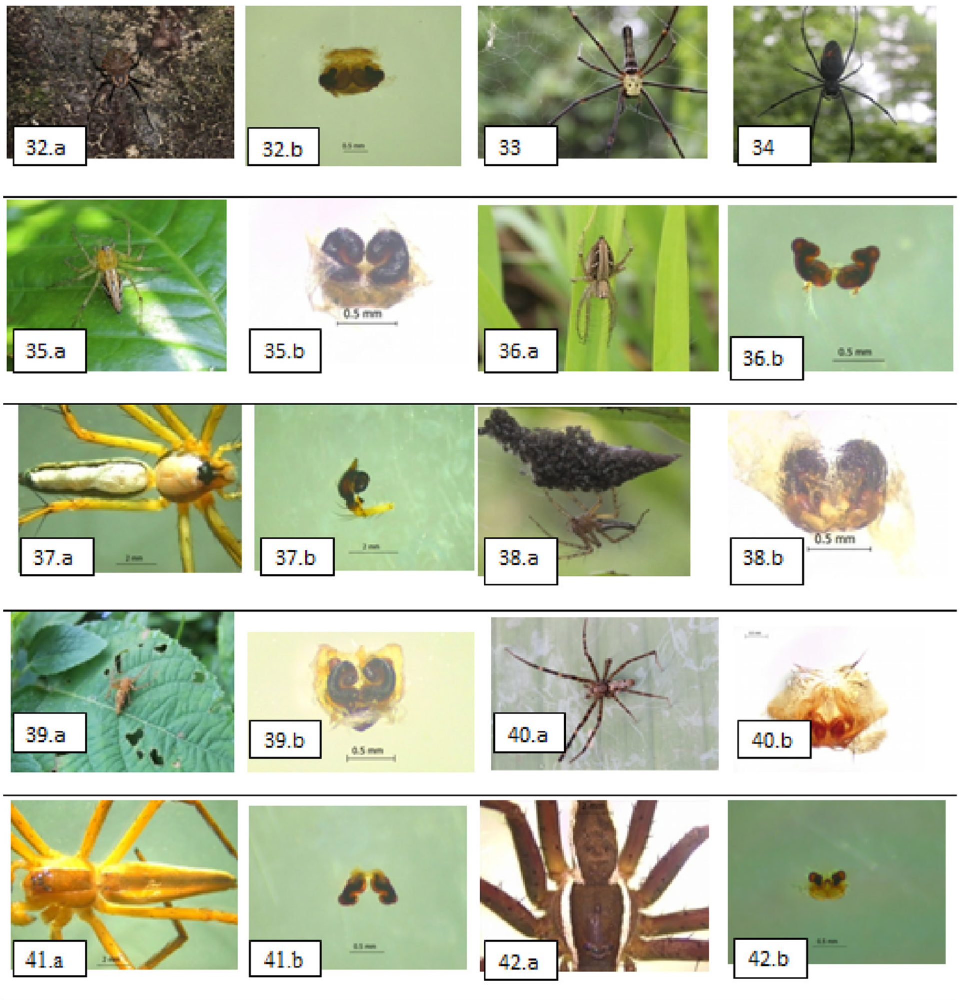

Plate 1D. Plates showing spider diversity of the study area: (32.a) *Herennia multipuncta,* (32.b) Epigyne of *Herennia multipuncta,* (33) *Nephila pilipes,* (34) *Nephila kuhlii,* (35.a) *Oxyopes birmanicus,* (35.b) Epigyne of *Oxyopes birmanicus,* (36.a) *Oxyopes javanus,* (36.b) Epigyne of *Oxyopes javanus,* (37.a) *Oxyopes shewta,* (37.b) Pedipalp of *Oxyopes shewta,* (38.a) *Oxyopes linearis,* (38.b) Epigyne of *Oxyopes linearis,* (39.a) *Oxyopes sikkimensis,* (39.b) Epigyne of *Oxyopes sikkimensis,* (40.a) *Psechrus torvus,* (40.b) Epigyne of *Psechrus torvus,* (41.a) *Perenethis venusta*, (41.b) Epigyne of *Perenethis venusta*, (42.a) *Thalassius albocinctus,* (42.b) Epigyne of *Thalassius albocinctus.*

percentage of the study sites recorded was in the range of 0 to 90% with a mean average of 47.22±6.406SE percentage. The litter-cover percentage of the various sites ranged from 0 to 60% with a mean average of 29.15±3.870SE percentage. Similarly, the litter depth recorded from various sites during the study period was in the range of 0-5.3 cm with a mean average of 3.78±0.445SE centimeter.

Principal component analysis

During the study period, the Eigenvalues for the first four axes were found to be 2.27, 1.48, 0.99, and 0.16 respectively. Axis 1 explained a 45.53% correlation and the other 3 axes correspond to a 53.03% correlation between environmental parameters and spider species abundance. The results of the first

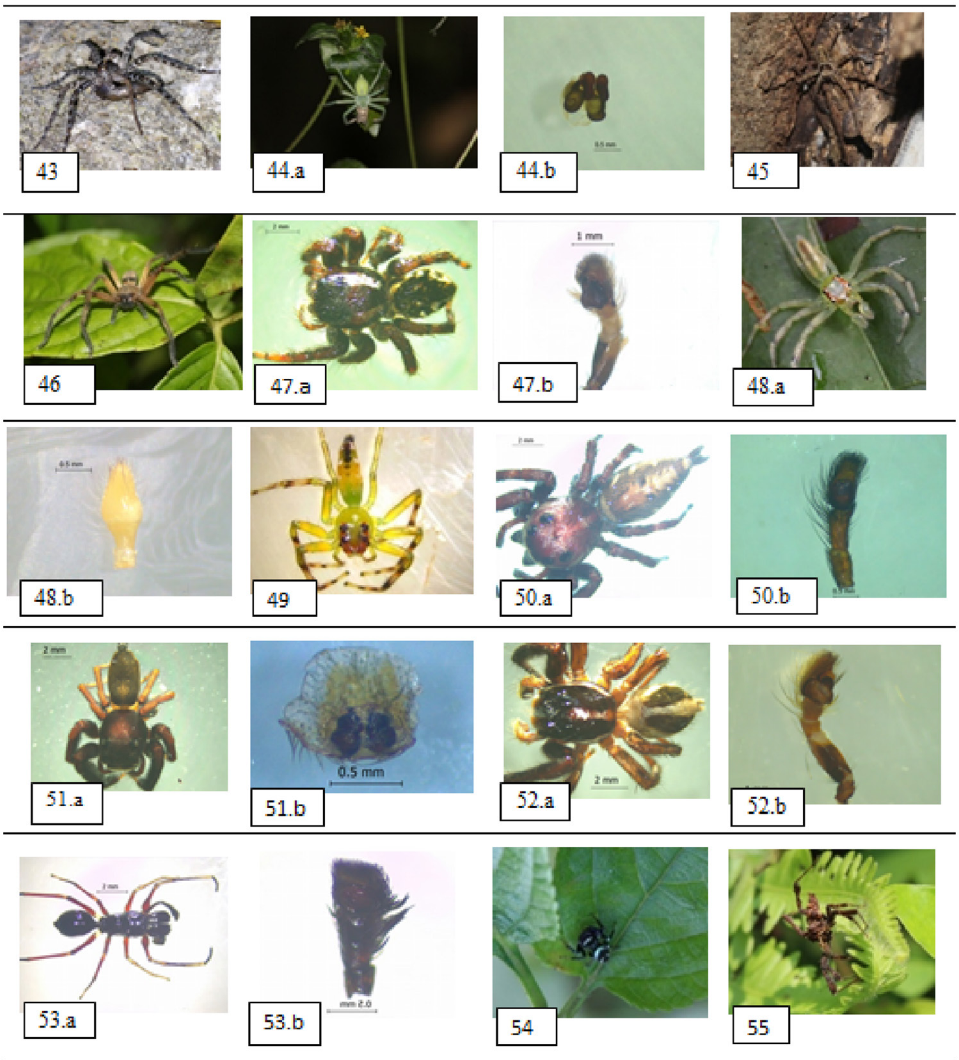

Plate 1E. Plates showing spider diversity of the study area: (43) *Dolomedes* sp., (44.a) *Olios milleti,* (44.b) Epigyne of *Olios milleti,* (45) *Heteropoda venatoria,* (46) *Heteropoda nilgirina,* (47.a) *Carrhotus viduus,* (47.b) Pedipalp of *Carrhotus viduus,* (48.a) *Epeus tener,* (48.b) Pedipalp of *Epeus tener,* (49) *Epeus indicus,* (50.a) *Hyllus semicupreus,* (50.b) Pedipalp of *Hyllus semicupreus,* (51.a) *Bianor angulosus,* (51.b) Epigyne of *Bianor angulosus,* (52.a) *Plexippus paykulli,* (52.b) Pedipalp of *Plexippus paykulli,* (53.a) *Myrmarachne kuwagata,* (53.b) Pedipalp of *Myrmarachne kuwagata,* (54) *Phintella vittata,* (55) *Portia fimbriata.*

two axes were plotted in Fig. 6. The species S19 (*Gasteracantha diadesmia*), S47 (*Gasteracantha hasselti*), S34 (*Leucauge tessellata*), S25 (*Nephila kuhlii*), S18 (*Opadometa fastigata*) showed positive correlation with canopy cover. The species S54 (*Pardosa pseudoannulata*), S68 (*Lycosa tista*), S45 (*Pardosa sumatrana*), and S62 (*Psechrus torvus*) were influenced by litter cover.

DISCUSSION

The present study is the first of its kind to have focused on the diversity of spiders in Manas National Park. The present study observed 73 species of spiders

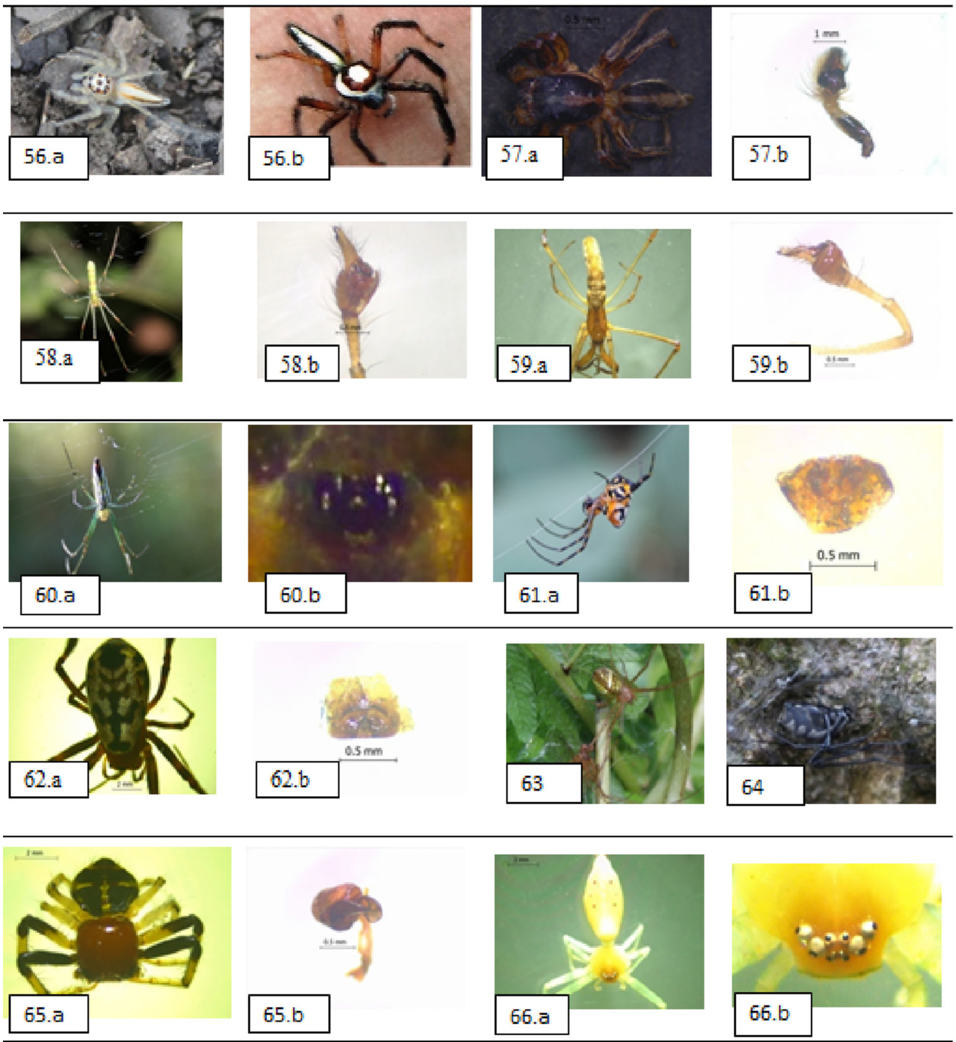

Plate 1F. Plates showing spider diversity of the study area: (56.a) *Telamonia dimidiate* (Female), (56.b) *Telamonia dimidiate* (Male), (57.a) *Plexippus petersi,* (57.b) Pedipalp of *Plexippus petersi,* (58.a) *Tetragnatha mandibulata,* (58.b) Pedipalp of *Tetragnatha mandibulata,* (59.a) *Tetragnatha cochinensis*, (59.b) Pedipalp of *Tetragnatha cochinensis,* (60.a) *Leucauge decorata,* (60.b) Epigyne of *Leucauge decorata,* (61.a) *Opadometa fastigata*, (61.b) Epigyne of *Opadometa fastigata*, (62.a) *Leucauge tessellata,* (62.b) Epigyne of *Leucauge tessellata,* (63) *Tylorida striata,* (64) *Leucauge* sp., (65.a) *Camaricus formosus,* (65.b) Pedipalp of *Camaricus formosus,* (66.a) *Oxytate virens,* (66.b) Eyes of *Oxytate virens.*

which represent 25% of families and 8.45% of all currently recorded spider genera from India owing to the mosaic of habitats in MNP and as existence of numerous microhabitat conditions (see Plate-1A-1G). Family Araneidae and Salticidae were the most dominant in terms of the number of species and were also widely distributed throughout the National park as they are habitat generalist species. The highest number of individuals were recorded from the family Lycosidae in the habitats where regular practices of annual prescribed burning are going on and where the food species become available for the species in those areas of the study area. A similar result was also reported by Niwa and Peck (2002) for the spider

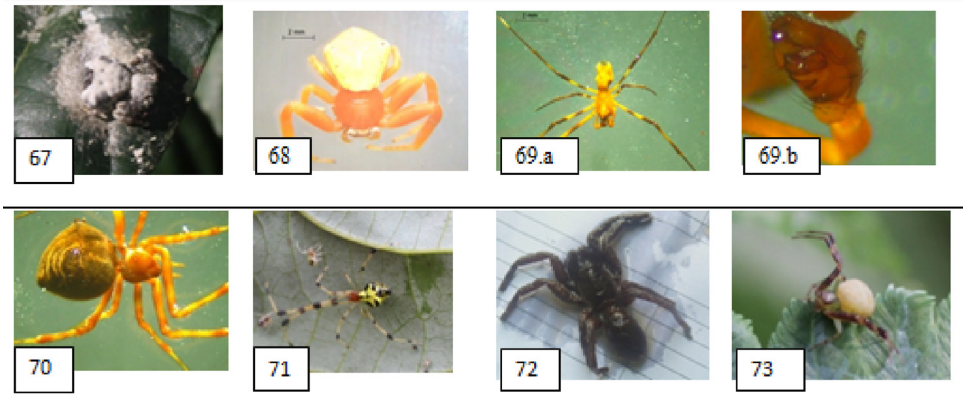

Plate 1G. Plates showing spider diversity of the study area, (67) *Phrynarachne* sp., (68) *Thomisus pugilis*, (69.a) *Argyrodes flavescens,* (69.b) Pedipalp of *Argyrodes flavescens,* (70) *Argyrodes* sp., (71) *Theridion* sp., (72) *Lyrognathus saltator*, (73) *Misumena* sp.

family of Lycosidae in Southwestern Oregon where forest fire was apparent. The authors also stated that spider species belonging to the family Lycosidae preferred open and warm areas and were repeatedly caught in high numbers at burned localities which are in conformation with the present study.

There is a significantly different value of diversity in different habitats, despite the small distances between the habitats studied. Earlier studies also have established clear associations between spider abundance, species richness and diversity, and the structural diversity of the habitat (Samuel and Marcos 2011, Pinzon *et al.* 2013). In the current study, the highest spider diversity was found in woodland habitats. This result is confirmed by the study of Maija and Voldemars (2016) who have suggested that the structure of the vegetation directly influences the diversity of spider by providing vertical stratification for attaching a web and sites for refuge and ambush. The woodland of the study area comprises tree species belonging to the semi-evergreen forest and mixed moist deciduous forest and the undergrowth mainly comprises *Leea aequata, Coffea benghalensis, Phlogacanthus thyrsiflorus, Adhatoda vasica, Clerodendrum infortunatum* and *Piper diffusum,* which form a structurally complex habitat for the spider fauna. Furthermore, structurally diverse habitat harbors a greater variety of food resources and as a result, increases prey densities. These high prey densities create a positive effect

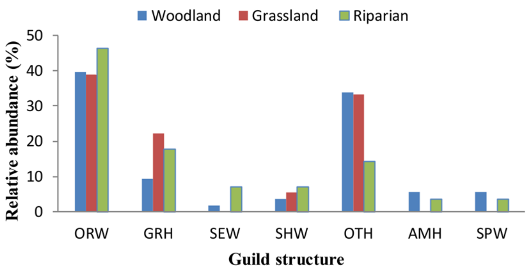

Fig. 4. Composition (%) of feeding guilds of spiders across different habitat of the study area (ORW, Orb waver; GRH: Ground hunters; SEW: Sensing web, SHW: Sheet web, OTH: Other hunters, AMH: Ambush hunters, SPW: Space web).

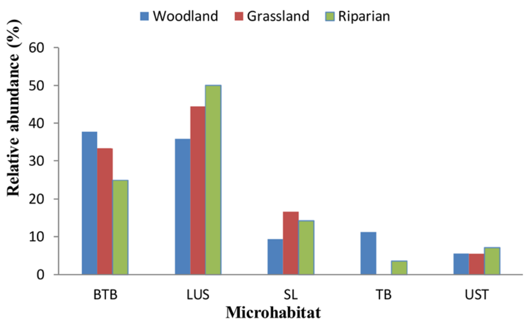

Fig. 5. Microhabitat variations of spiders at different habitats of the study area (BTB: Between tree or branch, LUS: Surface of a leaf or among leaves, SL: Soil or Ground zone, TB: Tree bark, UST: Under stones or bottom/hole of a tree).

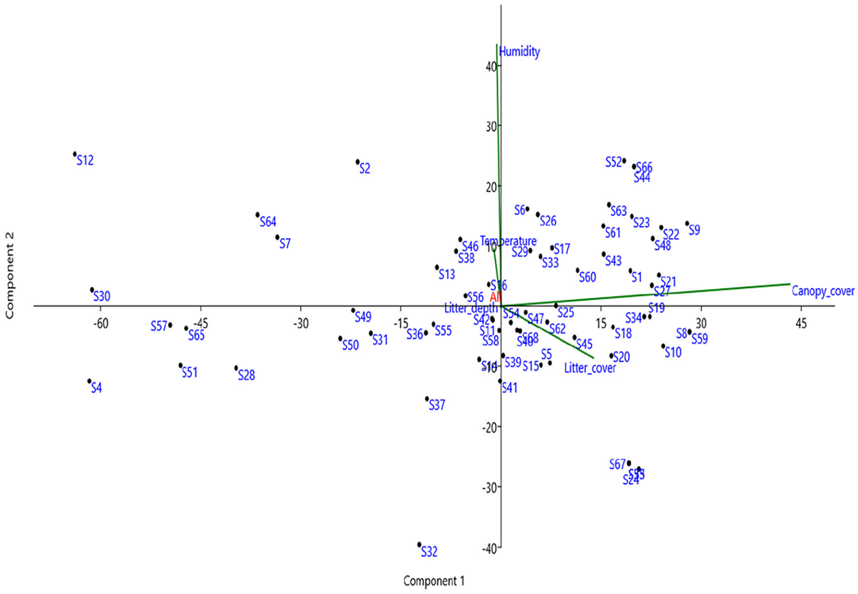

Fig. 6. PCA ordination bi-plot of spider species assemblages and environmental variables (temperature, humidity, litter depth, canopy cover, litter cover,) in the study sites of MNP.

on the diversity of spiders in the woodland habitat. According to the result, the highest species evenness was found in grassland habitats. This might be due to the occurrence of similar environmental conditions in almost all parts of the grassland. All the grasslands of the study area are dominated by grass species like *Saccharum narenga, Imperata cylindrica, Phragmites karka, Arundo donax, and Saccharum spontaneum,* which may have formed a similar environmental condition in almost all parts of the grassland. A similar result has also been reported from the upper Hanthana Mountain Area of Central Sri Lanka (Chathuranga and Ranawana 2017).

The relative abundance of the different guilds and microhabitats was remarkably different with respect to the habitat. The presence of spider species clearly depends on plant architecture and special structures like leaves or buds. Among the three different habitats studied, the woodland and riparian were found to support the highest web builder species. The web-building spider greatly depends on the physical structure of the environment because they need more structural complexity to build their webs. So, this may be the reason for the high web builder species in woodland habitats. We recorded a high relative abundance of ground hunters in grassland habitats. This is probably due to the high abundance of the family Lycosidae in grassland habitats which belongs to the ground hunter guild. (Haddad *et al*. (2013) has also reported that in grassland, the ground-dwelling fauna is dominated by the family Lycosidae. Sensing web and Space web waver guild was not recorded from grassland. This finding is well supported by Chathuranga and Ranawana (2017) who have suggested that the lack of structurally complex vegetation and the effect of strong wind in grassland habitats lower the occurrence of web-building spider species. The highest abundance of microhabitat was recorded Between a tree or branch and the Lower or upper surface of a leaf or among leaves, which clearly indicates that spider species diversity strongly influences by the vegetation structure of a habitat. Changes in the structural complexity of the vegetation have been related to changes in spider diversity. Among the three different habitats studied, the grassland was found to support the highest soil and ground zone microhabitat. This result is also confirmed by the study of Haddad *et al.* (2013) who have suggested that the spider species found in grassland are mainly free-living and actively hunting on the soil surface. Spider species that prefer under stones or the bottom hole of a tree as a microhabitat were recorded maximum from riparian habitat. This is probably due to the formation of Bhabar in a major portion of the study area which delivers boulders, pebbles, and gravel to the riparian habitat (Saikia 2012). The principal component analysis showed a positive correlation between the spider species distribution and canopy cover with the spider species of the Araneidae family. When the canopy cover is more in an area, it facilitates for better web-building conditions by providing sites for web attachment. The species distribution was also found to be positively correlated with the litter cover present in different sites of the study area. Litter cover and litter depth facilitate burrow formation for ground-dwelling spiders, in addition to this more litter provides better availability of prey for the spider species (James *et al.* 2009).

The present study is the first effort to record the spider species of Manas National Park and definitely serves as baseline information for future studies. Spiders appear to be good subjects for studying biodiversity patterns. Further, an in-depth study will undoubtedly raise the number of species to a great extent. This will help to study the diversity patterns of the National Park and eventually in the development of a conservation plan. The family and species composition of spider is distinctive in relation to the habitat types of the study area which indicate that all habitats are important if the spider diversity of the study area is to be conserved.

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REFERENCES

Ahmed M, Anam J, Saikia MK, Manthen SV, Saikia PK (2014a) Records of new genus Chrysilla (*Group* Spider: Sub-order: Araneae: Family: Salticidae) in India at Agroecosystem, at Sonitpur, Assam. *J New Biol Rep* 3: 38–43.

Ahmed M, Anam J, Saikia MK, Manthen SV, Saikia PK (2014,b) New records of spider species under *Wadicosa* genus (Sub-order: Araneae; Family: Lycosidae) from the Agricultural field of Sonitpur District, Assam, India. *J New Biol Rep* 3: 60 – 65.

Ahmed M (2015) Diversity of spider fauna in agro-ecosystem of Sonitpur District, Assam. PhD thesis. Submitted to Gauhati University. Assam, India Unpublished.

Ankhade V, Manwar N (2013) Diversity and Guild structure of spider fauna at Sawanga Vithoba Lake (Malkhed Project) area in Pohara Forest DIST Amravati, Maharashtra, India. *Int J Zool Res* 3: 7-16

ASBB Assam State Biodiversity Board. (2015) Common spiders from select protected areas of upper Assam.

Basumatary P, Brahma D (2017) Checklist of spiders from Chakrashila Wildlife Sanctuary, Assam, India. *Int J Zool Studies* 2(5): 22-25.

Basumatary P, Das S, Kalita J, Brahma D (2018) New record of *Hyllus diardi* (Walckenaer 1837) (Araneae: Salticidae) from India. *Acta Arachnologica* 67: 35-37. Doi: 10.2476/as jaa. 67.35.

Basumatary P, Brahma D (2019a) A new species of *Paraplectana* Brito Capello, 1867 (Araneae: Araneidae) from north-east India. *Arachnology* 18 (3): 276-279. Doi: 10.13156/arac. 2019.18.3.276.

Basumatary P, Brahma D (2019b) A new species of the genus *Meotipa* Simon 1895 (Araneae: Theridiidae) from India. Acta *Arachnologica* 68 (1): 21-24. Doi: 10.2476/asjaa.68.21.

Basumatary P, Brahma D (2021) One new burrow spider of the genus *Gravelyia* Mirza and Mondal 2018 (Araneae: Nemesiidae) from north-east India. *Acta Arachnologica* 70: 39-46. Doi: 10.2476/asjaa.70.39.

Caleb JTD (2020) Spider (Arachnida: Araneae) fauna of the scrub jungle in the Madras Christian College campus, Chennai, India. *J Threatened Taxa* 12(7): 15711–15766. Doi: 10.11609/jott.5758.12.7.15711-15766.

Cardoso P, Pekar S, Jocque R, Coddington JA (2011) Global patterns of guild composition and functional diversity of spiders. *PLoS ONE* 6: e21710. Doi: 10.1371/journal pone 0021710.

Chathuranga WGD, Ranawana KB (2017) Spider fauna (Arachnida: Araneae) of Upper Hanthana Mountain area, Central Sri Lanka. *Ind J Arachnol* 6: 1-14.

Chetia P, Kalita J (2012) Diversity and distribution of spiders from Gibbon Wildlife Sanctuary, Assam, India. *Asian J Conserv Biol* 1:5-15.

Coddington J, Young L, Coyle F (1996) Estimating spider species richness in a Southern Appalachian cove hardwood forest. *The J Arachnol* 24: 111-128

Deshmukh US, Raut NM (2014) Seasonal diversity and status of spiders (Arachnida: Araneae) in Salbardi forest (Satpura Range), Maharashtra, India. *J Entomol Zool Studies* 2 (5): 278-281.

Eberhardt LL (1978) Transect Methods for Population Studies

The J Wildlife Manag 42(1) : 1–31. Doi: 10.2307/3800685.

Haddad CR, Dippenaar-Schoeman AS, Foord SH, Lotz LN, Lyle R (2013) The faunistic diversity of spiders (Arachnida: Araneae) of the South African Grassland Biome. *Transactions Royal Soc South Africa* 68: 97-122. Doi: 10.1080/0035919X.2013.773267.

Hao L, Qingdong S, Imin B, Kasim N (2020) Methodology for optimizing quadrat size in sparse vegetation surveys: A desert case study from the Tarim Basin. *PLoS One Aug* 26, 15(8): e0235469. Doi: 10.1371/journal.pone.0235469.

Hore U, Uniyal VP (2008) Diversity and composition of spider assemblages in five vegetation types of the Terai Conservation Area, India. *The J Arachnol* 36: 251–258. Doi: 10.1636/CT07-53.1.

Hotelling H (1933) Analysis of a complex of statistical variables into principal components. *J Educational Psychol* 24(6) : 417–441. Doi: 10.1037/h0071325.

Ian TJ, Jorge C (2016) Principal component analysis: A review and recent developments. *Phil Trans R Soc A* 374 : 20150202. Doi: 10.1098/rsta.2015.0202.

James W, Søren T, Wise D (2009) Spatial stratification in litter depth by forest-floor spiders. *J Arachnol* 31: 28-39. 10.1636. Doi: 10.1636/0161-8202(2003)031[0028:SSILDB]2.0.CO;2

Jocque R, Schoeman ASD (2006) Spider families of the world. Royal Museum for Central Africa. Belgium, pp 336.

Keswani S, Hadole P, Rajoria A (2012) Checklist of spiders (Arachnida: Araneae) from India-2012. *Ind J Arachnol* 1: 1-129.

Kim TK (2017) Understanding one-way ANOVA using conceptual figures. Korean *J Anesthesiol Feb* 70(1): 22-26. Doi: 10.4097/kjae.2017.70.1.22.

Konopiński MK (2020) Shannon diversity index: A call to replace the original Shannon's formula with unbiased estimator in the population genetics studies. *Peer J* 8: e9391. Doi: 10.7717/peerj.9391.

Maija S, Voldemars S (2016) The influence of vegetation structure on spider species richness, diversity and community organization in the *Apšuciems calcareous* fen, Latvia. *Animal Biodiver Conserv.* 39 : 221-236. Doi: 10.32800/ abc.2016. 39.0221.

Niwa C, Peck R (2002) Influence of prescribed fire on Carabid Beetle (Carabidae) and Spider (Araneae) assemblages in forest litter in Southwestern Oregon. *Environm Entomol* 31: 785-796. Doi: 10.1603/0046-225X-31.5.785.

Padayatty SD (2011) Systematic study on Salticidae (Arachnida: Araneae) from Kerala, India- with notes on habit and habitat of common forms. PhD thesis. Submitted to Mahatma Gandhi University, Kottayam, Kerala, India.

Pinzon J, Spence J, Langor D (2013) Diversity, species richness, and abundance of spiders (Araneae) in different strata of boreal white spruce stands. *The Canadian Entomologis*t 145(1) : 61-76. Doi: 10.4039/tce.2012.93.

Polchaninova N, Savchenko G, Ronkin V, Shabanov D (2023) Spider diversity in the fragmented forest-steppe landscape of Northeastern Ukraine: Temporal changes under the impact of human activity. *Diversity* 15 : 351. Doi: 10.3390/ d15030351.

Punjoo SB (2015) Eco- Diversity of Araneid community of Dachigam National Park. PhD thesis. Submitted to University of Kashmir, Srinagar, India.

Quasin S, Uniyal VP (2011) Spider diversity along altitudinal gradient and associated changes in microclimate attributes in Nanda Devi Biosphere Reserve, Uttarakhand, India. *ENVIS Bull Arthropods Conserv India* 14: 219-232.

Rajeevan S, Smija MK, Varghese T, Kandambeth PP (2019) Spider diversity (Arachnida: Araneae) in different ecosystems of the Western Ghats, Wayanad Region, India. South Asian *J Life Sci* 7(2): 29-39. Doi: 10.17582/journal.sajls/2019/ 2019/7.2.29.39.

Rajkhowa DJ, Bhattacharyya PN, Sarma AK, Mahanta K (2014) Diversity and distribution of Earthworms in different soil habitats of Assam, North-East India, an Indo-Burma Biodiversity Hotspot. *Proc Natl Acad Sci, India, Sect B Biol Sci* 85: 389–396. Doi: 10.1007/s40011-014-0380-1.

Saikia BP (2012) Ecology of the Asian elephant *Elephas maximus* Linn. 1758 in Manas National Park, Assam, India. PhD thesis. Submitted to Department of Zoology, Gauhati University, Assam, India.

Saikia MK (2011) Impact of tropical forest degradation on nymphalid butterflies: A case study in Chandubi tropical forest, Assam, India. *Int J Biodiver Conserv* 3(12): 650-669.

Samuel PB, Marcos M (2011). Effects of land management on the abundance and richness of spiders (Araneae): *A meta-analysis; Biol Conserv* 144 (2) : pp 683-690. Doi: 10.1016/j. biocon.2010.11.024.

Sebastian PA, Mathew MJ, Beevi SP, Joseph J, Biju CR (2005) The spider fauna of the irrigated rice ecosystem in central Kerala, India across different elevational ranges. *The J Arachnol* 33: 247-255. Doi: 10.1636/05-08.1

Sebastian PA, Peter KV (2009) Spiders of India. Universities Press, pp 614.

Sethy TR, Ahi J (2022) A pioneering study on the spider fauna (Arachnida: Araneae) of Sagar district, Madhya Pradesh, India. *J Threatened Taxa* 14(6): 21227–21238. Doi: 10.11609/jott.7807.14.6.21227-21238.

Shannon CE, Wiener WW (1963) The mathematical theory of communications. Urbana, USA: University of Illinois.

Shivarama B, Srikumar KK, Raviprasad TN (2013) Seasonal diversity and status of spiders (Arachnida: Araneae) in cashew ecosystem. *World Appl Sci J* 22: 763-770. Doi: 10.5829/idosi.wasj.2013.22.06.73114.

Siliwal M, Molur S (2007) Checklist of spiders (Arachnida: Aranea) of south Asia including the 2006 update of Indian spider checklist. *Zoo's Print J* 22: 2551-2597. Doi: 10.11609/JoTT.ZPJ.1509.2551-97.

Singh S, Borkotoki A, Sarma CK (2012) Species distribution of spiders in Barpeta district of Assam: Diversity measure. *E-Int Scientific Res J* 4: 47-57.

Sudhikumar AV, Mathew MJ, Sunish E, Sebastian PA (2005) Seasonal variation in spider abundance in Kuttanad rice agroecosystem, Kerala, India (Araneae). *Europ Arachnology* 1: 181-190.

Tikader BK (1963) Studies on some spider fauna of Maharashtra and Mysore status. Part I. *J Univer Poona Sci Technol* 24: 29-54.

Tikader BK (1966) Studies on spider fauna of Khasi and Jaintia Hills, Assam, India. *J Assam Sci Soc* 9:1-16.

Tikader BK (1968) Studies on spider fauna of Khasi and Jaintia Hills, Assam, India. Part II. *J Assam Sci Soc* 10:102-122.

Tikader BK (1970) Spider fauna of Sikkim. *Records Zoolo Survey India.* 64 : 1- 83. Doi: 10.26515/rzsi/v64/i1-4/1966/161523.

Tikader BK (1987) Handbook of Indian Spiders. Zoological Survey of India, pp 251.

Weaver JE (1918) The quadrat method in teaching ecology. *The Pl World* 21 (11) : pp 267-283.

Zar JH (1996) Biostatistical Analysis. 3rd edn. Prentice Hall, Upper Saddle River, pp 662.