DIVERSITY AND STRUCTURE OF SPIDER ASSEMBLAGES IN TERAI CONSERVATION AREA (TCA)

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Certificate

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Mr. Hore has put in more than six terms of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted for any other University or Institution.

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Summary

Introduction:

Monitoring a few indicator species is an intuitively appealing method of measuring the ecological sustainability of forest management because it is impossible to measure and monitor the effects of forest management on all species or environmental conditions of interest. Invertebrates and in particular spiders (Araneae), have been widely recommended as bioindicators. Here I examine the evidence for spiders as bioindicators, using the Terai forests of India as a case study. The Terai forest provides an ideal case study for the development of an indicator framework because it is disturbance driven, where the dominant disturbance factor is changing from fire to plantation. This provides a clear context for developing explicit indicator objectives. This approach however can be applied more generally to other ecosystems. The present study was carried out in Terai Conservation Area (TCA) which represents one of the last remnants of Indian Terai ecosystem. The TCA is an important regional, national and international centre for biodiversity. The resulting complex of woodland-grassland-wetland ecosystems of TCA harbours a wide variety of floral and faunal life, including several charismatic and obligate species. This area has witnessed dramatic changes in land use policies, forest management practices, and persistent factors like forest fire, flooding and livestock grazing. Keeping in view these perspectives, this study intends to document the extent of spider assemblages that exists amongst various habitats, identify factors underlying the patterns of association, and assess the effect of grassland fire on spider diversity in the TCA.

Faunistic Inventory of Spiders in Terai Conservation Area:

Spiders currently comprise 109 families, about 3,733 genera, and nearly 40,700 species. Strong evidence supports spider monophyly: cheliceral venom glands, male pedipalpi modified for sperm transfer, abdominal spinnerets and silk glands, and lack of the trochanter-femur depressor muscle. The study began with defining the systematic position of the spiders and reviewing the available taxonomic knowledge of the taxon. It also addresses the past studies in India, the region and the continent. This study provides a baseline inventory of the diversity of spiders including description of anatomical features of spider in general, their relation to classification, and genera of spiders sampled from the TCA during three years of fieldwork.

Diversity and Composition of Spider (Araneae) Assemblages:

This study deals with the comparison of spider diversity and composition in a complex landscape of the TCA characterized by alluvial floodplains of tall grassland interspersed with woodland, swamps, and riparian patches. High water table, annual flooding, and annual grassland fire maintain its dynamic complexity. Spiders were sampled from March 2005 to August 2006 by using pitfall traps and other semi-quantitative collection methods along transects. A total of 3666 adult spiders representing 22 families, 60 genera, and 160 species were recorded. Using the abundance-based estimator, Chao1, the predicted richness for the total area sampled is 173 ± 8.32 (SD) species. This indicates that the inventory was almost complete at the regional scale (92%). With similar proportions of captured species, rarefied richness value showed that species richness was highest in riparian swamp forest. Comparison of different sites revealed that species composition was much more similar within the same vegetation type than among different vegetation types. Assemblage composition differed most between riparian swamp forest and plantation. Family composition varied considerably in relation to the structural quality of vegetation. On a coarse scale, this study revealed the relative importance of diverse habitat types on diversity and composition of spider assemblage in TCA.

Habitat Association of Spider Assemblages:

The habitat heterogeneity hypothesis states that the more complex the habitat, the higher the species diversity and structure. The present study analyses the effect of local habitat factors on regional spider richness and diversity. The objective is to untangle the relative importance of habitat structure and other environmental variables. Richness and diversity values of the spider species and family were modeled using multiple regression and a set of independent variables extracted from NMS ordination of vegetation, microclimate and disturbance variables. Vegetation structure, especially height variation in shrubs, plant species richness, tree and shrub densities were found to be important predictors for richness and diversity. The species and family composition is highly influenced by vegetation cover, litter cover and management intensity. Here I also examine the efficacy of spider assemblages as ecological indicators of habitat condition. Using correspondence analysis and weighted averaging, I identified potential indicator species (13 species out of 65 species) analyzed and showed gradients in response to reflect overall habitat condition.

Effect of Grassland Burning on Spider (Araneae) Assemblages:

Annual low-intensity fire is a conspicuous management strategy in virtually all floodplain grassland of protected areas in India. While it is primarily used to reduce fuel levels and to facilitate regeneration of desired species for wild ungulate communities, little is known about the effects of its repeated use on natural ecosystems over long periods of time. The increased use of prescribed fire generates questions regarding the effects of burning events on spider assemblage, and recovery of these grassland spiders following fire disturbance. This chapter describes the ecological consequences of burning tall grass of Terai on spider assemblages at different seasons and with different frequencies. It examines the effects of grassland fire on diversity and structure of spider assemblages at a coarse level of resolution. Grassland characteristics were also delineated to measures impacts of the fires and to assess variability and heterogeneity of the grassland environment. These analyses have a fairly coarse level of resolution and the study aims to establish its sensitivity to the disturbances caused by fire.

Higher Taxa Surrogacy and Efficiency in Conservation:

A critical issue in conservation biology is the establishment of a strong relationship between species richness and a surrogate index. Such a relationship could provide the basis for the establishment of cost effective and easy to monitor methods for measuring biodiversity, providing an alternative for the prioritization of sites for conservation. Both family and genus richness are tested in their ability to predict the number of spider (Araneae) species independently of sampling detection, spatial autocorrelation, area, geographical location and type of habitat. Data from two protected areas of TCA was used as a test case. Genus richness is considered a good surrogate of species richness, despite some caution being needed regarding the comparison of sites with considerably different sampling effort. Only genus alone is found to be reliable either for ranking sites according to taxa richness or for determining near-minimum sets of sites for conservation. The study recommends surrogacy at this higher taxonomic level as a promising approach for the prediction of spider species richness or evaluation and ranking of areas according to their conservation importance.

*****

CHAPTER 1

INTRODUCTION

1.1 Challenges for Invertebrate Conservation

Invertebrates are the most diverse and abundant animals in most natural ecosystems but their importance in sustaining those systems is commonly not appreciated (New, 1995). Determining the distribution of invertebrates is an integral part of assessing their conservation status and to determine their possible management needs. Invertebrates, and in particular insects, can therefore not be ignored in the assessment of biodiversity (Holloway and Stork, 1991). The number of species in existence varies widely and that of insects ranges from an estimated three to 50 million (Wilson and Peters, 1988). More recent assessments of available literature estimate the number of species to be closer to 10 million (Dobson, 1996). The wide variation in the estimates of the number of insect species in the world arises from the variation in the method of calculation of those estimates (Hawksworth, 1991; Solbrig et al., 1996). Samways (1993a) estimates that only 7 - 10 % of all insect species have been described and of those, only a small percentage have enough known about their biology to allow the construction of informed conservation plans.

In the past, invertebrates were largely ignored in the design of conservation areas. Their conservation in existing parks and reserves has been incidental (New, 1999; Skerl and Gillespie, 1999). The reluctance of using invertebrates in conservation studies is mainly because of: (1) the time constraints, (2) lack of knowledge of the taxon (taxonomy, biology and distribution), (3) unstandardised sampling methods and (4) inadequate number of experts to do the species identifications. Furthermore, invertebrate surveys generate very large samples which demand a considerable effort to process in terms of time and expertise (New, 1999). Despite the above negative aspects of working with invertebrates, they represent a group of organisms that are potentially useful when assessing the biodiversity of an area because of: (1) their generality of distribution, (2) trophic versatility, (3) rapid responses to perturbations and (4) ease of sampling (Holloway and Stork, 1991). There are too many undescribed taxa for which the expertise to identify organisms to the level of species does not exist for us to even contemplate surveying the complete diversity. At the current rate it will take several thousand years to describe all the species or have an idea about the diversity if traditional taxonomic methods are used (McNeely et al., 1995). This is because of (1) the formal determination of species names is time consuming and, in those groups where formal taxonomy is poorly developed, may not be possible; identifications are costly and (2) few professional taxonomists to have expertise on those groups (Oliver and Beattie, 1996).

Both the magnitude and the urgency of the task of assessing global biodiversity require that we make the most of what we know through the use of estimation and extrapolation (Colwell and Coddington, 1994). Likewise, future biodiversity inventories need to be designed around the use of effective sampling and estimation procedures especially in “megadiverse” groups such as arthropods (Colwell and Coddington, 1994; Hawksworth et.al., 1995). It is in the light of this problem that other more rapid methods of diversity estimation have been suggested. The use of diversity indicators (Faith and Walker, 1996; McGeoch, 1998; Noss, 1990), higher taxon level identification (family or genus-level) and morphospecies level (Oliver and Beattie, 1993) identification as surrogate methods for species richness that may make the task of estimating global species diversity more manageable (Prance, 1994; Williams and Gaston, 1994; McGeoch, 1998). These measurements have often proved useful but limitations are often not recognised (Balmford et al., 1996a). Furthermore, other studies have emphasised inaccuracy of conclusions based on indicator species (Lawton et al., 1998; Van Jaarsveld et al., 1998). Although it is very appealing to use quicker methods for biodiversity assessment the data obtained may not be adequate for conservation decision making, e.g. rare and endemic species may be missed when higher levels of identification are used. Despite this, indicator taxa and higher taxon level identifications are being adopted more widely. This study aims to evaluate the use of indicators, higher taxon level identification and morphospecies level identification as surrogates for species richness, using spiders to test their usefulness.

1.2 Spiders for Biodiversity Assessments

Arachnids are an important but generally poorly studied group of arthropods that play a significant role in the regulation of insect and other invertebrate populations in most ecosystems (Russell-Smith, 1999). Previous conservation efforts in India have focussed on the larger vertebrates, while invertebrates were largely ignored and were only incidentally conserved in existing parks and protected areas. There is now a growing need to conserve all species and not only the large vertebrates (Samways, 1990). Surveys of invertebrate fauna have therefore become more important, especially in conserved areas where conservation strategies are already in place. Spiders, which globally include about 40, 700 described species (Platnick, 2008) and are estimated to number 60,000-170,000 species (Coddington and Levi, 1991), comprise a significant portion of this terrestrial arthropod diversity. Spiders are the most-diverse and abundant invertebrate predators in terrestrial ecosystems (Wise, 1993). They employ a remarkable diversity of predation strategies, occupy a wide array of spatial and temporal niches, and are characterized by high within habitat taxonomic diversity, exhibit taxon and guild responses to environmental change, extremely sensitive to small changes in habitat structure, including vegetation complexity, litter depth and microclimate characteristics (Uetz, 1991). Their high relative abundance, ease of collection, and diversity in habitat preferences and foraging strategies allows for effective monitoring of site differences (Yen, 1995). This ubiquity, diversity and ecological role of spiders makes them a promising focal group for invertebrate conservation and useful indicators of the effects of land management on local biodiversity (Clauseu, 1986; Churchill, 1997; Topping and Lövei, 1997; Maelfait and Hendrickx, 1998; Marc et al., 1999; Riecken, 1999). Spiders also show potential as a group to be used for higher taxonomic surveys. Oliver & Beattie (1996) found that non-specialists could be quickly trained to make remarkably accurate count of spider morphospecies. However, considerable work is still needed to clarify the usefulness of spiders as indicators, relevance to high taxon surrogacy and to develop standardised sampling techniques (New, 1999). This study aims to contribute towards an improved understanding of these issues. In order to know how and where to protect biodiversity, it is imperative to know the patterns of diversity of terrestrial arthropods, which may comprise 80% or more of the earth's surface but have been too often neglected by the resource mangers and conservation planners (Wilson, 1992; Kremen et al., 1993; Colwell and Coddington, 1994; Longino, 1994).

1.3 Forest Management Practices and Spiders

Sustainability of forest management activities have recently begun to centre on the notion of disturbance emulation. The general hypothesis is that sustainable forest management practices should not affect wildlife populations differently than would natural disturbance over multiple scales of space and time (McLaren et al., 1998). Sustainable forest management is a widely held international goal (Mulder et al., 1999; Montreal Process, 2000; UNCSD, 2001) and in many cases a legislated mandate (Statutes of Ontario, 2001; Commonwealth of Australia, 2001). Monitoring indicators of sustainability has been proposed (Montreal Process, 2000) as a mechanism for assessing sustainability. However, the choice of indicators and determining how they should be monitored is far from resolved. Monitoring a few indicator species is an intuitively appealing method of measuring the ecological sustainability of forest management because it is impossible to measure and monitor the effects of forest management on all species or environmental conditions of interest (Landres et al., 1988). Biological indicators of sustainable forest management are ecological indicators in that they must provide information on the effects of forest management on the functioning of the forest ecosystem to be useful. They can be keystone species, dominant species, sensitive species or species that reflect the ecological effects of a disturbance regime. The requirement for a bioindicator of sustainable forest management should have a functional role, rather than a descriptive role, provides a more concrete basis for interpreting the importance of change. For example, the amount of change in vegetation composition and structure can be measured directly, but ecological indicators can help understand the impact of these changes on the biotic components of that system. Viewed in this manner, bioindicators can both monitor ecosystem change, and help identify and address ecosystem stressors and guide forest management.

Ecological indicators must meet four criteria: they must be feasible and cost effective to sample, be easily and reliably identified, and be functionally significant and respond to disturbance in a consistent manner. Ground beetles and spiders readily meet the first three criteria. In summary, spiders are predators and important ecologically because of their role in regulating decomposer populations (Clarke and Grant, 1968). Their high biomass also makes them an important resource for larger forest predators such as salamanders, small mammals and birds. Invertebrates and in particular ground beetles (Coleoptera: Carabidae) and spiders (Araneae), have been widely recommended as bioindicators (e.g. Duchesne and McAlpine, 1993; Niemelä et al., 1993; Butterfield et al., 1995; Beaudry et al., 1997; Atlegrim et al., 1997; Churchill, 1997; Duchesne et al., 1999; Bromham et al., 1999; Werner and Raffa, 2000; Heyborne et al., 2003). Churchill (1997) briefly reviewed the potential of spiders as ecological indicators in Australia.

Specifically, there are two questions that need to be asked of spiders when evaluating their potential as bioindicators of sustainable forest management. First, can individual species or species groups be identified that respond consistently to habitat disturbance, including timber harvesting or silvicultural treatments or wildfire. Second is the response of spiders to anthropogenic disturbance different to that of natural disturbance such as wildfire. Research suggests that ground beetles and spiders are strongly associated with habitat structure and/or associated microclimatic factors (Samu et al., 1999). Though much less is known of the response of ground spiders to fire. In Canada, three studies have examined the spider communities inhabiting recently burnt forest (Koponen, 1993; Aitchison-Benell, 1994; Buddle et al., 2000), although no studies have compared the pre- and post-burn condition or the immediate response of spiders to fire. Burned sites tend to be characterized by open habitat, non-web-building species, with a gradual transition to web-building families as the vegetation regenerates (Koponen, 1993; Buddle et al., 2000). Aitchison-Benell (1994) suggests that the composition of burnt and unburnt habitats depends on site moisture, with mesic sites having a different species response than drier sites. In Europe, Huhta (1971) found that an intense burn removed the spider fauna. It is not clear how well spiders survive a light burn.

1.4 Spiders in Conservation Research and Future Direction

Like many other 'little things that run the world' (Wilson, 1987), spiders remain peripheral to mainstream conservation research and action. Despite their ecological role in many ecosystems, high diversity, documented threats and the known imperilment of some species, spiders have received little attention from the conservation community (Skerl, 1999). While this lack of attention may be related to negative public attitudes towards spiders (Kellert, 1986), a paucity of compiled information on spider conservation status and distribution may be a more important issue. However, it is important that imperilled and vulnerable spiders and other invertebrates are not left out of conservation planning efforts, as they may have unique ecological requirements or require particular site selection and management activities. Without knowledge of their locations in conservation databases, it is possible that habitats with vulnerable spider species would not otherwise be selected for conservation attention. The inclusion of spiders in conservation planning will depend on the amount of compiled information on their distribution and conservation status. Additionally, the most critical and useful habitat association data is not found in checklists. Such data are lacking for many spider species, particularly those with cryptic habits. Resources including all records and specific habitat associations would be most useful and spider survey in TCA may serve as a model for future efforts. Nevertheless, there exists a growing body of work on spiders as they relate to conservation issues – both as conservation tools and as explicit targets for conservation action. Efforts to characterize the ecological value of spiders, examine their potential as ecological indicators, document threats to spider diversity, and develop effective conservation programmes are taking place around the globe.

1.5 Aim and Objectives

The goal of study is to document the extent of spider assemblages that exists amongst various habitats, identify factors underlying the patterns of association, and assess the effect of grassland fire on spider diversity in the Terai Conservation Area. In order to achieve the above goals, following objectives were framed for the present study:

1. To provide comprehensive overview of baseline inventory of the diversity of spiders in different habitats of TCA.
2. To compare diversity and community composition of spider assemblage in various habitats.
3. To assess habitat association pattern of spider assemblages.
4. To assess effect of grassland fire on the diversity and composition of spider assemblage.
5. To evaluate the use of higher taxa surrogates and their efficiency in conservation decisions.

1.6 Organization of the Thesis

The present thesis is organized into eight chapters that include first two introductory sections, followed by five main chapters and last chapter as concluding remarks. Chapter 1 deals with general concepts on invertebrate conservation and presents a brief account of past studies on effect of forest management practices on spider assemblages with conservation notes and direction for future research needs. Chapter 2 contains a concise description on Terai Conservation Area (TCA) - the present study area with notes on physiography, soil, climate, drainage, and flora and fauna of the landscape. Chapter 3 reviewed the available taxonomic knowledge of spiders and provides detailed description of inventory of spider fauna in TCA. Chapter 4 deals with the comparison of spider diversity and composition in a complex landscape of the TCA and discusses importance of diverse habitat types on diversity and composition. Chapter 5 untangles the relative importance of habitat structure and other environmental variables on species diversity and structure of spider assemblages and assess the efficacy of spider assemblages as ecological indicators of habitat condition. In Chapter 6, I examined the effects of grassland fire on diversity and structure of spider assemblages and assess nature of association of spiders with the variability and heterogeneity of the grassland environment. Chapter 7 seeks to examine possible usefulness of the higher taxa surrogacy approach with spiders in Terai, testing it as species richness predictor and evaluation and ranking of areas according to their conservation importance. Chapter 8 concluded the study by relating conservation issues and ecological impact of forest management practices on spider diversity and structure.

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CHAPTER 2

STUDY AREA

2.1 Terai Conservation Area- Global Priority Region for Conservation

The Terai ecoregion, which the Terai Conservation Area (TCA) represents, is one of the most threatened ecosystems of the India (Kumar et al., 2002). Terai region was included in the list of 200 Eco region represents ecosystem harboring globally important biodiversity and ecological processes, needs conservation attention (Olson and Dinerstein, 1998, 2002). The region is a vast flat alluvial plain lying between the Himalayan foothills and the Gangetic plains. It forms the integral part of the Terai-Bhabar biogeographic subdivision of the Upper Gangetic biotic province and the 7-Gangetic plains biogeographic zone (7A-Upper Gangetic Plain and 7B-Lower Gangetic Plain) (Rodgers et al., 2002). Rodgers and Panwar (1988) explained that this Gangetic plain is topographically homogeneous for hundreds of kilometer and one of the most fertile areas in the world and supports a dense human population. Furthermore, they raised concern over the rapid conversion of natural vegetation into agricultural land in this landscape.

This ecoregion contains the highest densities of tigers, rhinos, and ungulates in Asia. One of the features that elevate it to the Global 200 is the diversity of ungulate species and extremely high levels of ungulate biomass recorded in riverine grasslands and grassland-forest mosaics (McGinley, 2008). The alluvial grassland fragments of this ecoregion now represent remnants of a once-extensive ecosystem. The extremely productive alluvial grasslands, which provide important habitats to endangered large animals such as tigers and elephants, are also good arable land, and most of the grasslands have been converted to agriculture. Perhaps no more than 2.0 percent of the alluvial grasslands of the Gangetic floodplain remains intact, and the best-conserved examples of floodplain grasslands are in Royal Chitwan National Park, Royal Shukla Phanta Wildlife Reserve, Dudhwa National Park, and to a lesser extent Royal Bardia National Park. An extensive network of reserves has been established in the Terai; the challenge now is to connect these reserves to allow wide-ranging species, such as tigers, elephants, and rhinoceros, to move among reserves (McGinley, 2008).

2.1.1 Location and Extent

The TCA lies in the four district *viz.* Lakhimpur Kheri, Pilibhit, Shahjahanpur and Bharaich of the state of Uttar Pradesh and is situated between Latitude N 27^{o}49´ and 28^{o}43´ and longitude E 80^{o}00´and 81^{o}19´ (Fig. 2.1). The TCA constitutes a spatial heterogeneous landscape of Protected Areas (PAs) including Dudhwa National Park (DNP) and Kishanpur Wildlife Sanctuary (KWLS), and Managed Forests (MFS) of North Kheri and South Kheri Forest Divisions within a matrix of private agricultural lands. The Indo-Nepal border forms much of the northern border of the TCA, particularly the DNP (Kumar et al. 2002). The TCA Forest in DNP, KWLS, NKFD and SKFD are under different management objectives and also different administration.

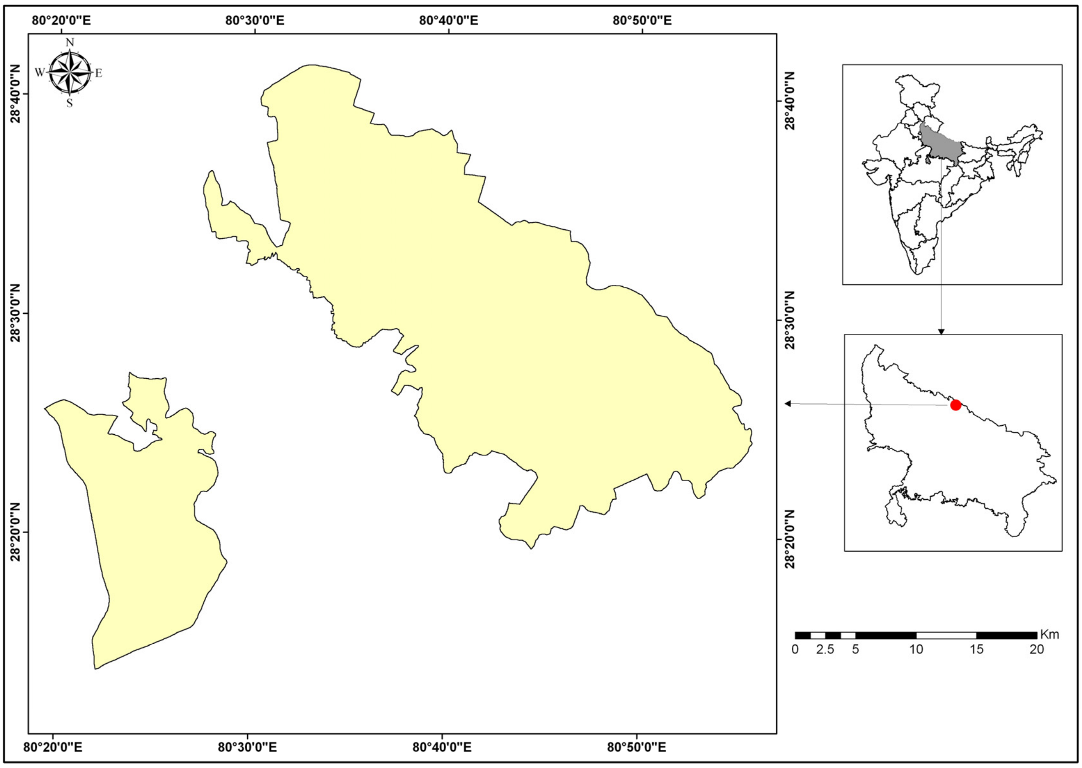

Fig.2.1 Base map of Terai Conservation Area (TCA)

Dudhwa National Park is located in the Nighasen Tehsil of district Lakhimpur Kheri, covers an area of 490.3 sq km and shares border with Nepal. Reserved forest area (adjacent managed forest) of 190.0 sq km serves as its buffer. (Table 2.1). Both park and buffer were once part of North Kheri Forest Division, they are separated and DNP was declared in 1977 (De, 2001).

Kishanpur Wildlife Sanctuary (KWLS) was once part of South Kheri Forest Division and later was separated in 1972 which covers area of 203.4 sq km. This two protected areas (DNP and KWLS) constitute the Tiger Reserve, though separated physically, are by themselves compact and consists of continuous forest tracts.

Table 2.1Terai Conservation Area –Constituent Areas and Extent

Constituent Areas	**Area (sq. km)**
Dudhwa National Park (DNP)	490.30
Buffer Area of National Park	190.00
Kishanpur Wildlife Sanctuary (KWLS)	203.40
North Kheri Forest Division and South Kheri Forest Divisions	842.80
Total Extent of Terai Conservation Area	1726.50
Agriculture Matrix	6170.00
Total Landscape Area	**7896.50**

2.1.2 Physiography, Soil, Drainage and Climate

The TCA is on the flat alluvial flood plains of the Suheli, Mohana and Sharda rivers. The general aspect of drainage in TCA is north-west to south east .The altitude ranges from 182 m a.m.s.l in the north to 150 m a.m.s.l in the south-east. The altitude at Dudhwa is 163 m, 183 m at Gauriphanta and 143 m at Mailani (Kumar et al., 2002).

The soils of TCA forests are a recent alluvial formation (Singh, 1965) of the Genetic plains. A soil profile showed a succession of sand and loam beds, varying in depth. The surface soil is sandy, in more elevated portions and along the high banks of the river to loamy in the level uplands, and clayey in depressions. There is no boulder formation as in Bhabar sal tracts.

Relevance of water in TCA is reflected in the fact that some 20 rivers and their tributaries flow through the PAs alone. The TCA itself is drained by Ghagra river and their tributaries *viz*., Mohana, Suheli, Ull, Barrach and Katna rivers. Flooding rivers inundate large areas of lowland grasslands for 3-4 months during the monsoon. Flooding rivers and meandering channels have considerable influence on the spatial pattern of the landscape, particularly grasslands and riverine forests. Erosion and accretion elsewhere are inherent dynamic process of the Terai ecosystem.

The climate of this conservation area represents tropical monsoon climate. TCA experience three distinct seasons; winter (October to March), summer (March to June) and monsoon (June to October). The TCA experiences extremes of temperature and humidity during different seasons. Nights during winter are cold and foggy. Usually fog sets in evening hours after sun set and persists until about middle of the next day. There is heavy dew fall during winter months and the vegetation remains damp. Frosts occur frequently during December to middle of February. These are attributed to the general cooling effects of the cold winds that flow down the Sharda valley and are most severe in open grasslands (phantas). The months of May and June are hottest with the mean maximum temperature rising upto 42.7°C. The high temperatures during the day time are associated with hot westerly winds. These are gradually replaced by easterly winds, which are prevalent during the rainy season. Usually, the onset of monsoon is by the end of June or early July. The monsoon is active during July- August and starts withdrawing by the middle of September. Usually November and December are the driest months. The entire landscape is very humid throughout the year.

2.1.3 Floral and Faunal Diversity

The resulting complex of woodland-grassland-wetland ecosystems of TCA harbours a wide variety of floral and faunal life, including several charismatic and obligate species *viz*, Tiger (*Panthera tigris*), Great One horned Rhinoceros (*Rhinoceros unicornis*), Swamp deer (*Cervus duvauceli*), Hog deer (*Axis porcinus*), Spotted deer (*Axis axis*), Bengal florican (*Houbaropsis *bengalensis*), and Hispid hare (*Caprolagus hispidus*) (Kumar et al., 2002). Forest in TCA belongs to the tropical moist deciduous forest type and can be broadly group into four categories *viz.,* moist sal forests, moist mixed deciduous forests, riparian swamp forests and savannah (upland and lowland grassland).

Studies on ‘Management of Forests in India for Biological Diversity and Forest Productivity’ were conducted in TCA by Kumar et al. (2002). They described the concept and approach of TCA in relation to landscape fragmentation and wildlife habitat use potentiality. The Terai with its characteristics complex of Sal forest, tall grassland and swamps maintained by periodic flooding, is one of the most threatened ecosystem of the India. Most of the Terai has succumbed to anthropogenic pressure, land encroachment for agriculture and homesteads replacing the rich natural vegetation.

2.1.4 History of Forest Management Practices

The history of TCA forests prior to 1861 is little known, except that they were under the control of the Raja Khairigarh for hunting reserves and commercial uses (Leete, 1902). Most forests came under government control in 1861 and forest management started in 1886 with the development of the first Forest Working Plan. A succession of Working Plans has guided forest management up to the present time (Srivastava, 1993; Srivastava, 2000; and De, 2001). All reserved forests in the region were managed for the commercial production of wood products and for the subsistence needs of the local people. Extensive plantations were raised in gap areas or after clear felling of Sal or mixed Sal forests. Exotic species like *Tectona grandis* and *Eucalyptus citriodora* were introduced during this period. After 1947 large numbers of people were resettled from Pakistan and provided with private forest, grasslands and wetlands to clear or drain. The present extent of tall grasslands in the TCA forms an integral part of the forestlands, controlled by the forest department which is the custodian of wildlife and natural ecosystems in India (Sawarkar, 2000). Till very recently, foresters considered them ‘unproductive’, and administrative and political decisions in favour of local or regional development have diverted large tracts of grasslands to other uses. Grasslands are overgrazed, subjected to uncontrolled fires, and taken over by an abundance of weeds, which ultimately leads to degradation (Kumar et al., 2002).

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CHAPTER 3

FAUNISTIC INVENTORY OF SPIDERS IN TERAI CONSERVATION AREA

3.1 Introduction

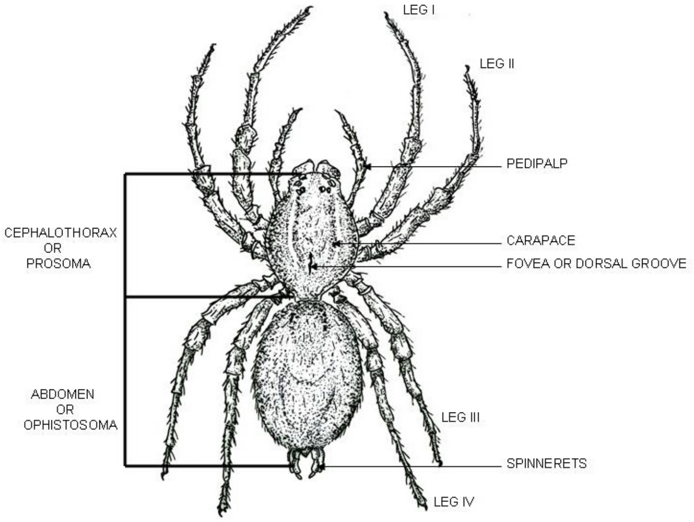
There are approximately 40, 700 spider species that have been described worldwide belonging to 3733 genera and 109 families (Platnick, 2008). Out of these, 2299 spider species belonging to 552 genera and 67 families are reported from South East Asia (Siliwal and Molur, 2007). Of 552 genera, 49 (9%) are monotypic, represented by single species and there are 65 genera (12%) is endemic to one or more South Asian countries. Around 1830 species (80%) are endemic South Asia. Out of the 67 families of spiders in South Asia, seven families have not been reported from India. India represents 1520 spider species belonging to 377 genera of 60 families (Sebastian and Peter, 2009). 21 of 361 genera are endemic to India while 13 are endemic to South Asia. Of these species, 1002 are endemic to the Indian Mainland, 71 species are endemic to Andaman and Nicobar Islands and one species is endemic to Lakshadweep (Siliwal et al., 2005). The families represented by the highest number of genera and species in India are the Salticidae (66 genera and 192 species) followed by the Thomisidae (38 genera and 164 species).

3.2 The Classification of Spiders

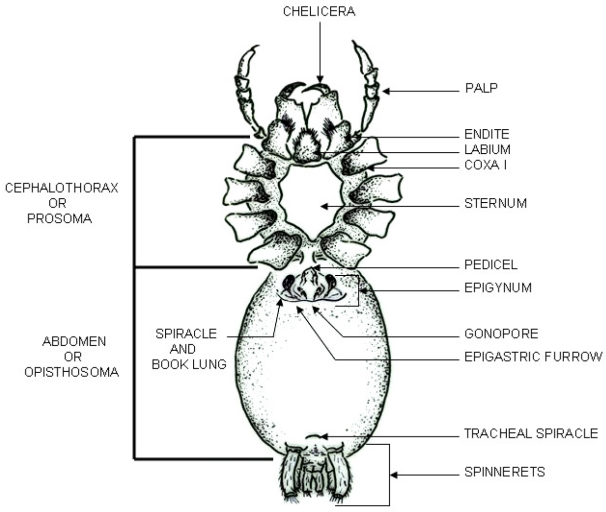
Spiders are one of the eleven orders of the class Arachnida, which also includes groups such Palpigradi (rnicrowhipscorpions), Amblypygi (tailless whipscorpions), Thelyphonida (whipscorpions), Schizomida (no common name), Ricinulei (no common name), Acari (mites and ticks), Opiliones (harvestmen), Scorpiones (scorpions), Pseudoscorpiones (pseudoscorpions) and Solifugae (sunspider, windscorpion, or solpugid). Before 1880, spider classification was based on broad categories of lifestyles resulting in a paraphyletic arrangement. Today, the monophylogeny of Araneae is supported by several complex and unique synapomorphies. The most important of these are abdominal appendages modified as spinnerets, silk glands and associated spigots, cheliceral venom glands, male pedipalpal tarsi modified as sperm transfer organs, and loss of abdominal segmentation (Coddington and Levi, 1991). Within the Araneae, three major groups are generally recognized: Mesothelae, Mygalomorphae, and Araneomorphae. The suborder Mesothelae contains the single family Liphistiidae (5 genera, 87 species) limited to China, Japan, Southeast Asia, and Sumatra (Platnick and Sedgwick 1984). The infraorder Mygalomorphae (15 families, 300 genera, 2500 species) include the Theraphosidae (tarantulas), Ctenizidae, Actinopodidae, and Migidae (trapdoor spiders), Atypidae (purse-web spiders), Hexathelidae (funnel web spiders), and several groups with no common name**.** The infraorder Araneomorphae (94 families, 3200 genera, 36,000 species), sometimes referred to as "true" spiders, includes all remaining spider taxa (Platnick, 2005). Araneomorphs include over 90% of known spider species: they are derived in numerous ways and appear quite different from mesotheles or mygalomorphs. Mesotheles are the only spiders with an anterior median pair of distinct spinnerets and mygalomorphs have lost them completely. A complex, important synapomorphy of araneomorphs is the fusion and reduction of the anterior median spinnerets to a cribellum, a flat sclerotized plate that bears hundreds to thousands of silk spigots that produces very fine, dry, yet extremely adhesive, silk (cribellate silk). Arachnida evidently originated in a marine habitat (Dunlop and Selden, 1998, Dunlop and Webster, 1999), invaded land independently of other terrestrial arthropod groups such as myriapods, crustaceans, and hexapods (Labandeira, 1999), and solved the problems of terrestrialization (desiccation, respiration, nitrogenous waste removal without loss of excess water, and reproduction) in different ways. Although the phylogeny of Arachnida is still controversial, specialists agree that the closest relative of Araneae is a group of orders collectively known as Pedipalpi: Amblypygi, Schizomida, and Uropygi (Shultz, 1990).

3.3 Spider Anatomy

The spider body consists of two main parts, an anterior portion, the prosoma (or cephalothorax) and a posterior part, the opisthosoma (or abdomen). A narrow stalk, the pedicel, connects these parts (Fig 3.1-3.2).



DORSAL VIEW



VENTRAL VIEW

Fig. 3.1 External morphology of spiders showing the dorsal and ventral views.

With respect to functions, the prosoma serves mainly for locomotion, for food uptake, and for nervous integration. In contrast, the opisthosoma fulfills tasks associated with digestion, circulation, respiration, excretion, reproduction, and silk production. The prosoma is covered by a dorsal and a ventral plate: the carapace and the sternum, respectively. It serves as the place of attachment for six pairs of appendages: one pair of biting chelicerae and one pair of leg-like pedipalps are situated in front of four pairs of walking legs. In mature male spiders, the pedipalps are modified into copulatory organs. The "head" part of the prosoma bears the eyes and the chelicerae. Most spiders have eight eyes, which are arranged in specific patterns in the various families.

Usually the eyes lie in two rows, and accordingly they are referred to as anterior lateral eyes (ALE), anterior median eyes (AME), posterior lateral eyes (PLE), and posterior median eyes (PME) (Fig. 3.2).

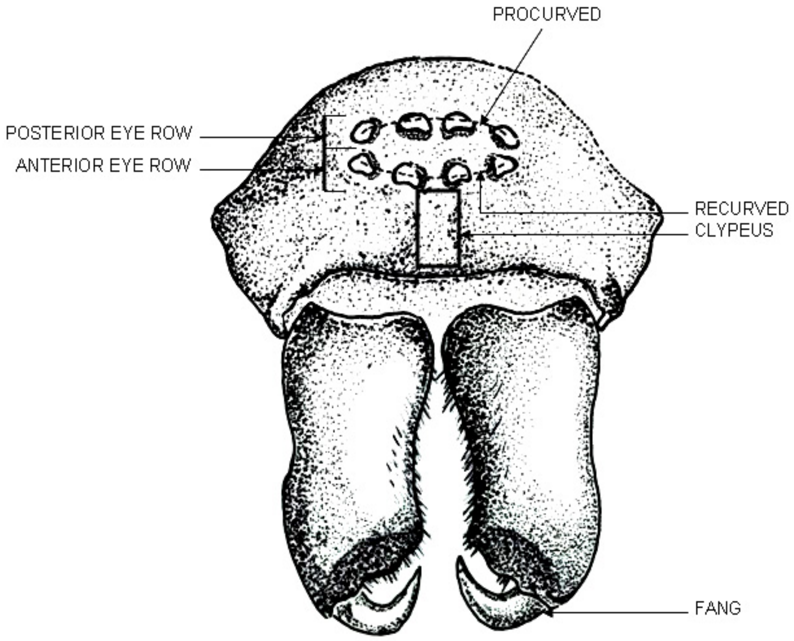


Fig. 3.2 Eye morphology and eye patterns of various eye parts.

The chelicerae are the first appendages of the prosoma. Each chelicera consists of two parts, a stout basal part and a movable articulated fang. Normally the fang rests in a groove of the basal segment like a blade of a pocketknife. When the spider bites, the fangs move out of their groove and penetrate the prey. At the same time poison is injected through a tiny opening at the tip of the fang. Both sides of the cheliceral groove are often armed with cuticular teeth. These act as buttresses for the movable fangs and, in addition, allow the spider to mash a prey item into an unrecognizable mass. Spiders without such teeth can only suck out their victims through small bite holes formed by the fangs. The second pair of appendages is the pedipalps. With the exception of an absent metatarsus, pedipalpal segmentation corresponds to that of the legs. Despite their general resemblance to legs, the palps are usually not used for locomotion. Instead, they often play a manipulative role during prey catching. The most notable modification of the palps is found in male spiders. Male palps act as copulatory devices by first sucking up freshly deposited sperm on the male's sperm web and then depositing this into the female's copulatory organs.

The mouth opening is bordered laterally by the maxillae, in front by the rostrum, and in the back by the labium. The four mouthparts form the mouth proper, which leads into a flattened pharynx. The pharynx consists of a movable, hinged front (rostrum) and a back wall (labium) and is lined by cuticular platelets. These contain very fine grooves covered by small teeth which together function as a micro filter. The pharyngeal lumen can be widened by the action of several muscle bands. Thus, the pharynx acts as a suction pump and the spider does not chew its food but instead sucks the contents of its prey through the holes or macerated sections it makes in the prey's exoskeleton. Four pairs of legs fan out radially from the pliable connection between carapace and sternum. These legs are referred to as legs I, II, III, and IV starting from the anterior pair. Each leg has seven segments: a short coxa, a short trochanter, a long femur, a knee like patella, a slender tibia and metatarsus, and finally a tarsus with two or three claws. The tip of the tarsus bars two bent claws, which are generally serrated like a comb; a third claw may be present between them (Fig. 3.3).

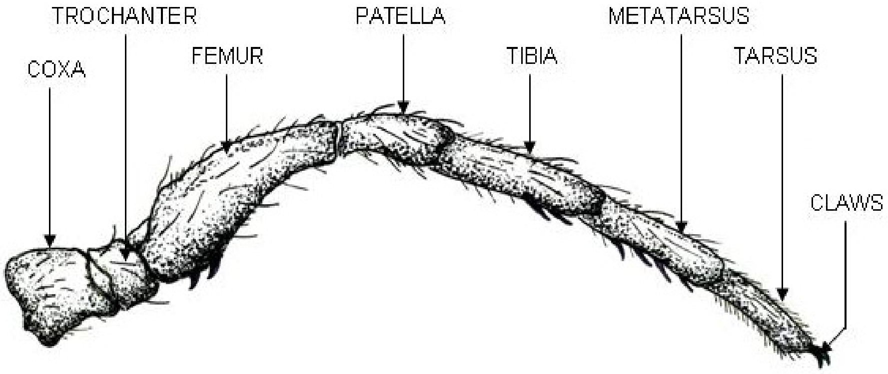


Fig. 3.3 Segments of typical spider leg.

Most spiders bear a soft, expansible and unsegmented opisthosoma. Only the Mesothelae, believed to represent an ancient form from which present-day spiders are derived, possess a clearly segmented abdomen (Platnick, 1995). The anterior dorsal surface of the opisthosoma may possess a darkly coloured, triangular mark that may stretch to the midway mark toward the spinnerets. This is the heart mark and under it is found the spider's primitive heart. On the under surface, again toward the anterior end, is a pair of book lungs and a single epigastric furrow. Both the male and female's reproductive organs are found beneath this furrow. In females however, this furrow is normally sclerotized forming an epigynal plate with a pair of pores, one on either side of the midline. These openings allow the insertion of a male's charged palps and lead directly to the sac-like spermathecae where semen is stored until oviposition. Retrolateral to the furrow are the book lungs. Primitive spiders have a second pair of book lungs found toward the posterior end of the abdomen directly in front of the spinnerets. A pair of spiracles and associated tracheae in advanced spiders replaces these posterior book lungs.

A spider has three pairs of spinnerets on its abdomen, which represent modified appendages. The spinning glands terminate in little spigots on the surface of each spinneret. All three pairs of spinnerets, anterior, median, and posterior, are extremely mobile because they are equipped with a well-developed musculature. The anterior median pair is often extremely reduced and many spiders (such as Linyphiidae, Theridiidae, and Thomisidae) have only a vestigial bump, which is referred to as the colulus (Fig 3.4). In the remaining spiders, the colulus are absent altogether.

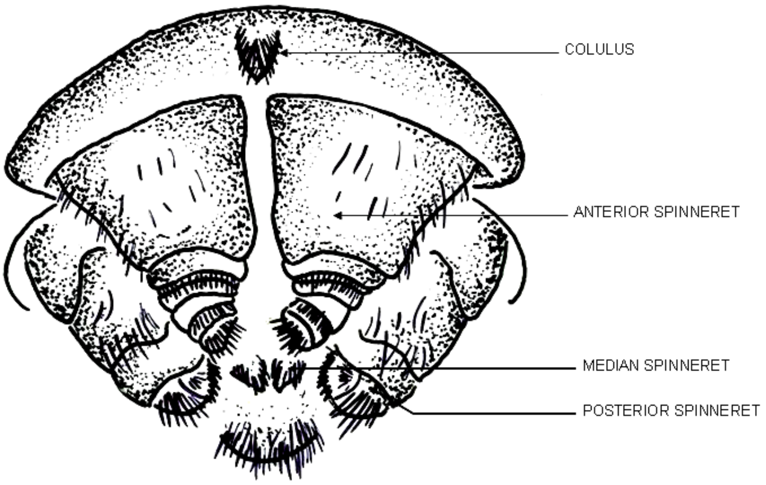


Fig. 3.4 Ventral view of spider showing various parts of spinnerets.

Numerous spiders possess an additional spinning organ, the cribellum, a small plate located in front of the three pairs of spinnerets (Fig. 3.5). The cribellar area is densely covered with many tiny spigots through which are extruded thin silk threads of the "hackle band". These thin silks are combed out of the cribellum by rhythmic movements of the calamistrum, a row of comb shaped hairs situated on the metatarsi of the fourth legs.

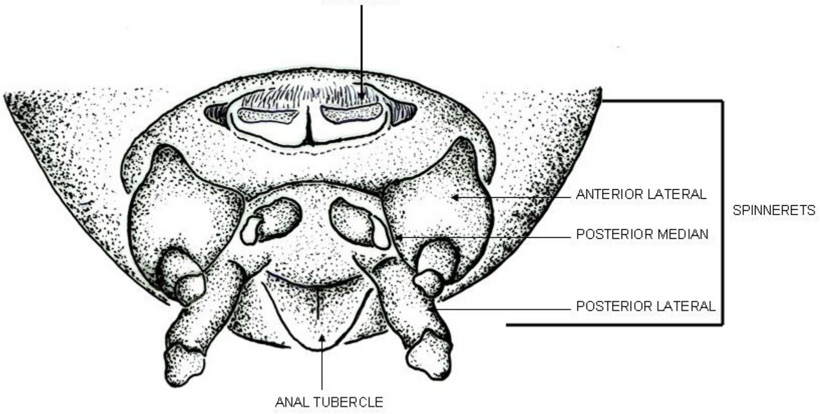


Fig. 3.5 Ventral view of cribellum of typical cribellate spider.

3.4 Anatomy as it Relates to Classification

The classification of spider families relies on the structure of the spinnerets, chelicerae, tarsal claws, and the labium. Genital structures however, are used mainly for the separation of species and are the only features that afford any reliable identification. Consequently, only adult specimens may be accurately identified to species level. Dondale and Redner (1989, 1982, and 1978) and Platnick and Dondale (1992) gave excellent accounts on sexual organ anatomy. The tarsus, pretarsus, and the tibia of the male palpus are modified to form a copulatory organ called the pedipalp. The pedipalp consists of a dorsal shield-like cymbium and a rounded genital bulb. The pedipalps of male spiders vary greatly in form and complexity. In their simplest form, each pedipalp bears on its cymbium a teardrop shaped genital bulb. The more complex pedipalp organs are formed of hard parts and soft parts called sclerites and hematodochae respectively; the sclerites bear processes called apophysis. (Fig. 3.6)

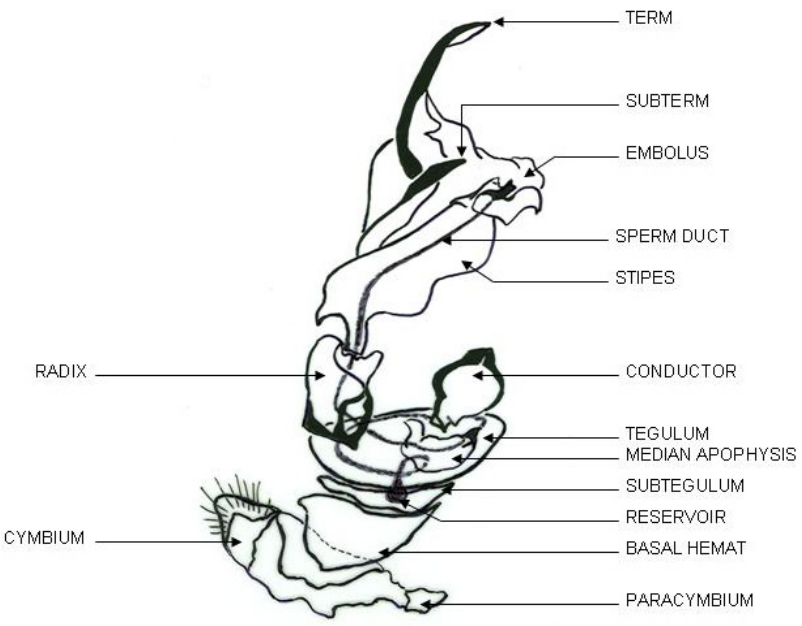


Fig. 3.6 Ventro-lateral view of an expanded palpal organ of a male spider.

The genital bulb in these spiders consists of a well sclerotized tegulum, within which are found an intromittent organ called the embolus, the seminal duct and the seminal reservoir. A terminal apophysis is associated with the embolus and a median apophysis is associated with the tegulum. All of the variously shaped apophysis is heavily used to classify adult males to species. Female spiders possess a pair of ovaries in the opisthosoma. The lumen of each ovary leads into an oviduct, and the two oviducts unite to form a uterus (also called the vagina). The uterus opens to the outside in the epigastric furrow. Many spiders possess a complexly structured sclerotized plate just in front of the epigastric furrow. This plate, called the epigynum, extends over the genital pore and bears the copulatory openings. This epigynum is heavily used to classify adult females to species level.

3.5 Research and Studies on Indian Spiders

Studies in the Indian part from different biogeographic regions have started in the late 19th Century by several European taxonomists and later by Indian Arachnologists. Review of available literature reveals that the earliest contribution by Blackwell (1864,1867); Stolickza (1869); Karsch (1873); Thorell (1877); Simon (1897a,b); Pocock (1895, 1899a,b, 1900a,b, 1901) and Sheriffs (1919, 1927, 1928, 1929) were the pioneer workers of Indian spiders. They described many species from India, Burma and Sri Lanka from mostly preserved specimens. In the twentieth century studies on Indian spiders were documented by Gravely (1921); Narayan (1915); Reimoser (1934) and Dayal (1935). Tikader (1980, 1982) and Tikader and Malhotra (1980) described spiders from Central India. Major contributions to the Indian Arachnology were made by Pocock (1900) and Tikader (1980 -1987), have highlightened spider studies to the notice of other researcher. Pocock (1900) described 112 species of spider from India. His book provided the first list of spiders, along with enumeration and new descriptions in British India based on spider specimens at the British Museum, London. Tikader (1987) also published the first comprehensive list of Indian spiders, which included 1067 species belonging to 249 genera in 43 families. Identification keys provided in these publications are still followed. Gajbe (1987- 1999) studied the spiders of

Madhya Pradesh and Chattisgarh region. Spiders of protected areas studied by Gajbe (1995a) in Indravati Tiger Reserve while recorded 13 species. Gajbe (1995b) also documented 27 species of spiders from Kanha Tiger Reserve. Patel (2003) described 91 species belonging to 53 genera from Parambikulam Wildlife Sanctuary, Kerala. Gajbe (2003) documented checklists of spiders of Madhya Pradesh and Chattisgarh area. Centre for Indian Knowledge System, Chennai has also conducted ecological studies of spiders in a cotton agro ecosystem of Guindy National Park. A brief account of major spider families is also provided by Vijayalakshmi and Ahimaz (1993). De (2001) overviewed and listed 19 species of spider from Dudhwa Tiger Reserve in his Management Plan. Biswas and Biswas (2004) contributed significantly by rendering comprehensive lists of new recorded spider species from Manipur and West Bengal. Recently, an updated checklist of Indian spiders was compiled by Siliwal et. al. (2005) provides taxonomic re-evaluation of described species of Indian mainland. Uniyal (2006) had conducted a survey of Ladakh region in order to explore Trans Himalayan spiders. Uniyal and Hore (2006) have recorded 17 species belongs to 16 genera from mixed Sal forest in Chandrabani area of Dehradun. Using standardized sampling protocols, Uniyal and Hore (2008) explored spider species diversity in various habitats of TCA. Hore and Uniyal (2008a) have studied the effect of prescribed fire on spider assemblages in Terai grasslands and also compared the community structure of spider assemblages in different vegetation types of TCA and explained the possible effect of habitat characteristics on species occurrence (Hore and Uniyal, 2008b). Subsequent study by Hore and Uniyal (2008c) have also identified indicator spider species of specific habitat type and found species mostly influenced by canopy cover and moisture regimes of the habitat. However, very little biodiversity research has been done on North Indian spiders especially, the Himalayan and sub Himalayan foothills region. Thus a there exists pressing need to explore diversity and distribution of spiders in the Northern part of the country. Keeping in view the taxonomic urgency, the current study provides a preliminary checklist of the spiders of TCA, India. It is expected that the current checklist will add to the existing knowledge of Indian spiders and serve to provide a base for future research on the poorly studied North Indian spider fauna since it might not be easy to carry out meaningful ecological/conservational based studies when the fauna is poorly known.

3.6 Inventory of Spiders in Terai Conservation Area

A total of 186 species belongs to 77 genera and 27 families were collected during entire sampling periods (Table 3.1). Of these, 67 species (36% of all species) belong to morphospecies. Since many morphospecies are still to be identified with consultation with specialists, many more new species and records are expected in future. General appearance, natural history and biology of genera of spider families sampled in TCA are described below followed by Kaston, 1978; Preston-Mafham and Preston-Mafham, 1984; Filmer, 1991; Dippenaar-Schoeman and Jocqué, 1997; Koh, 2000; Leroy and Leroy, 2000; Cushing, 2001; Sebastian and Peter, 2009 and observations in field. The families have been listed alphabetically. Genera containing potentially new species are indicated by asterisks.

Family Agelenidae (Funnel-web spiders)

Family Agelenidae, represented by 42 genera and about 515 species occur worldwide (Platnick, 2008). Two genera are known from India (Siliwal et al., 2005). These spiders resemble wolf spiders. They are usually dark grey to mottled brown, with the abdomen decorated with a reddish brown folium and a series of yellow to white spots or bands. The carapace is long and narrow in front with the eyes (equal size) situated in two procurved rows. The legs are long and narrow toward the extremities and are hairy with spines. The abdomen is oval and tapers posteriorly. They have two elongated posterior spinnerets tapering at the ends. The funnel web of agelenids is very characteristic, consisting of a flat, slightly concave silk sheet with a funnel-shaped retreat at one end, close to the soil surface. Agelenids are common in the grassland habitat but owing to their sedentary life-style, are not often collected during general surveys. Only one genus, ***Agelena***, was sampled from the study area, and was sampled from only in grassland habitat type.

(i) Genus *Agelena* usually make their webs in low vegetation such as grass and low shrubs. The abdomen is with reddish tinge and several clearly marked chevrons. Posterior spinnerets are noticeably long. This genus lives permanently on a large, sheet-like web with a funnel retreat made close to the substrate.

Family Araneidae (Orb-web spiders)

The Araneidae is a large family comprising more than 2985 species in 167 genera, 29 of which occur in India (Sebastian and Peter, 2009). Several subfamilies are recognised. Araneids are a diverse group of orb-web weavers occupying a wide range of habitats. Their most prominent characteristics are three tarsal claws and the third leg always being the shortest. They form an important component of the spider fauna of the grass and herb layer. The araneids were the most abundant family in the study are (42% of all captures) and were widely distributed. They were found in all habitats within the area. There are 13 genera sampled from the study area included: *Arachnura, Araneus*, Argiope, Cyclosa*, Cyrtophora, Eriovixia, Gasteracantha*, *Gea*, *Larinia**, *Neoscona, Parawixia*, Poltys, Zygiella*.* Members of the subfamily Araneinae are diverse in morphology as well as behaviour.

(i) Genus ***Arachnura*** construct a widely spaced orb web in low vegetation. They resemble much like a twig or dead leaf. When alarmed, they coils lower abdomen over the body giving an appearance of a scorpion. The cephalothorax is quite long and narrower interiorly. The abdomen of *Arachnura* is uasually elongated with prominent shoulder humps and with posteriorly tapering tail-like tubercles.

(ii) In genera ***Araneus*** and ***Neoscona*** (hairy field spiders) the carapace is moderately convex without any horny outgrowth. Colour varies from cream to brown to black, usually with distinct patterns dorsally. Eyes are set in two rows, median ocular quadrangle forming trapezium, not much longer than wide, median eyes are usually longer than wide with lateral eyes almost contiguous and usually situated on prominent tubercles. The abdomen is usually wider than it is long, raised near the anterior, oval or triangularly oval in outline. Pedipalp of male is large with terminal apophysis and spiny patella. *Araneus* is a large genus widely scattered in all regions of the world. They construct orb web in low vegetation and rest in silken retreat constructed with leaves in the side of the web.

(iii) Genus ***Argiope*** (cross spiders) is easily recognised by their large size and brightly coloured abdomens. Females are more than 9 mm and males are very small. The cephalothorax extremely flat, clothed with thick layer of white pubescence. Eyes are set in two rows, ocular quadrangle forming trapezium, longer than wide, and wider posteriorly, posterior row of eyes strongly procurved, anterior lateral eyes smaller than posterior laterals, lateral eyes close and situated on conspicuous tubercles. Chelicerae is small, weak and with a small boss. Legs are long and strong, combined length of patella and tibia shorter than metatarsus and tarsus. The abdomen usually flat and of variable shape, and generally decorated with darker bands, and the edge of the abdomen is often scalloped. They are diurnal spiders encountered in the hub of their orb-webs during the day. The webs are often provided with a stabilimentum consisting of zigzag silk bands.

(iv) Genus ***Cyclosa*** (garbage line spiders) is usually built in shrubs and is common in open woodland. The stabilimentum often consists mainly on the prey remains attached in a vertical line to the centre of the web. Cephalothorax of *Cyclosa* usually with anteriorly narrow cephalic region, and distinctly separated from thoracic region by an oblique groove. Eyes are set in two rows, ocular quadrangle forming trapezium, much narrower behind than in front, posterior median eyes very close, laterals close and situated on conspicuous tubercles, rows of both eyes recurved. The first pair of legs is longer than the others. The abdomen of *Cyclosa* has a distinct caudal

(v) ***Cyrtophora*** (tent web spiders) are widely distributed throughout the world. The colour varies from cream to black with white markings. Carapace of *Cyrtophora* is almost flat and without hairs. Ocular quadrangle is usually slightly wider than long, lateral eyes contiguous and subequal in size, not situated on prominent tuberceles. Legs are moderately long and stout. The abdomen is usually longer than it is wide, and high, with distinct paired tubercles along the very high anterior end. They build specialised web in grassy vegetation, resembling that of Linyphiidae. The webs consist of a fine-meshed sheet, similar to the enlarged central area of the orb-webs, but made of dry silk and arranged horizontally.

(vi) ***Eriovixia*** (bird dropping spiders) construct vertical orb webs usually among plants and shrubs. Cephalothorax of *Eriovixia* is slightly longer than wide, clothed with pubescence and hair. Ocular quadrangle is slightly longer than wide and situated on an elevation. The abdomen is usually flattish with pronounced tail like extension at the rear. These spiders are often seen in its typical resting posture legs are pulled in around the abdomen and carapace thus forming a circular outline.

(vii) Genus ***Gasteracantha*** (spiny spiders) are brightly decorated with yellow, red or black and white patterns and ornamented with spines and sigilla. Cephalic region of *Gasteracantha* is much elevated at the middle and sloping anteriorly and posteriorly. The abdomen is shiny and dorsally flattened and has a number of spiny projections laterally and posteriorly. Median spines are often the longest. The bright red, orange, yellow, white and black on the abdomen render this spider unmistakable. Spinnerets are forming circular space ringed by a thick flange. *Gasteracantha* is most common in the tropics. They construct vertical orb webs, often in open spaces between the branches of tall shrubs. In its typical posture the front portion of abdomen covers the thoracic portion of cephalothorax and only the cephalic portion is visible from above.

(viii) ***Gea*** is a large genus comprising less than 30 species scattered in the Oriental, Australian, Neotropical and Ethiopian region. They often constructs small orb web in low vegetation close to ground without stabilimentum. Cephalic region of *Gea* is usually convex and clothed with hairs. The eyes are set in two rows, ocular quadrangle forming trapezium, wider behind than in front, eyes of anterior row evenly spaced, median eyes are close to lateral eyes than to each other. Chelicerae is weak, smallest, and with a small boss. Tarsi are longer than patellae and tibiae together. Tibia of male is curved and armed with spines. The abdomen is longer than wide, almost pentagonal in shape.

(ix) Genus ***Larinia*** differs from the related genus *Araneus* by the elongate, oval abdomen, often with an anterior, median tubercle and sometimes projecting behind and above the spinnerets. The light coloured carapace of *Larinia* may have a double, black, longitudinal line behind the eyes that fuses into a single median longitudinal line. The anterior median eyes are the largest, usually separated by a diameter or more. The posterior medians slightly smaller, are separated by their diameter at most, and are often in contact. The ocular quadrangle is narrower behind than in front. The abdomen usually has a dorsal pattern of longitudinal marks, and ventral with median white markings on black. Species of this genus often constructs webs on low vegetation, and sits in the hub of the web at night, on vegetation to the side of the web in daytime.

(x) Members of genus ***Neoscona*** have a longitudinal thoracic groove in the cephalothorax. Median ocular quadrangle is slightly longer than wide, forming a trapezium. Anterior median eyes are the largest or sub equal in diameter than posterior median eyes.

Posterior lateral eyes are the smallest. Abdomen is variable in shape-ovoid, subovoid, triangular, or sub triangular. Epigynum is simple and tongue-like. *Neoscona* is common through the different regions of the world. They are more common in moist woodland habitats than in drier woods. Juvenile stages usually begin making vertical orb webs about dusk and take the orbs down shortly after dawn. During the day, each spider stays in a retreat made of leaves curled together and tied with silk, located at the attachment of an upper frame thread; frame threads are sometimes left in place. Adult females often leave their webs up and hunt during the day. This may be due to their need for additional food for developing eggs along with a decrease of nocturnal prey in the cooler nights.

(xi) ***Parawixia*** constructs vertical orb web with an open hub. Webs looks abandoned with damage portions to avoid further searching by predators. Spiders sit at the centre of web; hide in rolled leaf retreat or sites in open, resembling dead leaf. Cephalothorax of *Parawixia* is longer than wide, narrow in front, clothed with pubescence, hairs and spines with granular bases. Anterior row of eyes are procurved when viewed frontally. Ocular quadrangle is slightly wider in front, with anterior rows of procurved eyes. The abdomen is usually triangular in shape with prominent shoulder humps and sharp tubercles at the front and end. Epigynum is simple with a prominent beak-like scape borne on a swollen base.

(xii) ***Poltys*** is a rather distinctive araneid genus that can be recognized by a combination of widely separated lateral eyes and a pear-shaped carapace, where the “stalk” of the pear is an eye tubercle. Genus *Poltys* (tree stump spiders) contains some of the most unusually shaped of spiders. They construct very fine orb webs in the early hours of the night and destroy them just before dawn. The spiders are cryptically camouflaged and during the day they hide motionless on vegetation with the legs drawn tightly around the prosoma and just the median eyes, which are situated on the

(xiii) Spiders of genus ***Zygiella*** construct webs that have many radii and very fine mesh. Adults of several well-known species of *Zygiella* spin incomplete orb webs by omitting sticky spiral lines and radii from a sector about equal to the space between two or three radii, which is accomplished by their spinning back and forth many times in rounded loops instead of complete circles. A strong trap line is strung from the hub through this free zone, but not always in the same plane, to the retreat, which is an open silken tube hidden in a crevice or under bark. These mostly nocturnal spiders hang from their webs at night and lie hidden in their retreats by day. The *Zygiellas* are araneine orbweavers with short, oval, moderately sclerotized abdomens unadorned by humps or spinose outgrowths. The eyes of the posterior row are subequal in size and subequidistantly spaced.

Family Clubionidae (Leaf-curling sac spiders)

The Clubionidae are represented by 14 genera of which 3 genera occur in the India (Sebastian & Peter 2009). Clubionids are free-living, nocturnal hunters commonly encountered in sac-like retreats amongst foliage on living trees, in dead, rolled-up leaves, under bark, stones and logs and amongst debris on the ground during the day. They usually have a long, narrow body and the chelicerae are in contrast with the rest of the body. They are two clawed spiders. They are aggressive and use their front legs to detect and grab prey. They have long legs with scopulae on the tarsi. Their eyes are small and are situated in two transverse rows. While many of the species within this family are drab in colour, there are some brightly coloured species and also some species are incredibly good. In summer, the females are usually found enclosed within their retreats, closely guarding their flattened egg sacs of white silk. One genus, *Clubiona** (sac spiders), was found in the study area and was sampled in only two habitat types.

(i) Genus ***Clubiona*** has distinct long cephalothorax, narrowed in front, and covered with silky hairs. Eyes nearly straight or slightly procurved, posterior row markedly longest. Anterior medians closer together than posterior medians. Their forth legs the longer than the first and second legs with tarsi and metatarsi conspicuously scopulate. The abdomen usually with notable dagger shaped mark, which starts at the front of the dorsal side and runs along the middle for half the length. They are frequently encountered under the bark of trees, on fallen bark on the ground, but can also be common on various plants amongst foliage. The young spiderlings hatch within a few weeks and remain with the retreat and the female for a considerable period before moulting and gradually dispersing. Mature spiders feed on a wide variety of bark- and leaf- dwelling insects and other spiders. *Clubiona* is a large genus and described species scattered in all the geographical regions of the world.

Family Braychelidae (Trapdoor baboon spiders)

They are two clawed, medium to large sized mygalomorph spiders. The species from family Barychelidae possess a conspicuous rastellum on the anterior face of the basal cheliceral segment, minute posterior median eye, eye tubercle low and scopulation of legs as follows : entire and thin pads on palpal tarsus and metatarsi I and II, thin pad divided by a band of short setae on tarsus III . Scopulae are absent on tarsus IV and metatarsi III and IV. The labium bears some 25 cuspules on the anterior half of its length. Posterior spinnerets are usually with dome shaped apical segment. These spiders are mostly ground living and burrowing in habit, generally, but not always are close to the burrow with a trap door. Outer surface of the burrow is usually covered with soil particles and leaves. In many species, the burrow is provided with one or two trapdoor entrances. A total of five species belonging to four genera are reported from India so far. Two genera of Barychelidae were sampled from the study sites. These included *Sason* and *Sasonichus*.

(i) Genus ***Sason*** is known from the Seychelles, Andaman and Mariana Islands, India, Ceylon, northern Australia, and New Guinea. The retreat consists of a very short tube with a door at each end. The outer surface of the retreat is usually impregnated with particles of soil and leaves. They are small, compact, and stout-legged, lack a strong rastellum and, unlike many barychelids, their eyes are usually not on a tubercle and the eye group is rectangular. Carapace is glabrous but with numerous short bristles, especially in males. Ocular quadrangle is about twice as wide as long, rectangular. Eye tubercle is absent or low, and if present, usually excludes anterior lateral eyes. Clypeus is absent. Chelicerae is short, sloping, with one row of teeth on furrow. Legs are stout, sometimes with distinct annulations.

(ii) Genus ***Sasonichus*** is endemic to India, recorded from Southern India. They dig burrow which is lined with a thick layer of silk. A disc-shaped plug of thick, strong silk is constructed by the spider and is fitted tightly into the entrance or entrances of the burrow. They differ distinctly from all other allied species by recurved thoracic fovea. Carapace is low and about as long as Tibia of first leg in male is without apical spur. Legs are highly furnished with bristles. Tarsus of labial palp is much longer than wide and with large rounded internal lobe.

Family Corinnidae (Ant – mimicking sac spiders)

Family Corinnidae is closely related to the families Clubionidae and Gnaphosidae and many of the species in the family were first described as clubionids or gnaphosids. Family Corinnidae comprising about 80 genera and 956 species worldwide (Platnick, 2008). Nine genera and 36 species occur in India (Sebastian and Peter, 2009). Corinids are free living ground dwellers, usually found in woody derris, litter or humus on the forest floor in shaded areas. Members of the genus *Castianeira* appear to be mimics of ants and velvet ants. It is a medium-sized family and occurs mostly in the tropical and sub-tropical regions of the world. Many of the species mimic ants upon which they feed. The spiders of this family can be identified by the eye formation. The eight eyes (small to medium sized) are situated on a slightly raised eminence at the anterior end, which is long and tapering, and the eyes are positioned in two recurved, widely separated rows. The lateral eyes are slightly smaller than the median eyes. Two genera of Corinnidae were sampled from the study sites. These included *Oedignatha* and *Trachelas*.

(i) Genus ***Oedignatha*** commonly occur in dry grass litter complex and often in disturbed habitat. Cephalothorax is usually punctuate oblong, with cephalic shield present. The abdomen part is oblong covered with sclerotized dorsal shield ornamented by white spots. During the summer the female constructs a flat, white, disc-shaped egg-sac of brittle silk measuring about 5-9 mm diameter, usually placed under a fallen log or under a piece of bark on a tree. They are commonly parasitized by wasps. The mature spiders feed on a wide variety of ground-dwelling insects and other arthropods.

(ii) Members of ***Trachelas*** commonly occur at the base of plants, in grasses and in ground debris. They are hunting spider and make no web. However, it builds a sac like tube to hid and rest in diurnally which is also used to protect its eggs. They tend to forage on other dead arachnids and insects which can cause its bite to be particularly unpleasant due to infections. Cephalothorax is longer than wide, with enlarged chelicerata. Abdomen is oblong, with darker markings on the dorsal side.

Family Desidae

This family contains mainly small to medium-sized eight-eyed spiders, measuring usually less than 20 mm long, with short, prominently spherical to ovoid abdomens, and like the family Uloboridae (see later), they possess a cribellum and calamistrum. They posses large chelicerata almost as long as carapace, with teeth on both rows. Most species construct irregular sheet webs; each sheet consists of several parallel to radially-arranged silken threads between which are numerous cross-threads arranged in a zigzag to wavy pattern. Family Desidae comprising about 38 genera and 182 species worldwide (Platnick, 2008). Only one genus and 2 species occur in India (Sebastian and Peter, 2009). Only one genera *Desis*, was sampled from the study area.

(i) Spider belongs to genus ***Desis*** has dark reddish-brown carapace, with cream grey abdomen. Chelicerata long and pointed forward, abdomen densely covered with short pale hairs.

Family Dictynidae (Mesh web spiders)

Family Dictynidae, represented by 48 genera and about 561 species occur worldwide (Platnick, 2008). 11 species belongs to eight genera are known from India (Sebastian and Peter, 2009). Most dictynids of the subfamily Dictyninae live in a nest consisting of a retreat and a web. The web consists of parallel threads criss-crossed with cribellate silk to form a ladder structure. The retreat is made within the mesh. Webs are usually constructed on the stems and leaves of plants, but some species construct their webs on walls. Some dictynid species are ground-dwelling while others live in the intertidal zone. These small spiders have a wide cribellum and a uniserate calamistrum but are generally recognised by their unique webs. The abdomen slightly overlaps the carapace and is usually decorated with light and dark patterns. The carapace is distinctly high and usually clothed in white hairs. The eyes are arranged in two straight rows and are almost the same size. The anterior median eyes are dark and the rest of the eyes appear pearly white. The chelicerae are long and indented. Only one genus, *Dictyna* was sampled from all habitat types.

(i) Spiders of genus ***Dictyna***, are small, less than 4mm long. They are mostly brownish or black in colour. Carapace is markedly elevated in front, converge slightly anteriorly and posteriorly. Eyes are more or less equal size and evenly or rather widely spaced. Clypeus is wide. Male chelicerata is long and excavated on their inner margins, labial palp with conical lateral projections at the tip. Tarsi and metatarsi are without trichobothria. The abdomen is void, and almost white with a pattern of yellowish brown areas. The entire body is covered with long hairs, longest in the carapace. These spiders spin an irregular cribellate webs in heads of plants, both living and dead, and in bushes.

Family Dipluridae (Funnel web tarantula spiders)

The Dipluridae are one of the better known families of mygalomorph spider, found in tropical to sub-temperate regions on all continents. Though little is known about diplurids of India, represents only 4 species belongs to two genera (Sebastian and Peter, 2009). However, most of the species are uncommon and live in remote areas and are rarely encountered. They are mostly large, hairy, dark brown to black spiders, living in silken burrows in the ground or occasionally holes in trees above ground. Their burrows are rarely attached with doors but are sometimes adorned with an expansive silken sheet or curtain-like sheet threads over the entrance.

(i) Only one genus, ***Indothele***, was captured from the study area. The generic name, which is feminine in gender, is derived from the name of the subcontinent, India, where most species of this genus live. Body size usually small to medium, has carapace with moderately dense covering of thin hairs; abdomen marked with longitudinal series of 5-7 pairs of pale unpigmented spots, anterior pair round to elongate oval, rest obliquely transverse and thinner posteriorly. The webs of many species are more common on steep river banks and rocky slopes or outcrops than in the more gently sloping terrain nearby. Some species also build their webs in shrubs and on rough or plant-covered tree trunks. Key microhabitat requirements for all species are natural crevices, cavities, or other small concealed spaces to house the retreat portion of the web and enough surface irregularities, rocks, exposed roots, branches, or leaves to support the capture web. Webs consist of two functionally distinct parts, a tubular retreat hidden in an enclosed space and an exposed capture web.

Family Gnaphosidae (Flat-bellied ground spiders)

The Gnaphosidae are a large family comprising about 110 genera and 1500 species worldwide (Platnick, 2008). Twenty eight genera and about 139 species occur in India (Sebastian and Peter, 2009). Gnaphosids are free-living ground dwellers, with only a few living on plants. Most of the ground dwelling species construct a silk retreat under stones or surface debris within which they remain during non-active periods. Some gnaphosids attach their egg-sacs to the substrate whereas others spin complex egg-sacs in their retreats. Gnaphosids catch their prey using speed, force and agility. Their eyesight is poor and their prey is perceived by tactile or chemotactic stimuli. Surveys have shown that gnaphosids are more common in dry habitats. They are occasionally encountered in wet fields but very rarely in dense forest patch. They are dull coloured spiders and some genera have markings on the abdomen. They have hairs on the abdomen which may glisten). The shape of the carapace is variable – ovate to narrow. The eyes are in two rows, commonly both procurved, with the posterior median eyes in some species oval and set at an angle. The chelicerae are robust and they have dark fangs curving inwards and overlapping. The spinnerets are cylindrical and are markedly parallel to and separate from each other. Five genera of Gnaphosidae were sampled. These included *Drassodes; Gnaphosa; Haplodrassus, Herphyllus* and *Zelotes.* Gnaphosids were widely dispersed in the study area.

(i) Spiders of genus ***Drassodes*** commonly found under some type of ground cover, usually stones. Female spiders are usually guarding single egg sacs within their hibernacula. The hibernacula consisted of silken tubes stretched across the undersides of rocks, or of silk-lined burrows extending straight down into the ground. The female would not leave her hibernaculum until it was broken open; she would then seize the egg sac in her chelicerae and attempt to drag or push it to safety. The presence of notched trochanters and two dorsal spines on tibia IV readily distinguishes this genus from *Haplodrassus*. The only genus likely to be confused with *Drassodes*, from its general appearance, is *Scotophaeus* but the latter has large anterior median eyes.

(ii) Like most gnaphosids, ***Gnaphosa*** are primarily nocturnal hunters, and remain during the day in retreats under stones and logs. Females are often found with their characteristically flattened egg sacs, which can contain up to 250 eggs. *Gnaphosa* may be distinguished from all other gnaphosids by the presence of a serrated keel on the cheliceral retromargin and by the rounded endites. Carapace oval in dorsal view, flattened, with ocular area narrowed; light orange to dark brown, with dark border. Cephalic area only slightly elevated; thoracic groove longitudinal. From front, anterior eye row slightly recurved to procurved, posterior row straight to slightly recurve. Abdomen is dark orange to brown, longer than wide, with dark, shiny anterior scutum in males. Six spinnerets are widely separated anteriorly.

(iii) Spiders of genus ***Haplodrassus*** differs from *Drassodes* in lacking deep notches on trochanters and lacking dorsal spines on tibia IV. Sometimes distinct dark markings are present on carapace and occasionally an abdominal pattern is present. However, in some species carapace is unmarked and abdomen uniform grey or brown; and this sometimes occurs in species which usually have markings. The males of some species of *Drassodes* enclose immature females in hibernacula adjacent to their own. Thirteen males were found sharing hibernacula with females. Of these, mature males were found cohabiting with penultimate females and one mature male was found in a hibernaculum with a mature female. The hibernacula varied from a sac just large enough to enclose the two spiders to silken tube s 12 cm or longer.

(iv) ***Herpyllus*** most easily recognized by genital characters: the male embolus is basally broadened and the median apophysis is elongated. Carapace is elongate oval, widest, gradually narrowed anteriorly, light to dark brown, lightest medially, with short recumbent dark setae. From above, the anterior eye row is slightly recurved, while posterior row is straight. Leg segments present with dorsal trichobothria. Abdomen is brown to dark grey, sometimes with distinct pattern. *Herphyllus* are commonly found along eroded river banks, rocky outcrops, and grasslands.

(v) ***Zelotes*** are often found in association with termites. The spiders of this genus were commonly found along a lake shore, under rocks, and in tall grass. These spiders are difficult to capture, building transparent, lustrous blue webs where they operate to capture potential prey. Cephalothorax is oval, narrowed markedly in front covered with fine hairs. Eyes are rather closely grouped, posterior row of eyes slightly longer than the anterior row. Chelicerata is not very strong, vertical, with a number of hairs on inner part of anterior surface. Legs are moderately long, tibiae and metatarsi III & IV with or without ventral spines. Abdomen is dark or black, covered with fine short hairs and three pairs of spots or impressions dorsally.

Family Hahniidae (Comb-tailed spiders)

The Hahniidae family comprising about 26 genera and 238 species worldwide (Platnick, 2008). Three genera and about 4 species occur in India (Sebastian and Peter, 2009). Spiders of the family Hahniidae are usually small (3-6 mm) in body size. They differ from other spiders by transverse arrangement of three pairs of spinnerets and the relatively large tracheal spiracle located on well beyond the spinnerets. Most of the hahniid spiders dwell under stones, in leaf litters, mosses, and soil cervices on the ground or even tree bark where they build delicate sheet webs and mainly feed on spring tails. They are three clawed, eight eyed spiders. Cephalothorax of Hahniidae is usually longer than wide. Cephalic region is narrow, generally light to dark brown with dark pattern and black margin. Abdomen is oval, usually with double row of oblique, pale markings on grey background. Two genera, *Hahnia* and *Neoantistea* were found in the study area.

(i) The members of genus ***Hahnia*** spp. are commonly found in leaf litter and detritus, or even on the leaves of shrubs and trees. The spiders spin delicate sheet webs near soil surface. This genus is the smallest of all genera in the family Hahniidae in terms of body length. It has along broad carapace, varying from light to dark brown, with grey to black pattern, and margined with black. Cephalothoraxes of these spiders are oval, longer than wide and narrowed in front. Anterior median eyes are smaller than anterior lateral eyes. Laterals side of chelicerata with stridulating organ. Abdomen is ovoid and slightly pointed posteriorly with transverse light markings on grey background.

(ii) Genus ***Neoantistea*** is the largest of all members in the family Hahniidae. They spend their time within the leaf litter rather than walking on the ground surface. Carapace is convex, about as broad as long. Eyes are large, the anterior row procurved, straight from above, the medians slightly smaller, equal to, or larger than the laterals, equidistantly spaced. Posterior row are of eyes slightly procurved, the medians farther apart, equal to or smaller than the laterals. Segments of lateral spinnerets are almost equal in length. Pedipalp of male is without apophysis in the femur.

Family Hersiliidae (Long-spinnered spiders)

The Hersiliidae family has worldwide distribution that comprises 12 genera and about 159 species (Platnick, 2008). Three genera occur in India (Sebastian and Peter 2009). Hersiliids have diverse life-styles, ranging from wandering tree-dwellers to ground-dwelling web-builders. They build small, silken traps nearby to where they rest, which are triggered by the prey and when detected, the spider races quickly and entangles it in silk. Their flattened body allows them to lie pressed to bark without casting shadows or enables them to hide in cracks. They are extremely fast runners and are occasionally encountered on walls and lichen-covered rocks. Body colour varies widely within species but they are often cryptically coloured to match their substrate. They generally have two long spinnerets protruding well beyond the posterior of the abdomen. Their eyes are in two recurved rows situated on a large protuberance at the front of the carapace. Two genera, *Hersilia* and *Neotama,* were found in the study area. The genera sampled from all habitat types except plantation habitat.

(i) ***Hersilia*** is a small genus comprising less than ten species, distributed in the African and Oriental region. They occur on tree-bark where its mottled appearance camouflages it well. They do not spin webs, but will attack pedestrian prey. While facing away from prey, they circle and fix it to bark with bands of silk emanating from long spinnerets, which they rotate rapidly to encapsulate the prey. Mature spiders feed on various small insects, other spiders and ants. Egg sacs are attached to the bark and camouflaged with bits of bark and debris. Cephalothorax is flat, angular laterally and slightly broader than long, with prominent high clypeus. Tarsi of legs I, II, and III are double segmented. Abdomen is flat, almost circular, slightly broader than long. Anterior and posterior row of eyes are strongly recurved. Posterior lateral spinnerets are very long, much longer than abdomen. Distinct colulus separate the anterior pair of spinnerets.

(ii) Members of ***Neotama*** are arboreal forest dwellers, usually found under bark. During summer the female constructs a broadly oval shaped egg-sac of white silk, strongly attached to the outside of the bark. They are difficult to see as the female camouflages them with dirty coloured silk. Mature spiders feed on various small insects, other spiders and ants. Carapace is long as wide; cephalic region is narrow and dorso ventrally flattened. Clypeus is short and not projecting beyond eye tubercles. Abdomen is wider than long and widest in posterior third. Posterior lateral spinnerets are conical in shape and narrowing distally to tapers at the end.

Family Linyphiidae (Hammock-web spiders)

Linyphiidae is the second largest family of spiders, comprising 482 genera and 4,359 species (Platnick, 2008). Sixteen genera occur in the India (Sebastian and Peter, 2009). Members belonging to the subfamily Linyphiinae are all small spiders. Linyphiids spin delicate sheet webs between branches of trees or shrubs, in tall grass and sometimes close to the ground. Spiders are suspended upside-down under the sheet and they have no retreat. Prey is bitten through the sheet from below. It is then pulled through the sheet before being consumed. They differs from others families by the form of and position of paracymbium and characteristics of male palpal organ, presence of horizontal stridulating striae on the outer side of each chelicerata, and absence of serrated ventral bristles in tarsus IV. Members of the family have variable shape of carapace. Eight eyes present in tow rows, heterogeneous, with anterior median eye darker than the rest. Legs are slightly short and stout to thin and long, with or without spines. The abdomen tends to be globose and usually shiny black to dark brown. Three genera were sampled, *Erigone*, *Linyphia**, and *Oedothorax**, and as yet, undetermined 14 linyphiid species. Linyphids were widely dispersed in Pure Sal and Riparian habitat.

(i) Genus ***Erigone***, is a moderately large genus of small-sized spiders, less than 3 mm long. They are readily separated from other members of the family by the presence of teeth in the margin of cephalothorax and chelicerae. Posterior row of eyes are straight, anterior recurved, ocular quadrangle longer than wide. Metatarsus is longer than tibia and metatarsus IV is without trichobothrium. Male pedipalp is excavated and producing a deep pit. Female epigynum is simple and usually with a procurved rebordered posterior edge. These spiders build very small sheet webs in mud and pits in soil between sand particles.

(ii) ***Linyphia*** spp. constructs sheet-web consists of an unordered meshwork of fibres of different thicknesses. The sheet is connected to the scaffolding by means of attachment discs. The spider runs upside down on the lower surface of the sheet. Threads of silk that function as a knockdown trap extend above the sheet and are attached to surrounding vegetation. Eyes are fairly small, widely spaced on black spots. Legs are usually long, metatarsi as long as tarsi. Abdomen present with dorsal transverse bands.

(iii) Dwarf spiders of the genus ***Oedothorax*** are approximately 3 mm long and the females are bigger than the males. Most of the time, copulation takes place upside down in the web. They mostly found in damp and swampy areas. Cephalothorax longer than broad, highest point of the male carapace is situated in the anterior part, and there is typically a pale region in the middle of the abdomen of the female. Abdomen is longer than wide.

Family Lycosidae (Wolf spiders)

The Lycosidae are represented by 110 genera and more than 2300 species (Platnick, 2008). India has a rich fauna with 17 genera belongs to 126 species (Sebastian and Peter, 2009). They are commonly called wolf spiders because of their method of capturing prey. They are vagrant hunters, mainly on the ground or amongst low-growing foliage or around the margins of lakes and swamps and on sandy riverine patches, preying on a wide variety of ground insects and other invertebrates, usually by striking and pouncing on the victims which are often much larger than the spiders themselves. Wolf spiders are often common and distinctive, small to medium-sized spiders, usually coloured dark grey or brown but often patterned in black, grey, brown, white or orange. Lycosids have a very characteristic eye pattern, the eyes are arranged in three rows (4:2:2). The anterior four eyes are very small and either straight or slightly procurved, the two larger posterior medians are situated on the vertical front of the carapace; and the smaller posterior lateral eyes are above and to the sides of the head. Most species, with the aid of their very strong chelicerae, construct a short, cylindrical retreat burrow in sand or soft soil. This burrow may be covered with soil particles, leaves or sticks, usually amongst grass or other low growing vegetation, dead or alive. A few species construct doors which are loosely attached to the entrance of the burrow with a few silken threads. Other wolf spiders construct a permanent web-sheet around the burrow entrance. Six genera sampled from the study area included: *Arctosa*, Evippa, Hippasa*, Lycosa, Pardosa,* and *Trochosa*. Lycosids predominantly found in moist riparian habitat type.

(i) Wolf spiders of the genus ***Arctosa*** are of medium to large size, with overall length (excluding legs) of 4.5 - 16.0 mm. They are swift runners, and possess relatively keen eyesight. Most dwell in sandy places such as seashores or the banks of rivers and lakes, though some occupy heath or lichen habitats in high mountains or arctic tundra. The principal body colours are grey, off-white, and tawny brown, in keeping with habitat. Females usually attend their eggs in silk-lined burrows rather than carry them about, and most species appear to be nocturnal. Carapace is broad, rather low, and approximately uniform in height between dorsal grooves. Posterior row of eyes are usually glabrous or nearly so, yellow, off-white, or mottled with grey, yellow, or brown. Anterior row of eyes is straight or somewhat procurved or recurved, longer than, shorter than, or equal to middle row in length. Pale legs are usually robust, with dark rings, and sparse scopulae. Abdomen is usually pale and mottled like carapace.

(ii) Members of genus ***Evippa*** dig burrow in soft and porous soil. The entrance to the burrow is usually adorned with, and often covered by, small twigs, bark, foliage and other debris, often arranged in a radiating or regular pattern. The spiders mature in summer and after mating, the female constructs a large, pill-shaped egg-sac of greyish-white to white silk. The egg-sac is protected and guarded at all times by the female in the burrow. The eggs take about 4 weeks to hatch and the young spiders cling onto the dorsal surface of the abdomen of the female in typical wolf-spider fashion. The mature spiders feed on a wide variety of ground-dwelling insects such as grasshoppers, beetles and sheltering moths near the ground, as well as other small spiders. Anterior portion of the cephalothorax is somewhat abruptly elevated thus forming an angel with posterior portion of thoracic region. Anterior row of eyes are generally procurved. Inner margin of chelicerae bears only two teeth, while the outer margin armed with three teeth. Clypeus is vertical. Metatarsus IV is longer than tibia plus patella together.

(iii) Genus ***Hippasa*** differs from other genera of wolf spiders in the appearance of the spinnerets. The posterior spinnerets are longer than anterior spinnerets and apical piece of posterior is as long as the basal piece. Carapace is longer than wide with cephalic part pale, with submarginal bands and dark streaks radiating near fovea. Anterior rows of eyes are wider than posterior row. Abdomen is elongated and oval with dorsal markings. They usually build sheet like webs with funnel retreat over which they run like members of family Agelenidae. They commonly occur in slopes of sandy river bank.

(iv) ***Pardosa*** is one of the largest wolf spider genera and scattered worldwide. They commonly found on the soil surface as well as on plants. *Pardosa* are smaller members of the family and are creamy brown to black. Some species of *Pardosa* are semi aquatic and are frequently encountered on the banks or stony beds of rivers and ponds and run with great agility on the surface of the water. Carapace is longer than wide, high and narrow, convex in the eye area, and clothed with pubescence. Usually procurved anterior eye row is distinctly shorter than posterior median eye row. Legs are moderately long, slender, pale or dark. Abdomen is oval, greyish or brown and mottled, cardiac mark at edge with white colour, and this mark is usually followed towards the rear by dark chevrons.

(v) Members of ***Lycosa*** are known as burrowing wolf spiders, living in silk lined burrows. The spiders dig an open, vertical burrow, usually in well compacted soil, often near rocky outcrops. They are often more common in disturbed areas such as along the forest clearings and forest fire sites where they may colonize the sites where the soil is looser as a result of recent disturbance. The burrow of this species is unlike that of many wolf spiders, in that it does not possess a silken/earth lid nor is there any evidence of a mound or elevated rim of soil, sticks or pebbles, around the entrance of the burrow. The spiders prefer to build their burrows in open areas that are not covered with leaf litter, twigs and other debris and do not appear to shelter the burrow entrance under rocks, herbage or logs, as do many other wolf spiders Their chelicerae are red and are displayed when they are threatened.

(vi) Genus ***Trochosa*** are moderately large lycosids, common in small hollows under stones or in the small cracks and cervices in bunds or levees in the field. The female constructs an almost spherical to spherical egg-sac. The egg-sac is well guarded by the female and is carried around attached to the end of the abdomen. The egg-sac contains non-glutinous, spherical eggs. After hatching, the young spiderlings are carried on the female abdomen until they moult and grow larger. The mature spiders feed on a wide variety of ground-dwelling insects such as small beetles and cockroaches and other spiders. Body is usually pale in colour. Median band of carapace is distinct, anterior part with a pair of longitudinal dark marks. Anterior eye row is straight or slightly recurved and as long as or shorter than posterior median eyes. Males are easily distinguished by the presence of palpal claw, sickle shaped terminal apophysis. Cymbium of pedipalp is with thick terminal setae.

Family Miturgidae (Dark sac spiders)

The Miturgidae represented by 25 genera and about 337 species worldwide. 3 genera are reported so far from India which includes 31 species (Sebastian and Peter, 2009). They are generally dark greyish brown to brown in general coloration with the abdomen often having black, white and/or grey marks on the dorsal surface. Their form and colour pattern resembles that of some of the wolf spiders, so much so, that they are often mistaken for the Lycosidae. They construct a broad, tubular retreat, which may measure up to 10 cm in diameter, near the ground in or under fallen logs, under and amongst stones and in low herbaceous plants such as herbs and grasses. Cephalothorax is longer than wide. Eight eyes are present in two rows. Legs are with two claws and claw tufts or with three claws. Abdomen is oval with markings, bands, chevrons and spots. One genus, *Cheiracanthium* was sampled from the study area.

(i) The genus ***Cheiracanthium*** was previously placed in the family Clubionidae and is very similar appearance and habitat to Clubionia. *Cheiracanthium* are small spiders measuring about 5-10 mm long and have body shape like silk sac retreats, hence commonly known as sac spider. They are mostly nocturnal, secretive and hide during the day in a silken retreat usually placed on the underside of leaves of broadleaved plants or in curled dead or living trees. Eyes are usually smaller, relative to distance between them. Posterior row of eyes are scarcely longer than anterior row of eyes. Legs relatively longer and slender, first leg longer than fourth.

Family Oonopidae (Dwarf six-eyed spiders)

The Oonopidae, represented by 75 genera and about 512 species, are widely distributed in the tropics (Platnick, 2008). 4 genera occur in India which includes 15 species (Sebastian and Peter, 2009). Oonopids are nocturnal, ground-dwelling hunters that active pursue their prey. They occur in a variety of habitats such as forested areas, bird's and termite nests and the webs of other spiders. During the day they hide under stones and plant debris, humus and leaf litter. Some oonopids are found in association with dry material, for example hay sheds. They are short legged and have six tiny closely grouped eyes. Chelicerata is present without teeth. Legs are without scopulae, while tibiae and tarsi is usually with series of paired spines. Oonopids either have soft abdomens (subfamily: Oonopinae) covered in fine, pale hairs or abdomens that are covered with a hard shield or scutum (subfamiliy: Gamasomorphinae).

(i) The three species of oonopids belong to genus *Gamasomorpha** were found in the study area*.* Species from the genus ***Gamasomorpha*** are usually small armoured oonopids with two chitinous scutes or shields covering the dorsal and ventral sides of the abdomen. The eyes are all light in colour and arranged in a compact group. Oonopids were found in all habitat types except riparian habitat.

Family Oxyopidae (Lynx spiders)

Oxyopids are a family comprised of 65 genera, four of which are known to India (Sebastian and Peter, 2009). Oxyopids are mainly plant dwelling spiders commonly found on grass, shrubs and trees. They are also known as lynx spiders because of their incredible agility and speed when moving from place to place, a behaviour pattern reminiscent of that of certain big cats. They are mostly small spiders measuring from about 5-8 mm body length. They have long, narrow legs which bear conspicuous spines situated at right angles (or nearly so) to the leg segments. Their spiky appearance makes them readily recognizable as a member of this family. They build no web-snare but are active hunters, frequenting grass, small shrubs and bushes, and other low vegetation (they are rarely found on the bare ground), where they use their very acute eyesight and jumping ability to capture prey and to avoid predators. Their eyes are characteristically arranged in a pattern of four rows of two eyes each. Oxyopids hunt both by day and night and have good vision which enables them to quickly detect prey. They actively search for prey on plants by leaping from leaf to leaf. Prey is caught with the legs, and often by jumping a few centimetres or more into the air to seize a passing insect or by executing small jumps in pursuit of prey flying over plants. Oxyopids feed on moths of the families Noctuididae, Geometridae and Pyralidae. Oxyopids are generally recognised by having long spines that stand out at a 90° angle to the leg surface. They also have a high angular carapace that is flattened in the front with a wide clypeus and a distinctive hexagonal eye pattern. The abdomen tapers to a point. Lynx spiders are easily recognized because of the sharp (usually black) spines on the legs, which presumably assist the spider in scrambling from leaf to leaf. One genera of Oxyopidae sampled from the study area was *Oxyopes*.

(i) Genus ***Oxyopes*** are often encountered on various grasses, weeds and other low-growing native plants. They build no web but are active solitary hunters during the day. They are usually inactive at night, hanging from a dragline attached to the underside of a leaf. They vary in colour from yellow-green to dull brown. Females produce a small, white, oval-shaped cocoon containing 30-45 eggs, usually amongst grass stalks or under a broad, curled leaf. The non-glutinous eggs are pale cream in colour and measure 0.6-0.7 mm in diameter. Adult spiders feed on small lace-bugs, moths, small soft-bodied flies and occasionally beetles. This genus is characterized by the strongly procurved posterior eyes row, equidistant from each other. Cephalothorax is high and rounded with anterior part vertical; abdomen long thin, rounded and widest at the front and then tapering all way to spinnerets. Face is almost vertical. Ocular quadrangle is longer than wide. A thin black straight line starts from each of the anterior medians down the vertical face and continues down the centre of the chelicerata to the tip. Abdomen elongate, widest behind base and tapering to the spinnerets.

Family Philodromidae (Small wandering crab spiders)

The Philodromidae are represented by 27 genera, seven of which occur in the India (Sebastian and Peter, 2009). Philodromids are free-living hunters commonly found on plants. Their movements are erratic and using their claw tufts and scopulae they are able to move around swiftly. In general philodromids have slightly dorsal-ventrally flattened bodies with slender, laterigrade legs and claw tufts are present. Most species have an elongated to oval abdomen, often with chevron type markings. There are teeth on the promargin of the chelicerae and the eyes are positioned in two recurved rows. Only one genus was found in sampled sites of TCA. Most of the Philodromids were sampled from the grasslands adjacent to marshes and swamps.

(i) ***Philodromus*** spp. occur on tree trunks, in low bushes and herbs. They are grey to brownish-yellow in colour and move about rapidly on plants, usually capturing prey by lying in ambush with legs extended. Eyes are small and uniform in size; anterior row slightly recurved, posterior row strongly recurved. Abdomen usually oval, angulated laterally, moderately flat, and dorsally bears heart shaped markings and chevrons.

Family Pholcidae (Daddy-long-leg spiders)

The Pholcids are a fairly large family comprising 85 genera and about 1000 species worldwide (Platnick, 2008). The Indian mainland has 6 genera and 9 species (Sebastian and Peter, 2009). They live in tangled space webs consisting of different configurations. Some are irregular with long threads criss-crossing in an irregular fashion, or the centre of the web consists of a large, more compactly woven sheet, with a network of irregular threads above and below. Pholcids characteristically vibrate the web rapidly when disturbed. The female carries the egg sac with her chelicerae. Several species are widely distributed and are commonly found in human habitations. These spiders are delicate with very thin long legs. They are commonly called Daddy-long Legs Spiders because of their legs. They are mainly secretive spiders and live in dark sheltered places. They usually have eight eyes, although this number is reduced to six in some species and in some cave-dwelling species, the eyes may be prominently reduced in size or are absent altogether. When disturbed, they usually undergo unusual defence behaviour; they begin to rotate and gyrate their bodies round and round, usually describing circles from right to left; they move so rapidly that their bodies often appear as a blur. Pholcids construct delicate webs in discarded boxes, under houses and verandahs and in other sheltered positions; in their native habitats they are frequent in caves and hollow tree-trunks. When resting in the web, they invariably hang body downwards or occasionally they may be detected resting in a vertical position, in which case, the head is positioned downwards. Unlike most spiders, the females of this family do not produce egg-sacs. Instead, the female wraps a loose covering of a small number of silken threads around the egg cluster which is held in position in the spider's chelicerae and is carried around until the eggs hatch. The two genera sampled in the study area were *Crossopriza* and *Smeringopus*. Pholcids were found mostly in pure sal and mixed sal habitat types.

(i) ***Crossopriza*** have an oblong abdomen, truncated posteriorly. The eye pattern is distinct; eight eyes in two recurved rows. Legs are very long, thin, and spotted with black streak. The spiders occur in caves and in hollow logs and trees. During the winter, the spiders rest, tightly pressed and motionless, against the underside of wood or other material in their hideouts. With the onslaught of warmer weather, they become active and build their snare webs which consist of a tangle of irregular, soft, silken threads. Sometimes these webs may be represented by a tangled sheet of up to about 30 cm in diameter. The spider always remains in the centre of the web, where it is suspended upside down and from where it captures moving prey nearby.

(ii) ***Smeringopus*** spp. have a cylindrical abdomen with a chevron pattern. The eye pattern of *Smeringopus* is distinct. There are two sets each of three contiguous eyes, on either side of the carapace, raised on slight tubercles, with two smaller anterior median eyes in the centre front of the carapace. This spider builds space web without sticky threads in abandoned deadwoods and rocky outcrops. Prey landing on the silk threads or moving below the web is caught with extended front legs, lifted to the chelicerata and bitten while the third and fourth pair of legs cast silk over it.

Family Pisauridae (Nursery-web and fishing spiders)

The Pisauridae are a fairly large family and 9 of the 53 genera occur in India (Sebastian and Peter, 2009). Pisaurids have diverse life-styles, some live in webs and others are free-living hunters. They have slender bodies and long legs. The elongated abdomen shows symmetrical patterns of black on brown to grey background. The long legs have numerous spines. There are three claws on each tarsus and colulus is present. Pisaurid females carry their eggs in their chelicerae. Just before the young emerge, the female constructs a framework of silk; know as a nursery web, in which the eggs are deposited. After emerging from the egg-sac the young remain in the nursery until dispersal commences. The two genera that were sampled from Terai were *Pisaura** and *Thalassius*. Pisaurids only found in grassland sites adjacent to swamps and lakes.

(i) ***Pisaura*** is lycosidae like genus, most species scattered in the Palaearctic, Ethiopian and Oriental regions. They live on leaves and make a small retreat. They are active hunters that pursue their prey in leaps and bounds across the substrate. They are commonly found in grasslands and open forests. Cephalothorax is longer than broad; dorso median band of carapace is usually divided by longitudinal white stripes. Anterior row of eyes are shorter and slightly recurved than posterior row of eyes. Posterior median eyes usually lager than anterior median eyes. Chelicerae are with three retro marginal and promarginal teeth each. Abdomen is longer than broad, and usually bears longitudinal pale bands. Body length is about 8.5 – 15 mm long.

(ii) Genus ***Thalassius*** is endemic in the Oriental and Ethiopian regions. They are fish eating spiders, and inhabit the fringes of freshwater pools. They can walk well on water as well as on land. The front legs are used in a sensory capacity much like the antennae of insects that are held in the air while the hind legs are dragged along. They hunt on the surface of the water, preying only on small fish, tadpoles, freshwater shrimps, insects and small toads. They dive into the water to grab their prey. They can be readily recognized from other pisaurids by the presence of strongly recurved anterior eyes, broad clypeus beyond ocular quadrangle and chelicerata with three retromarginal teeth.

Family Salticidae (Jumping spiders)

This is the largest spider family comprising more than 5000 species belongs to 563 genera worldwide (Platnick 2008). The Indian Mainland has a rich fauna that includes 192 species belongs to 62 genera (Sebastian and Peter, 2009). They are commonly called jumping spiders because most of the species are very active in warm weather, leaping from leaves, bark, twigs etc, to other resting or jumping posts in the search of prey or to escape from potential predators. Most of the species are brightly coloured while most bark-inhabiting species are dark in colour and mottled with clusters of brown, grey, white and/or black hairs. Salticids are diurnal, cursorial hunting spiders with well-developed vision. With their large eyes and complex retinas they have unique resolution abilities, unparalleled in animals of similar size. Generally males have ornate pedipalps and all have a squarish cephalothorax that is as large as or larger than the abdomen. The anterior median eyes are larger than the remaining eyes. Most salticids do not spin a capture web or use silk to catch prey. Silk is only used to build sac-like retreats in which to moult, oviposit and sometimes mate, or which they occupy during periods of inactivity. The retreats are small, made of densely woven silk and attached to various substrates. Salticids were widely distributed in the study area, occurring in all habitat types and all sites. The 7 genera sampled from the Reserve included *Marpissa, Myrmarachne*, Plexippus, Phintella, Portia, Rhene** and *Telamonia.*

(i) Members of genus ***Marpissa*** are small to medium-sized jumping spiders with relatively flat carapaces. Width of carapace is approximately two-thirds of carapace length. Eyes of anterior row are subcontiguous, with anterior medians twice the diameter or slightly less than twice the diameter of the anterior laterals. Eyes of median row are variable in position between anterior laterals and posterior eyes. First pair of legs is two to three times as heavy as remaining legs. Members of this genus are common in leaf mold and (drift as well as low herbaceous and shrub vegetation).

(ii) Genus ***Myrmarachne*** occurs throughout the tropics, and it is one of the most abundant among the salticids, comprising more than 200 species. They resemble ants, both in behaviour and morphology. The spiders do not prey on ants but the resemblance affords these spiders a measure of protection. These salticids have rather unique abilities, e.g. they are very efficient in catching moths and some eat the eggs of other spiders. They are ant like salticids with long and narrow cephalothorax. The pedicel connecting cephalothorax and abdomen is very conspicuous. Ocular quadrangle is nearly as long as broad. Chelicerae with several teeth in the retromargin, male chelicerae strongly developed. Abdomen is elongated, oval or spherical with a transverse depression in the male, dorsal scutum present in both sexes. Legs are slender with long segments.

(iii) Members of genus ***Phintella*** are small slender spiders (3-7 mm long) usually with dominantly pale grey brown body colour. The cephalothorax is quite high, with the cephalic region flat and the thorax sloping, slowly at first; and then steeply to the posterior margin. The sides are more or less vertical. The abdomen is oval and often with transverse light and dark streaks, or pale with grey indistinct linear patterns. The moderate spiny legs are long and slender and all of much the same size, with the front legs of the male marginally longer and stronger than the others. Metallic lustre in the cuticle and scale like setae present. They are often to be seen wandering about or sunning themselves on top of the leaves and sometimes to be found resting or in a cell under leaf. Salticids often build a retreat between and attached to two closely overlapping leaves. They rest during the day on the underside of the leaves in a silken retreat or may be observed resting on the leaf seeking insect prey. They are usually very wary and usually scurry into the shelter of leaf bases in the centre of the plant or move rapidly to the other side of the leaf if disturbed.

(iv) Genus ***Plexippus*** represents medium sized jumping spider group, less than 10 mm in length, widely represented in most zoogeographical regions of the world. Members of this genus have a high, moderately convex cephalothorax, with cephalic sides almost parallel and rounded in thoracic area. Height of the cephalothorax is less than one half of its length. The convex carapace truncated posteriorly, and then curves very gradually to just behind the front eyes where it briefly diverges. It is dark brown with the eye field black and a broad, white median band running from the posterior eyes (and sometimes from the front eyes) to the rear margin where it joins two equally wide, entire, submarginal bands. There is a narrow black marginal band. The abdomen is elongate oval with hunched shoulders anteriorly. It is dark brown in colour with a broad white median band, continuing the one on the carapace and almost reaching the spinnerets. The sides of the abdomen are white. At about a third of the way from the spinnerets there are two characteristic circular white spots adjacent to the white median band and two more near the spinnerets. They are also well adapted for living under bark and for moving between cracks and crevices in bark. They are rather rare but if encountered and disturbed, they usually become very active and scurry away to another crevice for protection.

(v) The ***Portia*** spp. belongs to the subfamily Spartaeinine and these spiders are renowned for their hunting skills. Prey may be caught outside the web during hunting raids, or in the web of the prey itself, which is stalked by means of aggressive mimicry when the salticid imitates the signal emitted by males of the prey. They generally prey on other spiders and have the ability to move over cribellate and ecribellate silk. The males of this genus are referred to as dandy because of its elaborate pedipalps and black hairs on its body and upper legs.

(vi) ***Rhene*** spp. is a quite a large, widespread genus of salticids. They are small beetle like jumping spiders clothed with conspicuous thick hairs. Body length is usually less than 7mm. They are often to be found spun up in retreats in the seed heads of plants. Typically the cephalothorax is fairly thick and flat on top. The carapace is broader than long and widest at the level of the rear eyes. The flat top is almost trapezoidal in shape, widest just behind the rear eyes and narrowest at the front row of eyes. The sides and most of the thorax are vertical, with the rear margin very wide and truncate. The abdomen is oval, slightly truncates at the front and slightly pointed at the rear. The legs are fairly sturdy with the femora, patellae and tibiae noticeably swollen. Leg I more robust and hirsute than leg II-IV.

(vii) ***Telamonia*** is moderately large and typically colourful salticid genera which occur in tropical forests. The genus is Oriental in its distribution. The cephalothorax is high, with the cephalus flat, the sides almost vertical and the thorax sloping steeply to the rear margin. The carapace is longer than wide, oval and moderately widely truncate at the rear. With the anterior lateral eyes just behind the medians, the pattern is more or less 2,2,2,2. The legs are long, slender and carry numerous thin spines. The colour patterns vary considerably between the sexes and between the species. Typically, the cephalic part of the carapace is usually coloured and there are usually two coloured longitudinal stripes running the length of the abdomen. The abdomen is long and tubular, rounded at the front and tapering gradually to a bluntish rear. The most distinguishing character separating it from other similar salticid genera is the presence of short, thick bristles on the lateral edges of the cymbium of the male pedipalp. Female epigynum is usually dome shaped with a pair of dark orifices separated by a pair of ducts medially. The spiders, especially the males, are often common during summer, hunting and dancing on leaves of shrubs during the day. They build a retreat of soft white silk amongst two or more leaves. The males are sometimes observed undergoing threat displays and are very agile in leaping from place to place.

Family Scytodidae (Spitting spiders)

Family Scytodidae is represented by a single genus, *Scytodes*, which includes 9 Indian species (Sebastian and Peter 2009). Scytodids are nocturnal, cursorial spiders that have a specialised way of catching prey. They are the only spiders known to possess prosomal glands that produce silk. These enormous, specialised glands consist of two parts: an anterior part that produces venom and a posterior part that synthesises gluey silk. Before being squirted, the fibres are packed in paracristaline form in the apical part of the glandular cells. Rapid contraction of the carapace muscles squirts a mixture of venom and gluey silk from the chelicerae up to a distance of 1- 2 cm. They prey is glued to the substrate and the contact with the venom results in paralysis. The carapace is domed in the thoracic region, sloping downwards towards the anterior aspect. They have six eyes arranged in three well-separated pairs. The colour of the different species varies from pale yellow to dark brown, with a series of dark symmetrical patterns on the dorsal side. The weak and basally fused chelicerata bear no boss, and the fang furrow bears hard lamella. The legs are long and slender without heavy spines. Only one genus, *Scytodes*, was found in the study area. Scytodids were not very abundant in the study area. They were mostly found in plantation habitat.

(i) Genus ***Scytodes*** is cosmopolitan in their distribution and usually found in the ground, usually in dry, sheltered situations amongst debris, dry leaves, and rocky outcrops. The female carries her brownish or purplish egg cocoons in her chelicerata held against sternum. Body length is about 5-7 mm. The cephalothorax is distinctive in being prominently arched towards the back and the abdomen, and slopes downwards to the chelicerae. Carapace lacks fovea or thoracic impressions, hump posteriorly, pale yellow with numerous black mottles forming irregular lines or patterns. The spider has six eyes, grouped in three pairs, two pairs of which are situated opposite to each other. The legs are very slender and spindly in relation to the rotund body and because of this unbalanced weight, the spider is unable to walk very fast; instead, it creeps along slowly in search of small prey such as soft-bodied flies, mosquitoes and silverfish. The abdomen is ovoid to sub globular and mottled like carapace.

Family Sparassidae (Huntsmen spiders)

The Sparassidae are a large family comprising 83 genera, 11 of which are known from India (Sebastian and Peter, 2009). Sparassids are free-living, nocturnal, wandering spiders with diverse lifestyles. They do not build webs, only silk retreats. Most of the species are large. Sparassid spiders have laterigrade legs like the unrelated Thomisidae and can run sideways as well as forwards. Their legs are often positioned outwards as well as forwards, and this feature allows them to move under loose bark, stones and in crevices in rocks with great ease to escape predation or to retreat after hunting. Most genera are covered with a fine pile of light straw-grey to brown hairs. The carapace is broader than it is long. The cypleus shows a white band (moustache) and the eye pattern is in two rows, with the anterior laterals often the largest. They have long robust legs, turned outwards in crab-like fashion. They are usually found on or under the bark of trees and amongst foliage. Some *Olios* species construct a silken retreat amongst dead leaves in trees. Two genera *Heteropoda* and *Olios* were sampled from the TCA. Sparassids were widely distributed in the study area except mixed sal and plantation habitat types.

(i) Hunting spiders of genus ***Heteopoda*** are usually with powerful mandibles and strongly spined legs, the tarsi having ungual tufts and only two claws. The genus *Heteropoda* has the cephalothorax squarish, generally raised behind; eyes of posterior line recurved, the lateral eyes larger and prominent, anterior eyes straight or procurved with their laterals larger than the medians; maxillae not crested; vulva consisting of two lobes (usually separated by a skeletal place, the sclerite) and not marked with circular pits. Mature spider feeds on a wide variety of insects (and other spiders) including moths, flies and other insect pests. Apart from occurring under stones and bark, and under slabs of stones on exposed rocky outcrops in natural habitats, these spiders have also been recorded living under pieces of corrugated iron, and amongst discarded wooden boxes and chopped firewood.

(ii) ***Olios***, are pale-brownish to grey-brown spiders which are easily identified by the colourful markings on the underside of the abdomen. Carapace of *Olios* is distinctly high and convex. Anterior row of eyes are straight, anterior medians largest, and larger than laterals and posterior of row of eyes slightly recurved. Second leg is usually longer than first. They build an oval retreat in the form of a finely webbed sac firmly attached to the underside of a stone or between two or three leaves fastened together with silk. They usually rest during the day under the bark of trees, or in fallen logs and in hollow, rotten tree-trunks. The mature spiders feed on a variety of insects such as moths, beetles and other bark dwelling insects and other spiders.

Family Tetrablemmidae

The armoured spiders of the family Tetrablemmidae make up a little- known group of animals distributed throughout the world tropics**.** Family Tetrablemmidae comprising of 30 genera, of which 4 are known from India (Sebastian and Peter, 2009). They are very small three clawed spiders, with eyes six in number. Though, few species are eyeless. Most tetrablemmids live in litter, bark or mosses in the forest. Some species construct web on the surface of dry leaves. Although these spiders seem to be very common in the soil litter, they are still poorly represented in zoological collections, probably due to the rare use of soil sampling techniques to collect arachnids.

(i) One genus ***Tetrablemma*** was collected during the entire sampling period. Carapace of *Tetrbalemma* males is strongly elevated, forming a conical shape. Only two single species of tetrablemmids found in grassland and riparian habitat respectively.

Family Tetragnathidae (Long -jawed spiders)

The Tetragnathidae are represented by 48 genera in several subfamilies (Platnick, 2008). The Indian mainland has 10 genera and 47 species (Sebastian and Peter, 2009). Members of the family Tetragnathidae are a rather diverse group of orb weavers of small to large size. These spiders are commonly known as the Long-jawed Spiders, because members of this group are easily recognized by the very long, dark-coloured chelicerae which prominently project from the front of the cephalothorax, and which together with the two long palps, give the appearance of the spiders having four “jaws”. Tetragnathids construct orb-webs and the behaviour and construction of these orb-webs varies between subfamilies. Five genera were found in TCA, *Leucauge** (sliver marsh spiders), *Meta*, Nephila* (golden orb spiders), *Tetragnatha* and *Tylorida *.* Tetragnathids were found in all habitat types except plantation habitat.

(i) ***Leucauge*** spp. has a remarkable silvery abdomen with a pattern of red, green and gold markings. Members of the genus *Leucauge* are builders of large webs in low shrubs, hedges, in damp places such as marshes or swamps, and similar habitats. Webs are often horizontal or nearly so, and have a great number of radii and spirals. There may be a barrier of irregular threads below the orb. Males and females differ little in size, and the legs of males exhibit no sexual modifications. The common body colouring is silvery. Carapace broad posteriorly, somewhat narrowed at sides anteriorly; Eyes subequal in size and posterior row of eyes straight or somewhat procurved. Chelicerae are stout and somewhat swollen on anterior surface. Legs I and II are long and slender, femora IV with double fringe of hairs or trichobothria. Abdomen is silvery, twice as long as wide, anterodoraslly with zero or more pairs of tuberceles.

(ii) Representatives of the genus ***Meta*** are dusky inhabitants of cool dark places such as caves, cellars, and moist stone piles in dense forests. The web is vertical or nearly so, and the spider rests at the hub. Egg sacs are suspended on a thread near the web. Males and females are approximately the same size, and the males possess no sexual modifications on the legs. Carapace is brownish, paler anteriorly, shiny, smooth, narrowed anteriorly at level of leg I. Eyes are approximately equal in size and posterior row somewhat procurved. Abdomen commonly with paired series of large dark spots on brownish background, broadly elliptical, plump, approximately as high as long. Their tendency toward living in moist dark habitats is also unusual among orb weavers.

(iii) The ***Nephila*** (Golden Orb Weavers) is large and impressive. *Nephila* are large (at least the female is) tropical spiders commonly known as Golden Orb Weavers because of their large webs built of strong golden silk. The web is usually supported between two trees and can span enormous spaces, metres wide, about 1.5 metres or more from the ground. The female is almost entirely black and the first, second and fourth pairs of legs have a brush of bristles on the tibia. Cephalothorax is with convex cephalic region more elevated than thoracic area and armed usually with a pair of tuberceles posteriorly. Median ocular quadrangle is squarish to slightly broader posteriorly. Legs are very long and strongly spinulose. Combined length of tarsi and metatarsi is longer than tibiae and patellae together. The abdomen is elongated (long oval) and is yellow with the posterior end black or blue with yellow speckles infusing forward into the yellow. Kleptoparasites like the dewdrop spiders of the genus *Argyrodes* (family Theridiidae) often inhabit the webs of *Nephila's* and they steal prey from the orb-webs of their hosts.

(iv) Members of the genus ***Tetragnatha*** are moderately large inhabitants of trees, shrubs, and tall grass in meadows or along the margins of lakes and streams. Some build their webs over running water, where emerging aquatic insects are the main prey. Some of these spiders may stand at the hub of their webs by day as well as night; others may be crepuscular. Some may also be found closely appressed to a grass stem near the web, extending legs I and II forward along the stem and III and IV backward in the same way, thus achieving a degree of camouflage. The webs are usually inclined from the vertical, sometimes horizontal, and may be 30 cm or more in diameter. The hub is usually open, and there is a well-defined free zone and narrow attachment zone. Body is prominently long and narrow, several times longer than wide. Carapace is oval, widest near the middle, flattened above, with conspicuous thoracic groove. Eyes are small, ringed with black pigment; lateral eyes on each side usually distinctly separated,

(v) Spiders of genus ***Tylorida***, mostly preferring moister places along damp ravines and overhanging stream banks. They build web, is vertical or nearly so, and has a small central spiral with the hub open. Though, web varies in orientation, even within species, from nearly vertical to nearly horizontal. When hunting, the spider often wraps its prey, hangs it in the web, and returns for an interval of time to the hub before feeding. Carapace is yellowish brown with grey markings, sometimes pitted, rather low, widest at mid length and gently narrowed anteriorly and posteriorly. Eyes are subequal in size; lateral eyes on each side touching; posterior row of eyes approximately straight. They posses very long leg I, and have single row of straight trichobothria on each of the legs I-IV. Abdomen is high and roughly forms right angle triangle in shape.

Family Theraphosidae (Bird-eating spiders)

The Theraphosidae are a large family that comprise 116 genera and about 920 species. Though there are only 10 genera reported from India (Sebastian and Peter, 2009). This is a small family of usually very large and hairy spiders. They are commonly called Bird-eating spiders because they have been known to kill and eat small birds. Other small vertebrates such as lizards and frogs are also preyed upon. Theraphosids, with heavy legs retain the basal diameter throughout the length of the leg. They have large, hairy pedipalps that look like another pair of legs. They are similar to barychelids but have a distinct lobe on the anterior aspect of the maxillae. They have a wide clypeus and their eight eyes are arranged on an ocular protuberance on the front portion of the carapace, behind the clypeus. Bird-eating spiders do not construct web but instead, they live in deep, sinuous burrows that may measure over half a metre deep. Unlike other spiders which live in holes in the ground (e.g. trap-door spiders), they do not construct a lid of silk at the entrance of their burrows. Their burrows concealed under rocks, and beneath roots of trees and fallen logs, and may also have a sheet-web surrounding the entrance.

(i) One genus, *Selenocosmia* was found in the study area. These spiders of genus ***Selenocosmia*** are nocturnal in habits and during the day they hide in a deep, sinuous burrow which measures up to 60 cm deep; a silk sheet is constructed around the entrance to capture inspects and ground-dwelling vertebrates. *Selenocosmia* are large spiders with dense, long hairs on the legs and tarsi and have stridulatory organs on the chelicerae. These consist of a cluster of short, hard spines on the anterior margins of the maxillae and a series of short hairs on the outer portion of the chelicerae. They are rapidly rubbed together to produce sound. Theraphosids were confined to river banks of all habitats sampled.

Family Theridiidae (Comb-footed spiders)

Theridiids are one of the larger spider families represented by 109 genera with over 2293 species so far described (Plantnick, 2008). The Indian Mainland represents 19 genera (Sebastian and Peter, 2009). They are small to medium sized spiders with a globular abdomen and long legs of which the third pair is the shortest. Theridiids have diverse life-styles. Most genera construct three dimensional, untidy-looking space-webs of different shapes. Some webs enable the spider to catch flying insects and consist of criss-cross threads or sheet platforms with viscid threads on the outside, while in other webs the viscid threads are lightly attached to the substrate. Some theridiids build special retreats inside or outside the frame and use plant material or soil particles to camouflage the web. Other theridiids construct regular webs or the webs can be reduced or absent. The members of this family are commonly called Comb-footed Spiders because of their “comb”, a series of serrated spines along the outside margin of the tarsi of the last (fourth) pair of legs. This comb is used to comb out the silk from the spinnerets. Theridiids wrap their prey in viscid silk using combs on tarsi IV. This technique is unique to this group. Several species of theridiids were found in the study area. Genera that were sampled included: *Achaearanea*, Argyrodes*, Chrysso** and *Theridion*.* The Theridiids had a very wide distribution in the study, while mostly occuring plantation habitat.

(i) Members of genus ***Achaearanea*** spin irregular network of fine threads built commonly in hidden habitat. Webs are also placed amongst rocks and rarely amongst foliage. The spider usually rests upside down in a sheltered part of the web where it is more closely woven but is not dense enough to conceal the spider. Occasionally, a mature spider may construct a web in an open, unsheltered situation. In this instance, the spider will often carry a piece of leaf or some other debris into the web which will act as a retreat for the spider. Mature spiders feed on a wide variety of insects, such as grass-hoppers, flies, beetles and moths. They have characteristically balloon shaped abdomen almost vertical and spinnerets at bottom. Anterior row of eyes procurved and posterior row slightly recurved or straight and square shaped median ocular area.

(ii) Genus ***Argyrodes*** (dew drop spider) represents the largest member in the family Theridiidae, with approximately more than 200 species described worldwide. Members of *Argyrodes* commonly known as the Quicksilver or Dewdrop Spider because of its bright silver coloration on the abdomen. They are kleptoparasites, live in the webs of larger spiders where they share the prey which is captured within their host’s snare. They usually rest on the outskirts of their host webs but they do not appear to be disturbed by their hosts and often feed on prey close by to the host. Cephalothorax is flat and rather low posteriorly in thoracic region. Chelicerae bear two or three promarginal teeth and one or two in retro margin, or row of small or equal sized denticles. General colouration of abdomen is uneven, usually silvery or with silvery patches. Abdomen bears tuberceles, extended sub triangular to very long. Dimorphisms of secondary sexual characters are pronounced in *Argyrodes*. Males are usually larger than females and have larger legs. Eye position and size also differs from females.

(iii) Genus ***Chrysso*** consist of small to medium sized spiders (1-5 mm) comb footed spiders. They are common in low vegetation and grasses and construct irregular webs in the lower side of leaves, very close to ground. Members of this genus are distinguished from other allied genera by following characters; longer than wide cephalothorax, anterior row of eyes slightly procurved, posterior rows of eyes straight or slightly recurved or procurved. Eyes sub equal in size or anterior median eyes slightly larger or smaller than the rest. Tarsal IV bears a tarsal comb. Cheliceral length is almost as long as clypeus height. Abdomen is longer than wide or tall extends beyond spinnerets. Male pedipalp bears a distinct radix, with curved embolus base.

(iv) ***Theridion*** (false button spiders) is the largest theridiid genus and distributed worldwide. They are smaller than true button spiders, often with a shiny, globular abdomen, and occur in a wide variety of habitats. They are found in bushes, on tree trunks, in the crevices in rocks and walls and frequently also in houses. These spiders build irregular tangles of silk as a snare, usually amongst foliage of living trees and bushes. Some of the strands of silk which hang vertically downwards from the tangled mass of silken fibres may have a sticky drop of fluid at the ends. When a small insect brushes onto the viscid droplet, the strand rapidly curls upwards entangling the prey with the droplet and silk. They possess longer than wide carapace without stridulating structures. Row of anterior eye is straight or procurved as viewed frontally, while posterior eye row is straight as seen dorsally. Enlarged chelicerae are present in males. They are long legged spiders, patella I and tibia I at least 1.5 times as long as cephalothorax. Abdomen usually spherical, longer than high, sometimes wider than long, sub triangular without plate or tuberceles. Male pedipalp is with distinct median apophysis, conductor and radix, though vary in positions.

Family Thomisidae (Crab spiders)

Thomisids are represented by 173 genera and about 2085 species in seven subfamilies (Platnick, 2008). 164 species belongs to thirty eight genera was recorded from India (Sebastian and Peter, 2009). Most thomisid spiders are characterized by having legs (the first two pairs of which possess ventrally paired spines), which are able to move forwards or sideways (i.e. laterigrade), in a manner similar to that of crabs; hence the popular vernacular name of Crab Spider for the group. They have also been called Aerial or Gossamer spiders on account of their remarkable ability of transporting themselves from place to place by a silken thread which is blown with the wind and attaches and carries the spider to other supports and retreats. Many species of Thomisidae frequent the ends of branches and flowers of low to high-growing trees or shrubs, while other species live under or on the bark of mature trees. Many species form connections between objects, such as twigs and leaves, which are widely separated from each other by long, single threads of silk, while other species conceal themselves amongst herbage, or in the corners of rough bark, rocks or walls. Thomisid spiders do not construct a web, but in order to capture their prey, they rely on concealment, attractive coloration or resemblance (mimicry) to their prey. This adaptive evolution has resulted in a myriad of forms and colours amongst the Thomisidae. A majority of the light-coloured species await in ambush at the centre of flowers, below petals and whole inflorescences, tips of leaves etc., with their anterior legs extended typically sideways and forwards to form half a circle. The eyes of Crab Spiders are arranged in two rows of four, sometimes raised on a tubercle either singly or together as a group. Their anterior eyes are usually larger than the posterior ones. Another remarkable characteristic of Crab Spiders is their ability to move the anterior median eyes in opposite directions at the same time. Male thomisids are usually much smaller than the females and are seldom encountered in the field. The females of most species construct a small, whitish egg-sac on a curved or doubled over, broad leaf or blade of grass, sealed with a thick covering of silk around the margins. The thomisids were abundant in this study and 5 genera were collected. Genera included *Diaea , Misumena, Ozyptila*, Runcinia*, and *Thomisus**. Thomisids display an interesting range of adaptations to their habitats.

(i) Most ***Diaea*** **s**pecies are small spiders (i.e. less than 1 mm in total length) and they have a distinctive oval to circular, somewhat flattened abdomen, sometimes broader and sharply pointed towards the posterior extremity. Their bodies are usually white, yellow or green, while their abdomens are smooth and coloured white, yellow, pink, orange and are often adorned with spots, marks or lines of red, orange and/or brown.

(ii) Spiders of genus ***Misumena*** generally are small to medium-sized thomisids, 3.00-10.00 mm long, scattered throughout the world. They are found in flowers and low plants or bushes. Carapace of these spiders is armed with very short fine spines. Eyes of anterior row are equidistant and in more or less recurved line. Lateral eyes situated on slightly elevated confluent tubercles.

(iii) ***Ozyptila*** spp. are often encountered on the ground under dry leaves. As these spiders are small, of a dull brown colour with indistinct marks and as they live on the ground they are easily overlooked. Cephalothorax is slightly elevated. Anterior and posterior rows of eyes procurved, posterior row longer, laterals larger than medians and on separate tubercles, the anterior being the larger. Ocular quadrangle is higher than wide, usually with parallel sides, but occasionally wider in front. Legs are short and stout, I and II longest, tibia and metatarsus with spines beneath. Abdomen is depressed, broad at base and rounded behind.

(iv) Members of the genus ***Runcinia***, often occur commonly on the brown seed heads of grasses and sedges where their colour pattern provides them with adequate camouflage against predation. The egg sacs are hidden amongst the seeding heads of the grasses. The spiders feed mostly on small moths which also live amongst the grasses. The genus *Runcinia* is well distinguished from the other thomisids by the flat, nearly as long as wide carapace lined with short hairs and head with short setae. Eyes are set in two rows, both rows recurved, posterior row wider than anterior row, anterior lateral eyes larger than anterior media eyes and ocular quadrangle longer than wide. Abdomen obliquely truncated at the front from the side, and more or less converging at thorax, terminating abruptly at the rear and just covering the spinnerets.

(v) ***Thomisus*** spp. is a paleotropical genus of medium- to large sized thomisids compromising approximately 80 species. They commonly occur on white flowers and amongst leaves of various native plants where they wait in ambush for flies, beetles, bees and other diurnal flying insects; it has also been recorded feeding on other spiders. Some species of *Thomisus* have the ability to change their colour to conform to their background. Thomisids are very common on plants and play an important role in the natural control of pests. Members of this genus are sexually dimorphic, with male darker than female. Cephalothorax is almost as long as wide without setae; head with laterally projected large horn like protuberances between lateral eyes. Eyes are small, subeqal in size, and poorly developed. Anterior lateral eyes are largest. Abdomen is wider than long, very pronounced in female and more sclerotized in male.

Family Uloboridae (Lace orb-web spiders)

The Uloboridae are cosmopolitan in their distribution, attaining great diversities in tropical and subtropical regions. The family comprises 19 genera in four subfamilies. 22 species belongs to five of the genera occur in India (Sebastian and Peter, 2009). Uloborids characteristically spin orb-webs of cribellate silk, ranging from a section of an orb to a single line. Lacking venom glands, these spiders first thoroughly wrap their prey and then kill it by grasping it with their palpal claws and pouring digestive juices over it. The chelicerae are little used in feeding, and their usual function of piercing and kneeding the prey is replaced by a greater use in wrapping silk. This thick wrapping of silk by which the spider enmeshes its captures may also be digested as feeding progresses. There is a large diversity of web types in this group of spiders, although the group itself is rather small in species numbers. The uloborids were found in all habitat types except plantation habitat. Two genera, ***Miagrammopes*** and ***Uloborus****, were sampled from the area.

(i) ***Miagrammopes*** (single-line web spiders) is moderately a small genus. The diagnostic characters are the prominently longer than wide cephalothorax and elongated abdomen. The eyes are arranged in two rows. The anterior eye row is reduced while the posterior eye row is recurved and widely spaced on the carapace. Cribellum and Calamistrum is present. Tarsi shorter than metatarsi and tarsus IV bears ventral row of macrosetae. They build webs of one or more sticky threads connected to a non sticky resting thread.

(ii) ***Uloborus*** (lace orb-web spiders) are characterised by its long front legs, rather humped abdomen and almost horizontal orb-web. It has a brush of coarse hairs on the tibiae of the first leg and hence its common name “feather-legged spider”. Members of the genus *Uloborus* build fully developed orb webs having a sticky spiral. The web is usually horizontal. They build webs in low bushes, between objects near the ground and are frequently found in and around buildings.

Family Zodariidae (armoured spiders)

The Zodariidae are a family represented by 74 genera, twenty of which, represented by 7 genera, are known to India (Sebastian and Peter, 2009). Zodariids have been regarded as relatively rare spiders. This is probably due to the fact that the ground fauna of tropical and subtropical regions has been studied very superficially. Zodariids are characteristic of semi-arid habitats in India where they are active nocturnal hunters. Some species of zodariids specialise in ants and termites as prey. They are eight-eyed hunting spiders very diverse in general appearance. Their eyes may be arranged in the traditional two rows of four eyes, or in three rows, consisting of 2, 2 and 4 eyes. In some genera the epidermis of the carapace is thick and looks like armour. The legs are usually similar in length and thickness. The anterior spinnerets are usually the longest and are situated close together. Zodariids were found predominantly in grasslands in habitat of all sites sampled.

They are usually small, terrestrial spiders; they live under stones, rotten logs and amongst litter. Some species live in burrows in the ground and construct a palisade of twigs or debris around the entrance of the burrow. They do not construct any web to catch prey and are best described as vagrant hunters.

(i) Members of ***Lutica*** make a silken retreat just under the surface of sandy dunes and ambush prey from within it. Only one genus was found in TCA was *Lutica.* *Lutica* is diurnal and are specialist ant eaters. They live in ant colonies where they have easy access to their prey. They do not dig burrows but use silk and sand grains to build small retreats which resemble inverted igloos on the underside of stones.

Table 3.1 Species and morphospecies of spiders captured during entire field work. Known distribution according to Siliwal et al., 2005.

Family	**Species**	**Author**	**Distribution**
Agelenidae.	*Agelena gautami*	Tikader, 1962	Endemic to India
	Agelena inda	Simon, 1897	Endemic to India
Araneidae	*Arachnura melanura*	Simon, 1867	India to Japan and Sulawesi
	Araneus bilunifer	Pocock, 1900	Endemic to India
	Araneus sp. nov.1		
	Argiope anasuja	Thorell, 1887	Endemic to South Asia
	Argiope pulchella	Thorell, 1881	India to China and Java
	Cyclosa confraga	(Thorell, 1892)	India, Bangladesh to Malaysia
	Cyclosa mulmeinensis	(Thorell, 1887)	Africa to Japan, Philippines
	Cyclosa simoni	Tikader, 1982	Endemic to India
	Cyclosa sp. nov.1		
	Cyrtophora bidenta	Tikader, 1970	Endemic to India
	Cyrtophora cicatrosa	(Stoliczka, 1869)	India, Pakistan to New Guinea
	Cyrtophora citricola	(Forskål, 1775)	Old World, Hispaniola, Colombia
	Cyrtophora feai	(Thorell, 1887)	India to Myanmar
	Cyrtophora ksudra	Sherriffs, 1928	Endemic to India
	Cyrtophora moluccensis	(Doleschall, 1857)	India to Japan, Australia
	Eriovixia excelsa	(Simon, 1889)	India, Pakistan, Philippines, Indonesia, Taiwan
	Eriovixia laglaizei	(Simon, 1877)	India, China to Philippines, New Guinea
	Gasteracantha dalyi	Pocock, 1900	Endemic to South Asia
	Gasteracantha geminata	(Fabricius, 1798)	India, Srilanka
	Gasteracantha hasselti	C.L. Koch, 1837	India, China to Moluccas
	Gea corbetti	Tikader, 1982	India, Bangladesh to Philippines, New Guinea
	Gea subarmata	Thorell, 1890	India, Bangladesh to Philippines, New Guinea

Family	**Species**	**Author**	**Distribution**
	Larinia chloris	(Audouin, 1826)	India, Middle East to Mozambique
	Larinia sp. nov.1		
	Neoscona biswasi	Bhandari & Gajbe, 2001	Endemic to India
	Neoscona mukerjei	Tikader, 1980	Endemic to India
	Neoscona odites	(Simon, 1906)	Endemic to India
	Neoscona theisi	(Walckenaer, 1842)	India, China to Pacific Island
	Neoscona vigilans	(Blackwall, 1865)	Africa to Philippines, New Guinea
	Parawixia dehaanii	(Doleschall, 1859)	India to Philippines, New Guinea
	Parawixia sp. nov. 1		
	Poltys illepidus	C. L. Koch, 1843	India to Philippines, Australia
	Zygiella indica	Tikader & Bal, 1980	Endemic to India
	Zygiella sp. nov.1		
Barychelide	*Sason robustum*	(O. P.-Cambridge, 1883)	India, Srilanka, Seychelles
	Sasonichus sullivani	Pocock, 1900	Endemic to India
Clubionidae	*Clubiona boxaensis*	Biswas & Biswas, 1992	Endemic to India
	Clubiona deletrix	O. P.-Cambridge, 1885	India, China, Taiwan, Japan
	Clubiona filicata	O. P.-Cambridge, 1874	India, Bangladesh, China
	Clubiona sp. nov.1		
Corinnidae	*Oedignatha indica*	Reddy & Patel, 1993	Endemic to India
	Trachelas himalayensis	Biswas, 1993	Endemic to India
Desidae	*Desis inermis*	Gravely, 1927	Endemic to India
Dictynidae	*Dictyna albida*	O. P.-Cambridge, 1885	India, China

Family	**Species**	**Author**	**Distribution**
	Dictyna turbida	Simon, 1905	India, Sri Lanka
Dipluridae	*Indothele rothi*	Coyle, 1995	Endemic to India
Gnaphosidae	*Drassodes gangeticus*	Tikader & Gajbe, 1975	Endemic to India
	Drassodes luridus	(O.P.-Cambridge, 1874)	Endemic to India
	Drassodes parvidens	Caporiacco, 1934	India, Pakistan
	Gnaphosa kailana	Tikader, 1966	Endemic to India
	Gnaphosa stoliczkai	O.P.-Cambridge, 1885	India, China
	Haplodrassus ambalaensis	Gajbe, 1992	Endemic to India
	Haplodrassus morosus	(O. P.-Cambridge, 1872)	India, Israel
	Haplodrassus tehriensis	Tikader & Gajbe, 1977	Endemic to India
	Herpyllus calcuttaensis	Biswas, 1984	Endemic to India
	Zelotes nainitalensis	Tikader & Gajbe, 1976	Endemic to India
	Zelotes pexus	(Simon, 1885)	Endemic to India
Hahniidae	*Hahnia mridulae*	Tikader, 1970	Endemic to India
	Neoantistea maxima	(Caporiacco, 1935)	Endemic to India
Hersiliidae	*Hersilia savignyi*	Lucas, 1836	Sri Lanka, India to Philippines
	Neotama punctigera	Baehr & Baehr, 1993	Endemic to India
Linyphiidae	*Erigone rohtangensis*	Tikader, 1981	Endemic to India
	Linyphia perampla	O.P.-Cambridge, 1885	Endemic to India
	Linyphia sikkimensis	Tikader, 1970	Endemic to India
	Linyphia sp. nov. 1		
	Linyphia sp. nov. 2		
	Linyphia sp. nov. 3		
	Linyphia sp. nov. 4		

Family	Species	Author	Distribution
	Linyphia sp. nov. 5		
	Linyphia sp. nov. 6		
	Linyphia sp. nov. 7		
	Linyphia sp. nov. 8		
	Linyphia sp. nov. 9		
	Linyphia sp. nov.10		
	Linyphia sp. nov.11		
	Linyphia sp. nov.12		
	Linyphia sp. nov.13		
	Linyphia straminea	O.P.-Cambridge, 1885	Endemic to India
	Linyphia urbasae	Tikader, 1970	Endemic to India
	Oedothorax globiceps	Thaler, 1987	Endemic to India
	Oedothorax sp. nov.1		
Lycosidae	*Arctosa indica*	Tikader & Malhotra, 1980	India, China
	Arctosa sp. nov.1		
	Arctosa sp. nov.2		
	Arctosa sp. nov.3		
	Evippa solanensis	Tikader & Malhotra, 1980	Endemic to India
	Hippasa himalayensis	Gravely, 1924	Endemic to India
	Hippasa pisaurina	Pocock, 1900	Iraq, India, Pakistan
	Hippasa sp. nov.1		
	Hippasa sp. nov.2		
	Lycosa tista	Tikader, 1970	Endemic to India
	Pardosa birmanica	Simon, 1884	Pakistan to China, Philippines, Sumatra
	Pardosa kupupa	(Tikader, 1970)	India, China
	Pardosa minuta	Tikader & Malhotra, 1976	Endemic to India
	Pardosa timidula	(Roewer, 1951)	Yemen, Sri Lanka, Pakistan
	Trochosa himalayensis	Tikader & Malhotra, 1980	Endemic to India
Miturgidae	*Cheiracanthium adjacens*	O. P.-Cambridge, 1885	China, India
Oonopidae	*Gamasomorpha*	Simon, 1907	Endemic to India

Family	Species	Author	Distribution
	clypeolaria		
	Gamasomorpha sp.nov.1		
	Gamasomorpha sp.nov.2		
	Gamasomorpha sp.nov.3		
Oxyopidae	*Oxyopes birmanicus*	Thorell, 1887	India, China to Sumatra
	Oxyopes elongatus	Biswas et al., 1996	India, China to Sumatra
	Oxyopes shweta	Tikader, 1970	India, China
Philodromidae	*Philodromus pali*	Gajbe & Gajbe, 2001	Endemic to India
Pholcidae	*Crossopriza lyoni*	(Blackwall, 1867)	Cosmopolitan
	Smeringopus pallidus	(Blackwall, 1858)	Cosmopolitan
Pisauridae	*Pisaura decorata*	Patel & Reddy, 1990	Endemic to India
	Pisaura sp.1		
	Thalassius albocinctus	Doleschall, 1859	Myanmar to Philippines
Salticidae	*Marpissa decorata*	Tikader, 1974	Endemic to India
	Myrmarachne himalayensis	Narayan, 1915	Endemic to India
	Myrmarachne sp.nov.1		
	Myrmarachne sp.nov.2		
	Phintella bifurcata	Prószyn'ski, 1992	Endemic to India
	Plexippus paykulli	(Audouin, 1826)	Cosmopolitan
	Plexippus redimitus	Simon, 1902	Endemic to South Asia
	Portia albimana	(Simon, 1900)	India to Vietnam
	Rhene indica	Tikader, 1973	India, China
	Rhene sp.nov.1		
	Rhene sp.nov.2		
	Rhene sp.nov.3		
	Telamonia sikkimensis	(Tikader, 1967)	Endemic to India

Family	**Species**	**Author**	**Distribution**
Scytodidae	*Scytodes pallida*	Doleschall, 1859	India, China, Philippines, New Guinea
Sparassidae	*Heteropoda buxa*	Saha, Biswas & Raychaudhuri, 1995	Endemic to India
	Heteropoda fabrei	Simon, 1885	Endemic to India
	Heteropoda venatoria	(Linnaeus, 1767)	Pantropical
	Olios tikaderi	Kundu, Biswas & Raychaudhuri, 1999	Endemic to India
Tetrablemmidae	*Tetrablemma deccanense*	(Tikader, 1976)	Endemic to India
Tetragnathidae	*Leucauge celebesiana*	(Walckenaer, 1842)	India to China, Japan, Sulawesi, New Guinea
	Leucauge decorata	(Blackwall, 1864)	Paleotropical
	Leucauge sp. nov.1		
	Meta sp. nov.1		
	Nephila pilipes	(Fabricius, 1793)	China, Philippines to Australia
	Tetragnatha chamberlini	(Gajbe, 2004)	Endemic to India
	Tylorida ventralis	(Thorell, 1877)	India to Taiwan, New Guinea
Theraphosidae	*Selenocosmia himalayana*	Pocock, 1894	Endemic to India
Theridiidae	*Achaearanea budana*	Tikader, 1970	Endemic to India
	Achaearanea sp. nov.1		
	Achaearanea sp. nov.2		
	Achaearanea triangularis	Patel, 2003	Endemic to India
	Argyrodes cyrtophorae	Tikader, 1963	Endemic to India
	Argyrodes fissifrons	O.P.-Cambridge, 1869	India, Sri Lanka to China, Australia
	Argyrodes sp. nov.1		
	Argyrodes sp. nov.2		
	Argyrodes sp. nov.3		
	Argyrodes sp. nov.4		

Family	**Species**	**Author**	**Distribution**
	Chrysso picturata	(Simon, 1895)	Endemic to India
	Chrysso sp. nov.1		
	Chrysso sp. nov.2		
	Theridion incertum	O.P.-Cambridge, 1885	Endemic to India
	Theridion manjithar	Tikader, 1970	Endemic to India
	Theridion sp. nov.1		
	Theridion sp. nov.2		
	Theridion sp. nov.3		
	Theridion sp. nov.4		
	Theridion sp. nov.5		
	Theridion sp. nov.6		
	Theridion sp. nov.7		
	Theridion sp. nov.8		
	Theridion sp. nov.9		
Thomisidae	*Diaea subdola*	O.P.-Cambridge, 1885	Russia, India, Pakistan to Japan
	Misumena indra	Tikader, 1963	Endemic to India
	Misumena mridulai	Tikader, 1962	Endemic to India
	Ozyptila manii	Tikader, 1961	Endemic to India
	Ozyptila sp. nov.1		
	Runcinia affinis	Simon, 1897	Africa, India to Japan, Philippines, Java
	Runcinia roonwali	Tikader, 1965	Endemic to India
	Thomisus pugilis	Stoliczka, 1869	Endemic to India
	Thomisus sp. nov.1		
	Thomisus sp. nov.2		
	Thomisus sp. nov.3		
	Thomisus sp. nov.4		
	Thomisus sp. nov.5		
	Thomisus sp. nov.6		
	Thomisus sp. nov.7		
	Thomisus sp. nov.8		
	Thomisus sp. nov.9		
	Thomisus sp. nov.10		
Uloboridae	*Miagrammopes gravelyi*	Tikader, 1971	Endemic to India

Family	**Species**	**Author**	**Distribution**
	Miagrammopes indicus	Tikader, 1971	Endemic to India
	Uloborus danolius	Tikader, 1969	Endemic to India
	Uloborus sp.1		
Zodariidae	*Lutica bengalensis*	Tikader & Patel, 1975	Endemic to India

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Species account of spiders across the study area

Agelena inda

Araneus sp.1

Arctosa indica

Argiope anasuja

Cheiracanthium adjacens

Chrysso picturata

Plate 1

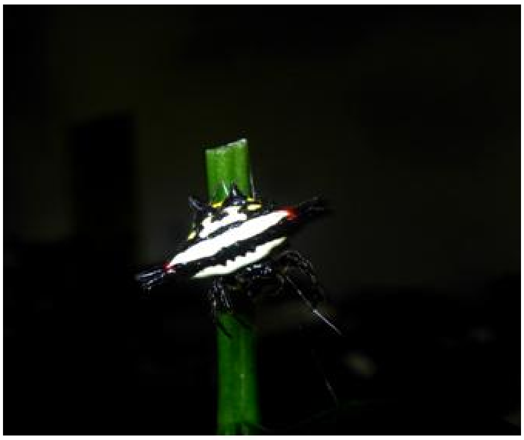
Species account of spiders across the study area

Cyclosa simoni

Cyrtophora bidenta

Diaea subdola

Evippa solanensis



Gasteracantha geminata

Gasteracantha hasselti

Plate 2

Species account of spiders across the study area

Hersilia savignyi

Heteropoda venatoria

Larinia chloris

Leucauge decorata

Linyphia straminea

Lycosa tista

Plate 3

Species account of spiders across the study area

Marpissa decorata

Misumena mridulai

Neoscona biswasi

Neoscona mukerjei

Neoscona odites

Nephila pilipes

Plate 4

Species account of spiders across the study area

Olios tikaderi

Oxyopes birmanicus

Oxyopes shweta 1

Parawixia dehaanii

Pardosa minuta

Plexippus paykulli

Plate 5

Species account of spiders across the study area

Portia albimana

Rhene indica

Runcinia affinis

Scytodes pallida

Selenocosmia himalayana

Telamonia sikkimensis

Plate 6

Species account of spiders across the study area


Tetragnatha chamberlini


Thalassius albocinctus


Theridion manjithar


Thomisus pugilis


Argyrodes sp.1 close to
Argyrodes flavescens


Trochosa himalayensis

Plate 7

Various forms of web formation by spiders across the study area


Funnel Web


Grass Web


Orb Web


Sheet Web


Tangle Web


Tube Web

Plate 8

CHAPTER 4

DIVERSITY AND COMPOSITION OF SPIDER (ARANEAE) ASSEMBLAGES

4.1 Introduction

Despite their fundamental roles in natural ecosystems, ecosystem services and potential use in identifying conservation priority areas, arthropods have largely been ignored in conservation studies (Franklin, 1993; Kremen et al., 1993; New, 1999a, b). When corrected for knowledge bias, data on arthropods show that risk of extinction is as real for them as it is for vertebrates (Thomas and Morris, 1994; MacKinney, 1999; Dunn, 2005). As a consequence of the current data and knowledge deficit, nowadays most conservation studies and decisions necessarily rely on data predominately from plants, birds and mammals, but their function as good indicators for conservation priorities which ought to be relevant for all other living beings still needs to be proved. When this assumption is tested on comparable datasets, at least birds and mammals appear to be rather ineffective in relation to the use of various arthropod taxa (Lund and Rahbek, 2000; Lund, 2002).

Spiders (order Araneae) represent one of the most speciose arthropod orders. It has been estimated that one hectare of tropical forest may support between 300 and 800 species of spiders at any given time (Coddington and Levi, 1991). They are among the most numerous arthropods in many samples in all kinds of habitats (Basset, 1991; Borges and Brown, 2004). Although considerable effort has been invested in recording spider diversity in temperate habitats (Russell-Smith, 1999), only recently have studies on species diversity in tropical ecosystems been undertaken (Dippenaar-Schoeman and Jocqué, 1997).

In India, most ecological studies on spiders were prevalent in agroecosystems mainly in rice ecosystem and coffee plantations (Sebastian et al., 2005; Kapoor, 2008). Little is known about the composition of the arachnid communities of forest or natural ecosystems, especially undisturbed conserved areas in India. In India, earlier work on the inventory of protected area arachnids has been undertaken for purposes other than biodiversity assessment. In addition, earlier studies used a restricted range of sampling techniques which are likely to have provided a biased sample. Here I present a description of diversity and species composition as well as contrast between sites found in different habitat types within the study area. The aim of the study was to investigate the spider species composition in different habitat types within terai ecosystem and to compare sites in terms of their family and species composition. The objectives were to describe the diversity and characteristics of species assemblages found in different habitat types. In addition, greater understanding of the heterogeneity of diversity at local scale could be achieved by conducting surveys within this area. Using this information, the communities of spider assemblages in different vegetation types was compared and the possible effect of habitat characteristics on species occurrence and observed pattern was explained.

4.2 Methods

Spiders were sampled in localities across five habitat types (Fig 4.1) that contained contiguous and relatively homogeneous areas of each vegetation community. These were identified subjectively based on apparent differences in vegetation type, physiography and soil characteristics, *viz*, (a) Riparian swamp forest- this forest type was found in swampy depressions along streams and remain under water continuously for a long period during the rains or where deep black heavy waterlogged soils occur and are structurally characterized by extremely diverse overstorey and understorey structure relative to other vegetation types. This densely vegetated forest type is associated with rich humus soil. The most common tree species were *Syzygium cumini*, *Barringtonia acutangula* (patches occurred along rivers), *Trewia nudiflora, Terminalia alata*, *Lagerstromea parviflora* and *Ficus* *racemosa. Clerodendrum viscosum, Glycosmis pentaphylla* and *Murraya koenigii* are the prominent shrubs.

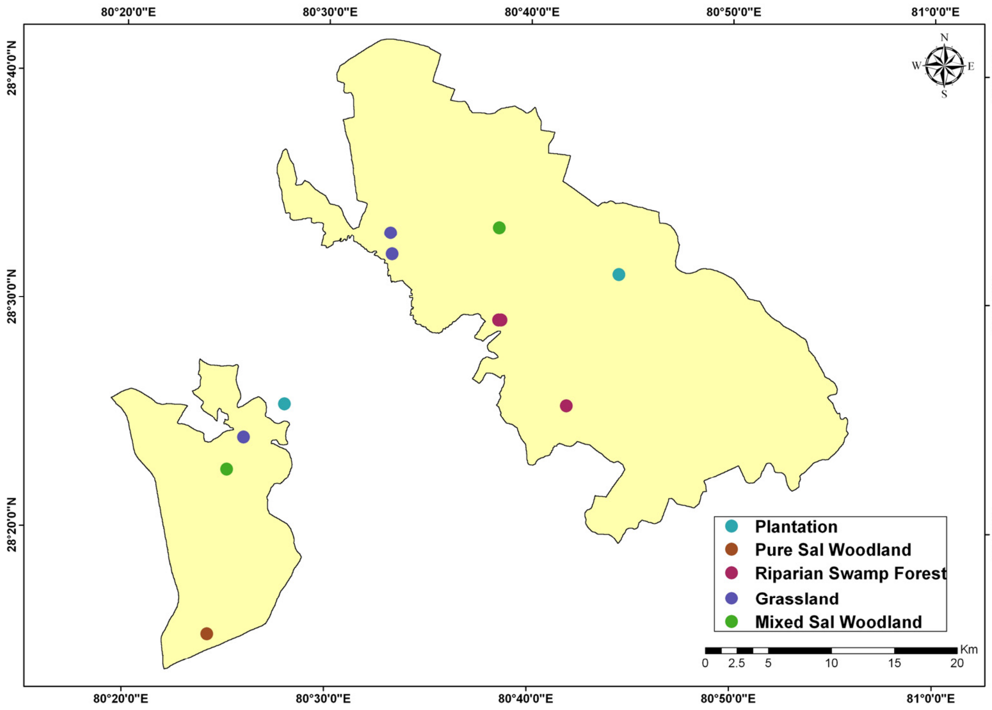


Fig. 4.1 Base map of Terai Conservation Area (TCA) showing sampling sites in five different habitat types. In TCA only intensive sampled sites of Dudhwa National Park and Kishanpur Wildlife Sanctuary were showed here.

Ageratum conyzoides, *Dioscorea belophylla* and *Corchorus aestuans,* were the important herbs in this type of forest. *Syzygium cumini* formed a dense crop with long clean boles. Structurally, this habitat typically have a mixture of sparse and closed canopy, a diverse understorey, and a deep layer of leaf litter (b) Grassland - Grasslands occurred in low-lying areas or depressions, which were water logged or marshy in nature. Such areas had alluvial soils, mostly sandy with clayey patches. These depressions mark old river channels. Structurally, these grasslands are characterized by an absence of trees and moderate to low herbaceous ground cover. Floristically, these grasslands were composed primarily of native and introduced grass species, and a few, scattered shrubs. These areas are annually burnt as part of the management practices in TCA. Prominent tree species were *Bombax ceiba, Ficus racemosa* and *Syzygium cumini.* Prominent grasses were *Arundo* *donax, Phragmites karka, Themeda arundinacea, Sclerostachya fusca, Saccharum spontaneum* and *Saccharum narenga.* These grasslands have interspersed swamps. (c) Pure sal woodland – This habitat type represents moist deciduous forest that occurred on higher alluvial terraces. *Shorea robusta* (Sal) occupied a major part of this woodland. This woodland was often associated with flat topography and loamy soil. Variation in overstorey structure is limited by the dominance of *Shorea* and the understorey structure is relatively diverse, composed of *Ardisia solanacea, Colebrookia oppositifolia, Clerodendrum viscosum* and *Murraya koenigii*. Woody climber *Tiliacora acuminata* formed a dense carpet on ground in several patches. (d) Mixed Sal woodland**.** This was the rarest vegetation type, which occurred only in five patches in the entire study area and was confined to the gentle slopes and old river terraces around grasslands. The overstorey was composed of old *Shorea robusta* with *Bridelia squamosai*, *Bauhinia racemosa*, *Mallotus philippensis*, *Syzygium cumini* and *Terminalia alata*. Mixed Sal woodlands are structurally characterized by closed overstorey of *Shorea robusta and Terminalia alata*, while the dense understorey layer is composed of *Ardisia solanacea*, *Clerodendrum viscosum* and *Glycosmis pentaphylla*. (e) Plantation. - Extensive plantations of *Acacia catechu, Ailanthus excelsa, Bombax ceiba, Dalbergia sissoo, Eucalyptus citriodora* and *Tectona grandis* have been raised as gap planting as well as after clear felling. This vegetation type mostly represents large scale mechanised plantations of teak (*Tectona grandis*) and *Eucalyptus*. This habitat type were chosen to represent disturbed condition, since most of the patches were proximal to villages and on the periphery of the protected areas, continue to undergo grazing and other biomass extraction to varying extents. Structurally, plantations are characterized by moderate to low canopy cover and least herbaceous ground cover.

4.3 Sampling Design and Techniques

Spiders were collected along 50 m x 10 m transects, with 20 transects per habitat type. These transects were treated as our basic sampling units, hereafter sites. Transects were placed randomly within stratified vegetation types. Sampling was carried out over three periods, winter (November 2005 – February 2006), summer (March 2005 – June 2005), monsoon (July 2005 – October 2005). Spiders were sampled along these transects using six sampling techniques (pitfall traps and semi-quantitative sampling). Pitfall sampling was operated for 64 weeks and other five semi-quantitative sampling performed on 64 occasions (once every week) at the same sampling sites. The principal purpose of this sampling design was to produce a relatively complete species list and associated abundance data for a representative example of each habitat type in the region, and of the region as a whole.

4.3.1 Pitfall Sampling

Pitfall traps consisted of cylindrical plastic bottles of 10 cm diameter and 11cm depth (Churchill and Arthur, 1999). Six pitfall traps were laid along each transect line at an interval of 10 m each. Traps were filled with preservative (69 % water, 30% ethyl acetate and 1% detergent). After 7 days, specimens were removed from traps, which allowed me to maintain spider specimens in good condition before laboratory processing and identification. Since the limitations of this method are that the number of individuals trapped is affected by environmental, weather and species-specific factors (Mitchell, 1963; Krasnov and Shenbrot, 1996; Parmenter et al., 1989; Ahearn, 1971), other time constrained semi-quantitative collection methods were employed after Coddington et al., (1996) to maximize capture.

4.3.2 Semi-quantitative Sampling

Aerial sampling (for upper layer spiders up to 1.5 m) involved searching leaves, branches, tree trunks, and spaces in between, from knee height up to maximum overhead arm’s reach. Ground collection (for ground layer spiders) involved searching on hands and knees, exploring the leaf litter, logs, rocks, and plants below low knee level. Beating (for middle layer spiders up to 1 m) consisted of striking vegetation with a 1m long stick and catching the falling spiders on a tray held horizontally below the vegetation. Litter sampling was done by hand sorting spiders from leaf litter collected in a litter collection tray. Sweep netting (for middle layer spiders up to 1 m) was carried out in order to access foliage dwelling spiders. Each sampling method comprised 1 hour active sampling, measured with a stopwatch.

All adult spiders were identified to family and species using existing identification keys wherever possible (Pocock, 1900a; Tikader, 1982, 1987; Cushing, 2001; Koh, 2000). Voucher specimens of each spider species collected are deposited at Wildlife Institute of India, Dehradun and Arachnida Section, Zoological Survey of India, Kolkata.

4.4 Analysis

4.4.1 Species Richness and Local Diversity

Spiders captured by pitfall traps and semiquantitative methods were pooled for each site for quantitative analysis. Species richness was estimated for each habitat type, as well as for the regional data set using the nonparametric estimators Chao1 and Jacknife2. Accumulation curves were generated after 100 randomizations using EstimateS 8.0 (Colwell, 2006). Chao1 gives an estimate of absolute number of species in an assemblage based on number of rare species (singletons and doubletons) in a sample. Chao1 estimate of species richness is recommended for inventory completeness values, completeness being the ratio between observed and estimated richness (Sørensen et al., 2002; Scharff et al., 2003). Jacknife estimators in general, and Jacknife2 in particular, have been found to perform quite well in extrapolation of species richness, with greater precision, less bias and less dependence on sample size than other estimators (Palmer, 1990, 1991; Baltanás, 1992; Brose et al., 2003; Petersen et al., 2003; Chiarucci et al., 2003).

Many indices have been developed to measure and compare diversity (Magurran, 1988). Spider assemblages of Terai are very rich (see results) and were not completely covered by sampling regimes. Under this condition species numbers are not accurate descriptors of diversity (Gotelli and Colwell, 2001). I therefore calculated Fisher's alpha of the log series as measure of total diversity using EstimateS 8.0 (Colwell, 2006). Log series-type distributions are commonly occurs in nature and measures such as Fisher's alpha are suitable to characterize such datasets. Fisher's alpha has also been extensively used in many other arthropod studies, thus facilitating comparisons between studies (Shochat, et. al., 2004). Non-parametric Kruskal-Wallis ANOVA was used to compare the diversity indices of spiders among habitats.

To compare the species richness values of sites, and to calculate expected species richness, individual-based rarefaction was used (Gotelli and Colwell, 2001). These curves standardize different datasets on the basis of number of individuals and not on number of samples. The software program EcoSim7.0 (Gotelli and Entsminger, 2001) was used for rarefaction analyses. Thereafter, the curves were rarefied to the lowest number of individuals recorded in a vegetation type (300) to ensure valid comparisons of species richness between different sites (Gotelli and Colwell, 2001). Rarefaction was used as a diversity index because it considers the number of individuals collected and species richness (Magurran, 2004), allows comparison of diversity between sites at similar sample size, and by showing the rate of new species accumulation, allows for verification that enough samples were collected to make proper comparisons of diversity (Gotelli and Colwell, 2001; Magurran, 2004; Buddle et al., 2005).

4.4.2 Site Similarity and Cluster Analysis

The similarity across sites was depicted as Bray-Curtis similarities (Krebs, 1989), using both species and guild composition. Multidimensional scaling (MDS) plots were constructed based upon similarity values of species composition across habitat types in program PRIMER (Clarke and Gorley, 2001). Analysis of similarities (ANOSIM – Clarke, 1993) was performed between each pair of habitat types to determine whether there were significant differences between the spider assemblages in the five main habitat types. The data were fourth-root transformed before analysis to reduce the weight of common species (Clarke and Warwick, 1994a). The ANOSIM procedure of PRIMER is a nonparametric permutation procedure applied to rank similarity matrices underlying sample ordinations (Clarke, 1993). This method generates a global *R*-statistic, which is a measure of the distance between groups. An *R*-value that approaches one indicates strongly distinct assemblages, whereas an *R*-value close to zero indicates that the assemblages are barely separable (Clarke, 1993). These *R*-values were used to compare spider assemblages between habitat types. Where ANOSIM revealed significant differences between groups, SIMPER analyses (PRIMER) were used to identify those species that contributed most to the observed assemblage differences (Clarke and Gorley, 2001). Similarity percentages (SIMPER) allowed identification of species and guild important in discriminating between groups that differed significantly from each other. Cumulative contributions were cut arbitrarily at 50%. The species with the highest dissimilarity to standard deviation ratios were identified as good discriminators for each comparison (Clarke, 1993).

4.5 Results

4.5.1 Species Richness and Local Diversity

A total of 3666 adult spiders were captured representing 22 families, 60 genera and 160 species, which represent 11% of spider species recorded in Indian mainland (see Appendix 4.1 for the habitat wise list of spider species observed during sampling). The pooled species accumulation curve reached an asymptote for both Chao1 and Jacknife2 (Fig. 4.2), indicating that sampling was almost complete at regional level.

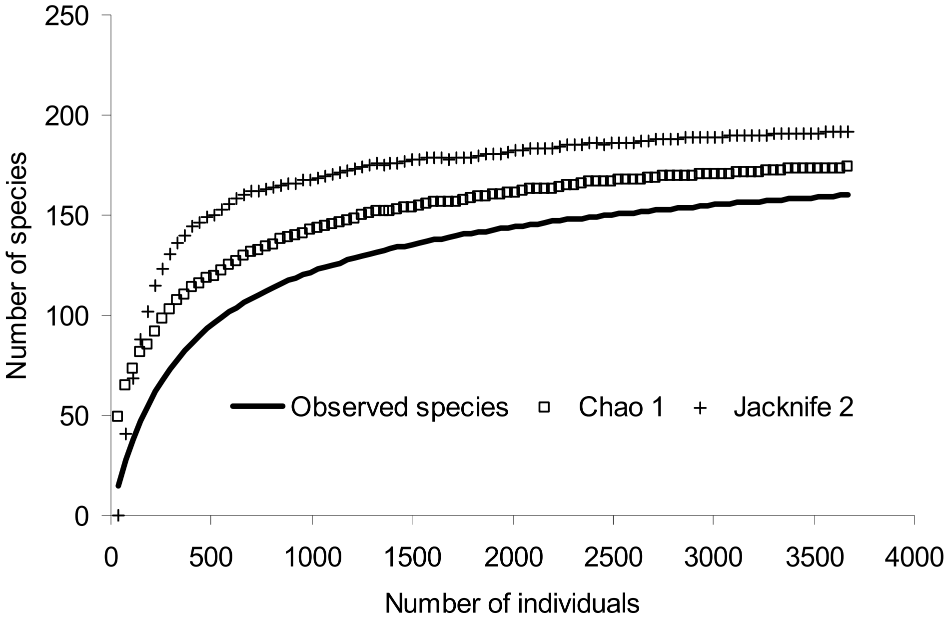


Fig. 4.2 Species-Accumulation curve and estimation curves Chao1 and Jacknife 2, for the regional (all samples pooled) dataset. Curves are generated from 100 randomizations.

The estimated total species richness using Chao1 was 173 ± 8.32 (SD), and using Jacknife2 191±1.82 (SD) for the complete sample. The ratio of observed to estimated (Chao1) number of species was 92% suggesting that at least 8% more species are to be expected in the area than were actually collected. However, at local level, in plantation and grassland, I failed to collect such a high percentage of species (44% missing) compared with other habitat types (Table 4.1).

Table 4.1. Measures of species richness estimates and inventory completeness for each habitat type and for the regional dataset. Richness estimator values (Chao 1 & Jacknife2) represent the mean of 100 randomizations of sample order. Ratio of estimated and observed richness represents inventory completeness. All values rounded to the nearest integer.

	Pure sal woodland	**Mixed Sal woodland**	**Plantation**	**Grassland**	**Riparian swamp forest**	**Regional**
No. of specimens	777	805	301	729	1054	3666
Observed richness	87	76	41	76	95	160
Number of Singletons	19	18	8	13	28	35
Number of Doubletons	11	7	5	3	10	13
Chao1	103	99	73	135	127	173
Jacknife 2	108	98	60	99	136	191
% Completeness	84	77	56	56	75	92

From all species recorded, 35 were singletons (21% of all species) and 13 were doubletons (8% of all species). The most abundant species was *Chrysso picturata*, Simon 1895 (Theridiidae) (112 individuals) and most of the individuals (70% of total catches) were found at plantation sites. The highest species richness was found in the riparian swamp forest (90 species), while lowest species richness was in the plantation sites (41 species). The remaining three habitat types did not differed statistically in richness considering the overlap of confidence intervals of richness value (Fig. 4.3). The fraction of local singletons relative to species numbers recorded per site varied between 26% and 77%. The highest contribution of singletons was found in riparian swamp forest. Plantation and grassland habitat had lower proportion of singletons, these were lowest at sites with more regeneration or at early successional phase.

Values of Fisher's alpha (Fig. 4.4) were high at all sites, but varied considerably (range= 23.6-55.2). Highest spider diversity was observed in

Riparian swamp habitat, followed by Pure Sal, while it was significantly lower in the plantation habitat.

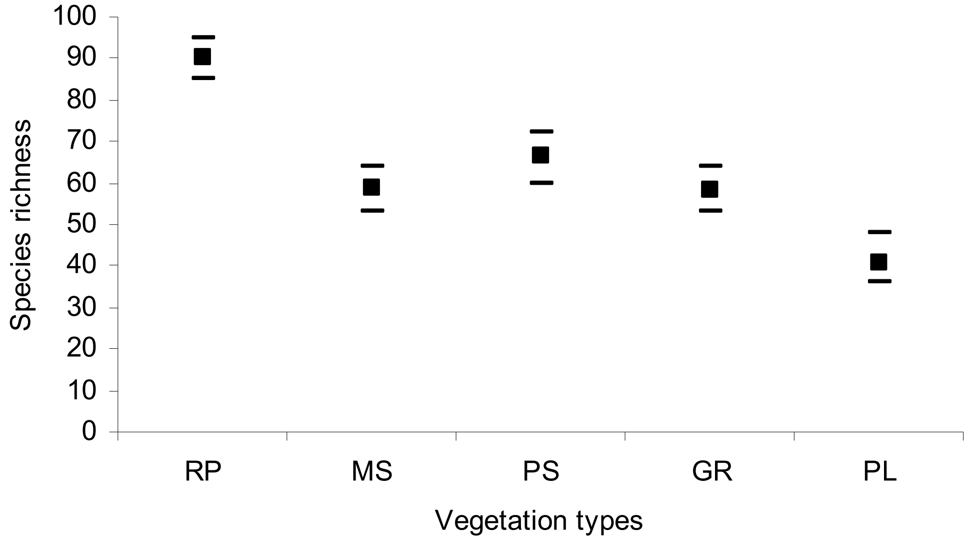


Fig 4.3 Comparison of species richness values (±95% confidence interval) at lowest number of individuals (300) derived from individual-based species rarefaction curves of spider assemblages across the different habitat types. RP, Riparian; MS, Mixed Sal; PS, Pure Sal; GR, Grassland; PL, Plantation.

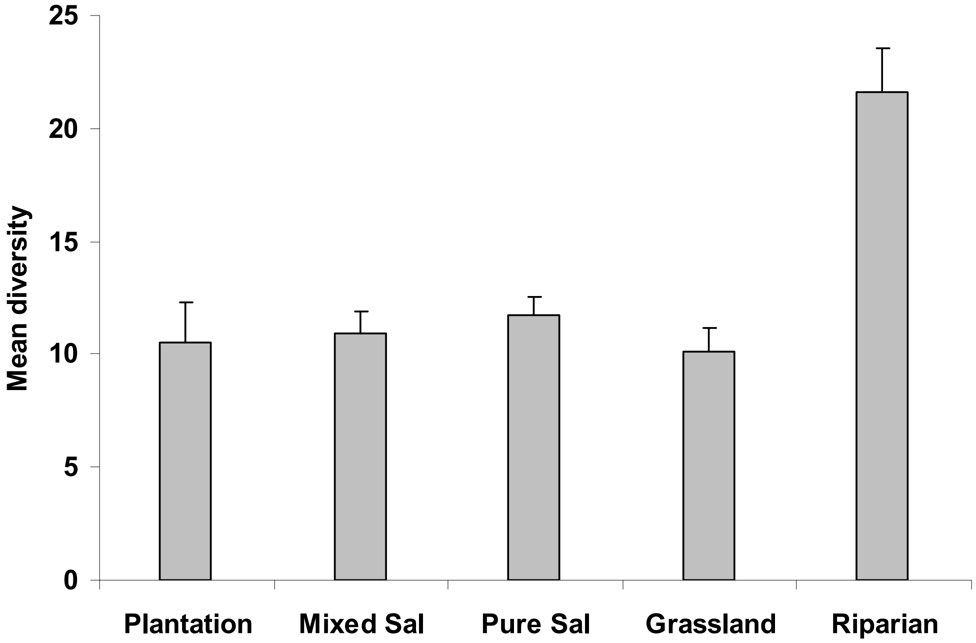


Fig. 4.4 Mean spider diversity (fisher's alpha) in five habitat types. differences between groups are significant (KS test: Chi square=44.24, df=4, P<0.01).

4.5.2 Species Composition and Site Similarity

Comparing among different sites revealed that on average, species composition was much more similar within the same habitat type than among different habitat types. MDS plot generated from relative abundances of different spider species in each habitat type showed that sampling sites from each habitat type clustered together (Fig. 4.5). Sampling sites of homogeneous grassland and plantation were well separated from heterogeneous forest habitats, which clustered together. Sampling sites in pure sal and mixed sal woodland grouped together, and showed little overlap with other habitat types. Pair wise ANOSIM test showed most difference in species composition occurred between riparian swamp forest and plantation sites (*R* = 0.79, *P* = 0.001), while the least difference was seen between pure sal and mixed sal woodland (*R* = 0.34, *P* = .011). Further comparisons of dissimilarity in composition were made to identify the species contributing to the difference between groups of sites that differed most.

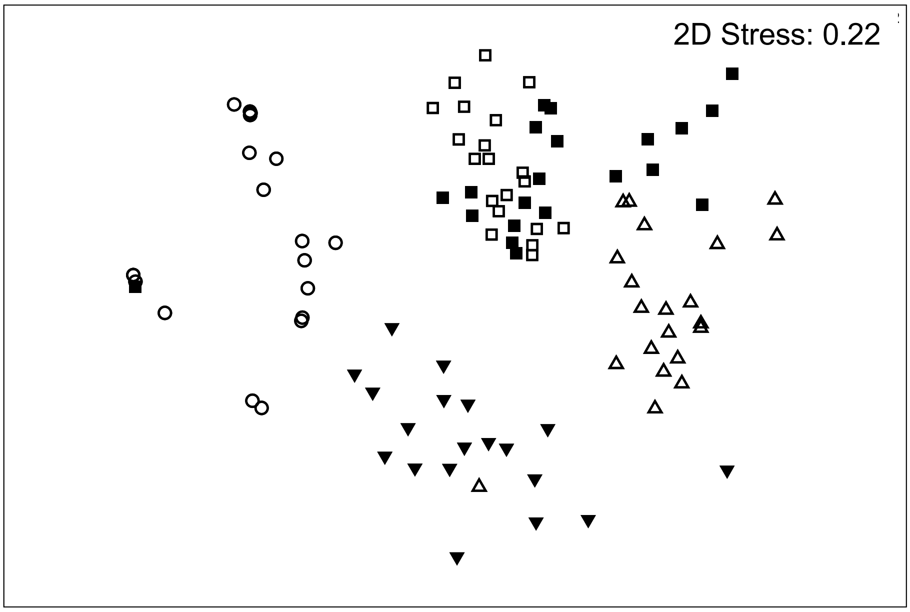


Fig. 4.5 MDS ordination plots of sampling sites in the TCA, generated by species composition sorted according to habitat types (open triangle: Riparian sites, inverted closed triangle: Grassland sites, open square: Pure Sal sites, closed square: Mixed Sal sites; open circle: Plantation sites).

Fifteen species contributed around 50% to the difference between groups of sites. These species differed in mean abundance, which was reflected in the degree of group association. Eleven species of family Araneidae, were almost absent from plantation sites and present in high abundance in riparian swamp forest, whereas *Chrysso picturata*, *Achaearanea triangularis* and *Argyrodes* sp. 2 of family Theridiidae were found in greater abundance at plantation sites compared to riparian forest (Table 4.2).

Table 4.2 SIMPER analysis of differences in the species of spider assemblage contributing to the dissimilarity between most dissimilar habitat types found.

Groups Riparian & Plantation (Average dissimilarity= 98.30%)			
	Plantation	Riparian	
Species	Mean Abundance	Mean Abundance	Cumulative contribution%
Chrysso picturata	4.45	0.10	6.88
Leucauge decorata	0.00	2.30	10.66
Cyrtophora ksudra	0.00	2.15	14.04
Cyclosa sp.1	0.00	2.20	17.09
Achaearanea triangularis	1.75	0.65	19.98
Neoscona theisi	0.05	1.70	22.68
Argiope anasuja	0.00	2.10	25.33
Lycosa tista	0.00	1.70	27.97
Hippasa sp. 2	0.00	1.70	30.60
Neoscona biswasi	0.00	2.10	33.23
Eriovixia laglaizei	0.80	1.50	35.80
Poltys illepidus	1.50	0.00	38.22
Gasteracantha geminata	0.00	1.40	40.44
Argyrodes sp.2	1.30	0.00	42.56
Neoscona vigilans	0.00	1.10	44.63
Araneus bilunifer	0.00	1.50	46.61

4.5.3 Family Composition and Site Similarity

The most abundant families were Araneidae (41.78% of all captures), and Theridiidae (12.46%). Other dominant families comprised Lycosidae (295 individuals, 11 species), Tetragnathidae (253, 17), Linyphiidae (211, 19), Clubionidae (170, 4), Salticidae (133, 12), and Gnaphosidae (123, 7). All other families (14) were represented by less than 100 individuals each, and contributed only 29 species.

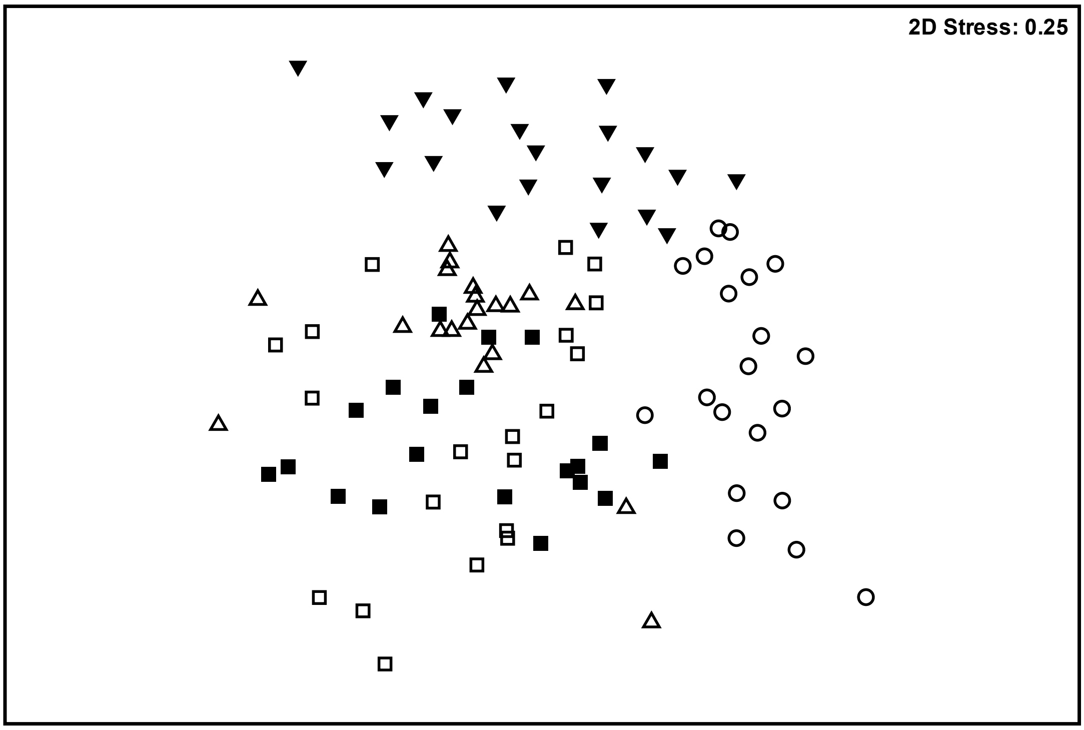


Fig. 4.6 MDS ordination plots of sampling sites in the TCA, generated by family composition sorted according to habitat types (open triangle: Riparian sites, inverted closed triangle: Grassland sites, open square: Pure Sal sites, closed square: Mixed Sal sites; open circle: Plantation sites).

The MDS plot generated from relative abundances of spider guilds was similar to that generated from spider species with respect to habitat associations (Fig. 5.6). Plantation plots were well separated from forested plots and those in three forest habitats (riparian, pure sal & mixed sal) showed overlapping. Pair wise ANOSIM test showed most difference in family composition occurred between riparian swamp forest and plantation sites (*R* = 0.66, *P* = 0.001), while the least difference was seen between pure sal and mixed sal woodland (*R* = 0.35, *P* = 0.001). Results of SIMPER analysis (Table 4.3) revealed that family Araneidae contributing mostly in group difference between riparian and plantation sites. Spiders belong to family Araneidae and

Tetragnathidae, mostly constructs delicate orb web are predominant in riparian sites, while members of family Theridiidae those spin irregular network of space web were most abundant in plantation sites. Most species of lycosid spiders are found abundant in riparian sites construct a short, cylindrical retreat burrow in sand or soft soil.

Table 4.3 SIMPER analysis of differences in the families of spider assemblage contributing to the dissimilarity between most dissimilar habitat types found.

Groups Plantation & Riparian (Average dissimilarity = 76.53)			
	Plantation	Riparian	
Family	Mean Abundance	Mean Abundance	Cumulative contribution%
Araneidae	3.10	23.95	38.66
Lycosidae	0.00	8.35	54.18
Theridiidae	8.00	4.10	66.18
Tetragnathidae	0.00	3.45	72.97
Gnaphosidae	0.00	3.55	79.60
Salticidae	0.40	2.80	84.77
Thomisidae	1.25	1.65	88.75
Linyphiidae	1.00	2.10	92.44
Sparassidae	0.05	1.05	94.93
Oonopidae	0.50	0.90	96.57

4.6 Discussion

The present study, a systematic inventory of spiders, is the first of its kind in Terai and is one of the few studies on spider communities in India. As there is no species list available for TCA, it is difficult to know precisely what proportion of the actual local and regional species richness the study captured (Hore and Uniyal, 2008b). However, based on estimated richness inventory was almost complete at the regional scale (92%). In spite of the relative success of this study, it still cannot be described as comprehensive – undoubtedly species were missed at local scales. Sampling additional sites or using different methods would capture more species. Additionally, lacking access to the canopy, I restricted sampling to the understorey layer. Thus, species that predominantly or exclusively occur in the canopy are under sampled. Moreover, sampling efficiency was reduced in the dense forest vegetation. Therefore, capturing cryptic species in dense vegetation habitat is probably less complete by sampling than those from open habitats. However, using a sample-size independent diversity measure like Fisher's alpha (Hayek and Buzas, 1997) should minimize distortions of between-habitat comparisons. Nevertheless, the inventory protocol utilized here provided a sufficiently thorough sample of local and regional spider species to permit an accurate comparison of species richness of different habitat types. The spider diversity found not similar in different habitat types. Comparatively, riparian swamp forests exhibit highly diverse assemblages, possibly due to higher structural complexity. The relatively open and diverse overstorey and understorey structure of riparian swamp forest supported the highest number of spider species while closed canopy woodland and plantation sites supported relatively few. Additionally, these swamp forests are subjected to annual flooding, which may ‘‘reset’’ areas to earlier successional stages due to removal of existing substrate, organic matter, and organisms, and the deposition of sediments (Junk et al., 1989; Sparks et al., 1990; Richards et al., 2002). These processes may affect spider communities by alteration of microhabitats and their relative availability. The disturbances of successive floods are cumulative, and may lead to a highly heterogeneous patchy habitat condition. However, it is unclear whether such flooding may create higher species richness through removal of dominant species and creation of ecological space for other opportunist species, or through creation of diverse microhabitats, or a combination of these. The intermediate disturbance hypothesis (Connell, 1978) might provide an explanatory framework for the pattern observed. According to this hypothesis species diversity is greatest in communities experiencing intermediate levels of disturbance, so both very early as well as very late stages of recovery from disturbance should exhibit lower diversity. Disturbance creates novel opportunities for species not found in undisturbed forest, and the habitat mosaic resulting from regeneration after patchy disturbance further increases the number of niches available. Intriguingly, results showed high species richness and diverse assemblage in grassland, considering the low structural diversity of this vegetation type. One of the possible reasons for this pattern may be the practice of annual, low intensity prescribed burning in the grassland. Burning is a management tool used to reduce fuel levels and facilitate regeneration of desired grass species for wild ungulate communities. This annual fire essentially increases structural complexity of grassland, where characteristic elements of both sparse and dense vegetation occur in close proximity, providing a rich mosaic of microclimatic conditions, capable of supporting a large number of spider species (Moretti et al., 2002). However, it would be interesting to observe what proportion of locally and regionally endemic or restricted species are affected negatively or positively by this practice. In our study the proportion of unique singletons was 21%, but fractions of local singletons mostly ranged around 30%. Singletons were more prevalent in the mature forest understorey. One plausible explanation for this high proportion is that species represented as singletons are “true forest species”, which occupy special niches and occur at low densities (Basset et al., 1998, 2001; Novotny and Basset, 2000). The spider composition in plantation showed the most dissimilar assemblage in comparison with those of other habitat types. Possible reasons may be the scarcity of understorey vegetation, single tree species dominance, and isolation from nearest forest habitat, affecting the amount of different microhabitats available to spiders. Patch isolation can act as a barrier to spider dispersal from other patches. Bonte et al., 2004 showed that the distribution of spider species depends on their aerial dispersal potential and on habitat connectivity. Plantations had higher abundance of space weavers and relatively few orb weavers belongs to family Theridiidae and Araneidae respectively. This pattern probably resulted from lack of suitable microhabitats for orb web construction (vegetation dominated by a few species of dense and short grasses, with low densities of herbaceous ground flora), as well as exposure to wind and rain due to relatively open canopy. Compared with orb weavers, space weavers can endure a higher level of disturbance, which may explain why they are more abundant (Tsai et al., 2006). In contrast, relative abundance of orb weavers (Araneidae and Tetragnathidae) was much higher in pure sal and mixed sal woodland, where dense canopy and stable microclimate prevails year round. These habitats have high vertical stratification (Robinson, 1981; Scheidler, 1990; Balfour and Rypstra, 1998) and may offer more physical structures for web attachment, such as different kinds of branches. Such variation in species abundance of orb weavers can potentially be used to monitor changes of structural quality of vegetation parameters and habitat disturbances. However, as with most tropical arthropods species, data on life cycles and habitat requirements of Indian spiders are presently too scant to allow for an assessment of that hypothesis (Kapoor, 2008).

In conclusion, despite small distances between habitats studied, local ecological processes were strong enough to allow for a differentiation between spider assemblages from mature forest and naturally disturbed sites. At disturbed sites spider assemblage retained considerable diversity, partially even higher than in the mature forest, suggesting that landscape mosaics at the edge of nature reserves may support the survival of many of the more common spider species. Such areas could play an important role as buffer zones around protected areas (Schulze, 2000).

Habitat types sampled for spiders across the study area

Riparian Swamp Forest

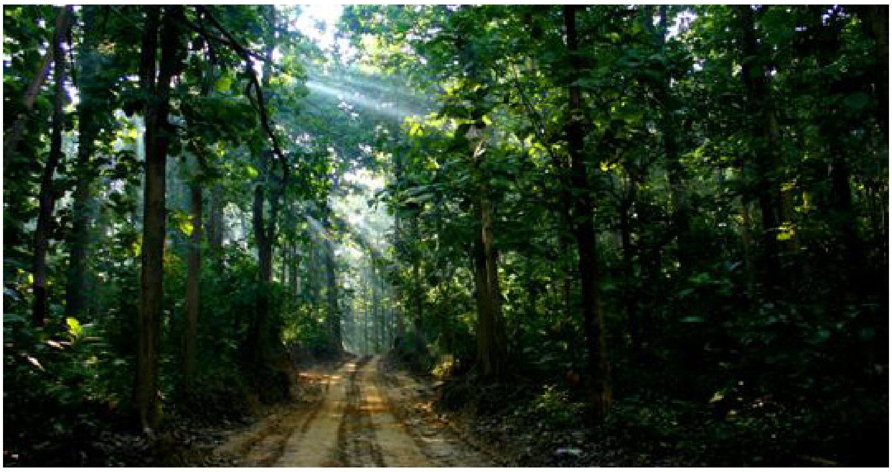
Lowland Grassland

Plate 9

Habitat types sampled for spiders across the study area

Forest edge with Grassland

Mixed Sal Woodland



Pure Sal Woodland

Plate 10

Habitat types sampled for spiders across the study area

Plantation (mainly *Eucalyptus* & *Tectona* spp.)

Forest edge with Agriculture matrix

Upland Grassland

Plate 11

CHAPTER 5
HABITAT ASSOCIATION OF SPIDER ASSEMBLAGES

5.1 Introduction

5.1.1 Habitat Heterogeneity Hypothesis

The ‘habitat heterogeneity hypothesis’ is one of the cornerstones of ecology (Simpson, 1949; MacArthur and Wilson, 1967; Lack, 1969). It assumes that structurally complex habitats may provide more niches and diverse ways of exploiting the environmental resources and thus increase species diversity (Bazzaz, 1975). In most habitats, plant communities determine the physical structure of the environment, and therefore, have a considerable influence on the distributions and interactions of animal species (Lawton, 1983; McCoy and Bell, 1991). For example, for bird species diversity in forests MacArthur & MacArthur (1961) evidenced that the physical structure of a plant community, i.e. how the foliage is distributed vertically, may be more important than the actual composition of plant species. Although positive relationships between vegetation-shaped habitat heterogeneity and animal species diversity are well documented on both local and regional scales (Davidowitz and Rosenzweig, 1998), empirical and theoretical studies have yielded contradictory results. Depending on the taxonomic group, the structural parameter of the vegetation and the spatial scale, species diversity may also decrease with increase in habitat heterogeneity (Ralph, 1985; Sullivan and Sullivan, 2001). Moreover, effects of habitat heterogeneity may vary considerably depending on what is perceived as a habitat by the species group studied. Structural attributes of the vegetation that constitute habitat heterogeneity for one group may be perceived as habitat fragmentation by another taxonomic group (Okland, 1996).

5.1.2 Patterns and Process of Global Diversity

Global patterns of diversity can be attributed to climate, area, latitude, altitude; productivity, available resources and habitat complexity (MacArthur, 1972; Rosenzweig, 1995; Trevelyan and Pagel, 1995). Most major terrestrial groups are more speciose in tropical than temperate regions. These global patterns of species diversity are well established (Trevelyan and Pagel, 1995; Gaston, 2000a). Determining why these differences occur has long been the core objective of ecologists (Menge and Olson, 1990; Gaston, 2000a). The past decade has seen a proliferation of studies documenting broad-scale spatial patterns in biodiversity. While there is extensive literature on the patterns of diversity at a global scale, the underlying processes driving the local and regional patterns of diversity have not been considered in such detail. The processes influencing groups such as mammals (Munthali and Banda, 1992; du Toit, 1995) and birds (MacArthur and MacArthur, 1961; MacArthur, 1972; Fretwell and Lucas, 1970) are well studied. Far less research has been conducted on the processes influencing the diversity patterns of invertebrates and even less on spiders. In addition, our knowledge of these groups is geographically biased with the majority of the studies being conducted in temperate latitudes (Trevelyan and Pagel, 1995). A better understanding of processes influencing the diversity of invertebrates is clearly desirable. It has often been assumed that invertebrate communities are primarily dependent upon the vegetation species composition and structure (Curry, 1987) and that management practice for the vegetation should therefore be of equal benefit to the invertebrate communities (Panzer and Schwartz, 1998). In recent decades, the conservation of insects and arthropods has received increasing attention, not only because they are worth conserving, but also because some insect groups have been shown to be particularly good bioindicators which react very quickly to environmental alterations. However, the basic knowledge on habitat specificity, necessary to construct such a predictive system, is still scarce, and in most groups even absent (Lobry de Bruyn, 1997; van Straalen, 1997).

5.1.3 Habitat Factors and Spider Assemblage

Habitat structure, and more precisely, vegetation complexity, has been consistently recognised as one of the most important factors in determining the presence of spider, as well as their species richness and composition (Colebourn, 1974; Hatley and Macmahon, 1980; Robinson, 1981; Urones and Puerto, 1988; Döbel et al., 1990; Uetz, 1991; Wise, 1993; Downie et al., 1995; Balfour and Rypstra, 1998; Downie et al., 2000; Borges and Brown, 2001). Despite the absence of strong spider association with host plants, vegetation type can be an important factor in determining spider assemblages because of their relationship with vegetation structure (Urones and Puerto, 1988). Additionally, other climate and topographic factors have been highlighted as relevant for spiders: humidity (Coulson and Butterfield, 1986; Rushton et al., 1987; Rushton and Eyre, 1992; Bonte et al., 2002) and temperature (Rypstra, 1986). Many spiders often rely on a distinct complex of environmental habitat factors with respect to species-specific ecological demands. And there is experimental evidence that habitat alterations due to forest succession, natural disturbances, or forestry practice result in structural changes of the spider community (Pearce et al., 2004; Ziesche et al., 2004; Oxbrough et al., 2005; Finch and Szumelda, 2007). In particular, the formation of ground vegetation and the resulting microclimate are most likely to affect the abundance and distribution of spider species and this is probably a major reason for the formation of specific species assemblages in a habitat (Bultman and Uetz, 1982; Hurd and Fagan, 1992; Gibson et al., 1992). In this context, the formation of tree crown canopies creates distinct and often small-scale microclimates at the soil surface (Mc Caughey et al., 1997) and thus exerts important controls on the composition of the ground vegetation and many biochemical processes, along with seasons (Grimmond et al., 2000). Although many forest ecosystems appear to be homogeneously structured, a diverse microhabitat mosaic exists at the forest floor with respect to various relevant environmental parameters such as irradiation, humidity, ground vegetation, litter layer, and other soil characteristics (e.g., Niemelä et al., 1996; Holst et al., 2004; Oheimb et al., 2005). Based on this knowledge, it is natural to assume a species specific distribution pattern of spiders on a small-scale spatial and temporal level.

Experiments involving artificial habitat manipulations have provided evidence that spider communities quickly react to these variations in vegetation structure (Wise, 1993). As a rule, spiders are highly sensitive to habitat structure. Therefore, variations in spider communities can give an index of zoological changes associated with natural or anthropogenic (human) changes in vegetation structure. The analysis of spatio-temporal changes in the constitution of spider communities could offer an approach for biodiagnosing the evolution or stability of different biotopes when vegetation is affected by human activities. Due to the position of spiders in the trophic scheme, other ecological information relating to other components of the fauna (potential prey and predators of spiders) inhabiting the habitat could be inferred from the spider community analysis (Marc et al, 1999).

Apart from vegetation structure and microclimate spider assemblages is also influenced by availability and size of the insects as potential prey items which affects the diversity and density of spiders within a habitat (Enders, 1974; Rypstra, 1985, 1986). The degree of food limitations for spiders varies spatially and temporally, and evidence of such from responses to changes in food availability; i.e. from the effects of food shortage on foraging behaviour (Gillespie, 1981). Rypstra (1985) has provided experimental evidence that the orb weaver *Nephila clavipes* aggregates in areas of high prey density in a subtropical Peruvian forest, and the relationship between increased insect abundance and greater spider number have been shown in a number of previous studies (Cherret, 1964; Schaefer, 1972). Furthermore, field experiments conducted in enclosures have shown the web building spiders leave areas of low prey abundance and tend to remain where areas of prey captures are greater (Turnbull, 1964; Gillespie, 1981; Olive, 1982; Vollrath, 1985).

The aim of the present study is to assess the habitat affinities of spider assemblages and to examine how these affects the components of assemblage structure and composition. More specifically, I test whether vegetation, microclimate, prey availability or disturbance are good predictors of spider richness or diversity. Primarily the study intends to (1) assess the small-scale spatial distribution pattern of spider assemblages in different habitat types, (2) reveal the environmental key factors leading to a separation of species assemblages, and (3) identify those key factors that are intrinsic features of the habitat heterogeneity and disturbances.

Using a range of environmental variables as surrogate measure for disturbance and heterogeneity, the study also intends to judge the response of the spider assemblages to the habitat condition. From these species I identify a group of ecological indicator species those provide accurate indication of immediate environmental stress and change than a single indicator species. In this study I present one such group of spiders as potential indicators of habitat conditions in Terai Conservation Area (TCA), India.

5.2 Methods

Spiders were collected along 50 m x 10 m transects, with 20 transects per habitat type. These transects were treated as basic sampling units, hereafter sites. Transects were placed randomly within stratified vegetation types. Sampling was carried out over three periods, winter (November 2005 - February 2006), summer (March 2005-June 2005), monsoon (July 2005 - October 2005). Spiders were sampled along these transects using six sampling techniques (pitfall traps and semi-quantitative sampling, see details in chapter 3). Within each site in a given sampling period habitat variables were measured from 10 x 10 m quadrats adjacent to each transects used for spider sampling. [See Appendix 5.1 for list of the sampling sites and their attributes]. There are 20 quadrats per habitat type was assessed for all habitat variables selected. Thus quantitative variables measured encompassed the putative response of spider assemblages.

5.2.1 Vegetation Variables

Vegetation data were obtained from permanent quadrats established included standard measures of vegetation structure and cover variables. Vegetation structure data included 5 variables *viz*., foliage height diversity (FHD), shrub height variation (HRS), mean litter depth (AVLD), plant species richness (PSR), and tree and shrub density (TSD). Vegetation cover data included 5 variables viz., tree canopy cover (TCC), shrub canopy cover (SCC), ground herb cover (GHC) and litter cover (LCC).

(a) Foliage height diversity (FHD)- was estimated from four random points in each quadrats using 4m long pole placed vertically, and number of times vegetation came into the contact with pole in each height class (1= 0-0.5m, 2= 1-1.5m, 3=1.5-2m, 4=2-2.5m, 5=2.5-3m, 6=3-3.5m) was recorded. Height diversity was calculated using the Shannon index, $\text{FDH}=\sum P_i * \log (p_i)$. Foliage height diversity was expected to be increased with the increase of structural quality of the habitat condition.

(b) Shrub height variation (HRS)-four measurement of shrub height were taken with measuring ruler. The standard deviation was determined as measure of variation in shrub height.

(c) Mean litter depth (AVLD)-mean litter depth was measured four random points with the quadrate. Depth was measured inserting a measurement ruler into the leaf litter until the harder soil layer was encountered. Normally, disturbed sites are likely to accumulate higher litter on the ground as decomposition rate was marginal.

(d) Plant species richness (PSR)-total number of all plant species were recorded in each quadrate including trees, shrubs, herbs and grasses. Decrease in plant species richness was expected to be accompanying early-to-mid level response by plants to disturbance.

(e) Tree and shrub density (TSD)- total number of trees and shrubs per quadrate area was summed and density was calculated for site. Tree and shrub density was expected to be lower in disturbed habitat patches.

(f) Tree canopy cover (TCC)- mean percentage of canopy cover was estimated from four points in each quadrate using densitometer. Tree canopy cover was expected to be lower in disturbed habitat patches.

(g) Shrub canopy cover (SCC)- Forty (20 x 50 cm) quadrats, systematically spaced at 1.5 m intervals along two parallel 10 m lines 2 meters apart, were used for the quadrate method: canopy coverage was estimated within six cover classes: (I) 0-5, (2) 5-25, (3) 25-50, (4) 50-75, (5) 75-95, and (6) 95-100%, with the midpoints of each class used in computing the mean. Shrub canopy cover was expected to increase with increase heterogeneity of the sites.

(h) Ground herb cover (GHC)- percentage herb cover was estimated visually in four sub quadrate (1x1m) within each quadrate. Herb cover was expected to decrease with increased disturbance of tree layer.

(i) Litter cover (LCC)- percentage litter cover was estimated visually in four sub quadrate (1x1m) within each quadrate. Litter cover was expected to increase with disturbance as decomposition rate in complex habitat of forest floor are quite lower.

5.2.2 Microclimate Variables

Microclimate features, including soil pH (SPH), soil moisture (SM) and soil temperature (ST), were measured using a soil pH and moisture tester and a WekslerTM mercury soil thermometer. Precipitation (mm/year), mean temperature (°C), diurnal temperature range (°C) data were extracted from CRU high resolution surface climatology data (http://cru.uea.ac.uk/cru/data

/tmc.htm). Ambient moisture was measured using hygrometer (Taylor Mason's hygrometer).

5.2.3 Prey Biomass

All insects from the pitfall traps and the sweep nets were kept. These insects were sorted to level of order and divided into size classes. Body length measurements (from the head to the end of the abdomen) were recorded using a pair of callipers. The values were then used to calculate the biomass of insects. The biomass of insects (prey available to spiders) was then determined by calculating the weight (mg) from a weight versus length relationship (Rogers, et. al., 1975). The following equation was used to calculate the biomass:

$W = 0.0305\ L^{2.62}$

Where: W = the weight (mg); L = the body length (mm)

The invertebrates were regarded as an indication of the prey base available to spiders (predators) in that particular site. The biomass of insects from sweep samples and pitfall traps was used in the multiple regression analysis.

5.2.4 Disturbance Variables

Potential habitat variables were selected based ongoing disturbances effects as well as the outcome of the previous disturbance events. Because of the difficulties of estimating habitat disturbances for spider assemblages, a score based management intensity index (MII) was calculated following Downie et al. (1998, 1999). Five broad variables were considered at each site. Each variable at each site were assigned to 0 to 3 in ascending order of intensity related to disturbance (low, moderate and high). Variables included: (a) grazing intensity (0,none, no pellets or dung; 1, low, 1-20/m^2; 2, moderate, 20-30/m^2; 3, high, >30/ m^2); (b) extent of fire (0, none, no area burnt; 1, low, 1-25% area burnt; 2, moderate, 25-50% area burnt; 3, high, >50% area burnt) (c) snag density (3, very high, 0/m^2; 2, high, 1-5/m^2; 2, moderate 5-10/m^2; 0, low, >10/m^2) (d) number of termite mounds (3, very high, no mound/m^2; 2, high, 1-2/ m^2; 1, moderate, 5-2/m; 0, low, >5/m); (e) number of visible webs

(3, very high, no webs; 2, high, 1-10; 1, low, 10-25; 0, low, >25); dead wood debris (density) (3, very high, 0/m; 2, high, 1-5/m; 1, moderate, 5-15/m; 0, low, >15/m). Observed values lay between 5 and 16 (5= sites least disturbed; 16= sites most disturbed) within the potential range from 0 to 3. In addition, percentage bare ground (BCOV) and number of trampling sign (NDOS) were also considered additional disturbance variables for the study.

5.2.5 Analysis

5.2.5.1 Richness, Abundance, Diversity and Habitat Variables

Many commonly used statistical techniques (e.g., regression) are unable to deal with sparse data matrices (i.e., matrices with many zeroes, as are often encountered with species abundance data) (Legendre and Legendre, 1998), or become difficult to interpret in the presence of multicollinearity (Graham, 2003), as is also often observed with ecological data (such as habitat data). Ordination techniques have been recommended for variable reduction of predictor variables as a solution to the problem of multicollinearity in multiple regression analyses (Graham, 2003), which also addresses the problems of sparse data matrices. Nonmetric multidimensional scaling (NMS) is an iterative ordination method that places sample units in *k*-dimensional space using the ranked distances between them. As in other ordination methods (e.g., principal components analysis, detrended correspondence analysis), sample units that are more similar to one another (based on species composition, for example) have scores that are closer together than sample units that are less similar (Fasham, 1977). Ordered positions of the sample units in the final configuration (i.e., reduced dimension) are optimized to maintain a monotonic relationship between the distances of the ordinated points and the distance matrix generated from the raw data (Legendre and Legendre, 1998; McCune and Grace, 2002). Departures from monotonicity are indicated by “stress” (higher values of stress suggest poorer fit between the raw data and the NMS configuration). In contrast to other ordination methods, the numbering of the axes is arbitrary; the first axis of an NMS ordination does not necessarily explain more variation among the sample units than the second, and so on (McCune and Grace, 2002). Correlations between the *k* axes of the ordination and the original variables can be used to interpret the axes. Because NMS does not assume linearity or monotonicity of the underlying data structure, it is particularly appropriate with the kinds of ecological data in this study (Fasham, 1977; Minchin, 1987; McCune and Grace, 2002).

To reduce the dimensionality of the vegetation structure, vegetation cover and microclimate data matrices, I used NMS with the Sørensen distance measure (PC-ORD 4, 1999, MjM Software Design, Gleneden Beach, Oregon). PC-ORD implements global NMS. I used PC-ORD's autopilot mode, which performs 40 runs with the raw data and 50 runs with randomized data using a random starting configuration each time; the program calculates one-dimensional through six-dimensional solutions for each run and reports the recommended *k*-dimensional solution. I used transformed (ARCSINE) percent cover data to perform ordinations of the vegetation cover data matrices. Species occurring in fewer than ten percent of the all individuals in a sampling site were omitted from the ordinations (McCune and Grace, 2002). I then used the *k* axes from each NMS analysis as variables in multiple linear regressions using SPSS 16.0, employing all possible subsets regression for variable selection. I used the vegetation cover axis (VGC), vegetation structure axis (VGS), microclimate axis (MCV), management intensity index (MII) and prey biomass (PB) as predictors of spider assemblage structure (abundance, species richness, species diversity [fisher’s alpha], family richness and family diversity[fisher’s alpha]). Responses of assemblage structure (dependent variables) to regression variables (independent variables used in regressions model) were interpreted based on the signs of the correlation coefficients of both predictor and response variables with the NMS axes, and the signs of the parameter estimates from the final regression models. As this is an observational rather than experimental study, I did not use a sequential Bonferroni correction, due to the increased risk of Type II errors associated with it.

5.2.5.2 Community Composition and Habitat Variables

The pattern of variation in the species and family composition of spider assemblage was examined by Canonical Correspondence Analysis (CCA). The effect of each of 21 habitat variables belongs to vegetation, microclimate, prey biomass and disturbances (Table 5.1) on species composition was explored using CCA (using PC-ORD software, McCune and Grace, 2002). The sites were then ordinated, which combines both ordination and multiple regression (ter Braak, 1988). The advantage of this form of ordination is that the axes are chosen in the light of known environmental variables by imposing the extra restriction that the axes be linear combinations of the environmental variables (Direct Gradient Analysis). Prior to ordination analyses, rarer taxa were removed from the data set (those taxa occurring only at one site, or those for which the total number caught by all sampling techniques comprised less than 0.50 % of total abundance). CCA was employed to position sites, and spider species and family data in ordination space constrained by same 21 habitat attributes, which are plotted as vectors from the origin (0,0) and where the lengths of vectors reflects the relative degree of influences. Mantel Test was performed to test the null hypothesis that there is no relationship between the species, sites, family and variable matrix. The significance of Mantel statistic (*r*) was based on 999 repeated randomizations. Hill's scaling method was followed in CCA ordination (ter Braak and Smilauer, 1998).

5.2.5.3 Indicator Species

To identify potential indicator spider species sensitive to habitat condition (heterogeneity and disturbance), the relationship between variables of habitat condition and abundance of spider assemblages was directly examined by CCA and WA (weighted averaging method). The simplest way to estimate species optimum is by calculating the weighted average (WA(Sp)) of the values of environmental variables in the *n* samples where the species is present. The species importance values (abundances) are used as weights in calculating the average:

$$\mathrm{WA(Sp)} = \frac{\sum_{i=1}^{n} \mathrm{Env}_i \times \mathrm{Abund}_i}{\sum_{i=1}^{n} \mathrm{Abund}_i}$$

Where Env_i is the value of environmental variable in the *i*th sample, and abund_i is the abundance of the species in the *i*th sample. The species tolerance value can be calculated from the model as the square root of the weighted mean of the squared difference between the species optimum and the actual values in the sample. This value is analogous to the standard deviation. The standard deviation value was therefore taken for subsequent analysis. The overall habitat condition score was calculated from the summed score of (a) CCA axis value (species score rescaled from 1-10), (b) indicator weight value of species (IWV std) as weighted standard deviation in WA model (IWV std score rescaled) and (c) abundance score of species as counts of individual per sampling area (1-8 with increasing abundance value). CCA extracts gradients in the spider composition that are constrained to be a function of explanatory variables and allows species that are most responsive to the explanatory variables to be identified. The effect of variables on the composition of the spider assemblage was tested with a Monte Carlo permutation test. Species that showed a significant response along the first CCA axis were selected as potential indicators of habitat heterogeneity and disturbance correlated with that axis. The centroid of abundance of each species along canonical axes was estimated by the weighted average score of indicator species along CCA axis 1 was indexed by rescaling the eigenvector scores of indicators species to scale of 1 to 10, with 1 representing the scores of that species located first and 10 the position of the last species along the gradient. The subsequent data analysis I use CCA to determine the ‘environmental gradient’ for the weighted averaging (WA) modeling. Using CCA I reduced the multivariate data of the community composition to a linear scale and used it as input into a linear model, namely weighted averaging (WA). WA has often been used to explore species-specific responses to human impact (ter Braak, 1987; ter Braak and Juggins, 1993; Smith et al., 2007). WA establishes species optima on the assumption that species follow a unimodal response curve in relation to an environmental variable (ter Braak and Prentice, 1988; Birks, 1995). In the first step, an estimate of each species' 'optimum' (used as indicator value) was calculated as the abundance-weighted average of the rescaled CCA sample scores for the sites. The weighted standard deviation (WSD) around the optimum is called 'tolerance' and indicates the breadth of the species' occurrence along the environmental gradient. The value of WSD was then rescaled from 1-5 (decreasing tolerance order) for disturbance axis and 10-1 for heterogeneity axis (decreasing tolerance order). In WA models, the abundance weighted standard deviation or 'tolerance' reflects the ecological amplitude of a given species across the environmental gradient. Species may have a narrow distribution pattern along impact gradients, which makes them good indicators, or they may be distributed over a broad range with only a flat peak rendering them of little use as indicators (Johnson, 1995). To take these differences in niche breadths into account, tolerance downweighing can be applied in a WA model using the inverses of the squared tolerances as additional weight. I used the raw indicator weight W as a second weighing factor, similar to the one used in the Saprobien System. W is derived from the tolerance in following Friedrich (1990) setting tolerance ranges and assigning ranked indicator weights. The smaller the standard deviation in a species' distribution range, the better an indicator this species is which is expressed in a high indicator weight.

5.3 Results

5.3.1 Richness, Abundance, Diversity and Habitat Variables

Because initial NMS analyses with all 100 transects indicated separation of the habitats based on all data matrices (microclimate, vegetation structure and vegetation cover), but no separation based on sampling month or year, I analyzed the data with sites. Details of the NMS ordination results were given in the Table 5.1. Seven microclimate variables, six vegetation cover variables and five vegetation structure variables are included in the analysis. The vegetation cover and structure data were reduced to two dimensions (VGCI & VGS1 axes) and as well the microclimate data to one dimension (MCV1 axes) in for all 100 sites. All final configurations met the criterion of instability < 0.001 (instability measures changes in stress). The vegetation structure ordination axes explained the 27-57% of the variation among the sampling units, while the vegetation cover and microclimate axes explained 20-57% and 40-59% of the variation respectively. Stress (Kruskal's stress Formula 1 x 100) was found greater in microclimate data (49.03) in compare to vegetation structure (36.29) and vegetation cover (41.04). While the microclimate stress value is considered high (i.e., exceeding 20 [McCune and Grace 2002]), stress values are known to be higher with larger sample sizes or higher species counts (Clarke 1993; McCune and Grace 2002).

Table 5.1 Correlations of the habitat variables with the first and only significant NMS axis.

Vegetation Structure Variables	Axis 1 (VGS1)
AVLD	-0.181
HRS	0.220
FHD	0.133
PSR	0.459
TSD	0.367
Vegetation Cover Variables	Axis 1 (VGC1)
TCC	0.159
LCOV	-0.129
TVCOV	0.070
BCOV	-0.004
SCC	0.102
GHC	0.061
Microclimate Variables	Axis 1 (MCV1)
AMMOI	0.021
DTR	0.004
MT	-0.003
PRE	0.000
SPH	-0.002
SM	0.034
STEMP	-0.014

Components of general spider assemblage, such as number of individuals, species richness or species diversity were significantly predicted (α=0.05) by the all four variables vegetation structure component (VGS1 axis), prey biomass (PB), microclimate component (MCV1), and management intensity (MII) index and selected by the regression model except vegetation cover component (VGC 1 axis). In all three cases of significant regressions, whole model *p*-values were less than 0.01. In compare to species abundance and diversity, species richness showed strongest association with predictor variables, the model explained 51% of the variation in number of species. The other two models explained 26% and 44% of the variation in number of individuals and diversity of the assemblage. Responses to the all variables are presented in Table 5.2 as positive or negative based on the signs of the correlation coefficients and regression parameter estimates. All three variables (species richness, species abundance and species diversity) responded in the same way (i.e., all positively or all negatively) to the vegetation structure variable, although family richness responded differently. The prediction power of relationship varied differently as the R^2 value (0.51) for species richness is significantly higher than other two dependent variables. In case of family richness, values for richness were predicted negatively by management intensity (MII) and positively by prey biomass (PB) and vegetation components (VGC1 & VGS1) were included in the model (Table 5.3).

Table 5.2 Summary of multiple regressions model for spider species richness, abundance and species diversity in TCA. Models were chosen by best subset regression analysis.

(a)Species richness				
Regression model	**R**	**R^2**	***F***	***P***
Predictors (VGS1, MCV1,PB & MII)	0.720	0.519	52.330	<.0001
Variables	**Regression coefficient**	**SE**	***t***	***P***
Constant	17.719	3.841	4.613	<.0001
VGS1	67.900	9.530	2.281	0.003
MCV1	0.018	0.657	2.027	0.009
PB	0.061	0.019	3.236	0.002
MII	-0.574	0.262	-2.190	0.031
(b)Species abundance				
Regression model	**R**	**R^2**	***F***	***P***
Predictors (VGS1, PB, MII)	0.517	0.267	11.644	0.001
Variables	**Regression coefficient**	**SE**	***t***	***P***
Constant	24.887	3.736	6.661	<.0001
VGS1	3.393	2.085	2.627	0.007

MCV1	2.904	1.730	2.679	0.006
PB	0.179	0.050	3.350	<.0001
(c)Species diversity				
Regression model	**R**	**R^2**	***F***	***P***
Predictors (VGS1, PB & MII)	0.669	0.447	25.860	<.0001
Variables	**Regression coefficient**	**SE**	***t***	***P***
Constant	0.872	0.065	13.352	<.0001
VGS1	69.2	10.010	6.222	<.0001
PB	0.002	0.002	5.569	<.0001
MII	-0.010	0.004	-2.339	0.021

Table 5.3 Summary of multiple regressions model using family richness and family diversity in TCA. Models were chosen by best subset regression analysis.

(a)Family richness				
Regression model	**R**	**R^2**	***F***	***P***
Predictors (MII & PB)	0.501	0.251	16.259	<.0001
Variables	**Regression coefficient**	**SE**	***t***	***P***
Constant	-6.027	4.123	-1.462	0.147
MII	1.533	0.274	5.591	<.0001
PB	0.590	0.019	3.087	0.003
(b)Family Diversity				
Regression model	**R**	**R^2**	***F***	***P***
Predictors (VGS1)	0.244	0.059	6.185	0.015
Variables	**Regression coefficient**	**SE**	***t***	***P***
Constant	0.352	0.142	2.487	0.015
VGS1	2.802	0.142	19.794	<.0001

5.3.2 Community Composition and Habitat Variables

CCA using vegetation, microclimate and disturbance variables, without the confounded effects of seasons, revealed significant patterns for all canonical axes (*P*<0.001). For species-environment data, the first two axes represented more than 94 percent of variation, while family-environment data, the percentage variation explained was 90 percent (Table 5.4a). In species matrix, plantation sites were well separated from the other sampled sites on CCA axis 1 (Fig. 5.1). Sites belong to riparian, pure Sal and mixed Sal habitats did not separated as clearly in their response to the explanatory variables, but the ordination suggests that the mixed Sal sites are intermediate in response between riparian and pure Sal sites. Grassland sites were also well separated from the riparian, pure Sal and mixed Sal sites on CCA axis 2. In family matrix, the overall pattern of site separation on CCA axis 1 is similar, though on CCA axis 2 the grassland sites were well separated in their response to explanatory variables (Fig. 5.2). The second axis of CCA was strongly associated with increasing habitat heterogeneity and decreasing disturbance, while in contrary first axis represents increase of disturbance and decrease in heterogeneity (Fig. 5.4). CCA for species-environment association showed that tree canopy cover (r=0.87), plant species richness (r=0.74), total vegetation cover (r=0.72), shrub canopy cover (r=0.64) and ground herb cover (r=0.59) were positively associated with CCA axis 2, but this axis was negatively associated with litter cover (r= -0.91) and management intensity (r= -0.62) (Fig. 5.3). CCA axis 1 represented variability positively associated with litter depth (r=0.47) and management intensity (r=0.37), while negatively associated with foliage height diversity (r= -0.81), prey biomass(r= -0.62), and ground herb cover (r= -0.62) (Table 5.4 a). Sites with high management intensity predominantly grassland and plantation habitat, had vegetation characterized by low herb cover, less variation in foliage height and as hold fewer prey species for spiders. CCA for family-environment association exhibited that trampling frequency (r=0.69) and management intensity (r=0.66) were positively correlated with CCA axis 1, whereas ground herb cover (r= -0.72)) and foliage height diversity (r= -0.77) was negatively correlated with this gradient. CCA axis 2 represented variability positively associated with tree canopy cover (r=0.68) and negatively with increasing soil temperature (r=-0.71) and litter cover (r= -0.73). CCA for family-environment association revealed that tree canopy cover (r=0.68) was positively associated with CCA axis 1, and this variable explained most of variance, while soil temperature (r=0.72) and litter cover (r=0.74) were negatively related to this axis. CCA axis 1 was positively correlated with the management intensity (r=0.66) and trampling frequency (r=0.69), but negatively correlated with the foliage height diversity(r = - 0.77), ground herb cover (r = - 0.73), prey biomass (r = - 0.68) and shrub canopy cover (r = - 0.66) (Table 5.4 b). The result is encouraging since it confirmed the qualitative assessment of the condition of habitat complexes and heterogeneity: pure Sal, mixed Sal sites, least disturb, and high complexity; riparian sites, intermediate disturb and high complexity; grassland and plantation sites of most disturbed and low complexity.

Table 5.4 Summary of the canonical correspondence analysis (CCA) of spider (a) species composition and (b) family composition, with axes related to environmental variables.

(a) Species	Axis 1	Axis 2	Axis 3
Eigen Value	0.54	0.51	0.35
Species-Environment *r*	0.94	1.00	0.92
Cumulative percentage variance			
of species data	5.80	11.20	14.90
of species-environment data (Kendall rank)	0.65	0.57	0.67
(b) Family	Axis 1	Axis 2	Axis 3
Eigen Value	0.18	0.11	0.08
Family-Environment *r*	0.90	0.88	0.84
Cumulative percentage variance			
of family data	12.80	20.50	26.60
of family-environment data (Kendall rank)	0.65	0.70	0.55

Table 5.5 Correlations between environmental variables measured (vegetation, microclimate & disturbance) and eigen vector scores of axis from canonical correspondence analysis (CCA).

		Species		**Family**	
Variables Code	Variables	Axis 1	Axis 2	Axis 1	Axis 2
AMMOI	ambient moisture	-0.453	0.349	-0.248	-0.006
AVLD	mean litter depth	0.476	-0.424	0.219	0.114
BCOV	bare ground cover	0.016	-0.078	0.186	-0.274
DTR	diurnal temperature range	-0.070	0.189	0.103	0.276
FHD	foliage height diversity	-0.814	0.020	-0.771	-0.472
GHC	ground herb cover	-0.611	0.595	-0.729	0.099
HRS	height variation in shrubs (SD)	-0.237	0.355	-0.095	-0.124
LCOV	litter cover	0.092	-0.919	0.341	-0.734
MII	management intensity	0.372	-0.621	0.662	-0.413
MT	mean temperature	0.067	-0.334	-0.019	0.047
NDOS	number of trampling	0.263	-0.544	0.692	-0.444

		Species		**Family**	
Variables Code	Variables	Axis 1	Axis 2	Axis 1	Axis 2
	sign				
PB	prey biomass	-0.628	0.575	-0.680	0.082
PRE	mean precipitation	-0.093	0.032	0.170	0.111
PSR	plant species richness	-0.558	0.749	-0.560	0.195
SCC	shrub canopy cover	-0.528	0.649	-0.658	0.184
SM	soil moisture	-0.208	0.270	-0.218	0.138
STEMP	soil temperature	0.230	-0.377	0.205	-0.718
TCC	total canopy cover	-0.150	0.874	-0.375	0.684
TVCOV	total vegetation cover	-0.202	0.718	-0.206	0.344

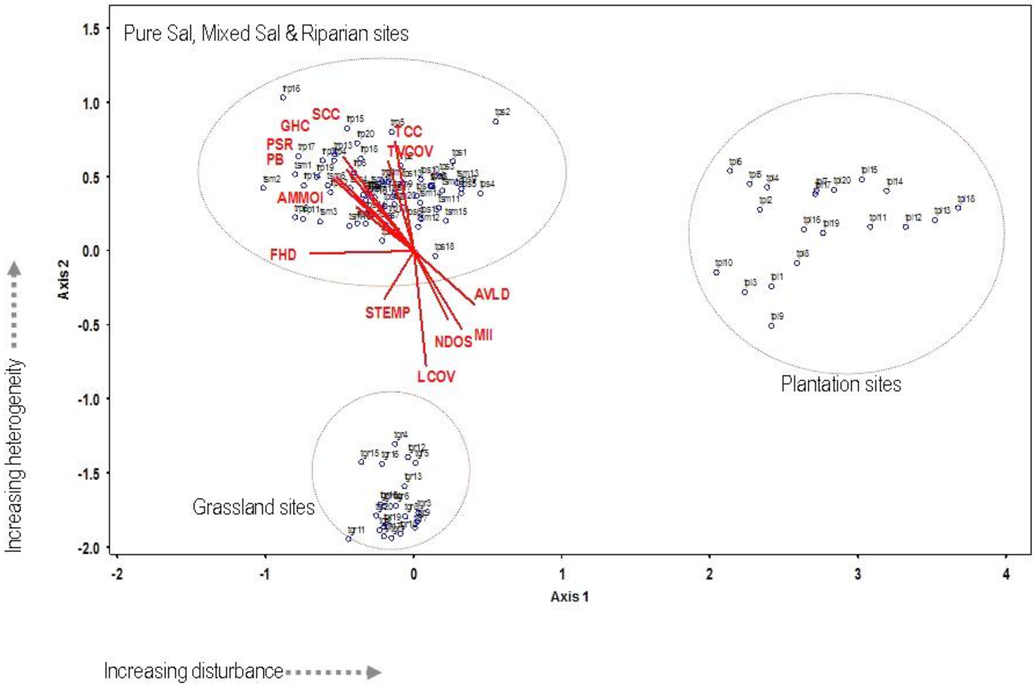


Fig. 5.1 Axis 1 and Axis 2 of CCA based on species composition and environmental variables with sites. For environmental variables see Table 5.5.

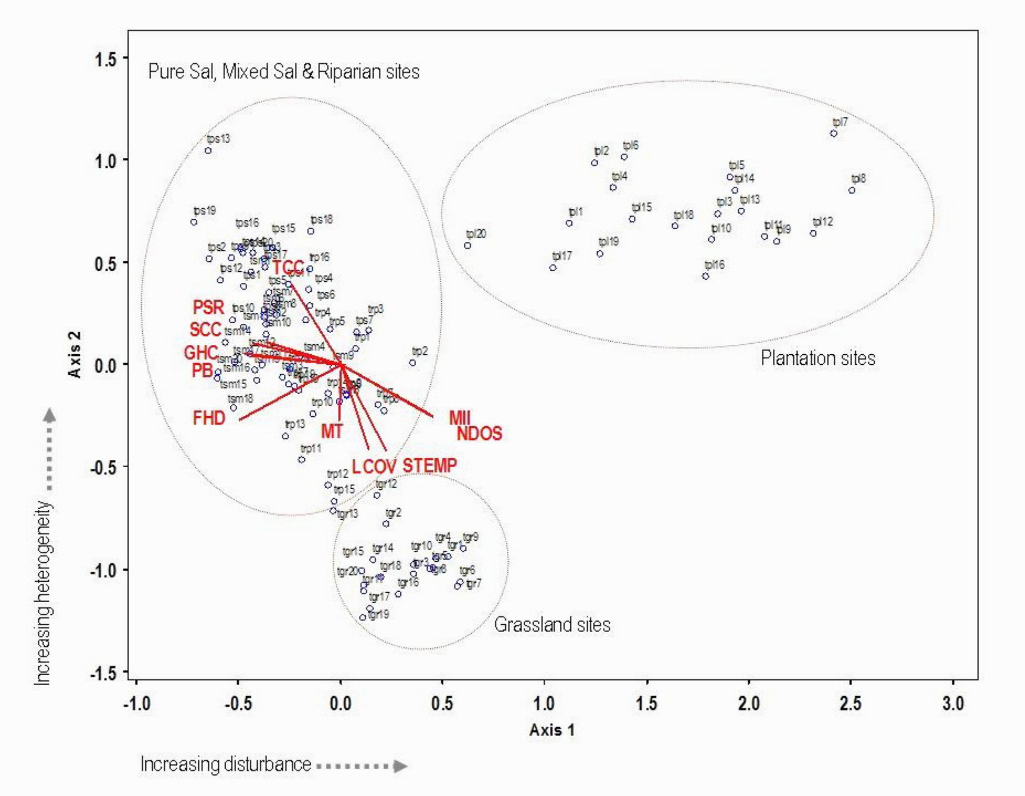


Fig. 5.2 Axis 1 and Axis 2 of CCA based on family composition and environmental variables with sites. For environmental variables see Table 5.5.

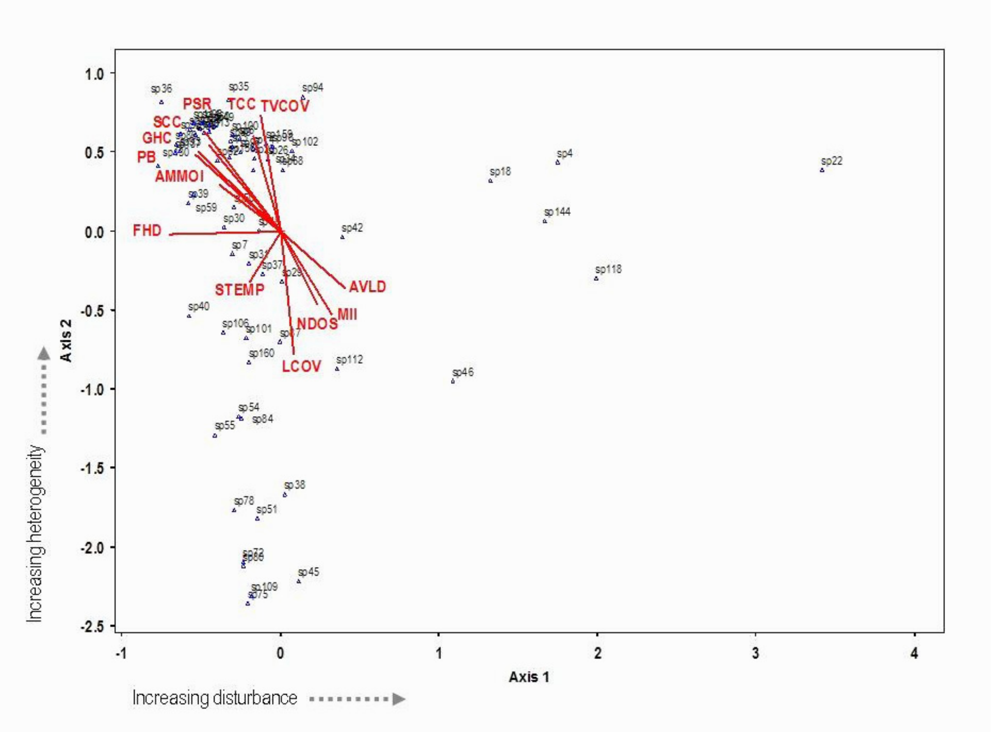


Fig. 5.3 Axis 1 and Axis 2 of CCA based on species composition showing species with sites.

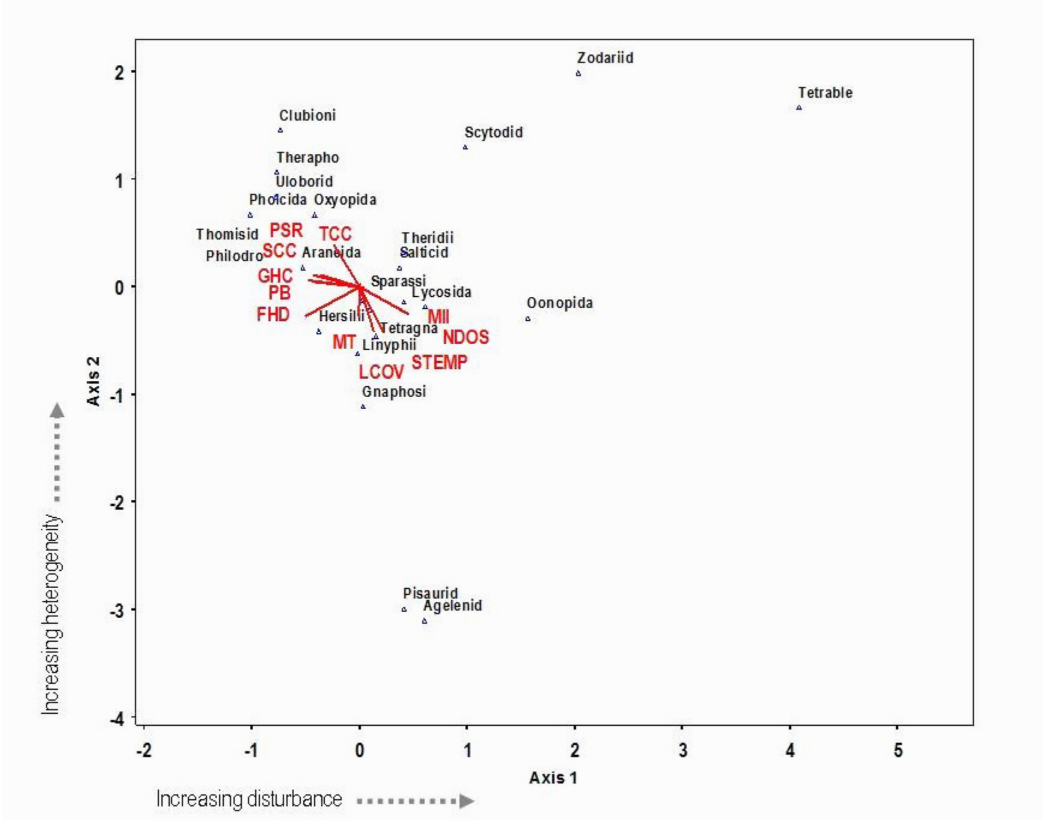


Fig. 5.4 Axis 1 and Axis 2 of CCA based on family composition showing species with sites.

5.3.3 Indicator Species

In general, the gradient in species and family composition across these habitat patches that range widely in variation to heterogeneity and disturbance, provides opportunity to identify species or species group i.e., family that respond to vegetation and microclimate attributes that change along the gradient. Based on these CCA results, the assumption was made that the first axis arranged the sampling sites objectively along an impact gradient which was primarily associated with increase of management intensity and, though to a lesser extent, with trampling component. Consequently, the site scores for the first axis represented the relative position of each site on the impact gradient. In contrary, second axis arranged sampling sites along habitat heterogeneity that was mostly associated with increase of moisture regime, vegetation cover, and vegetation structure component. The data set of the study allowed the calculation of species scores and indicator weights for 65 spider species. Five and thirty eight species had more than 10 percent of their variance accounted for CCA axes 1 and axes 2, respectively (Table 5.6). Out thirty eight species nine species were most abundant and closely associated with CCA axis 2, chosen as possible indicator species, whose relative position along the vegetation-microclimate gradient could be indication in the habitat complexity. Five species closely associated with CCA axis 1 showed marked opposite response, being most abundantly present along disturbance gradient. Scaling of indicator weight value of 8 species related to CCA axis 2, I found *Thomisus* sp.1 was the least tolerant to sites with high disturbance. The low standard deviation value of weighted average score in species distribution range reflecting the narrow distribution amplitude. They were restricted to minimally impacted habitat patches located in the study are. All other species have wider ecological amplitude and, hence, a lower weighted average score. On the other end of the scale, five disturbance indicator species were found, with indicator weight of 7.61 or less (Table 5.7). The lowest score of 4.87 was found for *Argyrodes* sp.2, which thrives at plantation patches with high density per site sampled.

Table 5.6 Cumulative fraction of the variance of each spider species accounted for by the first two axes of the CCA (fit) for species with > 10 percent fit.

Species	Family	Axis 1	Species	Family	Axis 2
Chrysso sp.1	Theridiidae	0.34113	*Thomisus* sp.1	Thomisidae	0.85368
Poltys illepidus	Araneidae	0.19860	*Cyrtophora citricola*	Araneidae	0.83287
Achaearanea triangularis	Theridiidae	0.17447	*Cyrtophora ksudra*	Araneidae	0.82446
Argyrodes sp.2	Theridiidae	0.13222	*Neoscona biswasi*	Araneidae	0.69113
Gamasomorpha sp.2	Oonopidae	0.10836	*Pardosa timidula*	Lycosidae	0.68791
			Hippasa pisaurina	Lycosidae	0.67209
			Gasteracantha geminata	Araneidae	0.66553
			Cyclosa sp.1	Araneidae	0.64741
			Argiope anasuja	Araneidae	0.62913

The summation value of axis score (sensitivity to environmental gradient), indicator weight score (tolerance to variation in environmental gradient) and abundance values will provide overall condition indicated by a species of habitat condition on a scale of 18 to 10 (18 = best, 10 = poorest) (Table 5.7). For example, high proportion of *Thomisus* sp.1 or *Cyclosa* sp.1 will represents sites with high habitat heterogeneity, whereas if the *Chrysso* sp.1 or *Argyrodes* sp.2 dominate then sites will be assumed to be highly impacted due to disturbances. In such weighted condition scoring procedure, the scores calculated for 100 sampling sites based on relative scoring of only chosen indicator species closely reflected the original order of sites along the CCA axis1 (r=-0.95) and CCA axis 2 (r=0.98) (calculated from all 65 common species).

Table 5.7 Eigen values of species along the first CCA axis of spider species composition, indicator weight value (IWV), abundance per sampled area, and scores reflect the increasing disturbance condition of habitat.

Species	Axis 1 value	IWV std	No. of individuals/ area	
Achaearanea triangularis	0.17447	8.42	0.128	
Argyrodes sp.2	0.13222	4.87	0.126	
Chrysso sp.1	0.34113	7.40	0.224	
Gamasomorpha sp.2	0.10836	6.54	0.038	
Poltys illepidus	0.19860	7.61	0.098	
Species	Axis Score	IWV(std) score	Abundance Score	Overall condition Score
Chrysso sp.1	10.00	3	5	18.00
Argyrodes sp.2	7.58	5	4	16.58
Achaearanea triangularis	8.79	1	5	14.79
Gamasomorpha sp.2	8.20	4	1	13.20
Poltys illepidus	5.82	2	3	10.82

Table 5.8 Eigen values of species along the second CCA axis of spider species composition, indicator weight value (IWV), abundance per sampled area, and scores reflect the increasing heterogeneous condition of habitat.

Species	Axis 2 Value	IWV std	No. of individuals/ area	
Cyclosa sp.1	0.64741	37.243	0.048	
Cyrtophora citricola	0.83287	43.071	0.058	
Cyrtophora ksudra	0.82446	40.723	0.118	
Gasteracantha geminata	0.66553	38.050	0.130	
Hippasa pisaurina	0.66553	47.794	0.054	
Neoscona biswasi	0.69113	42.028	0.134	
Pardosa timidula	0.68791	43.107	0.050	
Thomisus sp.1	0.85368	35.536	0.070	
Species	Axis Score	IWV(std) score	Abundance Score	Overall condition Score
Cyclosa sp.1	7.53	9	8	24.53
Thomisus sp.1	10	10	4	24.00
Pardosa timidula	8.00	6	7	21.00
Cyrtophora citricola	9.68	5	5	19.68
Cyrtophora ksudra	9.59	7	3	19.59
Gasteracantha geminata	7.74	8	2	17.74
Hippasa pisaurina	7.74	4	6	17.74
Neoscona biswasi	8.04	6	1	15.04

5.4 Discussion

The results of the study revealed vegetation structure (VGS1) and availability prey biomass were the most important variables influencing the richness, diversity and species abundance. Previous studies also have demonstrated that there are clear associations between spider abundance, species richness and diversity and the structural diversity of the habitat (Greenstone, 1984; Rypstra, 1986; Dennis et al., 1998; Halaj et al., 1998). Structural heterogeneity may also influence spider communities indirectly by its positive effect on prey densities; typical prey species such as herbivorous invertebrates (Nentwig, 1980) benefit from the greater variety of food resources available in more structurally diverse habitats (Siira-Pietikäinen et al., 2003). Increased vegetation complexity may also indicator of microhabitat features available and of the abundance of the resources, potential predators, and/ or competition in habitat. The availability of structures for attaching a web, and of ambush and refuge sites is probably the most direct effect of vegetative complexity, but other indirect effects may be related, such as, for example, microclimate, prey availability (Uetz, 1991; Marc et al., 1999). Regression model also indicated management intensity as an important factor determining spider diversity and richness. With high intensity management, spider communities often lack diversity and are dominated by a few *r*-selected species affiliated with bare ground. Low intensity management produces more complex communities introducing more niches for aerial web spinners and climbing spiders (Bell et al., 2001).

Ecologists increasingly use NMS as a tool for descriptive multivariate data analysis, and the principles and mechanics have been well documented (McCune and Grace, 2002). NMS is well suited to community data, particularly when β diversity is high (i.e., the data matrix contains many zeroes) (Faith et al., 1987) and provides robust analysis of many data types. In analyses of simulated data with known gradients, NMS has shown superior ability to recover underlying data structure compared to principal components analysis, principal coordinates analysis, reciprocal averaging, and detrended correspondence analysis (Fasham, 1977; Minchin, 1987). In the approach I present here, the NMS axes representing habitat variables are secondarily related to species assemblage structure through multiple regression analyses. This approach has several advantages for community analyses over the methods discussed above. It provides the opportunity for statistical hypothesis testing of complicated data sets by incorporating as much information from the raw data as possible while producing statistically tractable datasets for regression analyses, rather than simply being descriptive (Beals, 2006). Because the assumptions in NMS about the underlying structure of the data (e.g., response shapes) are less restrictive, it is more likely to produce ecologically meaningful variables for further analyses. The regression models for the data in this study explain relatively low amounts of variation. This is likely because other factors that influence spider communities, such as intra and inter specific competition or predation by vertebrates or other arthropods, were not incorporated. The low R^2 values indicate a problem with the data, not with the approach. The high stress values and comparatively lower variation explained in the variables ordinations suggest that the final configuration was not capturing the underlying data structure as effectively for this matrix, resulting in noise in the variables. In spite of the noisiness of the data, this approach allowed an interpretable analysis of complicated data sets in which the data themselves determined which of the original variables were important in these communities. Being able to explain at least some of the variation in these spider communities allows a broader understanding of the roles of habitat heterogeneity and disturbance factors. Animal communities are structured by a complicated set of interacting factors. Using an unconstrained, data-driven approach, this study has shown how multiple components of both habitat structure, cover, microclimate, disturbance and prey base are related to spider community structure, and elucidated the different responses of assemblage component (richness, abundance and diversity) at different taxonomic level (species and family). Understanding the simultaneous responses of assemblage to environmental variables constitutes an important step in community-level research. This study contributes not only to our knowledge of the community dynamics in an important group of terrestrial predators, but also to our ability to incorporate complicated community data in ecological research.

CCA has been widely used to analyse species–environment relationships. It is a direct method to ordinate sites along an environmental gradient (ter Braak, 1987). CCA in conjunction with WA had not been used before to establish sensitivity scores for spider assemblages. The idea to use numerical weights to account for observed differences in the species value or strength as indicator was introduced by Zelinka and Marvan (1961) for the Saprobien System, which was later revised by Friedrich (1990). Walley and Hawkes (1997) incorporated an indicator weight into the British BMWP scoring system (BMWP, 1978). The indicator weight strengthens and emphasises the species score. It also highlights those species that are highly tolerant to impact, either because they have a very broad ecological niche or because they are a group or cluster of species with different niche breadths rather than a single species. This study identify a suite of spider species that can be rapidly surveyed and used to judge the habitat and ecological conditions of the TCA, identify sites of high conservation value as well those in need of conservation and restoration. Of the 65 species analysed, the variation in the abundance of the nine species was significantly associated with the habitat heterogeneity gradient and five species with the disturbance gradient. Disturbance measured in this study relate to edge effects induced by the plantation forestry, increase frequency of fires in the grassland matrix, livestock farming at the forest edges, and indirect effect of flooding and siltation. Although current habitat conditions for spiders vary in TCA, with many causes, not addressed in the study, I show it is possible to link the heterogeneous habitat conditions to the response of individual species and species group such as family. The concept of indicator species here addressed because the management of the environment may be simplified and made more cost effective by considering a single or small group of indicator species whose response is easier to monitor than whole communities (McGeoch, 1998). A suite of spider species as ecological indicator here mentioned includes a broad range of species response that permit evaluation of habitat condition in general and not just perspective or single species used. Within the species here enlisted as potential indicators *Chrysoo* sp.1 and *Cyclosa* sp.1 exhibit significantly positive response to the disturbance and heterogeneity respectively. This two species are logical response if one species had to select.

In conclusion, spiders can be used as ecological indicators of Terai forests. This study shows that spider assemblages provide reliable assessment of the habitat condition in response to habitat heterogeneity and disturbance. Spiders seem well suited to discriminate habitat type and quality, since play important role as diverse and abundant invertebrate predators in terrestrial ecosystems. Forest managers should encourage the growth of ground layer vegetation species at all stages of the forest cycle, whilst retaining features typical of a mature forest in order to enhance the diversity of both open and forest species within a plantation patches. At a landscape scale, a mosaic of different aged plantations will provide the heterogeneity of habitat types necessary to sustain both open and forest specialists.

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CHAPTER 6

EFFECT OF GRASSLAND BURNING ON SPIDER ASSEMBLAGES

6.1 Introduction

6.1.1 Habitat Disturbance and Biodiversity

Globally, disturbances are recognized as important processes maintaining patterns of biological diversity in terrestrial and aquatic ecosystems (Rosenzweig and Abramsky, 1993). Disturbances alter habitat composition and resource availability through the loss of biomass, and as a consequence they can influence the diversity of assemblages that an ecosystem can support. In addition, disturbances have the ability to influence succession rates and trajectories, modifying vegetation associations and ecosystem diversity (Broncano et al., 2005; Farji-Brener et al., 2002; Ratchford et al., 2005). Therefore, because disturbances play a key role in determining patterns and processes which maintain biodiversity, successful management must be based on a sound understanding of the effects of major ecosystem disturbances on key components of biodiversity. Fires often lead to changes in environmental conditions, biomass, species diversity, and ecosystem function (Bengtsson, 2000). Ecological theory predicts that repeatedly and moderately disturbed ecosystems are likely to have the greatest species richness and to be highly resilient to disturbance (Connell, 1978; Walker, 1995). Local changes in environmental conditions after disturbance tend to switch the competitive balance between species, allowing a redistribution of dominance among species (Begon et al., 1999).

6.1.2 Prescribed Burning and Impact on Biodiversity

Prescribed burning is widely used to maintain native assemblages of fire-dependent plants and avoid destructive wildfires (Malanson, 1987). Using prescribed burning to reduce forest fuels, and thereby prevent or help suppress high intensity wildfires, has generated debate on the long term effects on biodiversity (Bradstock et al., 2002). Fire may indirectly affect arthropod communities by changing plant species composition and foliar characteristics, reducing the litter layer, and modifying soil moisture and temperature (Mitchell, 1990). Burning can lead to increased soil pH, and greater fluctuations in temperature and moisture, influencing vegetation composition (Haimi et al., 2000). Arthropods suffer exposure to greater extremes of temperature, light, and moisture, resulting in subsequent habitat loss (Buffington, 1967). However, arthropods protected from fire disturbance either by life history traits, location during fire, or behavioural characteristics that prevent mortality, can benefit following fire because of potential reductions in competitors and predators, increases in dead prey for scavengers, and more nutritional plant hosts. In particular, there is a paucity of information on the effects of fire on insects and other arthropods, which contribute most to faunal biodiversity and play key roles in ecosystem dynamics. This is a poor basis for effective ecosystem management (Andersen, 1999).

6.1.3 Tall Grasslands in India

The tall grasslands once extended across the Northern Gangetic plain from Uttar Pradesh, through the Nepalese Terai, to Bengal, north- western Assam, and South to West Bengal, being concentrated on the floodplains of Ganges and Brahmaputra rivers and their tributaries. However, these grasslands have suffered a rapid decline principally as result of land conversion for agriculture, intense livestock grazing, and are now entirely confined to protected areas of Uttar Pradesh, Assam and lowland Nepal (Peet et al., 1997).

These grasslands harbour a variety of floral and faunal life, including several endangered, charismatic and obligate species *viz.,* Great Indian One-horned rhinoceros (*Rhinoceros unicornis*), Swamp deer (*Cervus duvauceli duvauceli*), Hispid hare (*Caprolagus hispidus*) and Bengal florican (*Hubaropsis bengalensis*). Despite this, scant international attention has been paid to their conservation, and especially to applied management issues have yet to be addressed.

6.1.4 Tall Grasslands and Fire in India

Historically in Indian tall grassland, with a large area of habitat and a low human population, burning would probably have produced a mosaic of burned and unburned grassland and sites at different ages of post burn regeneration. Today, with increased human pressure on a limited habitat resource, virtually entire area of grassland inside protected area is burned annually. Tall grasslands are subjected to a high fire frequency making it advantageous for faunal species to exploit ephemeral habitat created by fire, ranging from fire front to post burn phases of vegetation regeneration. A range of habitats created by slow regeneration from fire over the years are not available as most areas are subjected to burn at least once annually. For faunal species a high degree of mobility is needed to exploit these ephemeral habitats. Apart from some obligate grassland species, most of the ungulates and birds exploit these habitats mainly for making use of food resources. Small mammals, reptiles, amphibians and invertebrates are generally less mobile and fire can have direct and indirect effects on these communities. The dramatic decline of hispid hare and pygmy hog has been partly due to annual burning of most of remaining tall grassland (Bell et al., 1990) in Terai.

6.1.5 Tall Grasslands, Fire and Biodiversity Conservation in India

While the effects of fire on vegetation are reasonably well documented in Terai Grasslands of India and Nepal (Lehmkhul, 1989; Peet et al., 1997; Kumar, 2002), for animals, and invertebrates in particular, there are no such studies (Peet et al., 1997; Kumar, 2002) addressed this issue. Within the Indian sub-continent, species inventories for invertebrates in tall grassland habitat are lacking and therefore, response of invertebrates to fire in this habitat is unknown (Peet et al., 1997). As fire occurs during dry seasons, with rising air temperature, drying soil and litter, its impact on invertebrates may be severe. The lack of understanding of fire effects is of particular concern given that fire is widely used as a management tool in many of the region's protected areas, where the primary aim has been the management of large game or, more recently, the conservation of biodiversity as a whole. Managers of protected areas alter the fire regime by deciding when, where and how fires should be lit. If the effects of these alterations on a variety of taxa are not well understood, then neither is their role in conserving biodiversity as a whole (Parr and Brockett, 1999; Keith et al., 2002). Given that there is a need to provide conservation managers with reliable information on the effects of burning on invertebrates, this study made use of fire experiment to investigate the responses of spider assemblage to burning regime.

By preying on decomposers at lower trophic levels, spiders influence ecosystem functioning (Lawrence and Wise, 2000, 2004). Moreover, spiders themselves respond to habitat variables altered by burning. Spiders respond markedly to altered litter depth, but also to changes in the structural complexity and nutrient content of litter (Uetz, 1991; Bultman and Uetz, 1982). Given their variety of functional roles, the responses of grassland spider to fire is likely to reflect the responses of a variety of other grass-layer invertebrates.

The aims of the current study were to (i) determine the effects season and frequency of burn and post-fire condition (time since fire) have on spider species richness and composition; (ii) compare the response of spider assemblages to fire in two different grassland types, and (iii) assess whether any changes in spider assemblage structure can be linked to differences in vegetation structure and habitat composition. I am particularly interested to determine the extent of the resistance (i.e. the extent of change following a disturbance) and resilience (i.e. the rate of return to a pre-disturbance state) of the spider assemblages to burning.

6.2 Methods

6.2.1 Study Site

The study was conducted at Dudhwa National Park which represents one of extensive tall grassland in Terai Region. The sub-tropical, tall wet grasslands in foothills of the Himalayas have been referred as ‘riverine’, ‘floodplain’, ‘tall’ or ‘Terai’ grasslands (Mathur, 2000; Lehmkuhl, 2000; Peet et al., 1999a, b; Wegge et al., 2000). These grasslands occur on the east-west stretch of northern alluvial lowland of Nepal and floodplains of river Ganges and Brahmaputra, well known as the Terai region. These grasslands are dominated by dense stands of perennial grass species belonging to family Poaceae, reaching up to 6-8 meters height, which form a dynamic complex with interspersed woodland and swamps. High water table, annual flooding, and the synergistic influence of annual grassland fires characterized this complex (Lehmkuhl, 1994; Peet et al., 1997 and 1999a, b). The topography is low lying, ill-drained, with a high water table. Rainfall is up to 4000 mm per annum. The soil reaction varies from very acidic to mildly alkaline, with a pH range of 4.5-7.5. The cover consists of nineteen principal grass species and 56 other herbaceous species, including sixteen legumes (Kumar et al., 2002). The tall grasslands in Terai are described as stages in the succession continuum between the primary colonization of new alluvial deposits by flood climax grass and herbaceous species, and the non-flooded climax deciduous Sal (*Shorea robusta*) dominated forest (Champion and Seth, 1968; Dabadghao and Shankarnarayan, 1973; Lehmkuhl, 1989, 1994). These grasslands are diverse and among the most productive in the world (Dinerstein, 1979a, b; Lehmkuhl, 1989). The two main grassland habitats within the park are the upland grasslands and lowland grasslands. The former occurred on drier or well-drained soils while the later type in low lying waterlogged sites or sites inundated during the monsoon or subsequent months. Floristically*, Imperata cylindrica, Saccharum spontaneum, Vetiveria zizanoides and Saccharum bengalensis* characterized the Upland grasslands. The Lowland grasslands were predominated by *Sclerostachya fusca,* *Phragmites karka, Arundo donax, Themeda arundinacea, Saccharum narenga* and *Saccharum spontaneum.* The grasses in upland grasslands usually attained height up to 2m while grasses in lowland grasslands were even 6m tall.

Sixteen grassland sites from burnt and unburnt areas in both grassland types were sampled from October 2006 to August 2007, representing 4 seasons of sampling. During sampling seasons a total of 8 sampling sites were established in each of the lowland and upland grassland habitats;4 on burnt areas and 4 on unburnt areas. Further, within burnt areas I assessed two fire regimes for their impact on grassland spider assemblage: (i) single fire, sites currently under management practices, burnt annually early in the dry season (January-February); (ii) repeated fire, sites burnt multiple times (as commonly occurs as uncontrolled) wildfires before the end of the dry season (January-May). At each site, ten plots were randomly established. Each plot consisted of a transect containing six sampling points at approximately 10 m intervals. These six points along transect were used for both spider sampling and grassland microhabitat assessment. Because the fires were relatively large in extent, it was ensured that sampling sites were at least 100m apart. Each plot measured approximately 60m × 60m and represented a different burning regime (season and fire frequency combination).

6.2.2 Spider Sampling

Spiders were collected using pitfall traps and sweep netting. One pitfall trap was set (pitfall traps consisted of cylindrical plastic bottles of 10 cm diameter and 11 cm depth. Traps were filled with preservative liquid (69 % water, 30% ethyl acetate and 1% detergent). After 2 days, specimens were removed from traps, which allowed me to maintain spider specimens in good conditions before taking them for laboratory processing and identification. Pitfall traps are an efficient means of collecting arthropods over long periods of time, despite their known drawbacks (Spence and Niemela, 1994). Sweep-nets were used to collect spiders from grass layer and above ground vegetation (up to 2 m in height) and I standardized the effort by sampling for 30 min. During which time sweep-net was stirred back and forth all ground layer herbs and shrubs till all vegetation in the sampling plot had been swept thoroughly. The sweep net consisted of a 91.4 cm handle, 40.6 cm ring, and collecting bag made of white canvas. A single sweep consisted of; 1) first stroke of the net started on the left and moved toward the right forming a 180 degree arc, 2) the second stroke covered the same area as the first stroke, but the net was moved in the opposite direction. Each sweep consisted of 500 strokes completed at 30 min interval. All adult spiders were identified to family and species using existing identification keys wherever possible (Pocock, 1900a; Tikader, 1982, 1987; Cushing, 2001; Koh, 2000). Juvenile spiders were excluded from the analyses as very few can be reliably identified to species (Norris, 1999). Voucher specimens of each spider species collected are deposited at Wildlife Institute of India, Dehradun and Arachnida Section, Zoological Survey of India, Kolkata.

6.2.3 Vegetation and Microhabitat Variables

Microhabitat variables were measured by placing a 1m^2 quadrat next to each pitfall trap. For each quadrat the percentage cover of grass (GCOV), litter (LCOV), and bare ground (BCOV) were visually estimated. Litter depth was the vertical height of the litter layer at each point. Litter depth (AVLD) was calculated as the average of 4 measurements from the quadrat. Number of grass species (GSC) of each quadrate was also counted. Grass height (GH) included the height of the tallest grass in each quadrat, as well as the standard deviation of the heights of the tallest grass in each of four points within the quadrat (a measure of structural heterogeneity; quadrats with relatively uniform heights of the tallest grass will have a lower SD than quadrats in which heights are high in one quarter and low in another, for example). Soil pH (SPH), soil moisture (SM) and soil temperature (STEMP) were measured using a soil pH and moisture tester and a WekslerTM mercury soil thermometer. Ambient moisture (AMMOI) was measured using hygrometer (Taylor Mason's hygrometer).

6.2.4 Analysis

Total species richness and abundance were compared between habitat types for all sampling periods using analysis of variance (ANOVA), and for each habitat type and sampling species richness and abundance were also compared between burnt and unburnt plots. ANOVAs were used to determine if there were any significant differences in species richness and abundance between unburnt (control) and burnt plot treatments for each sampling season separately, and combined. This was done for the upland and lowland grassland habitat separately. Because the use of ANOVA requires that data are normally distributed, data were log transformed where necessary.

To compare species richness between fire regimes, individual based rarefaction was used as a measure of sampling effort, as recommended by Gotelli and Colwell (2001). For direst statistical comparison of accumulation curves, I standardize curves of different datasets on the basis of number of individuals and not on number of samples and calculated the number of species observed ± the 95% confidence interval using the analytical formula proposed by Colwell et al., (2004). The software program EcoSim 7.0 (Gotelli and Entsminger, 2001) was used for rarefaction analyses. Thereafter, the curves were rarefied to the lowest number of individuals recorded (21) to ensure valid comparisons of species richness between different fire regimes (Gotelli and Colwell, 2001). I used the Bray-Curtis index based on abundance to examine the species turn over between fire regimes. The value of the index is one when species turn over of the data being compared are same and index drops to zero when there are no species common between samples (Magurran, 2003). I also counted the observed number of shared species. Given that any measure of the beta diversity depends on the number of shared and exclusive species between samples, I also calculated the estimated number shared species using procedure proposed by Chao et al., (2005) with the routine provided by Estimate S version (Colwell, 2005). The reason for comparing the observed and estimated number shared species is obtain additional information regarding the exactness of the measure of observed beta diversity (Chao et al., 2005).

A visual representation of diversity was provided by species-abundance distributions of k-dominance curves (Lambshead et al., 1983). In the curves, the percentage abundance of each species, ranked in decreasing order of dominance, is plotted cumulatively. Lambshead et al., (1983) noted that, whenever two k-dominance curves do not intersect, all diversity indices yield a higher diversity for the sample represented by the lower curve. However, when curves do intersect, the assemblage which is taken to be the more diverse depends on the diversity index chosen.

Multivariate community analyses were undertaken using PRIMER v.5.0 (Clarke and Gorley, 2001) to assess overall changes in spider assemblage composition. Bray–Curtis similarity measures were used to determine whether spider assemblage structure varied between seasons, and within and between- habitats. Data were fourth-root transformed prior to analyses to reduce the weight of common species. Analyses of similarity (ANOSIM) were used to establish if there were significant differences in the spider assemblages on plots that differed in burn season (Oct-Nov, Jan-Feb, Apr-May and Jul-Aug) and frequency (single fire, repeated fire and unburnt/control). The ANOSIM procedure of PRIMER is a non-parametric permutation procedure applied to rank similarity matrices underlying sample ordinations (Clarke and Warwick, 2001). ANOSIM produces a global *R*-statistic, which is an absolute measure of distance between groups. An *R*-value approaching one indicates strongly distinct assemblages, whereas an *R*-value close to zero indicates that the assemblages are barely separable. These *R*-values were used to compare spider assemblages between habitat types, fire frequency and burn plot treatments within and between sampling periods. *R*-values may occasionally be very low, indicating that assemblages are barely separable, but these values may also be significantly different from zero. This reflects a high number of replicates or samples, and the fact that *R* is inconsequentially small is of greater importance (Clarke and Warwick, 1994). The converse may also be found, where *R*-values may be very high (indicating that assemblages are almost completely different) but these values are not significant. This situation occurs when the sample size is small, and in such instances the *R*-value is of greater importance (Clarke and Gorley, 2001). The relationships between habitat types, fire frequencies and burn plot treatments for all sampling periods were displayed using non-metric multidimensional scaling (nMDS) ordinations. These were iterated several times from at least 10 different starting values to ensure that a global optimum was achieved (indicated by no decline in the stress value) (Clarke and Gorley, 2001). In addition, the similarity percentage (SIMPER) procedure was used to determine which species were good discriminators of differences in diversity between burnt and unburnt sites. SIMPER measures the percentage contribution of each species to the dissimilarity between samples (Clarke and Warwick, 2001).

Finally, spider species characteristic of the two habitat types, and of single fire, repeated fire and unburnt plots in each area, were identified using the Indicator Value method (Dufrêne and Legendre, 1997). This analysis assesses the degree to which a species fulfils the criteria of specificity (uniqueness to a particular habitat) and fidelity (frequency of occurrence). A high indicator value (IndVal, expressed as percentage) indicates that a species can be considered characteristic of a particular habitat or site. This method can derive indicators for hierarchical and non-hierarchical site classifications, and is robust to differences in the numbers of sites between site groups (McGeoch and Chown, 1998). Indicator values for each species were calculated based on a species abundance matrix, and Dufrêne and Legendre's (1997) random reallocation procedure of sites among site groups was used to test for the significance of IndVal measures for each species. Species with significant IndVals> 70% were considered as species characteristic of the site or habitat in question (subjective benchmark; McGeoch et al., 2002). Monte-Carlo randomization tests are used to determine if the value is greater than expected by chance; thus, species with only one or a very few total individuals are unlikely to be considered indicators, even if they appear in only one habitat type (McCune and Grace, 2002). PCOrd (McCune and Mefford, 1999) was used for this analysis.

The BIOENV procedure in PRIMER was used to examine the relationship between habitat variables on the plots and the spider assemblages (Clarke and Gorley, 2001). BIOENV produces a rank-correlation coefficient (choice of 3) among measures for the biological distance among sites (calculated by using assemblage composition data) plotted against measures for environmental distance among sites (calculated by using disturbance and habitat data in this study, Clarke and Ainsworth, 1993). This is first performed using single environmental variables, then pairs of variables, then three variables combined, and so on, until the full environmental data set is used. At each level of complexity, BIOENV calculates the degree to which the rank order of association measures within the association matrix (produced by the selected environmental variables) correlates with that produced using the biological data. The inclusion of variables that have no effect on the composition of assemblages tends to decrease the correlation, so that the optimum set of environmental variables and the degree to which they explain the underlying biotic pattern emerges.

BIOENV is a non-parametric analysis tool used for comparing two different similarity matrices (i.e. Bray–Curtis and Euclidean/biotic and abiotic) giving Spearman rank correlations for different combinations of variables (rho). A single, among site species similarity matrix was constructed using Bray–Curtis similarity measures, while several similarity matrices were constructed for each of the possible combinations of the specified habitat variables using Euclidean similarity measures. Spearman's rank correlation coefficients (ρ) were then calculated for the species matrix and each of the possible habitat matrices. The variable or set of variables that have the highest ρ-value are those that best explain the species data (Clarke and Gorley, 2001). Unfortunately this ρ-value does not produce an associated significance value. Data were (log+1) transformed where necessary in order to fulfil assumptions of normality for the Euclidean similarity matrices.

6.3 Results

6.3.1 Species Richness, Abundance and Fire Effects

A total of 10,172 individuals were collected during the entire sampling period, represents 98 species belonging to 58 genera and 22 families (Table 6.1). There was a significant difference in species richness between two grassland types (ANOVA, $F_{1,\ 158}$ = 48.10, $P<0.0001$). Mean species richness per plot was higher at lowland grassland (mean 24.81 species plot^{-1}, S.E. = 1.01) compare to upland grassland (mean 15.84 species plot^{-1}, S.E. = 0.79) (Fig. 6.1a).

Table 6.1. Abundance and species richness for each area in Terai grassland per sampling periods. n = total number of plots summed across all sites, and sampling seasons.

	Lowland Grassland	**Upland Grassland**
	(n=160)	**(n=160)**
Abundance		
Oct-Nov	3245	2509
Jan-Feb	246	40
Apr-May	817	172
July-Aug	1830	1298
Species richness		
Oct-Nov	80	80
Jan-Feb	24	5
Apr-May	74	29
July-Aug	79	74

There was significant difference in species richness between sampling seasons (ANOVA, $F_{3,365}$= 369.31, $P<0.001$) (Fig. 6.1.b). Mean species richness of spider significantly varied across sampling seasons for both lowland grassland (ANOVA, $F_{3,316}$=218.29, $P<0.005$) and upland grassland (ANOVA, $F_{3,316}$=209.68, P<0.005) types. When all burn plots were compared to unburnt plots, significant difference was found between mean species richness for upland (ANOVA, $F_{1,78}$=88.87, $P<0.0001$) and lowland grasslands (ANOVA, $F_{1,78}$=189.30, $P<0.0001$) (Fig.6.1.a).This was inconsistent for all sampling seasons: Oct-Nov ($F_{1,158}$= 124.26 P<0.0001); Jan-Feb ($F_{1,158}$=13.31, P<0.0001); Apr-May ($F_{1,158}$=4.11, P<0.05); July-Aug ($F_{1,158}$=64.19, P<.0001). There was significant difference in spider abundance between two habitats (ANOVA, $F_{1,158}$=16.19, P<0.0001). Mean abundance was higher at lowland grassland (Fig. 6.1a). There was significant difference in abundance between burnt and unburnt, control plots for both lowland (ANOVA, $F_{1,78}$=191.11, P<0.0001) and upland grassland (ANOVA, $F_{1,78}$=123.64, P<0.0001) (Fig. 6.2b). Mean abundance of spider significantly varied across sampling seasons for lowland grassland (ANOVA, $F_{3,256}$=4.55. P<0.005) and upland grassland (ANOVA, $F_{3,256}$ =4.42. P<0.006) types. There was significant difference in mean abundance among sites of fire regimes (ANOVA, $F_{2,117}$=17.06, P<0.0001). The mean species richness also varied significantly (ANOVA, $F_{2,117}$=17.06, P<0.0001) among sites corresponding to three fire regimes (Fig. 6.3).

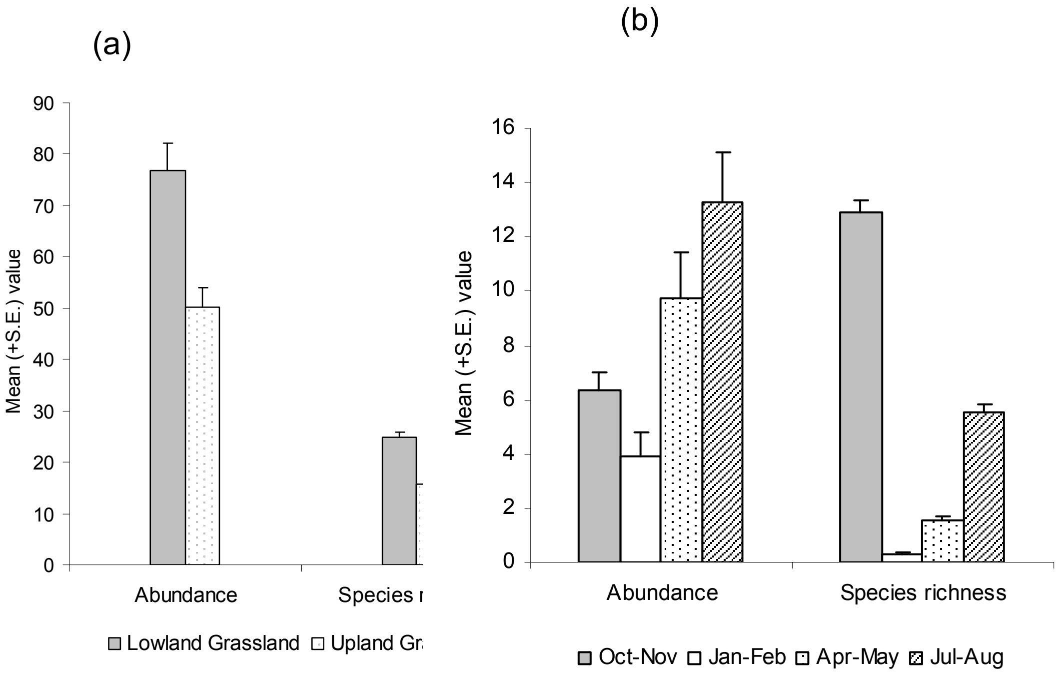


Fig. 6.1 Mean species richness and mean abundance of spiders in (a) two grassland types and (b) four sampling seasons. Error bars are +1 standard error.

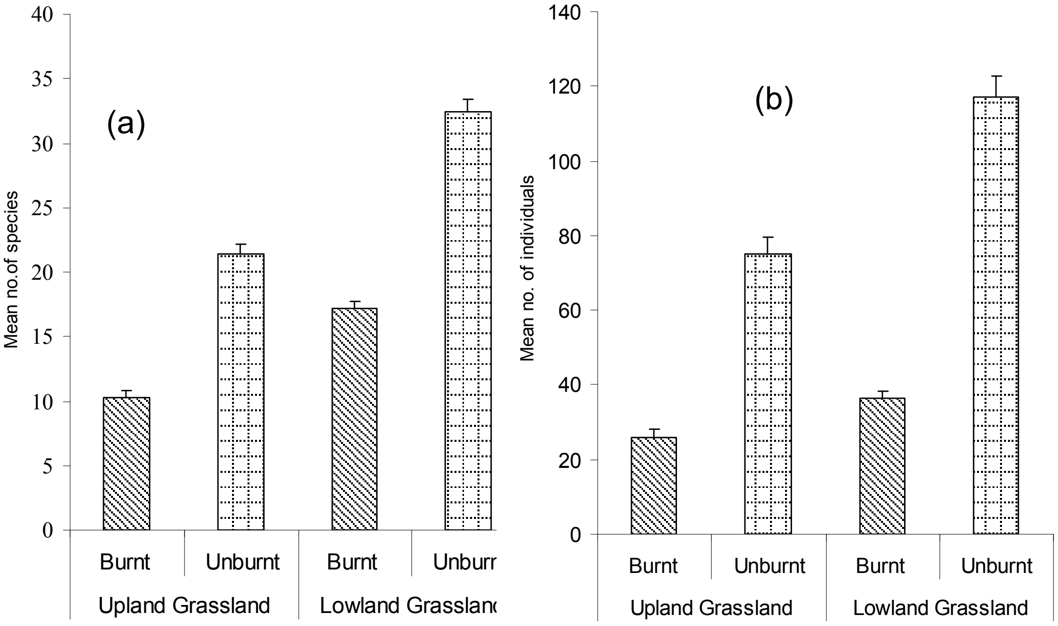


Fig. 6.2 Mean number of (a) species and (b) individuals of spiders in burnt and unburnt sites of lowland and upland grassland habitat. Error bars are +1 standard error.

Comparing species accumulation curve at the lowest abundance value (21 individuals), rarefied species richness seems to have higher in single fire sites than unburnt and repeated fire sites. However, the overlap of confidence interval of richness value for unburnt and repeated fire sites suggests there were no statistical difference exists (Fig. 6.4). The analysis of species turnover indicates that similarity was never greater than 60% (Fig. 6.5). According Bray-Curtis index single fire sites hold most dissimilar assemblage, while repeated fire sites showed maximum similarity. In all comparison, the number of observed species was lower than expected, most notably of single fire sites and unburnt sites. The observed mean number of shared species was 49 and 56 of single fire sites and repeated fire sites respectively.

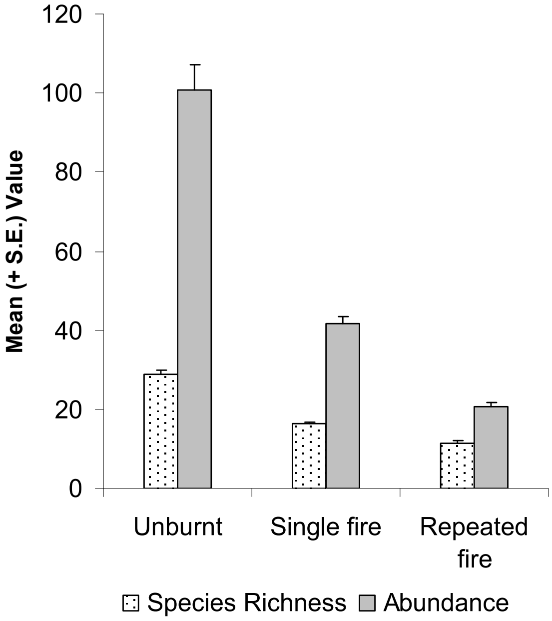


Fig. 6.3 Mean number of species and individuals of spiders in unburnt, single fire and repeated fire sites of grassland habitat. Error bars are +1 standard error.

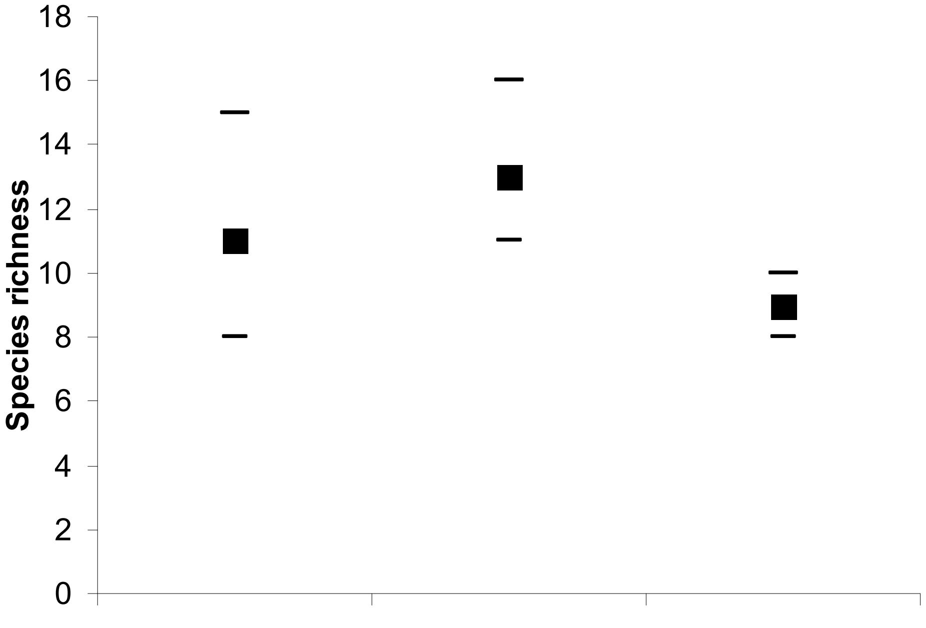


Fig. 6.4 Comparison of species richness values (±95% confidence interval) at the lowest number of individuals (21) derived from individual-based species rarefaction curves of spider assemblages across the different fire regimes.

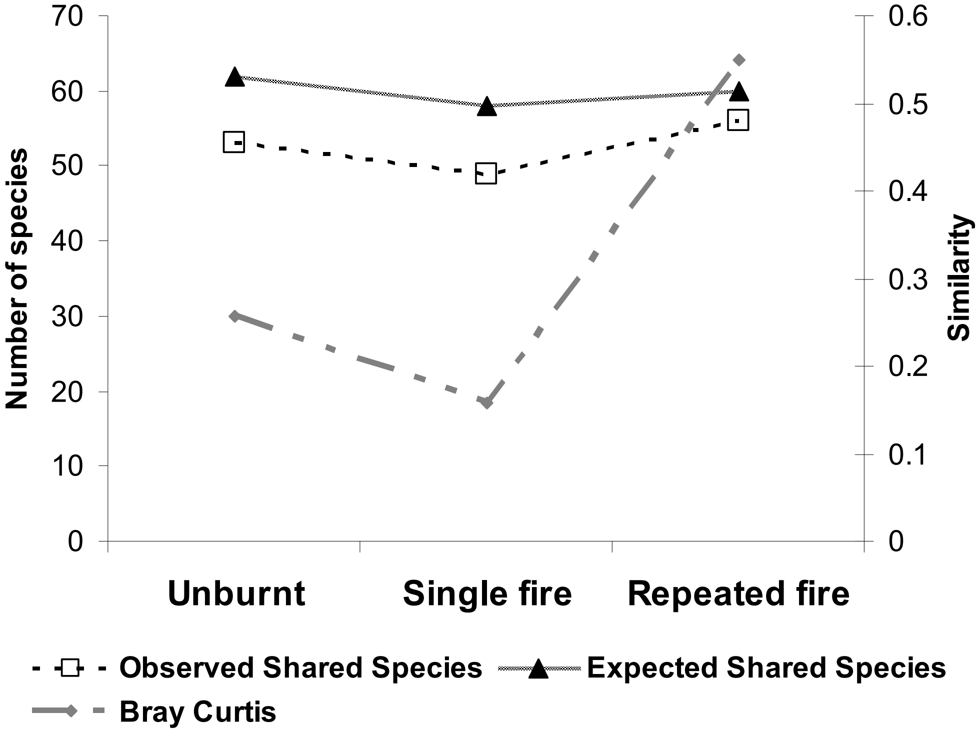


Fig. 6.5 Species turn over between fire treatments using Bray-Curtis Index. The observed number of shared species (open squares) and expected number of shared species (closed triangle) are also given.

Vertical distribution of diversity in unburnt and burnt sites for each sampling season is represented by means of k-dominance plots. In lowland grassland, highly diverse assemblage represented by unburnt plots of Oct-Nov, while least diverse assemblage was found for burnt plots of Jan-Feb (Fig. 6.6). In case of Upland Grassland there was no such consistent trend found, except burnt and unburnt sites of Jan-Feb which was significantly differed from other sites (Fig. 6.7). In upland grassland, season of sampling appeared to have a lesser effect on species rank-abundance curves.

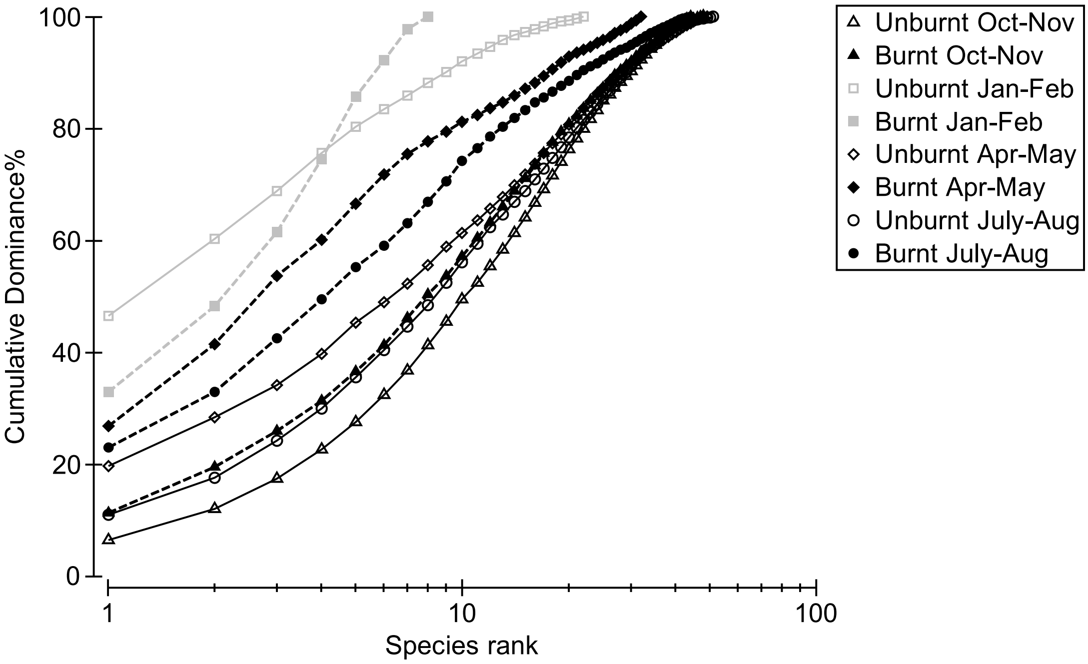


Fig. 6.6 K dominance curve (cumulative dominance vs species rank) for spider assemblage of burnt and unburnt sites in lowland grassland.

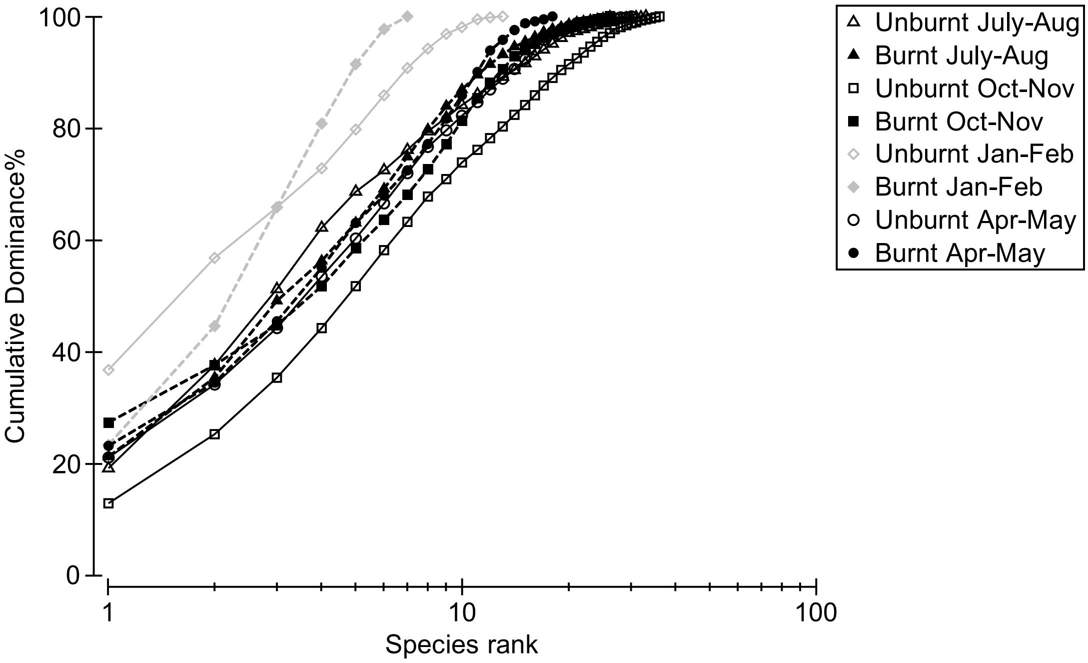


Fig. 6.7 K dominance curve (cumulative dominance vs species rank) for spider assemblage of burnt and unburnt sites in upland grassland.

6.3.2 Community Composition

There were significant differences between the spider assemblages occupying the two different grassland types (Global R= 0.351, P<0.002; Fig. 6.8). Pairwise ANOSIM test revealed that unburnt sites are significantly different form single fire and repeated fire sites in both the grassland (Table 6.2). Though, the effect of fire frequency was more pronounced in upland grassland, discriminating single fire and repeated fire sites (Fig. 6.9). MDS plots revealed that the effect of fire frequency on assemblage composition in lowland grassland is highly variable (Fig. 6.10). Compare to frequency of fire, ANOSIM result showed small effect of season of fire. Moreover, difference in spider assemblages to season of fire was more pronounced in upland grassland. Though, after burning assemblage differed significantly in lowland grassland. Results revealed a distinct shift in species composition from pre burn period (Oct-Nov) to post burn period (Jul-Aug) in upland grassland (Fig. 6.11-12). Similarity percentages revealed that the shift in community composition between pre and post burn period was driven by distinct difference in the occurrence of many taxa (Table 6.4). For example, *Leucage decorata*, *Oxyopes elongates* (Oxyopidae), *Oxyopes sertatus* (Oxyopidae) and *Pisaura decorta* (Pisauridae) occurred most frequently in the preburn period while conversely, *Myrmarachne himalayensis* (Salticidae), *Hippasa himalayensis* (Lycosidae), and *Cheiracanthium adjacens* (Miturigidae) were captured more frequently from sites having burnt late.

Table 6.2 Analysis of similarity (ANOSIM) for spider assemblage between sites for lowland and upland grassland of four sampling season.

Fire parameter	Lowland Grassland		Upland Grassland	
	R	*P*	R	*P*
Frequency				
Unburnt vs Single fire	1.000	0.007	1.000	0.006
Unburnt vs Repeated fire	1.000	0.007	1.000	0.006
Single fire vs Repeated fire	0.750	0.033	1.000	0.033
Season				
Oct-Nov vs Jan-Feb	0.195	0.056	0.249	0.013
Jan-Feb vs Apr-May	0.052	0.589	0.165	0.055
Apr-May vs July-Aug	0.171	0.033	0.051	0.221
Oct-Nov vs Apr-May	0.289	0.020	0.205	0.028
July-Aug vs Oct-Nov	0.520	0.001	0.165	0.061
July-Aug vs Jan-Feb	0.313	0.007	0.250	0.015

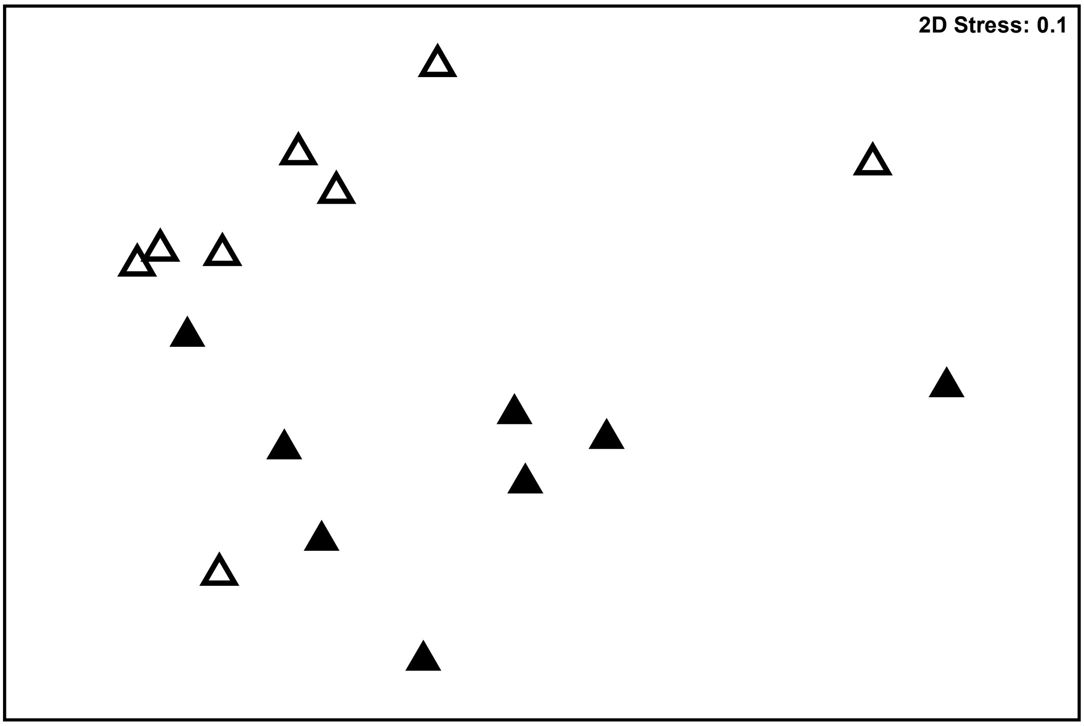


Fig. 6.8 Non-metric multi-dimensional scaling ordination of abundance of spider assemblages in two different grassland habitats in Terai grassland (open triangle, lowland grasslands and closed triangle, upland grasslands).

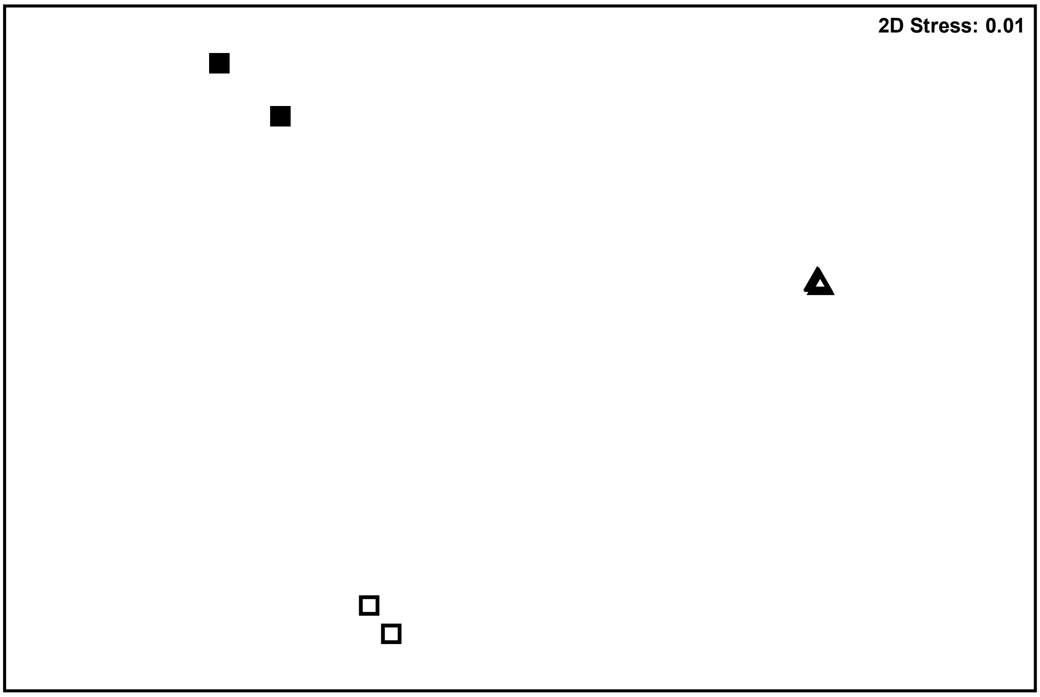


Fig. 6.9 Non-metric multi-dimensional scaling ordination of abundance of spider assemblages in upland grassland habitat in Terai grassland, based on frequency of burn (open triangle, unburnt sites; open square, single fire sites and closed square, repeated fire sites).

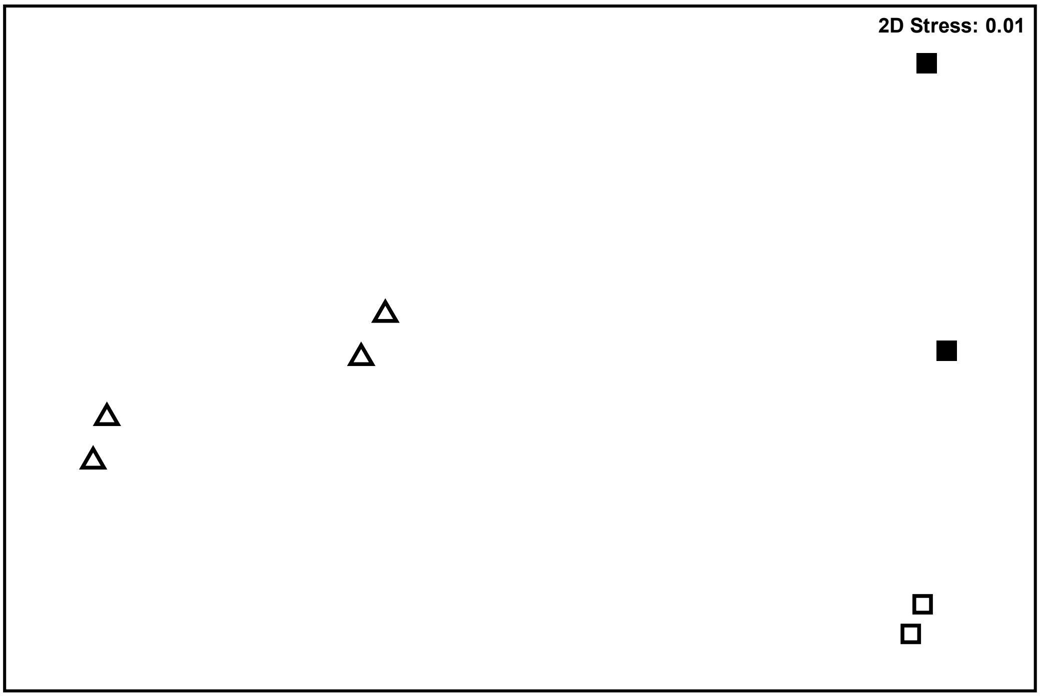


Fig 6.10 Non-metric multi-dimensional scaling ordination of abundance of spider assemblages in lowland grassland habitat in Terai grassland, based on frequency of burn (open triangle, unburnt sites; open square, single fire sites and closed square, repeated fire sites).

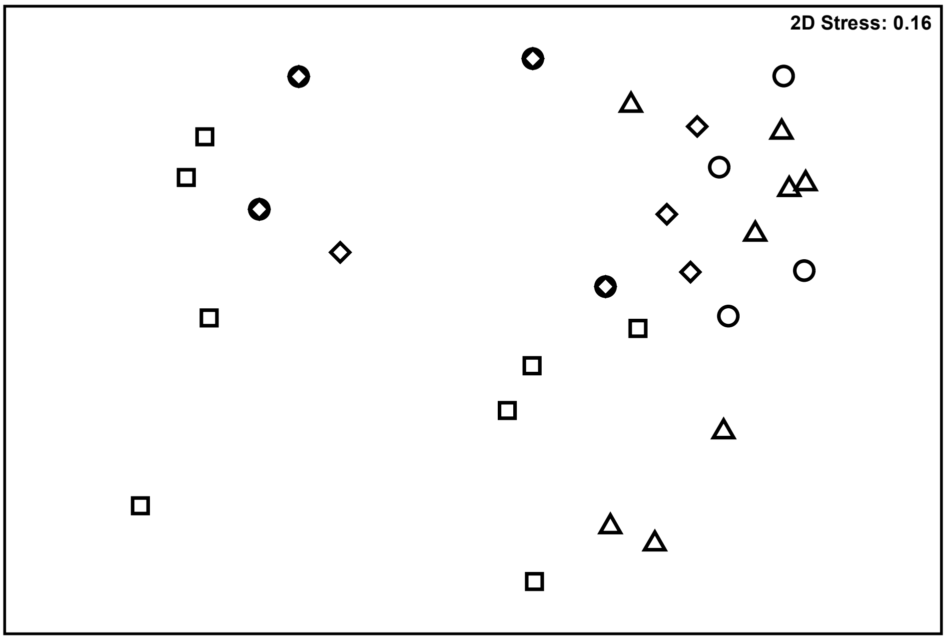


Fig. 6.11 Non-metric multi-dimensional scaling ordination of abundance of spider assemblages in lowland grassland habitat in Terai grassland, based on season of burn. open triangle, Oct-Nov (Pre burn); open square, Jan-Feb (Burn); open diamond, Apr-May (Post Burn 1) and open circle, (Post Burn 2).

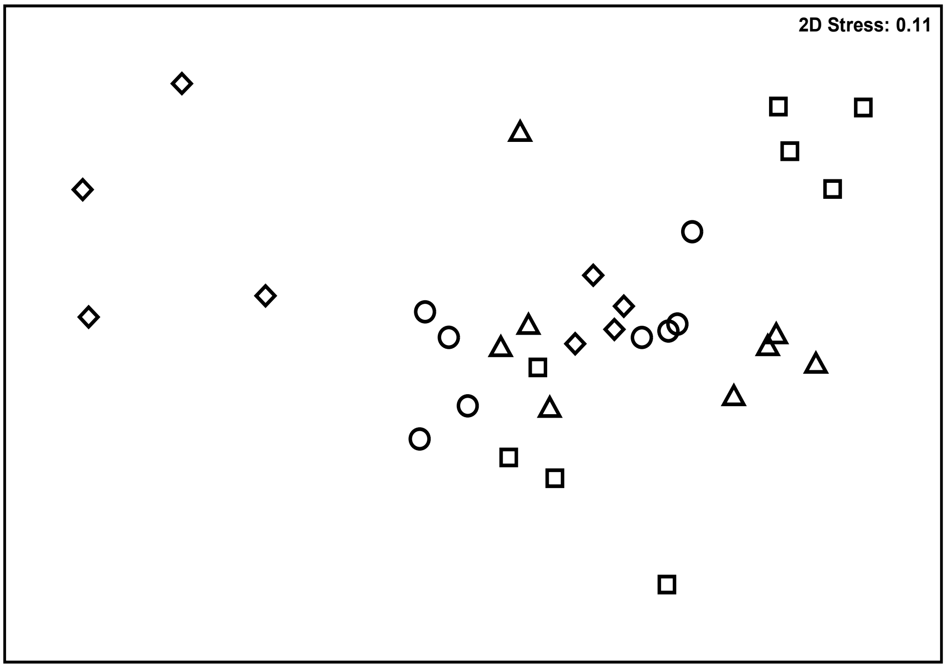


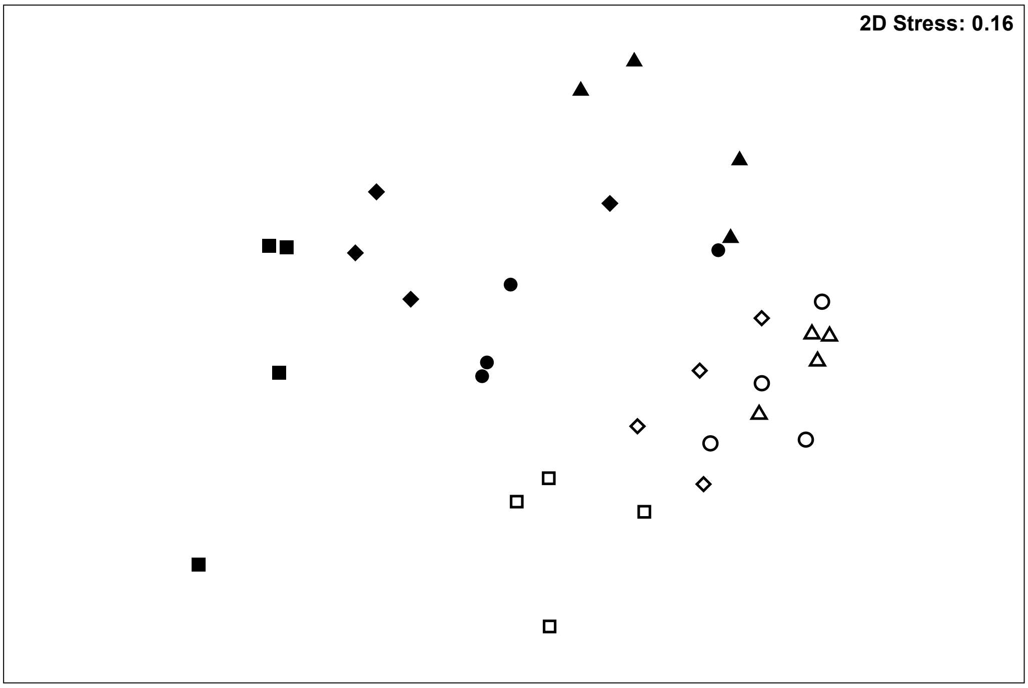
Fig 6.12 Non-metric multi-dimensional scaling ordination of abundance of spider assemblages in upland grassland habitat in Terai grassland, based on season of burn. open triangle, Oct-Nov (Pre burn) ; open square, Jan-Feb (Burn); open diamond, Apr-May (Post Burn 1) and open circle, (Post Burn 2).

Multivariate analysis indicated that response of spider assemblage between burnt and unburnt sites corresponding to two grassland types. Assemblage composition between burnt and unburnt sites during four sampling seasons differed significantly but more pronounced in upland grassland (R=0.721, *P*=0.001) than lowland grassland (R=0.661, *P*=0.001). However, in both the grassland type, species composition differed distinctly just after burring (Jan-Feb) (Table 6.3 and Fig. 6.9)

Table 6.3 Analysis of similarity (ANOSIM) for spider assemblage between burnt and unburnt sites for lowland and upland grassland of four sampling season.

	Lowland Grassland		**Upland Grassland**	
	R	*P*	*R*	*P*
Unburnt vs Burnt				
Oct-Nov	0.719	0.029	0.839	0.029
Jan-Feb	1	0.029	1	0.029
Apr-May	0.896	0.029	1	0.029
July-Aug	0.708	0.029	0.74	0.029

(a)



(b)

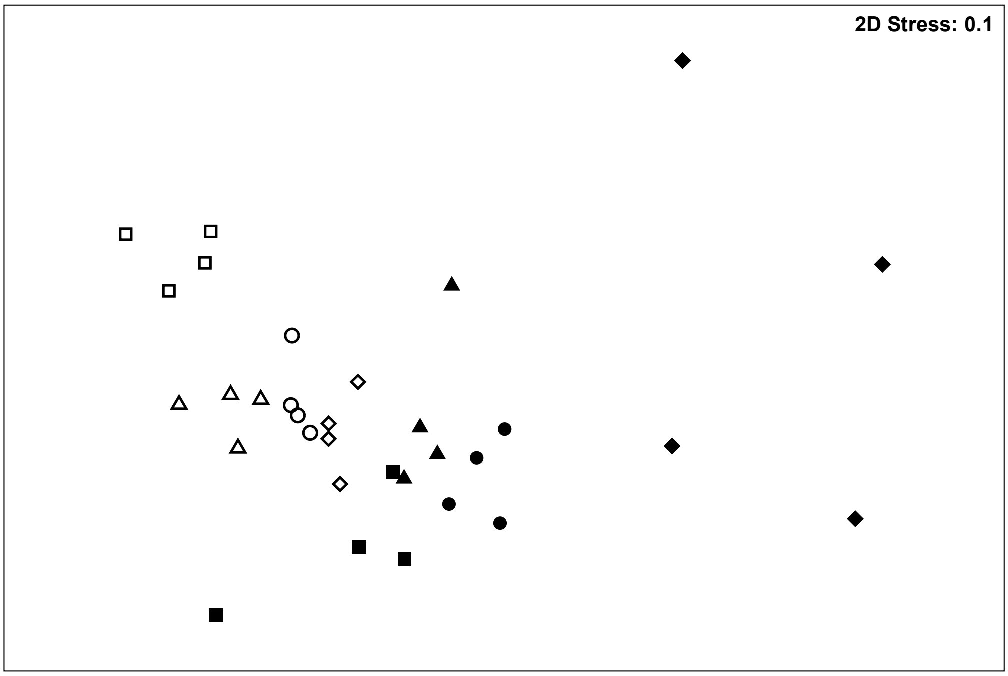


Fig. 6.13 Multi-dimensional scaling ordination for burnt and unburnt sites for four sampling season: (a) lowland grassland, and (b) upland grassland. (open triangle, unburnt Jul-Aug; closed triangle, burnt Jul-Aug; open square, unburnt Oct-Nov; closed square Oct-Nov; open diamond, unburnt Jan-Feb; closed diamond, burnt Jan-Feb; open circle, unburnt Apr-May; closed circle burnt Apr-May). Each point of the ordination represents a sampling site in the respective habitats and seasons.

Table 6.4 Species contributing most to average dissimilarity between burnt and unburnt sites for each of the sampling seasons. Results from SIMPER analysis shown as percentage contribution.

Habitat	Species	Percentage Contribution to Dissimilarity
Lowland Grassland		
Oct-Nov	*Achaearanea budana*	5.95
	Pardosa minuta	5.40
	Agelena inda	5.08
Jan-Feb	*Pardosa birmanica*	32.38
	Hippasa himalayensis	12.58
	Trochosa himalayensis	8.53
Apr-May	*Myrmarachne himalayensis*	13.15
	Leucauge celebasiana	9.25
	Pardosa birmanica	5.79
July-Aug	*Leucauge decorata*	9.70
	Myrmarachne himalayensis	8.92
	Oxyopes birmanicus	5.49
Upland Grassland		
Oct-Nov	*Gnaphosa stoliczka*	9.00
	Hippasa himalayensis	8.69
	Agelena inda	8.10
Jan-Feb	*Hippasa himalayensis*	35.78
	Hippasa pisaurina	16.28
	Pardosa birmanica	7.80
Apr-May	*Pardosa birmanica*	18.47
	Hippasa himalayensis	11.04
	Arctosa indica	8.93
July-Aug	*Pardosa birmanica*	15.47
	Trachelas himalayensis	14.18
	Hippasa pisaurina	11.11

6.3.3 Fire Regime Effect on Individual Species

Given that the responses of spider assemblages to fire lay between burnt and unburnt control plots only, and between burning seasons, IndVal analyses were carried out to identify characteristic species, first with lowland and upland grassland plots only, and secondly (based on hierarchical clustering) classified according to grassland and plot type (control and burnt plots) prior to analysis. This second IndVal analysis, using all burn plots classified either as burnt (including variable plots) or control plots, allowed the robustness and applicability of potential indicators identified from the first analysis to be confirmed. The third IndVal analysis was performed on sites differed by fire frequency (single and repeated fire).

Using abundance data from all plots, IndVal analyses revealed that there were three species considered as characteristic of upland grasslands and two of lowland grasslands irrespective of burnt and unburnt plots. Potentially reliable indicators for both the habitat type were found for the lowland and upland grassland areas (Table 6.5). At lowland grassland, there were only four species characteristic of control plots, and two species characteristic of burnt plot types were found. Upland grassland had fewer characteristic species with high abundance and high site fidelity than lowland grassland. For single fire sites, all three species identified as indicators of annually burnt plots were indicators of burnt plots when plots were classified as burnt plots, i.e. with a coarser classification (Table 6.6). This served to confirm the robustness of species such as *Drassodes parvidens* and *Plexippus redimitus* as indicators of burnt areas. Only one spider species could be considered indicator of the repeated burnt treatment, *Haplodrassus morosus*, a hunting spider belongs family to Gnaphosidae

Table 6.5 Percentage indicator values (Ind Val) of spider assemblages for each habitat and burn site type (hierarchical clustering). *P* Values of corresponding each IndVal value is less than 0.001.

Classification	Lowland Grassland	Ind Val	Upland Grassland	Ind Val
Habitat	*Dictyna albida*	73.5	*Drassodes parvidens*	43.3
	Cheiracanthium adjacens	59.4	*Oxyopes elongatus*	39.1
	Oxyopes birmanicus	48.8		
Lowland Grassland	Unburnt plots		Burnt plots	
	Telamonia sikkimensis	100	*Trochosa ruricoloides*	82.5
	Leucauge decorata	97.5	*Plexippus redimitus*	62.5
	Pardosa kupupa	92.5		
	Leucauge celebasiana	87.5		
Upland Grassland	Unburnt plots		Burnt plots	
	Pardosa kupupa	92.5	*Haplodrassus morosus*	62.5
	Arctosa indica	79.3	*Trochosa ruricoloides*	52.5
	Agelena inda	75.2		
	Leucauge decorata	72.5		
Fire Frequency	Single fire		Repeated fire	
	Plexippus redimitus	78.1	*Haplodrassus morosus*	62.5
	Clubiona deletrix	76.8		
	Drassodes parvidens	70.2		

6.3.4 Microhabitat Composition

Microhabitat composition varied considerably between burnt and unburnt sites in both habitats during each of the sampling periods. In the lowland grassland during the burn season (Jan-Feb) litter depth and grass height was four times greater in unburnt habitat; whilst bare ground on burnt sites was nearly double that on unburnt sites (Table 6.6). During the dry season in the lowland grassland habitat grass cover was again significantly higher on unburnt plots, whilst bare ground was higher on burnt plots (Table 6.6). During the same sampling period there were also significant differences in percent cover of exposed wood between burnt and unburnt lowland grassland sites. In the Upland grassland there were significant differences in the soil moisture, bare ground, and grass cover during the burn season (Jan-Feb), and except bare ground remaining all microhabitat variables vary significantly during the post burn seasons (Table 6.7). In all cases there was a greater percentage of grass, litter on unburnt sites, compared to an increase in exposed rock and bare ground on burnt sites (Table 6.7). This is consistent with the physical properties of fire: burning cured vegetation and leaf litter to expose bare ground and rocky substrates.

Table 6.6 Kruskal Wallis results for differences in mean of microhabitat variables between burnt and unburnt sites for lowland grassland habitat during four sampling seasons. (CSV denotes chi square value)

	Oct-Nov				**Jan –Feb**				**Apr-May**				**Jul-Aug**			
	Unburnt	Burnt	CSV	Sig	Unburnt	Burnt	CSV	Sig	Unburnt	Burnt	CSV	Sig	Unburnt	Burnt	CSV	Sig
SPH	6.19	3.09	57.18	0.00	6.16	7.00	50.97	0.00	3.82	4.76	28.91	0.00	3.16	4.59	53.75	0.00
SM	6.90	5.60	52.48	0.00	5.36	1.72	60.21	0.00	5.48	4.52	47.89	0.00	7.03	6.22	39.28	0.00
STEMP	6.03	6.43	0.59	**0.44**	18.40	30.98	46.68	0.00	22.50	24.40	14.40	0.00	10.75	14.58	52.63	0.00
AMMOI	87.23	82.88	18.34	0.00	75.58	72.95	5.41	**0.02**	84.13	74.08	59.62	0.00	89.75	83.18	47.98	0.00
GSC	5.38	2.30	58.40	0.00	4.40	1.50	56.25	0.00	4.40	3.85	2.74	**0.10**	6.28	3.68	37.60	0.00
LCOV	0.02	0.05	30.14	0.00	0.72	0.18	54.02	0.00	0.03	0.05	13.47	0.00	0.04	0.07	13.49	0.00
GCOV	1.24	1.09	49.74	0.00	0.81	0.06	61.66	0.00	0.99	0.86	57.98	0.00	1.18	1.02	60.33	0.00
BCOV	0.04	0.06	13.29	0.00	0.08	0.83	55.40	0.00	0.14	0.19	32.51	0.00	0.04	0.08	16.24	0.00
AVLD	6.94	2.99	59.49	0.00	4.22	0.47	60.22	0.00	3.98	2.49	56.62	0.00	5.85	2.81	40.69	0.00
GH	6.21	5.78	25.37	0.00	3.42	0.17	59.99	0.00	3.24	2.39	42.51	0.00	6.26	4.71	59.34	0.00

Table 6.7 Kruskal Wallis results for differences in mean of microhabitat variables between burnt and unburnt sites for upland grassland habitat, during four sampling seasons. (CSV denotes chi square value)

	Oct-Nov				**Jan –Feb**				**Apr-May**				**Jul-Aug**			
	Unburnt	Burnt	CSV	Sig	Unburnt	Burnt	CSV	Sig	Unburnt	Burnt	CSV	Sig	Unburnt	Burnt	CSV	Sig
SPH	6.11	2.52	59.98	0.00	6.17	7.27	58.81	0.00	4.03	6.54	59.32	0.00	6.11	2.52	59.47	0.00
SM	6.50	4.40	59.95	0.00	5.10	1.69	62.36	0.00	5.09	3.85	40.14	0.00	6.50	4.40	49.86	0.00
STEMP	9.60	10.20	4.50	0.03	17.35	40.15	59.48	0.00	21.33	27.18	51.65	0.00	9.60	10.20	60.41	0.00
AMMOI	80.10	75.55	27.15	0.00	86.07	67.05	51.88	0.00	82.02	67.38	59.98	0.00	80.10	75.55	46.26	0.00
GSC	5.18	1.95	60.60	0.00	4.73	1.42	58.23	0.00	4.30	1.52	60.50	0.00	5.18	1.95	61.38	0.00
LCOV	0.03	0.06	17.94	0.00	0.74	0.01	66.41	0.00	0.04	0.08	14.85	0.00	0.03	0.06	9.02	0.00
GCOV	1.22	1.03	58.73	0.00	1.34	0.02	65.22	0.00	0.92	0.80	60.36	0.00	1.22	1.03	61.03	0.00
BCOV	0.04	0.09	27.59	0.00	0.19	0.86	29.15	0.00	0.16	0.20	17.05	0.00	0.04	0.09	3.97	0.05
AVLD	6.30	2.37	59.62	0.00	5.42	0.74	59.42	0.00	3.33	1.74	58.75	0.00	6.30	2.37	42.12	0.00
GH	6.27	5.55	41.24	0.00	4.42	0.23	61.95	0.00	2.69	1.81	31.96	0.00	6.27	5.55	59.41	0.00

6.3.5 Habitat Variables and Fire Effects

BIO ENV analysis revealed that at lowland grassland the overall pattern in spider assemblages were best explained by grass cover (rho=0.83), grass height (rho=0.73) and soil moisture (rho=0.70). In upland grassland, habitat variables that best explained the overall pattern in spider assemblages were grass cover (rho=0.75), grass height (rho=0.62) and litter depth (rho=0.58). Combining habitat variables of two grassland types to contrast similarity between patterns explained by best variables for all spiders found highly correlated with grass cover (rho=0.78), soil moisture (rho=0.65) and grass height (rho=0.64).

6.4 Discussion

Annual low-intensity fire is a conspicuous management strategy in virtually all floodplain grassland of protected areas in India. Previous studies of the long-term effects of fire in Terai grasslands were limited to the successional studies of grass regeneration pattern and habitat use by ungulate community followed by burning (Lehmkhul, 1989; Peet et al., 1997, Kumar et al., 2002). Ecological studies of arthropod assemblages in tall grasslands of India are surprisingly rare, considering the diversity of arthropods in the state in general and their importance in Terai ecosystem. This is the first study which examined the impacts of grassland fire on the spider assemblage in the Terai Conservation Area. In this Terai Grassland, the effects of fire on spider assemblages varied with habitat type, frequency of burn and marginally with seasons of burn. The differential response is likely to be related to differing levels of habitat change in the two grassland types following fire. Spider assemblages are mostly affected by fire because of fire-induced habitat modification, altering microhabitats, resource availability and even interspecific relationships. The effect of fire on spider assemblages was most pronounced in the upland grassland habitat, with large and significant differences in spider assemblage composition and richness between burnt and unburnt sites.

In Terai Grasslands there is growing concern about the increasing frequency and extent of fires in the region; this shift in burning regime is thought to be damaging to biota, and links have been made to declines in a range of taxa (Peet et al., 1997). Results from this study indicate there can be great variation in response to fire; spider assemblages in upland grassland habitats being less resilient to fire than those in lowland grassland habitats and this has implications for the scale at which current fire management is implemented. In contrast to the upland grassland habitat, spider assemblages in the lowland grassland habitat showed little response to fire. Spider assemblages in this habitat exhibited a high degree of resilience to burning. In this habitat, annual and perennial grasses, which dominate the ground story, experience prolific seasonal growth and recover much more rapidly in post-fire period, thus structural changes to the habitat are short-term and minimal. The lowland grassland consist of tall, coarse grasses occurring in swampy and moist places and showed high affinity to moisture regimes. The early successional stages of tall perennial grasses are maintained by fluvial action and flooding during monsoon (Lehmkhul, 1989). On the contrary, upland grasslands are relatively homogenous on drier soils and consists of shorter perennial grasses predominated by *Imperata cylindrica* and *Vetiveria zizanoides*. In addition to this, the availability of annual fuel loads and prevailing drier condition in the upland grassland mean that large areas within this habitat are more susceptible to burnt than the lowland. Because this study suggests there are likely to be more species that occur only in lowland grassland, it may therefore be important from a conservation perspective to ensure, unburnt patches of lowland grassland persist in the landscape.

In the study I found species strongly associated with particular fire regime and rarefied species richness was higher at single fire sites, represented high diversity compared to unburnt sites. This diversity could be explained in terms of an increase in habitat structural heterogeneity, where characteristic elements of both sparse and dense vegetation occur in close proximity, providing a rich mosaic of microclimatic conditions (Morreti et al., 2002). This heterogeneity provides a wide range of microhabitats capable of supporting a large number of species. The above pattern was similar to that recorded following single fires in the Swiss Alps by Morreti et al. (2002); however the finding of the study was interpreted for short duration scale. Single fire qualified better considering prolonged time period allow recolonisation of spiders since aerial dispersal and colonization of neighbouring habitat patches are common phenomena among spiders (Bishop and Riechert, 1990). I found litter depth, grass height and bare ground cover were important variables that explained the fire related disturbance. Other studies also found that the proportion of bare ground as an important variable during pyric succession (Merrett, 1976; Brennan et al., 2006; Hore and Uniyal, 2008a). Fire had significant effect on the cover and diversity of the dominant grass species in a way that changes in the structure and composition of grass-layer vegetation appeared substantial. In several studies the depth of the litter layer was an important determinant of spider assemblage composition, as litter affects prey abundance, reduces temperature and humidity fluctuations, and provides structural retreats from predation (Uetz, 1991; Bultman and Uetz, 1982). Studies found that burning generally acts as a sanitation procedure by removal or reduction of plant structure and litter layer (Ismail and Yarborough, 1981). In addition, reduced litter cover on burnt plots is likely to result in the loss of some cryptic species from these areas. More importantly for spiders, the effects of repeated fires are primarily considered to be direct through changes in vegetation structure and habitat composition (Moretti et al., 2002). Here, the effects of fire on vegetation structure were more pronounced at upland grassland than at lowland. At upland grassland, low biomass accumulation at ground level probably accounted for the lack of difference in vegetation complexity. The high resistance and resilience of lowland spiders to burning, and the responses of spider assemblages to burning at upland grassland, can thus also be interpreted as a response by spiders to changes in habitat structure as well as habitat cover. The study advocate that a patchwork mosaic of both recently burnt and older ages might be necessary to meet the different habitat requirements of many taxa. Moreover, habitat variables altered by burning, such as the proportion of bare ground, litter depth, and grass height, are potentially useful predictors of spider assemblages.

Importantly, conservation and land managers need to be sensitive of how different habitats respond to fire, how this might vary seasonally, and thus what the consequences of different management actions might be. This study highlights the importance of considering land unit types and sensitivity to fire when burning for biodiversity conservation, and cautions against applying prescribed fire in a 'blanket-fashion' across the conservation area. Nevertheless, given that extensive areas of grasslands are highly resilient in relation to fire, a complex burning system with high levels of pyrodiversity may not be required for effective biodiversity conservation (Barrow et al., 2007). Finally, effective conservation management in these areas can only be achieved through active co-operation and communication of management plans protected area boundaries, potentially reducing the frequency of large, homogeneous burns.

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CHAPTER 7

HIGHER TAXA SURROGACY AND EFFICIENCY IN SPIDER CONSERVATION

7.1 Introduction

The biodiversity on Earth is rapidly diminishing, and conservation biologists are struggling in cataloguing and preserving the remaining of its natural variability. The rapid decline in biodiversity and practical challenges in describing and enumerating it rigorously enough, including money, effort, expertise and time (May, 1994), have urged conservation biologists to rely on surrogates for explaining patterns in biodiversity. Such approaches try to overcome the problem of the enormous amount of resources (e.g. time, money, taxonomists) required to reach close to complete inventories, if such goal is possible to achieve. Among the most popular is the use of higher taxa surrogates, as proposed by Gaston and Williams 1993 (see also Williams, 1993; Williams and Gaston, 1994). Others are the use of indicator (or surrogate) groups of overall richness (e.g. Pearson and Cassola, 1992; Beccaloni and Gaston, 1995; Prendergast and Eversham, 1997) and the inference of diversity from available information on environmental variables (e.g. Braithwaite et al., 1989; MacNally et al., 2003). Despite all the pros and counters all these have, the higher taxon approach has several advantages, namely by allowing obtaining information on a large number of taxa with relatively low effort and resource use. Another crucial advantage is the retention of broad biological information that allows the understanding of distribution patterns (Eggleton et al., 1994; Williams et al., 1994; Gaston et al., 1995) and more efficiency in the definition of conservation priority areas (Williams, 1993; Williams et al., 1994; Vanderklift et al., 1998), after all, the ultimate goal of conservation biology. Higher taxon approach was applied at both local and regional scales (Gaston et al., 1995; Larsen and Rahbek, 2005), which could be highly demanding in terms of performing direct species measurements. Recently, application of the higher taxon approach has been extended to evaluate effects of environmental changes, such as burning (Brennan et al., 2006) and has been used to study the association between plant richness and climatic based variation in water-energy dynamics (O'Brien et al., 1998). Although most previous work points to a reliable use of higher taxa surrogacy in many different kinds of organisms (Williams and Gaston 1994; Williams et al., 1994; Gaston and Blackburn,1995; Vanderklift et al.,1998; Balmford et al., 2000), caution should be given when applying the method and interpreting results since the method is subject to a series of limitations such as sampling effort, data quality, habitat type, geographic location and spatial autocorrelation (Gaston and Williams, 1993; Andersen,1995; Grelle, 2002; Cardoso et al., 2004). A potential criticism in the efficiency of higher taxon approach arises from the area effect on the analytical process (Andersen, 1995; Gaston, 2000b). A positive relationship between species richness and habitat area is rather expected, although the extent to which species—area relationships are reflected to higher ranked taxa is unclear. Another potential limitation on the efficiency of the method could arise because of variation in environmental conditions. Spatial heterogeneity is related to ecological process and variability and could act as a determinant of species richness and composition by favouring specific organisms and eliminating the distribution of others. However, the potential influence of spatial heterogeneity on the performance of the higher taxon approach has been ignored in most of the study so far.

Though nearly all studies of higher taxa surrogates have simply looked at the extent of correspondence in the richness of areas measured at different taxonomic levels. But efficient reserve networks consist not just of rich sites, but of sites which are rather different from one another biotically and which, therefore, exhibit high between-site complementarity (Pressey and Nicholls, 1989; Pressey et al., 1993; Williams, 1998). Hence a full evaluation of the utility of the higher-taxon approach for reserve planning should include consideration of the degree of cross-level correspondence in patterns of complementarity as well as richness, and an assessment of how well entire reserve networks designed using information on genera or families manage to capture species-level diversity (for examples of the latter, see Vane-Wright and Rahardja, 1993; Williams, 1993; Balmford et al., 1996a). One critical limitation is that even those tests which have addressed these other concerns have nearly always targeted relatively species-poor groups such as birds and mammals (Balmford et al., 1996a). This is not surprising, as very few good quality, local-scale datasets of highly speciose groups such as insects and arachnids currently exist. Nevertheless, rapid assessment methods are obviously most needed for megadiverse groups, for which a shortage of expertise is compounded by the long time required to sort records down to the level of species (Bloemers et al., 1997; Lawton et al., 1998).

With this work, I intend to provide evidence of the possible usefulness of the higher taxa surrogacy approach with spiders in Terai, testing it as species richness predictor. I also consider the effects of environmental and methodological factors in the validity of predictions. Finally, I test the use of this kind of surrogacy as a tool for a reliable definition of conservation priority sites, either by ranking them according to taxa richness or by considering complementarity of known taxa between sites to examine how well subsets of our sites capture species-level diversity when using information on species, genera, families and orders. Spider species richness and respective spatial distribution are virtually unknown in India with a certainly very low figure of 1520 species registered for the country (Sebastian and Peter, 2009). Although not even higher taxa data are available for most of the country's territory, given the difficulty in the identification of species, many remaining to be described or discovered, it seems advisable to test for future use such potential tools as are different surrogates of biodiversity.

7.2 Methods

Fieldwork design was implemented to test for several effects that can influence the higher taxa surrogates approach – geographical location, type of habitat and sampling effort. Two protected areas of Terai Conservation Area under the jurisdiction of Dudhwa Tiger Reserve were chosen, one in the north –Dudhwa National Park–and the other nearby area in south–Kishanpur Wildlife Sanctuary, sampled from 2006 - 2007 (Fig. 7.1).

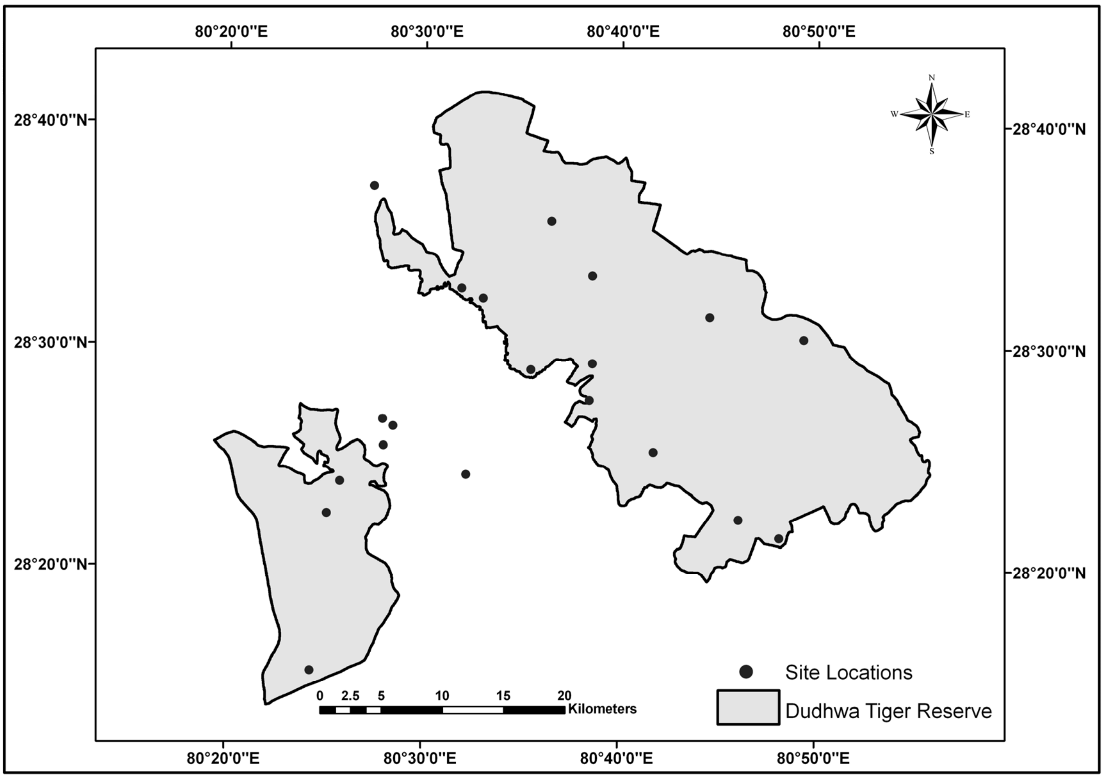


Fig. 7.1 Map showing sampling sites in TCA.

For a question of simplicity, these two areas are simply referenced from now on as belonging to north and south geographical regions. Ideally, all sites in all protected areas have been sampled during the same year. I chose such areas due to high habitat diversity and, by comparing the two regions, allowing the study of geographical effects on the surrogacy methods to be tested. In each area, I sampled several sites, summing 10, trying to cover the majority of the most significant habitats represented. This way, I also consider habitat effect by differentiating sites with and without arboreal cover and those with “natural”, vegetation, from the ones dominated by introduced vegetation or under severe human influence or management. Ten major vegetation types were identified and two sampling sites per vegetation types were selected for spider sampling. Size of the sampled sites ranged from 1.8 to 13.3 km^2. Spiders were sampled along the 50 m transects using pitfall traps and semi-quantitative sampling. 10 transects were placed randomly within each of vegetation types. Pitfall sampling was operated for 64 weeks and other semiquantitative sampling performed on 64 occasions (once every week) at the same sampling sites. Pitfall traps consisted of cylindrical plastic bottles of

10 cm diameter and 11 cm depth (Churchill and Arthur, 1999). Six pitfall traps were laid along each transect line at an interval of 10 m each. Traps were filled with preservative (69% water, 30% ethyl acetate, and 1% detergent). After seven days, specimens were removed from traps, which allowed me to maintain spider specimens in good condition before laboratory processing and identification. Semi-quantitative sampling involves aerial sampling (searching for upper layer spider in leaves, branches, tree trunks, and spaces in between, from knee height up to a maximum overhead arm's reach); ground collection (involved searching for ground layer spiders on hands and knees, exploring the leaf litter, logs, rocks, and plants below low knee level); beating (striking vegetation with stick and catching the falling spiders on a tray held horizontally below the vegetation); litter sampling (hand sorting of spiders from leaf litter collected in a litter collection tray); sweep netting (for middle layer spiders up to 1 m). Each sampling method comprised 1 hour active sampling, measured with a stopwatch.

7.2.1 Analysis

To test if either family or genus richness can be reliably used to predict species richness regression analysis was performed over all available data. Linear, log-log and exponential regression were tested. I used both the percentage of variance explained by the independent variable and visual evaluation of the scatter plots as a measure of adjustment, surrogacy reliability and predictive power. In search for the possible influence of sampling detection, geographical location and habitat type over surrogacy results, I also adjusted regression lines after separating sites according to their characteristics, one factor at a time. Analysis of covariance (ANCOVA) was order in order to test for statistically significant differences between regression lines. If differences were found, the factor involved was considered as potentially influencing the reliability of surrogacy. SPSS 16.0 software was used for statistical analysis. I estimated the relationship between study site areas. In order to test if the study site area affected the relationship between species richness and higher order richness, I regressed the residuals of the relationship with the site area. The pattern of diversity is known to be spatially autocorrelated (Lennon et al., 2001). Autocorrelation distorts systematically the classical tests of association and can generate misleading results in correlation coefficients, regression slopes and associated significance tests (Clifford et al., 1989; Lennon et al., 2001). To avoid this, I applied the modified correlation test of Clifford et al. (1989) that corrects the significance of the Pearson correlation coefficient for the spatial dependency within and between the two patterns examined. This correction uses the concept of 'effective sample size'. This is the equivalent sample size for the two patterns when the redundancy produced by spatial autocorrelation is removed. In the present study, the effective sampling size was always equal or close to the real sample size, and thus the spatial autocorrelation did not affect the estimated level of statistical significance.

Two approaches were tested for prioritisation and ranking of sites for conservation. A scoring approach, which uses the raw number of taxa represented in each site as the sole value for ranking (Table 7.1). Spearman rank correlation index was used to test for surrogacy reliability in the scoring of sites. In addition, scatter plots of family and genus richness versus species richness ranking of sites were used for visual inspection of reliability. I furthermore tested a more efficient iterative approach of conservation priority ranking. For each of the considered taxonomic levels (family, genus or species), I first choose site with highest species richness, then calculate complementarity richness by counting species that are not already present. Then, subsequently choose site with highest complementarity and repeat until all species are represented in data matrix. Finally I reorder by complementarity richness with carefully deselect sites if redundant in retrospect. I first chose the richest site and from it, in a stepwise manner, the one site that would further raise the number of represented taxa was added to the set of sites to be considered for protection. In case of ties, I chose the richest site in the respective taxa. By doing so, I test the effect of using higher taxa for choosing a near-minimum set of sites that potentially preserves the maximum number of species.

Table 7.1 Taxa richness of sampled sites and respective ranking.

Site	Richness			Rank		
	Species	Genera	Family	Species	Genera	Family
grsk2	45	27	13	1	3	4
pssk1	45	25	10	1	4	7
grsd2	44	31	17	2	1	1
rpsd2	44	28	10	2	2	7
pssd2	42	25	11	3	4	6
grsk1	41	31	15	4	1	3
mssd2	41	27	13	4	3	4
rpsk1	39	24	9	5	5	8
rpsd1	36	22	12	7	6	5
rpsk2	36	25	11	7	4	6
mssk1	32	21	10	8	7	7
pssd1	31	21	10	9	7	7
grsd1	30	24	16	10	5	2
mssd1	30	14	8	10	10	9
mssk2	29	21	12	11	7	5
plsd2	23	15	8	12	9	9
plsk1	19	15	8	13	9	9
plsk2	10	7	4	14	11	11
plsd1	7	6	5	15	12	10

7.3 Results

A total of 186 species belongs to 77 genera and 27 families were collected during entire sampling periods. Of these, 67 species (36% of all species) belong to morphospecies. All species were identified at least to genus level, since genus identification is required for most calculations. At generic level terai spider assemblage represents 20% of all genera described from India, which is considerably high and rich. Adopted nomenclature consistently follows Platnick's (2008) world spider catalogue.

7.3.1 Species Richness Prediction

7.3.1.1 Choosing the Best Surrogate

After fitting all previously defined regression types – linear, log-log and exponential - to family and genus taxonomic levels, I choose the ones with the highest regression coefficient value. A non-linear exponential relationship is found for the former and a linear relationship for the latter (Fig. 7.2). Both taxonomic levels present highly significant relationship with the number of species ($n=20$, $p<0.001$), however genus richness seems to have much better predictive power with high r^2 value.

7.3.1.2 Influence of Factors

Since genus richness was found to have high predictive power and represents linear relationship with species richness, in subsequent test for influence of factors on taxonomic level, genus level data is only considered. Comparing regressions line of sites representing different detection (frequency of occurrence of species to individual) level for individual species was found significantly different ($n= 20$, $p<0.05$) (Fig. 7. 3a). This was to be expected as heterogeneity in the detection probabilities of different species capture is varying with local and regional species pool. The same didn't happen with other factors, whose differences are not found to be statistically different.

Regression based analysis demonstrated only weak correlation between area and different taxonomic levels for all classes (R2 = 0.123 and 0.204, respectively). The correlation between area and the residuals of the relationship between species richness and higher taxonomic level richness was not significant ($a = 0.001$).The spatial autocorrelation among sites seems to be not a significant effect, since effective sample size deviated only slightly from real sample size without altering the results.

7.3.1.3 Cross-level Correlations in Complementarity

There was good congruence in complementarity patterns measured in terms of species and genera, but not across families (Fig. 7.4b). Between-site complementarity of species was quite closely related to between-site complementarity of genera (r^2=0.84, n=0 pairs of sites, p<0.001); thus sites with very different spider species also had very different spider genera, and vice However, species-level complementarity could be far less closely predicted from family-level complementarity (for species vs families, r^2=0.44, n=20, p<0.10). These results were apparently not confounded by variation in the difference in area of paired sites (since pairs are widely differing size).Thus, it appears that the match in how well sites complement each other when assessed in terms of species and genera is real, and alongside congruence in richness, explains why sets of sites identified using spider genera do so well at representing spider species.

7.3.2 Conservation Priority

7.3.2.1 Scoring Approach

Using the rank of sites according to their taxa richness, families found to have low predictive power of species based site ranking (Table 7.2), despite the high Spearman rank correlation value of 0.855. Examination of the rank scatter plot (Fig. 7.5b) also leads to conclude about the low reliability of the family surrogacy approach. Genera, on the contrary, seem to rank sites in much the same way as species do (Table 7.2) (Spearman rank correlation = 0.962). Predictive power is especially high at the highest and lowest ranked sites, being not as good at the middle ones (Fig. 7.5b).

7.3.2.3 Iterative Approach

Although a scoring approach to site ranking can be evaluated for future use, it is not the most efficient method for establishing conservation networks of sites. Complementarity is a fundamental issue to be taken into account. This way, scoring of sites was not done simply according to their richness values, but according to which ones will allow the protection of the maximum number of species not included in previously chosen sites. By using accumulation curves, effects of adopting this approach for the different taxonomic levels can be carefully. The objective is to check what proportion of species can be protected by using the same number of sites that protects all considered higher taxa. Genus level data was chosen for this analysis since it fitted best with species algorithm. The number of sites (13 sites; 65% of all sites sampled) necessary to include all genus is enough to protect, at most, 90% of species (Fig. 7.6).

7.4 Discussion

Results of the study suggest that only genus richness can be used as a significant and reliable surrogate of species richness, with much higher regression coefficient value and predictive power than families. Its linear relationship is also simpler than the more complex, non-linear, exponential relationship that family richness has with species richness. Previous studies also recognize the same high relationships between species and genera richness, while several studies highlight caveats on the use of family richness (Williams and Gaston, 1994; Gaston and Blackburn, 1995; Balmford et al., 1996a, 1996b; Roy et al., 1996; Grelle, 2002; Cardoso et al., 2004; Bergamini et al., 2005). However, there is evidence demonstrating family richness to be an equally good predictor of species richness (Williams et al., 1994; Negi and Gadgil, 2002; Báldi, 2003). Given our findings of high correlation and predictive power between higher taxonomic level richness and species richness, the study concluded that genera level richness could be used in describing patterns of species diversity. However, caution should be taken that the decision on the taxonomic level to be used in a similar analysis should be based on a preliminary analysis undertaken at the region of interest. This is mainly because the responses of organisms to environmental variability differ for the same group of species from region to region.

Species richness is known to increase as the sampling area and environmental variability (here measured as habitat diversity) increases. In the present study the relationship between species richness and area or habitat diversity was found generally weak. Neither geographical location or area or habitats were found to have significant influence over the usefulness of higher taxa surrogacy at genus level. When sampling effort is same, the only factor found that may limit the use of higher taxa surrogacy is imperfect detection of species in a single or multiple sites.

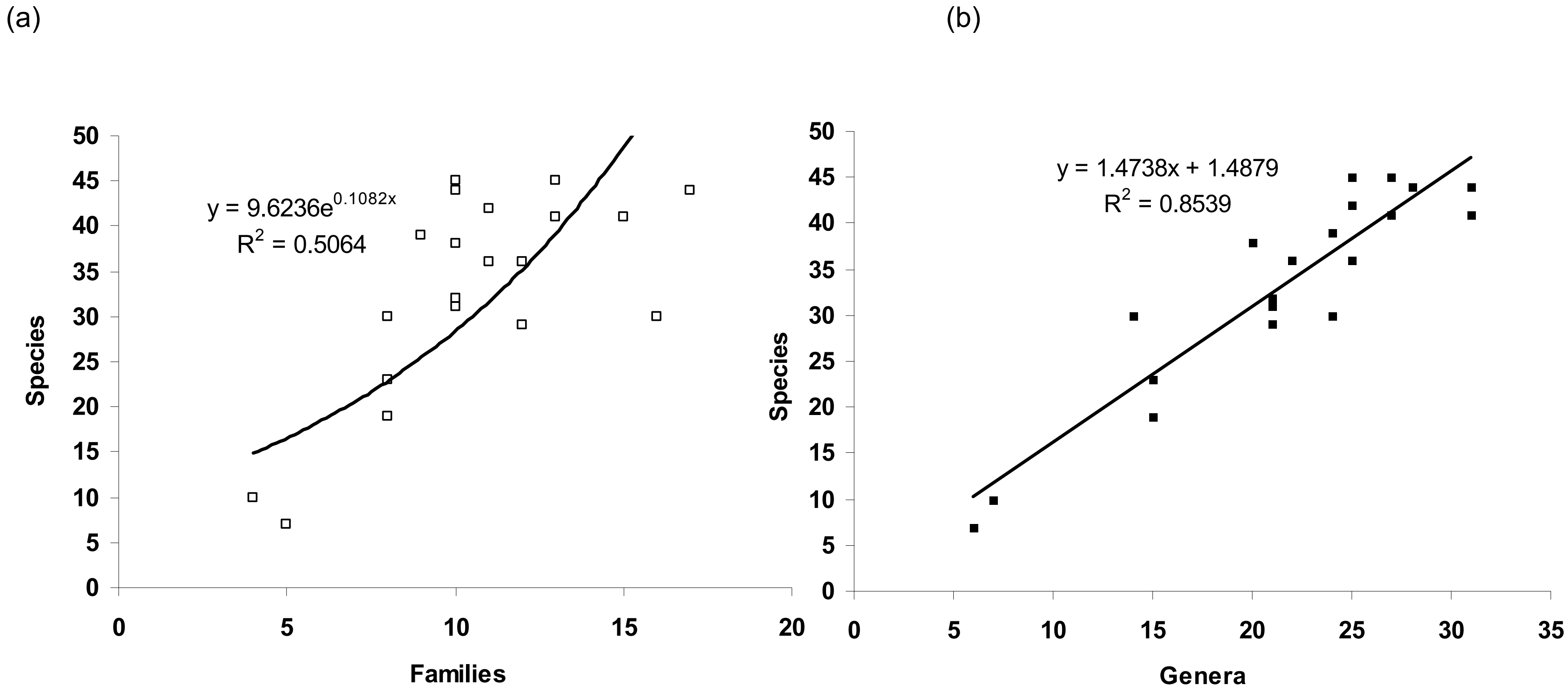


Fig 7.2(a) Exponential relationship between family and species richness, (b) linear relationship between genus and species richness in all 20 sites sampled for spiders in the study area.

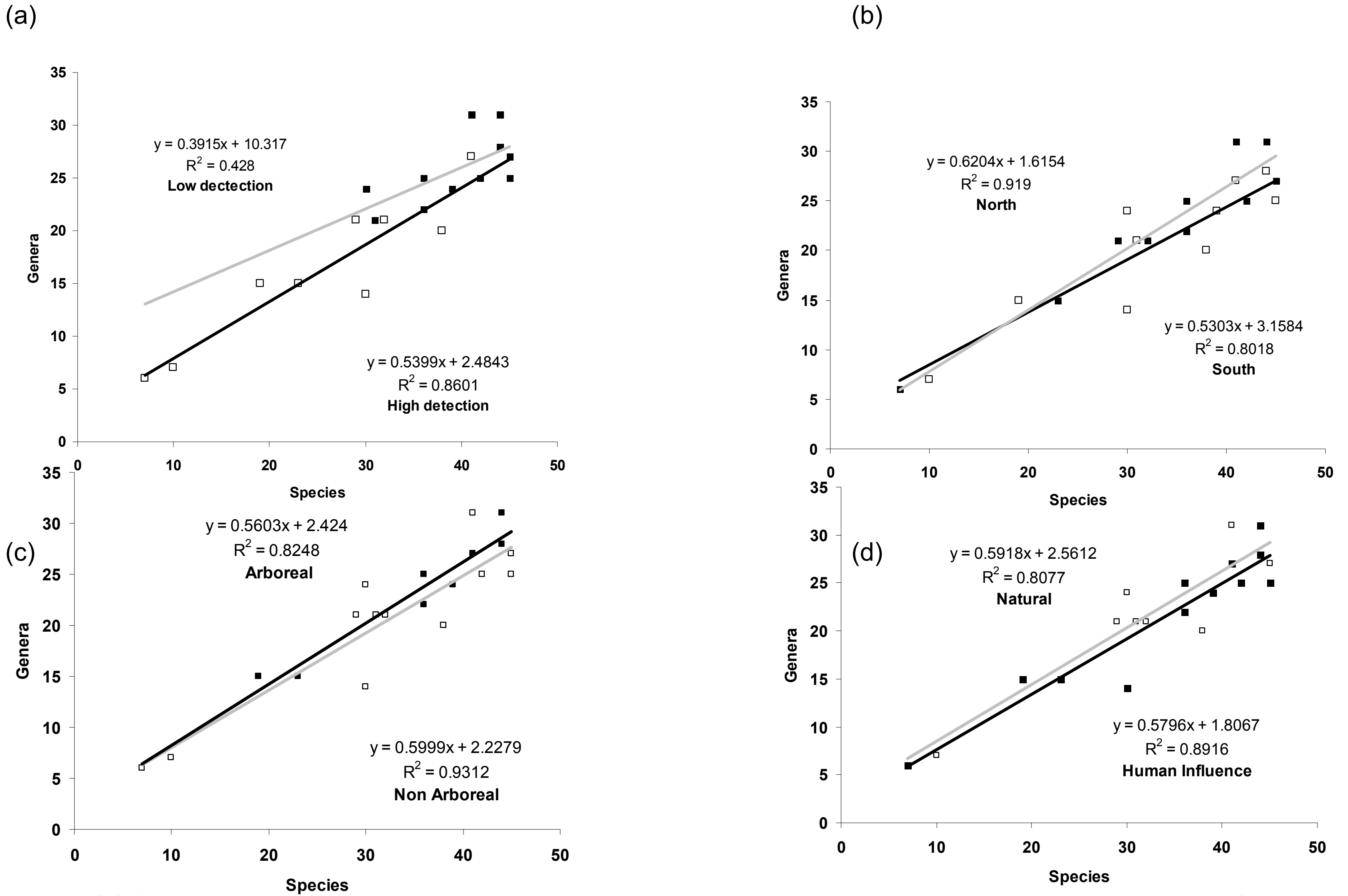
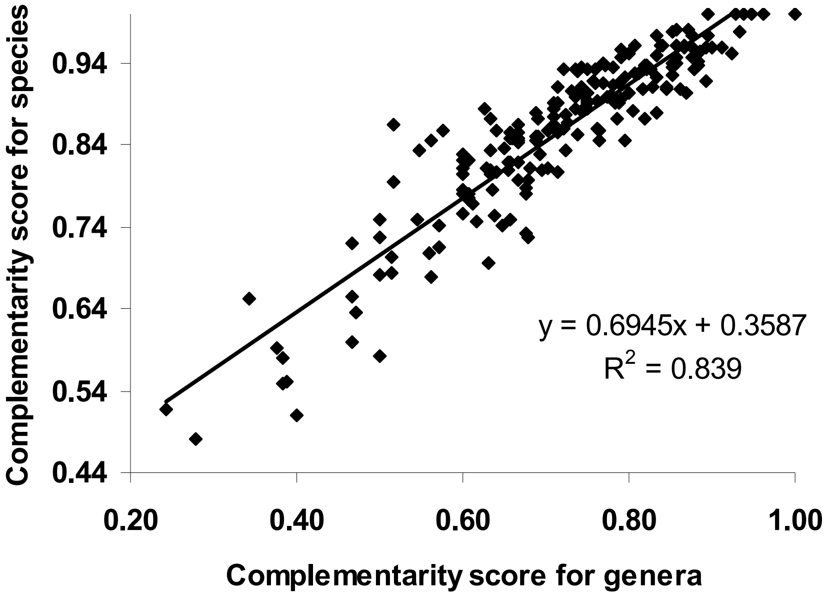


Fig. 7.3(a) Comparison of genus richness and species richness relationship between sites with high (open squares) and low (filled squares) detection (b) northern (filled squares) and southern (open squares) (c) with (filled squares) and without (open squares) arboreal cover. (d) "natural" (open squares) and those with high human influence (filled squares).

(a)



(b)

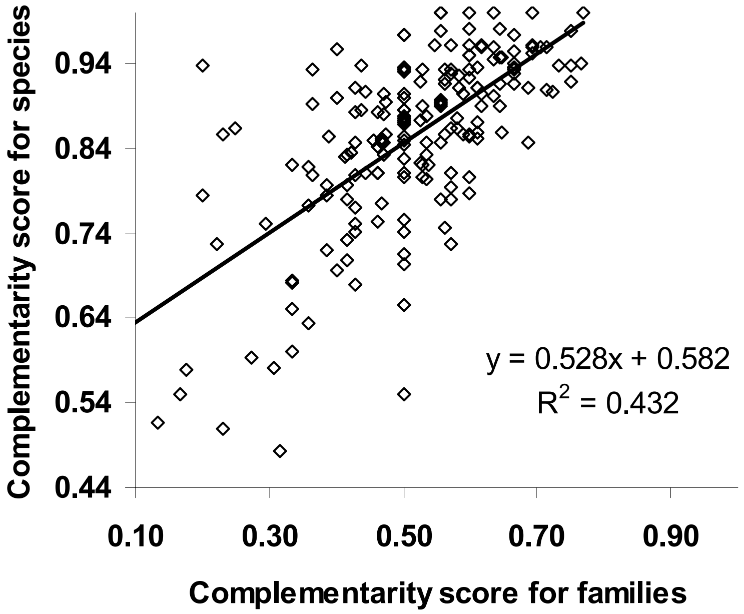
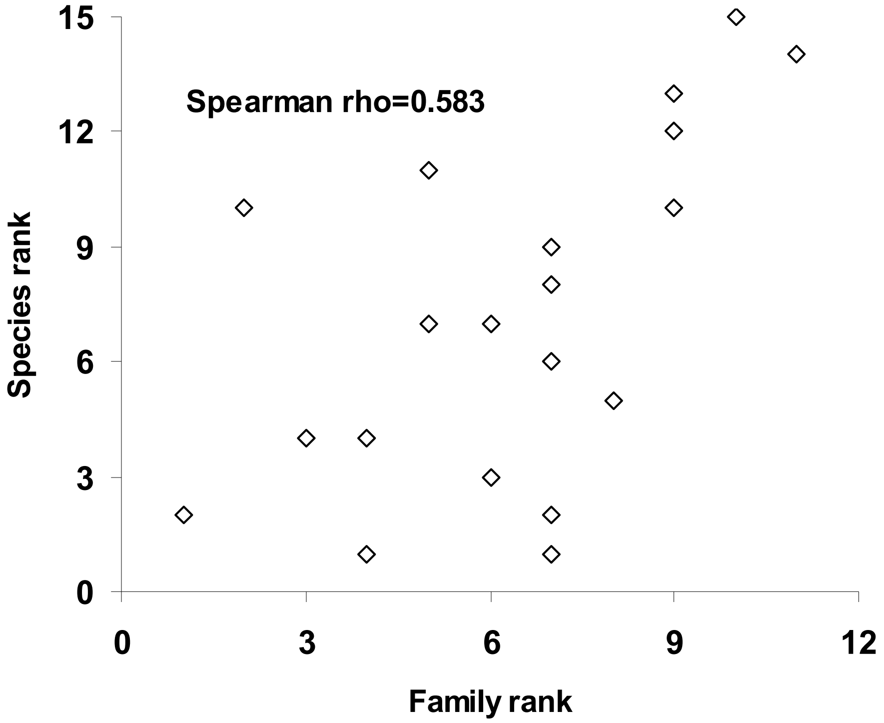


Fig. 7.4 Cross-level Congruence in the Complementarity of pairs of sites in the study area (a) species vs genera, and (b) species vs families. Complementarity scores are calculated as the number of species or genera or families found at just one or other site, divided by the combined total found at either or both (Colwell and Coddington, 1994).

(a)



(b)

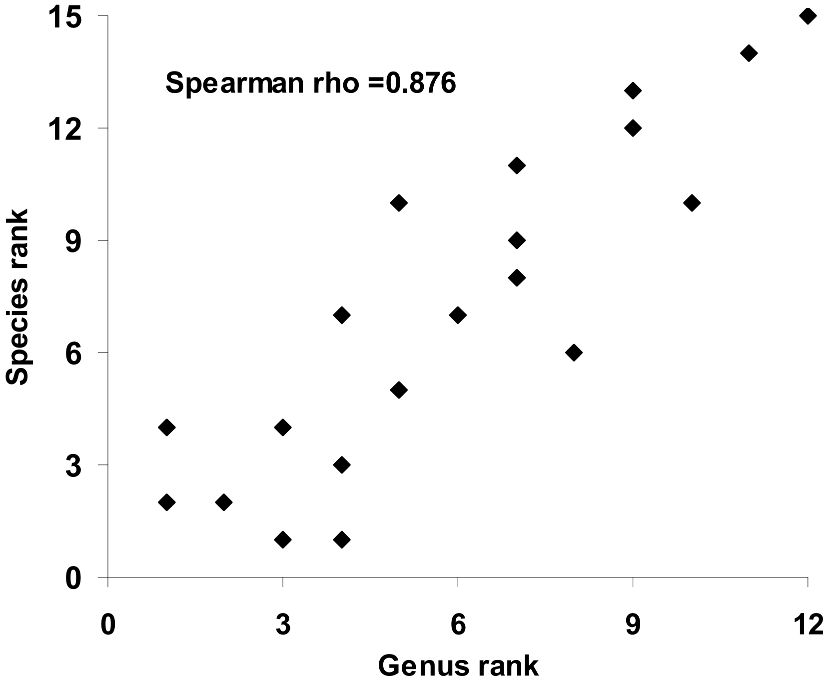


Fig. 7.5(a) Comparison of site ranking according to family and species richness. (b) Comparison of site ranking according to genus and species richness.

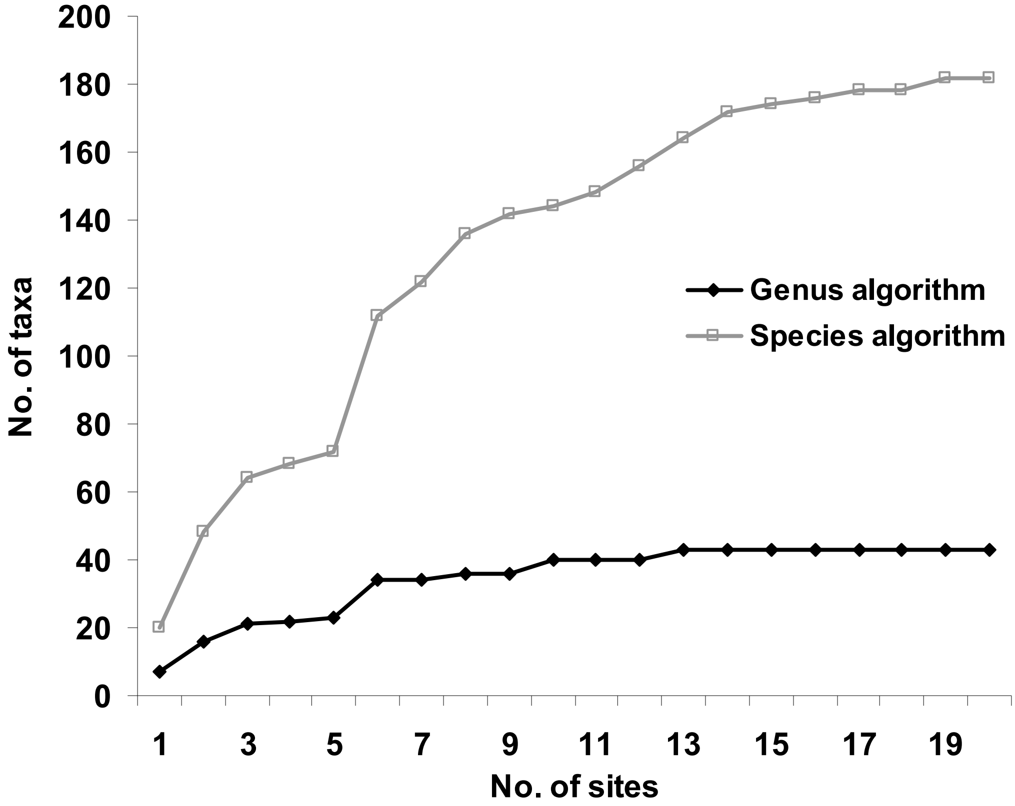


Fig 7.6 Accumulation curves of the number of taxa represented by the adding of sites in stepwise manner, considering complementarity algorithm.

Because species are detected imperfectly, some species that were not detected at the site may have in fact been present (i.e., a false absence), while others could be genuinely absent from the site (i.e., not part of the local community during that sampling period). Repeated surveys are needed to estimate detection probability and the assumptions need to be fulfil that the occupancy status of the site for each species does not change during the season, or that changes occur completely at random (i.e., the members of the local species pool present at the site are constant during sampling period) (MacKenzie et al., 2006). In future research, site occupancy approach that permit the direct estimation and modeling of this parameter, Ψ, as well as of the rate parameters that cause the relative species richness and species composition to change over time can increase and refine the predictive power of this proposed higher taxa relationship.

Results also show that for fine-scale variation in genus-level richness mirrors variation in species richness. It is also due to moderate cross-level correspondence in the extent to which different sites complements one another: sites that are highly complementary at the species level also tend to exhibit high complementarity at the genus level, and vice versa. In contrast, data on families and orders are much poorer predictors of patterns of species richness and species-level complementarity.

Recent attempts have been made to explore the performance of higher taxa approach in identifying priority areas for conservation (Balmford et al., 2000; Fjeldså, 2002; Whiting et al., 2000). Accordingly, some encouraging results have been drawn, at a continental scale, but only for large grain sizes (Larsen and Rahbek, 2005). Such an analysis was performed at regional scale, in order to explore the ability of different taxonomic levels to encompass species diversity. The aim was to investigate the efficiency of different levels of information to prioritize sites for conservation and also the reliability of the higher taxon approach. The analysis demonstrated that the higher taxon approach performed equally well as the species level approach. Yet, its use on reserve selection should follow further analysis.

Genera, but not families, are also considered a good surrogate for choosing priority sites for conservation. Either if I choose to apply a simple scoring approach or a much more efficient iterative algorithm approach to the problem of sites ranking, genera can be used as a surrogate of species, when no taxonomic data are available on these. The use of caution is suggested, and in case of doubt, a conservative approach should be taken, by trying to protect more sites than those expected to be necessary to represent all genera. This way this will guarantee that the proposed reserve network covers a large proportion of species.

From a practical point of view the method could be applied for monitoring and management proposes to frequently study and determine changes in biodiversity richness and distribution. The results show clearly that higher taxon approach could be used towards this direction for performing rapid area inventories. Assuming, very conservatively, that there are no savings from higher-taxon surveys in terms of field time, that subsequent identification of spiders in the laboratory takes no longer than fieldwork, and that the identification time required for genera is fully half that for species, it follows that genus-level surveys would take at the very most only 50% of the time required for sorting down to species. Perhaps more important than time savings, in most situations (e.g. the highly diverse tropics), the great majority of the work required for genus-level inventories of spiders could be conducted by well-trained parataxonomists or by nonspecialist using local or regionally based operational keys, rather than by expert scientists (see Oliver and Beattie,1996; Krell, 2004).

Apart from spiders the higher-taxon approach and the validity of the approach in other richer arthropod groups should continue to be encouraged, and the cautious use of genus- level surveys will represents a very promising route to putting priorities for megadiverse groups on the conservation map. The efficiency of the method to be used for prioritization of conservation areas needs to be demonstrated for different groups of taxa in different biomes and in different biogeographical areas (Balmford et al., 2000).

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CHAPTER 8

GENERAL DISCUSSION AND CONCLUSION

8.1 Introduction

Conservation issues mostly focus on the ecological impact of management practices, as their aim is to provide practical background for sustainable management (Spence, 2001; Aubert et al., 2003; Oxbrough et al., 2005). To achieve this purpose, an understanding of how management practices affect forest biodiversity is a necessary condition (Bengtsson et al., 2000). Forest management practices determine different forest structures. Thus, typical practices such as cleanings or plantations reduce the predominance of old-growth structures characterized by vertical and horizontal heterogeneity, wide range of age classes, presence of large trees and dead wood. Compared to naturally regenerating forests, succession in managed forests includes accelerated successional cycles and decreased vegetation heterogeneity (Essen et al., 1992; Buddle et al., 2006).

Management practices promote changes in community structure and composition of different animal groups (e.g., Gram et al., 2001; Dunn, 2004; Drever et al., 2008), including invertebrates (e.g., Finch and Szumelda, 2007; Pohl et al., 2007) due to the modification of forest structure that causes changes in environmental conditions, nesting sites and food resource availability. Among arthropods, spiders are the most abundant predators in many terrestrial ecosystems, playing an important role in ecosystem functioning throughout habitats (Van Hook, 1971). As generalist predators, they contribute to the regulation of herbivore populations in forest communities (Lawrence and Wise, 2000) and thus occupy a strategic functional position in terrestrial food webs (Ferris et al., 2000). While spiders in forest ecosystems contribute to the maintenance of insect community equilibrium, the distribution of species and the composition of assemblages are significantly influenced by environmental conditions (Ziesche and Roth, 2008).

The TCA being the last, largest representative of the Indian Terai ecosystem has also undergone several transformations during the past 8-10 decades, mainly through: (i) the long history of forest management including timber felling, raising of plantations, and (ii) habitat management practices *viz.,* grass harvesting, annual burning of grasslands, weed control, water management, and habitat restoration through protection (Kumar et al., 2002). The resultant combined effect of above management practices thus, provided an opportunity to study the existing mosaic of habitats and their ultimate effect on spider diversity and structure.

8.2 Faunistic Inventory of Spiders in Terai Conservation Area:

The present study, conducted at Terai Conservation Area (TCA), has made a significant contribution towards increasing knowledge of spider species distributions in this landscape. This area has extremely high spider diversity. A total of 186 species, 77 genera and 27 families were sampled during the study period. Considering the high spider diversity in this area, efforts should be continued to ensure that the area is conserved, not only for the large vertebrates (which attract considerable attention), but also for the invertebrates. No previous work on spiders has been conducted in this area thus the study represents new distribution records for all species recorded and 67 suspected previously undescribed species. Several genera that are endemic to India and South East Asia occur in this area which further highlights the importance of maintaining the conservation status of this landscape.

8.3 Diversity and Composition of Spider (Araneae) Assemblages

This was surprising to find that our sampling programme cover only five, albeit quite different, habitats located in a small region has detected more than 10% of Indian spiders. Obviously, many more habitats will have to study until the relationship between local and regional species pool of spiders can be understood. This study has considered diversity in spider assemblage with respect to sample size and habitat heterogeneity. However, other factors such as productivity, latitudinal gradient and size of the regional species pool have been suggested to influence species richness (Huston, 1994; Gaston, 1996). It was not possible to analyse the impact of these factors quantitatively as only 20 sites per habitat type was sampled. However, with its emphasis on the diversity patterns at small spatial scale the present study may help to shape ideas for the design of future inventory and monitoring programmes.

This study revealed that habitats other than plantation are worth recognizing and the value of plantations will depend on their size and location. Spider diversity and composition in plantations was different from the other forest habitats. Especially, plantation patch showed the most dissimilar assemblage structure no matter what taxon was analysed. Possible reasons are (i) the scarcity of understorey vegetation; and (ii) patch isolation. The amount of understorey vegetation has a strong influence on spider abundance and diversity, thus affecting the amount of habitat available to spider occurrence. Therefore, diversity can be maintained as far as suitable habitat structure is provided, so that spiders can perceive the connectivity of different habitats. Forest managers should encourage the growth of lower field layer vegetation species at all stages of the forest cycle, whilst retaining features typical of a mature forest in order to enhance the diversity of both open and forest species within a plantation. Future studies in this forest system should focus on processes influencing individual species responses to forest management. The river margins and the alluvial forests of TCA were the most species rich habitat, holding greatest number of stenotopic species. Different flood regimes of TCA benefit different spider species, an optimum in species richness which is assumed to be maintained by increased microhabitat heterogeneity (Uniyal and Hore, 2008). This allows for a narrow niche separation (Bonn and Kleinwächter, 1999), hence benefiting the persistence of species with divergent habitat preferences and interrelated sets of species traits.

8.4 Habitat Association of Spider Assemblages

Considering conservation aspects, given heterogeneity in TCA forests due to small spatial scale gradients of environmental parameters will promote species diversity. This applies particularly for taxa like spiders that are not strictly bound to tree species like many herbivorous insects. Thus, sustainable forestry practice may play an important role for maintaining spider diversity. When considering the implications of managing forests for spider diversity, establishing a set of easily recognisable and quantifiable structural indicators is vitally important. This study has shown that there may be straightforward ways to enhance spider diversity which correspond with the management of other invertebrate groups and plants. Indicators such as cover of field layer vegetation, canopy and litter layers could be assessed by foresters with little or no specialist taxonomic training making it possible for spiders to be incorporated into sustainable forest management strategies.

Invertebrates have been extensively used as ecological, environmental, and biodiversity indicator species (Stork and Eggleton, 1992; Brown, 1997; McGeoch, 1998). Groups of related species have been used as indicators, such as carabid beetles (Rainio and Niemelä, 2003) and butterflies and moths (Kitching et al., 2000). Our study suggests a group spider species provide reliable assessment of the habitat condition in relation to the heterogeneity and disturbance gradient. Spider assemblages are well suited to discriminate habitat quality, since many spiders often rely on a distinct complex of environmental habitat factors with respect to species-specific ecological demands. And there is experimental evidence that habitat alterations due to forest succession, natural disturbances, or forestry practice result in structural changes of the spider community (Pearce et al., 2004; Ziesche et al., 2004; Oxbrough et al., 2005; Finch and Szumelda, 2007). In particular, the formation of ground vegetation and the resulting microclimate are most likely to affect the diversity and distribution of spider species and this is probably a major reason for the formation of specific species assemblages in a habitat (Bultman and Uetz, 1982; Hurd and Fagan, 1992; Gibson et al., 1992).

8.5 Effect of Grassland Burning on Spider (Araneae) Assemblages

Tall grasslands in TCA form an integral part of the forestland. Ecological functions of grasslands in TCA have been ignored for a long time because of earlier policies. Mainly burning is being in practice to maintain grassland diversity and productivity. The complexities of management practices and their effects on grassland values and functions have been poorly understood. Mathur (2000) has reviewed the status of research and monitoring in protected areas of the Indian Terai and highlighted the need for experimental research on grassland management practices, which has lacked in the majority of Indian PAs. Peet et al. (2000) have reviewed researches on the tall grasslands in Nepal. They have summarized the research, and conclusions on management priorities based on the investigations addressing the effect of burning of grasslands and its impact on ungulates, and socio-economics of grassland harvesting.

This study recommends that the spider fauna of Terai grassland is rich and useful for monitoring work, and that support for the conservation of this area should be continued. More individual spider species need to be studied in order to evaluate their indicator values that would help in establishment of a longer list of indicator species for grassland habitat management. Thus, it might be wise to extend this survey to other Terai grassland within the Indian Sub continent that have slightly different rainfall but the same type of grassland ecosystem, since it might increase the number of the known species in this ecosystem.

Forest managers must establish goals and weighs ecological cost and benefits when establishing management regimes of fire. Some may choose to manage for a narrow range of rare or favoured species. In this case, suitable burn regime might range from annual fires, with everything burned as often as possible, to nearly fire exclusion. However, to preserve self sustaining systems replete with diversity of spiders, grasslands of TCA should be burned on rotational basis, with sufficient unburnt refugia maintained each year. Ideally, important microhabitats will be represented in all units. This study suggests rotational and patch burning are compatibles with the preservation of spider biodiversity as well. In contrast, annual burning of entire sites can be expected to reduce remnant grassland dependent spider species within this fragmented landscape of TCA. Although level of fire remnant-dependence, fuel loads and spider phonologies can vary geographically, perhaps resulting in contrasting response pattern. Therefore, additional studies should be conducted within contrasting systems to test the generalities of the result obtained here.

Past studies on other taxa like hispid hare (Bell, 1986) and pygmy hog (Oliver, 1980) have also shown adverse effects of above management practices. Whilst Laurie (1978 and 1982) and Dinerstein (1979a,b; 1980; and 1987) have documented that cutting and burning practices are essential to create the mosaic of habitats so as to maintain the viable populations of one horned rhinoceros and other wild ungulates in the Terai region, respectively. These studies advocated ‘patch burning’ as a conservation measure in fire-prone areas.

8.6 Higher taxa Surrogacy and Efficiency in Conservation

Scientific names have been given to approximately 1.4 million species of plants, animals, and microorganisms (Wilson and Peters, 1988; Ehrlich and Wilson, 1991) but this is only a fraction of all species. Estimates of arthropod diversity in tropical forests alone range from about 7-80 million (Erwin, 1982, 1983; Stork, 1988; Hammond, 1992), and other invertebrate phyla are even more poorly known. Estimates have been made that if the collection and description of new species were to continue at the current rate, using traditional methods, it would take several thousand years to catalogue the world’s biodiversity (Disney, 1986; Soulé, 1990), and in fact the rate is slowing down because funding for taxonomy has declined (Stork and Gaston, 1990; Whitehead, 1990). Since complete inventories are not a practical option, yet land use change is proceeding apace, some measurable biodiversity surrogates are required. Realistically, there are three kinds available: sub-sets of taxa or higher taxa, assemblages, and environmental variables or classes. In reality some combination of these surrogates will have to be used in most cases to identify biodiversity priority areas because the data available will normally come from a variety of sources (Nix et al., 2000).

Higher taxa (e.g. genera, families) might also be used if a relationship between the distribution patterns of higher taxa and the distribution patterns of species can be demonstrated. For the same breadth of taxonomic coverage, it would be cheaper and easier to identify samples at higher taxon levels (Williams and Gaston, 1994). Most taxa remain undescribed and even of the taxa that are known, only a small sub-set is sufficiently well studied, both in terms of taxonomic status and geographic distribution, to be used to identify priority areas. Higher taxon methods (family or genera) are an improvement. However, our data suggest that the relationship is stronger at the level of genus than family. It follows then that if higher taxon surveys are to be used for spider diversity assessment then estimates at the level of genus should be used. The results of this study show clearly that higher taxon approach could be used towards this direction for performing rapid area inventories. Neither geographical location or area or habitats were found to have significant influence over the usefulness of higher taxa surrogacy at genus level. When sampling effort is same, the only factor found that may limit the use of higher taxa surrogacy is imperfect detection of species in a single or multiple sites. Higher taxon data should only be used in situations where there are insufficient resources available for good species data to be a realistic alternative.

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Appendix 4.1 Lists of spider species recorded in each habitat type during sampling 100 sites in 5 habitat types in TCA. [Habitats are abbreviated as follows PL, Plantation, MS, Mixed Sal, PS, Pure Sal, GR, Grassland, and RP, Riparian]

Species	**Species code**	**Family**	**PL**	**MS**	**PS**	**GR**	**RP**
Achaearanea budana	*sp1*	Theridiidae	0	0	1	0	1
Achaearanea sp.1	*sp2*	Theridiidae	3	0	0	0	7
Achaearanea sp.2	*sp3*	Theridiidae	0	15	4	0	19
Achaearanea triangularis	*sp4*	Theridiidae	35	12	4	0	13
Agelena gautami	*sp5*	Agelenidae.	0	0	0	5	0
Arachnura melanura	*sp6*	Araneidae	0	4	20	0	11
Araneus bilunifer	*sp7*	Araneidae	0	6	11	17	30
Araneus sp.1	*sp8*	Araneidae	0	26	0	0	6
Arctosa indica	*sp9*	Lycosidae	0	0	1	0	0
Arctosa sp.1	*sp10*	Lycosidae	0	2	1	0	0
Arctosa sp.2	*sp11*	Lycosidae	0	0	0	0	13
Arctosa sp.3	*sp12*	Lycosidae	0	1	0	0	1
Argiope anasuja	*sp13*	Araneidae	0	19	36	0	42
Argiope pulchella	*sp14*	Araneidae	0	20	51	0	10
Argyrodes crytophorae	*sp15*	Theridiidae	1	1	0	0	0
Argyrodes fissifrons	*sp16*	Theridiidae	0	6	6	0	12
Argyrodes sp.1	*sp17*	Theridiidae	2	0	0	0	0
Argyrodes sp.2	*sp18*	Theridiidae	26	12	25	0	0
Argyrodes sp.3	*sp19*	Theridiidae	0	1	0	0	0
Argyrodes sp.4	*sp20*	Theridiidae	0	0	1	0	1
Chrysso picturata	*sp21*	Theridiidae	2	0	0	10	0
Chrysso sp.1	*sp22*	Theridiidae	89	19	2	0	2
Chrysso sp.2	*sp23*	Theridiidae	1	0	0	0	0
Clubiona boxaensis	*sp24*	Clubionidae	0	0	0	0	1
Clubiona deletrix	*sp25*	Clubionidae	0	0	11	0	1
Clubiona filicata	*sp26*	Clubionidae	0	0	22	0	0
Clubiona sp. 1	*sp27*	Clubionidae	0	0	0	0	1
Crossopriza lyoni	*sp28*	Pholcidae	0	32	2	0	0
Cyclosa confraga	*sp29*	Araneidae	0	10	30	13	0
Cyclosa mulmeinensis	*sp30*	Araneidae	0	27	27	15	12
Cyclosa simoni	*sp31*	Araneidae	0	41	21	22	0
Cyclosa sp.1	*sp32*	Araneidae	0	12	15	1	44
Cyrtophora bidenta	*sp33*	Araneidae	0	3	5	0	2
Cyrtophora cicatrosa	*sp34*	Araneidae	0	37	17	1	1
Cyrtophora citricola	*sp35*	Araneidae	0	3	7	0	19
Cyrtophora ksudra	*sp36*	Araneidae	0	8	8	0	43
Cyrtophora moluccensis	*sp37*	Araneidae	0	43	20	25	0
Diaea subdola	*sp38*	Thomisidae	1	1	1	17	4
Drassodes gangeticus	*sp39*	Gnaphosidae	0	0	0	2	18
Drassodes luridus	*sp40*	Gnaphosidae	0	0	0	8	19
Drassodes parvidens	*sp41*	Gnaphosidae	0	0	1	0	1
Eriovixia laglaizei	*sp42*	Araneidae	16	17	19	18	30
Evippa solanensis	*sp43*	Lycosidae	0	0	0	0	18
Gamasomorpha clypeolaria	*sp44*	Oonopidae	1	0	0	0	0
Gamasomorpha sp.1	*sp45*	Oonopidae	3	2	0	40	0

Species	Species code	Family	PL	MS	PS	GR	RP
Gamasomorpha sp.2	*sp46*	Oonopidae	6	3	2	8	0
Gamasomorpha sp.3	*sp47*	Araneidae	0	5	8	0	18
Gasteracantha dalyi	*sp48*	Araneidae	0	1	30	12	18
Gasteracantha geminata	*sp49*	Araneidae	0	11	26	0	28
Gasteracantha hasselti	*sp50*	Araneidae	0	1	4	3	26
Gea corbetti	*sp51*	Araneidae	0	0	6	24	0
Gea subarmata	*sp52*	Araneidae	0	0	2	0	0
Gnaphosa stocliczka	*sp53*	Gnaphosidae	0	0	0	4	13
Gnaphosan kailana	*sp54*	Gnaphosidae	0	0	0	11	8
Haplodrassus tehriensis	*sp55*	Gnaphosidae	0	0	0	19	12
Hersilia savignyi	*sp56*	Hahniidae	0	1	2	0	0
Heteropoda buxa	*sp57*	Sparassidae	1	0	1	0	1
Heteropoda faberi	*sp58*	Sparassidae	0	0	0	1	1
Heteropoda venatoria	*sp59*	Sparassidae	0	0	1	5	18
Hippasa pisaurina	*sp60*	Lycosidae	0	0	0	0	27
Hippasa sp. 1	*sp61*	Lycosidae	0	0	0	0	12
Hippasa sp. 2	*sp62*	Lycosidae	0	0	0	4	34
Larinia chloris	*sp63*	Araneidae	3	0	0	1	0
Larinia sp. 1	*sp64*	Araneidae	12	0	0	0	0
Leucauge celebasiana	*sp65*	Tetragnathidae	0	0	0	0	1
Leucauge decorata	*sp66*	Tetragnathidae	0	17	8	1	46
Leucauge sp. 1	*sp67*	Tetragnathidae	0	10	4	0	1
Linyphia perampla	*sp68*	Linyphiidae	1	7	12	0	1
Linyphia sikkimensis	*sp69*	Linyphiidae	7	0	2	0	0
Linyphia sp. 1	*sp70*	Linyphiidae	0	0	0	0	1
Linyphia sp. 10	*sp71*	Linyphiidae	0	0	1	1	2
Linyphia sp. 11	*sp72*	Linyphiidae	0	0	1	43	4
Linyphia sp. 12	*sp73*	Linyphiidae	0	0	0	13	1
Linyphia sp. 13	*sp74*	Linyphiidae	9	1	3	0	1
Linyphia sp. 2	*sp75*	Linyphiidae	0	1	2	44	0
Linyphia sp. 3	*sp76*	Linyphiidae	0	0	0	1	0
Linyphia sp. 4	*sp77*	Linyphiidae	1	0	0	16	0
Linyphia sp. 5	*sp78*	Linyphiidae	0	0	5	14	0
Linyphia sp. 6	*sp79*	Linyphiidae	0	3	3	1	0
Linyphia sp. 7	*sp80*	Linyphiidae	0	3	0	23	0
Linyphia sp. 8	*sp81*	Linyphiidae	0	1	3	0	0
Linyphia sp. 9	*sp82*	Linyphiidae	1	0	0	0	0
Linyphia straminea	*sp83*	Linyphiidae	0	0	8	6	0
Linyphia urbasae	*sp84*	Linyphiidae	0	0	0	16	12
Lutica bengalensis	*sp85*	Zodariidae	0	0	1	12	0
Lycosa tista	*sp86*	Lycosidae	0	0	0	0	34
Marpissa decorata	*sp87*	Salticidae	2	17	0	16	2
Meta sp. 1	*sp88*	Tetragnathidae	0	0	2	0	0
Miagrammopes gravelyi	*sp89*	Uloboridae	0	7	9	0	1
Miagrammopes indicus	*sp90*	Uloboridae	0	0	4	0	0
Misumena indra	*sp91*	Thomisidae	3	0	0	0	0
Misumena mridulai	*sp92*	Thomisidae	1	2	0	0	0
Myrmarachne himalayensis	*sp93*	Salticidae	0	9	0	0	22
Myrmarachne sp.1	*sp94*	Salticidae	2	1	16	0	16
Myrmarachne sp.2	*sp95*	Salticidae	0	0	0	0	7

Species	Species code	Family	PL	MS	PS	GR	RP
Neoscona biswasi	*sp96*	Araneidae	0	24	1	0	42
Neoscona mukherji	*sp97*	Araneidae	0	34	17	1	23
Neoscona odites	*sp98*	Araneidae	0	18	12	0	3
Neoscona theisi	*sp99*	Araneidae	1	25	36	0	34
Neoscona vigilans	*sp100*	Araneidae	0	80	9	0	22
Neotama punctigera	*sp101*	Hahniidae	0	10	15	18	0
Nephila pilipes	*sp102*	Tetragnathidae	0	12	22	0	2
Oedothorax globiceps	*sp103*	Linyphiidae	1	0	0	1	10
Oedothorax sp.1	*sp104*	Linyphiidae	0	1	0	1	10
Olios tikaderi	*sp105*	Sparassidae	0	0	0	0	1
Oxyopes shweta	*sp106*	Oxyopidae	0	8	0	14	7
Ozyptila manii	*sp107*	Thomisidae	0	0	0	0	1
Ozyptila sp.1	*sp108*	Thomisidae	0	0	0	0	2
Parawixia dehaanii	*sp109*	Araneidae	0	1	3	46	1
Parawixia sp. 1	*sp110*	Araneidae	0	1	1	1	0
Pardosa timidula	*sp111*	Lycosidae	0	0	0	0	25
Philodromus pali	*sp112*	Philodromidae	4	0	10	11	0
Phintella bifurcata	*sp113*	Salticidae	0	0	0	13	1
Pisaura decorata	*sp114*	Pisauridae	0	0	0	5	0
Pisaura sp.1	*sp115*	Pisauridae	0	0	0	5	0
Plexippus paykulli	*sp116*	Salticidae	1	2	1	0	0
Plexippus redimitus	*sp117*	Salticidae	1	5	7	1	0
Poltys illepidus	*sp118*	Araneidae	30	0	10	9	0
Portia albimana	*sp119*	Salticidae	0	1	2	0	7
Rhene indica	*sp120*	Salticidae	0	1	0	0	0
Rhene sp.1	*sp121*	Salticidae	1	0	0	0	0
Rhene sp.2	*sp122*	Salticidae	1	0	3	4	1
Rhene sp.3	*sp123*	Salticidae	0	0	1	5	0
Runcinia affinis	*sp124*	Thomisidae	3	0	0	0	0
Runcinia roonwali	*sp125*	Thomisidae	1	1	1	0	1
Scytodes pallida	*sp126*	Scytodidae	0	0	3	0	1
Selenocosmia himalayana	*sp127*	Theraphosidae	0	0	0	0	2
Smeringopus pallidus	*sp128*	Pholcidae	0	12	2	0	0
Tetrablemma deccanense	*sp129*	Tetrablemmidae	10	0	0	1	1
Tetragnatha chamberlini	*sp130*	Tetragnathidae	0	0	0	0	19
Thalassius albocinctus	*sp131*	Pisauridae	0	0	0	1	0
Theridion incertum	*sp132*	Theridiidae	0	2	6	0	0
Theridion manjithar	*sp133*	Theridiidae	1	3	2	1	0
Theridion sp.1	*sp134*	Theridiidae	0	2	0	3	2
Theridion sp.2	*sp135*	Theridiidae	0	0	0	13	1
Theridion sp.3	*sp136*	Theridiidae	0	0	1	6	1
Theridion sp.4	*sp137*	Theridiidae	0	9	0	1	9
Theridion sp.5	*sp138*	Theridiidae	0	2	4	5	0
Theridion sp.6	*sp139*	Theridiidae	0	0	1	0	0
Theridion sp.7	*sp140*	Theridiidae	0	0	0	1	12
Theridion sp.8	*sp141*	Theridiidae	0	0	0	1	0
Theridion sp.9	*sp142*	Theridiidae	0	6	5	2	2
Thomisus pugilis	*sp143*	Thomisidae	4	1	0	1	0
Thomisus sp.1	*sp144*	Thomisidae	10	4	5	2	2
Thomisus sp.10	*sp145*	Thomisidae	0	0	5	0	5

Species	**Species code**	**Family**	**PL**	**MS**	**PS**	**GR**	**RP**
Thomisus sp.2	*sp146*	Thomisidae	0	0	1	0	0
Thomisus sp.3	*sp147*	Thomisidae	0	0	0	1	10
Thomisus sp.4	*sp148*	Thomisidae	0	0	0	3	2
Thomisus sp.5	*sp149*	Thomisidae	0	0	0	2	0
Thomisus sp.6	*sp150*	Thomisidae	0	0	0	5	0
Thomisus sp.7	*sp151*	Thomisidae	2	0	0	0	0
Thomisus sp.8	*sp152*	Thomisidae	0	0	0	4	6
Thomisus sp.9	*sp153*	Thomisidae	0	0	0	3	0
Trochosa himalayensis	*sp154*	Lycosidae	0	0	0	0	3
Tylorida ventralis	*sp155*	Tetragnathidae	0	0	0	1	0
Uloborus danolius	*sp156*	Uloboridae	0	13	5	1	1
Uloborus sp.1	*sp157*	Uloboridae	1	3	6	0	0
Zelotes nainitalensis	*sp158*	Gnaphosidae	0	16	0	0	0
Zygiella indica	*sp159*	Araneidae	0	13	32	0	12
Zygiella sp.1	*sp160*	Araneidae	0	14	13	43	20

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Appendix 5.1 List of sampling sites with their attributes representing habitat gradient in the study area, TCA. The vegetation measurements are mean values averaged across season for each sampling plots. [Variables are abbreviated as follows tree canopy cover (TCC), litter cover (LCC), total vegetation cover (TVCOV), bare ground cover (BCOV), mean litter depth (AVLD), shrub height variation (HRS), plant species richness (PSR), shrub canopy cover (SCC), ground herb cover (GHC) foliage height diversity (FHD), and tree and shrub density (TSD).

Transect Code	Vegetation Type	TCC	LCC	TVCOV	BCOV	AVLD	HRS	PSR	SCC	GHC	FHD	TSD
tps1	Pure Sal	73.54	0.54	0.71	0.37	0.73	2.74	46.00	4.472	6.481	1.985	145.60
tps2	Pure Sal	68.15	0.59	0.62	0.47	0.75	1.82	42.00	4.583	6.708	2.108	158.40
tps3	Pure Sal	75.99	0.51	0.33	0.68	0.79	0.00	41.00	4.796	6.000	1.549	200.90
tps4	Pure Sal	75.50	0.51	0.52	0.52	0.79	0.00	44.00	4.899	5.657	1.601	180.50
tps5	Pure Sal	70.60	0.57	0.55	0.43	0.83	0.00	43.00	5.000	5.477	1.705	185.70
tps6	Pure Sal	73.54	0.54	0.71	0.33	0.76	0.00	48.00	4.899	5.568	1.517	184.70
tps7	Pure Sal	79.91	0.47	0.63	0.63	0.58	1.82	44.00	5.196	5.099	1.212	197.60
tps8	Pure Sal	82.85	0.42	0.47	0.58	0.79	3.04	47.00	5.292	5.385	1.828	168.90
tps9	Pure Sal	87.26	0.37	0.40	0.63	0.79	0.00	31.00	5.657	5.000	1.917	151.80
tps10	Pure Sal	78.93	0.48	0.63	0.63	0.58	3.04	35.00	5.831	5.745	1.993	153.90
tps11	Pure Sal	65.21	0.63	0.58	0.47	0.79	2.13	36.00	5.657	6.083	1.822	159.40
tps12	Pure Sal	73.54	0.54	0.52	0.47	0.83	2.74	35.00	5.568	6.245	2.108	158.90
tps13	Pure Sal	55.90	0.72	0.58	0.33	0.88	0.00	34.00	4.690	6.325	2.030	155.30
tps14	Pure Sal	60.80	0.68	0.47	0.40	0.94	3.04	38.00	5.657	6.403	1.760	143.20
tps15	Pure Sal	75.01	0.52	0.58	0.58	0.68	0.00	30.00	5.385	6.481	1.731	169.80
tps16	Pure Sal	75.50	0.51	0.73	0.33	0.73	0.00	36.00	5.292	6.633	1.966	178.80
tps17	Pure Sal	72.56	0.55	0.47	0.79	0.58	2.43	35.00	5.000	5.292	1.899	172.80
tps18	Pure Sal	40.22	0.88	0.52	0.47	0.83	0.00	39.00	5.916	5.196	1.571	175.30
tps19	Pure Sal	83.34	0.42	0.33	0.58	0.88	0.00	35.00	5.568	5.831	1.891	176.70
tps20	Pure Sal	76.97	0.50	0.52	0.33	0.94	0.00	36.00	5.477	5.916	1.512	192.50
tpl1	Plantation	44.14	0.85	0.33	0.33	1.10	0.30	3.00	2.236	1.000	1.000	20.00
tpl2	Plantation	23.07	1.08	0.58	0.88	0.33	1.52	4.00	2.000	2.236	1.371	22.00
tpl3	Plantation	36.30	0.93	0.33	0.58	0.88	0.00	5.00	2.449	2.646	0.000	24.00
tpl4	Plantation	43.16	0.85	0.58	0.58	0.58	1.52	2.00	2.646	2.828	1.000	21.00
tpl5	Plantation	42.18	0.86	0.68	0.58	0.22	0.30	7.00	2.828	1.732	1.000	26.00
tpl6	Plantation	56.88	0.72	0.68	0.58	0.88	0.30	8.00	1.000	3.000	1.000	26.90

Transect Code	Vegetation Type	TCC	LCC	TVCOV	BCOV	AVLD	HRS	PSR	SCC	GHC	FHD	TSD
tpl7	Plantation	54.92	0.73	0.63	0.58	0.94	0.30	3.00	0.000	2.449	0.000	28.00
tpl8	Plantation	49.04	0.79	0.63	0.58	0.94	0.30	4.00	1.414	1.000	0.000	30.30
tpl9	Plantation	38.75	0.89	0.68	0.58	0.88	1.82	5.00	2.828	0.000	0.000	32.00
tpl10	Plantation	52.96	0.76	0.58	0.58	1.00	1.82	6.00	1.732	1.414	0.000	31.00
tpl11	Plantation	48.55	0.80	0.22	0.58	0.79	0.91	7.00	0.000	1.732	0.000	10.50
tpl12	Plantation	24.54	1.06	0.33	0.58	0.58	0.91	9.00	0.000	2.000	0.000	10.60
tpl13	Plantation	36.30	0.93	0.22	0.58	1.17	0.91	1.00	0.000	2.449	0.000	28.40
tpl14	Plantation	37.77	0.91	0.33	0.58	0.68	0.91	3.00	0.000	2.646	0.000	22.30
tpl15	Plantation	42.18	0.86	0.73	0.58	0.22	0.91	4.00	1.414	1.732	0.971	25.50
tpl16	Plantation	55.90	0.72	0.58	0.58	1.00	2.13	10.00	1.732	2.828	0.000	21.50
tpl17	Plantation	59.82	0.68	0.52	0.58	1.06	2.13	7.00	2.000	3.000	0.918	22.60
tpl18	Plantation	27.48	1.02	0.47	0.58	1.10	2.74	5.00	1.000	1.414	0.971	22.70
tpl19	Plantation	50.02	0.79	0.58	0.58	1.00	1.52	2.00	2.236	1.732	0.918	22.80
tpl20	Plantation	52.96	0.76	0.58	0.58	1.00	3.04	1.00	2.449	1.000	1.906	22.90
tgr1	Grassland	0.00	1.57	0.22	0.58	0.73	0.91	5.00	2.449	3.317	2.193	156.70
tgr2	Grassland	0.00	1.57	0.33	0.58	0.68	0.30	1.00	2.646	3.464	2.281	54.90
tgr3	Grassland	0.00	1.57	0.22	0.58	0.88	1.22	6.00	1.732	3.742	2.163	56.70
tgr4	Grassland	0.00	1.57	0.33	0.58	0.58	1.22	12.00	1.000	3.873	2.236	53.90
tgr5	Grassland	0.00	1.57	0.33	0.58	0.73	1.22	10.00	1.414	4.000	2.135	69.20
tgr6	Grassland	0.00	1.57	0.22	0.58	0.88	1.22	9.00	3.000	4.123	2.117	73.80
tgr7	Grassland	0.00	1.57	0.22	0.58	0.94	1.22	3.00	2.828	4.243	1.922	84.80
tgr8	Grassland	0.00	1.57	0.22	0.58	0.94	1.22	8.00	2.646	4.359	2.097	92.50
tgr9	Grassland	0.00	1.57	0.22	0.58	0.88	1.22	6.00	2.236	3.317	2.064	98.50
tgr10	Grassland	0.00	1.57	0.33	0.58	0.83	1.22	6.00	2.449	3.162	2.175	63.90
tgr11	Grassland	0.00	1.57	0.00	0.58	0.40	0.61	5.00	2.646	3.464	2.077	80.60
tgr12	Grassland	0.00	1.57	0.33	0.58	0.58	0.61	11.00	0.000	3.606	2.127	67.70
tgr13	Grassland	0.00	1.57	0.22	0.58	1.06	0.00	12.00	1.000	3.742	2.239	88.00
tgr14	Grassland	0.00	1.57	0.00	0.58	0.68	0.61	7.00	2.236	3.873	2.197	145.40
tgr15	Grassland	0.00	1.57	0.22	0.58	0.40	0.91	8.00	2.449	4.359	2.227	113.70
tgr16	Grassland	0.00	1.57	0.22	0.58	0.63	1.22	9.00	2.646	4.123	2.197	128.90
tgr17	Grassland	0.00	1.57	0.22	0.58	0.73	1.22	3.00	3.000	4.000	2.047	91.20
tgr18	Grassland	0.00	1.57	0.33	0.58	0.79	1.22	11.00	2.236	3.873	2.074	90.00

Transect Code	Vegetation Type	TCC	LCC	TVCOV	BCOV	AVLD	HRS	PSR	SCC	GHC	FHD	TSD
tgr19	Grassland	0.00	1.57	0.00	0.58	1.00	1.22	11.00	2.646	3.742	2.098	85.40
tgr20	Grassland	0.00	1.57	0.00	0.58	0.83	1.22	13.00	1.732	4.243	2.000	83.20
trp1	Riparian Swamp	57.86	0.71	0.68	0.58	0.47	2.74	61.00	5.916	6.782	2.251	200.00
trp2	Riparian Swamp	29.93	1.00	0.33	0.58	0.00	3.65	68.00	6.000	7.483	2.317	198.20
trp3	Riparian Swamp	72.07	0.56	1.10	0.58	0.22	3.95	58.00	6.245	7.280	2.050	186.40
trp4	Riparian Swamp	62.27	0.66	1.17	0.58	0.22	3.95	56.00	6.325	7.211	2.108	175.30
trp5	Riparian Swamp	50.02	0.79	1.17	0.58	0.10	5.47	52.00	6.481	8.062	2.154	177.80
trp6	Riparian Swamp	82.36	0.43	1.25	0.58	0.30	4.26	64.00	7.000	6.403	2.158	179.30
trp7	Riparian Swamp	68.15	0.59	0.73	0.58	0.58	3.95	66.00	7.071	6.481	2.048	203.60
trp8	Riparian Swamp	69.13	0.59	0.58	0.58	0.00	3.04	65.00	7.211	6.856	2.123	223.90
trp9	Riparian Swamp	76.97	0.50	1.10	0.58	0.47	3.95	54.00	7.141	6.928	2.145	224.50
trp10	Riparian Swamp	75.01	0.52	0.88	0.58	0.52	3.34	51.00	7.416	7.616	2.167	226.70
trp11	Riparian Swamp	69.13	0.59	0.73	0.58	0.40	3.65	65.00	7.348	7.416	2.124	232.80
trp12	Riparian Swamp	55.90	0.72	0.22	0.58	0.00	3.95	69.00	7.280	8.000	2.190	170.50
trp13	Riparian Swamp	77.46	0.49	1.00	0.58	0.52	4.26	67.00	6.928	7.937	2.255	178.90
trp14	Riparian Swamp	67.66	0.61	0.83	0.58	0.58	4.26	68.00	7.000	7.746	2.259	191.70
trp15	Riparian Swamp	56.88	0.72	1.29	0.58	0.22	3.04	69.00	6.708	7.071	2.242	200.80
trp16	Riparian Swamp	77.46	0.49	1.33	0.58	0.17	0.00	65.00	6.782	8.062	2.296	202.30
trp17	Riparian Swamp	73.54	0.54	0.79	0.58	0.22	3.65	65.00	6.856	7.550	2.267	207.80
trp18	Riparian Swamp	64.72	0.63	0.58	0.58	0.22	4.26	56.00	7.211	7.616	2.316	203.40
trp19	Riparian Swamp	75.01	0.52	0.83	0.58	0.73	6.08	65.00	7.416	7.141	2.293	209.50
trp20	Riparian Swamp	66.68	0.62	0.83	0.58	0.68	6.08	59.00	6.164	7.810	2.281	208.40
tsm1	Mixed Sal	58.84	0.69	0.52	0.58	0.40	0.00	55.00	8.062	9.220	2.266	165.70
tsm2	Mixed Sal	72.07	0.56	0.68	0.58	0.22	0.00	51.00	8.246	8.185	2.290	178.90
tsm3	Mixed Sal	61.29	0.67	0.47	0.58	0.40	1.82	56.00	8.660	8.485	2.280	222.90
tsm4	Mixed Sal	55.90	0.72	0.63	0.58	0.47	1.22	58.00	8.485	8.775	2.233	202.40
tsm5	Mixed Sal	51.49	0.78	0.63	0.58	0.22	2.74	57.00	8.426	8.888	2.292	209.50
tsm6	Mixed Sal	58.84	0.69	0.63	0.58	0.22	3.95	51.00	8.367	9.000	2.307	204.80
tsm7	Mixed Sal	57.37	0.71	0.68	0.58	0.40	1.52	42.00	8.307	9.274	2.289	227.90
tsm8	Mixed Sal	51.98	0.76	0.73	0.58	0.52	1.82	43.00	8.307	8.832	2.275	234.50
tsm9	Mixed Sal	53.94	0.75	0.88	0.58	0.33	1.52	44.00	8.944	8.602	2.228	171.90
tsm10	Mixed Sal	54.43	0.75	0.58	0.58	0.52	1.22	44.00	8.718	8.307	2.227	173.60

Transect Code	Vegetation Type	TCC	LCC	TVCOV	BCOV	AVLD	HRS	PSR	SCC	GHC	FHD	TSD
tsm11	Mixed Sal	45.12	0.83	0.83	0.58	0.40	2.43	46.00	8.775	8.185	2.246	179.40
tsm12	Mixed Sal	48.06	0.80	0.73	0.58	0.47	1.22	45.00	8.832	8.000	2.194	174.60
tsm13	Mixed Sal	44.63	0.83	0.73	0.58	0.47	1.22	47.00	8.124	9.165	2.258	177.80
tsm14	Mixed Sal	49.04	0.79	0.68	0.58	0.52	0.91	49.00	8.185	9.110	2.249	172.90
tsm15	Mixed Sal	54.92	0.73	0.63	0.58	0.83	1.22	48.00	8.307	9.055	2.237	189.60
tsm16	Mixed Sal	53.94	0.75	0.73	0.58	0.33	0.91	55.00	8.426	8.944	2.254	199.40
tsm17	Mixed Sal	53.45	0.75	0.63	0.58	0.40	0.91	52.00	8.485	8.367	2.266	198.40
tsm18	Mixed Sal	57.86	0.71	0.63	0.58	0.40	1.52	51.00	8.602	9.000	2.253	192.80
tsm19	Mixed Sal	25.52	1.04	0.52	0.58	0.40	1.22	53.00	8.944	9.055	2.275	198.30
tsm20	Mixed Sal	41.20	0.88	0.52	0.58	0.40	3.04	50.00	8.775	8.944	2.263	212.50

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