

EFFECT OF PRESCRIBED FIRE ON SPIDER ASSEMBLAGE IN TERAİ GRASSLANDS, INDIA

Upamanyu Hore ¹ and Virendra Prasad Uniyal ¹

¹ Wildlife Institute of India, Post Box 18, Chandrabani, Dehradun, Uttaranchal, INDIA
E-mail: uniyalvp@wii.gov.in

[Hore, U. & Uniyal, V. P. 2008. Effect of prescribed fire on spider assemblage in Terai grasslands, India. Turk J Arach. 1 (1): 15-36.]

ABSTRACT: 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 desire 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 single-and multiple-burning events on spider assemblage, and recovery of these grassland spiders following fire disturbance. In this paper, we assessed the effects of prescribed fire regime of single and repeated fires on diversity and structure of spider assemblage in tall grassland of Terai. Spiders were sampled by pitfall trapping and sweep netting methods and for each fire regime spider abundance, richness, diversity and evenness were calculated. Grassland characteristics were also delineated to measures impacts of the prescribed fires and to assess variability and heterogeneity of the grassland environment. Following burning we found species strongly associated with particular fire regime and more diverse assemblage occurred at single fire sites. Species composition found substantially differed between fire regimes. These changes in species composition were considered to be a response to altered habitat conditions, particularly proportion of ground cover, moisture regime and soil temperature. Adaptive management of appropriate fire prescription should be taken account to provide wide range of microhabitats that support a large proportion of species and to meet conservation efforts for these grassland spider assemblages.

KEY WORDS: Spider assemblage, Terai grassland, Prescribed burning, Fire regime.

HİNDİSTAN TERAİ OTLAKLARINDA ÖNGÖRÜLEN YANGININ ÖRÜMCEK TOPLULUKLARINDAKİ ETKİSİ

ÖZET: Hindistanda koruma alanları olan sel havzası otlaklarında yürütülen yıllık düşük yoğunluklu yangın yönetimi stratejisi şüpheli bir yaklaşımdır. Temelde yakıt kullanım düzeyini azaltmak ve toynaklı hayvanların gereksinim duyduğu bitki türlerinin rejenerasyonunu sağlamak için kullanılan bu yöntemin doğal ekosistemlerde uzun süreli tekrarlı kullanımının yol açacağı etkiler hakkında çok az bilgi bulunmaktadır. Tavsiye edilen yangın çıkarma yöntemlerinin kullanımındaki artış tekli ya da ardışık yangın olaylarının örümcekler üzerindeki etkilerinin neler olabileceği ve örümcek populasyonlarının yangın tahribinden sonra nasıl toparlandığı sorularını gündeme getirmektedir. Bu çalışmada, Terai'nin uzun otlaklarındaki örümcek populasyonlarının çeşitliliği ve yapısı üzerinde tekli ve ardışık tavsiye edilen yangın çıkarma yöntemleri sonrasındaki durumlarının ortaya koyulması amaçlanmıştır. Örümcekler, düşürme tuzağı ve süpürme ağ metotları ile her yangın rejiminden sonra yakalanmış ve örümcek bolluğu, tür çeşitliliği ve tür sürekliliği verileri saptanmıştır. Tavsiye edilen yangınların otlak üzerindeki etkilerini ve otlaktaki değişkenlik ve heterojenliğin ortaya çıkarılması için otlak karakteristikleri de belirlenmiştir. Tür kompozisyonundaki bu değişimlerin, özellikle zemin örtüsü, nem rejimi ve toprak sıcaklığı gibi bozulmuş habitat koşullarına karşı verilmiş bir cevap olduğu düşünülmektedir.

ANAHTAR KELİMELER: Örümcek toplulukları, Terai Otlığı, Öngörülen yangın, Yangın rejimi

INTRODUCTION

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).

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. Here, we describe the responses of grassland spiders to different fire regimes in tall grasslands of Terai Conservation Area, northern India. Spiders warrant conservation interest because of their large contribution to biodiversity (Skerl & Gillespie 1999). Additionally, spiders are ideal bio-indicators as they are diverse and abundant predators (Churchill 1997). By preying on decomposers at lower trophic levels, spiders influence ecosystem functioning (Lawrence & 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 & 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. In this paper, we examined the effects of prescribed fires on diversity and structure of spider assemblage in tall grassland of Terai. Specifically, we assessed the effects of a prescribed fire management regime, employing single- and repeated (multiple) - burns.

MATERIAL AND METHODS

The study was conducted in alluvial flood plain of Terai Conservation Area (TCA) lying between the Himalayan foothills and the Gangetic plains in the state of Uttar Pradesh, India (Latitude N 27°49' and 28°43' and Longitude E 81°01' and 81°18') from October 2006 to August 2007. 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. 2000; 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 & 1999a,b). The topography is level, 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).

Sampling.-Sixteen grassland sites were selected in homogenous stands of tall grassland which was still undergone habitat management practices by forest departments. We assessed three fire regimes, each replicated four times in different seasons, 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 before the end of the dry season (January - May); and (iii) unburnt, fire excluded from sites. 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 habitat assessment. 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 (Churchill & Arthur 1999). Traps were filled with preservative liquid (69 % water, 30% ethyl acetate and 1% detergent). After 7 days, specimens were removed from traps, which allowed us 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 & Niemela 1994). Sweep-nets were used to collect spiders from grass layer and above ground vegetation (up to 2 m in height) and we 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.

Adjacent to spider sampling, we measured 9 habitat variables of sampled plots for each month (October-August), including litter cover (%), litter depth (cm), bare ground (ground debris > 6 cm, %), grass cover (%), number of grass species, soil pH, soil moisture, soil temperature and ambient humidity.

Spiders were identified to family and species using existing identification keys wherever possible (Pocock 1900; Tikader 1982, 1987; Cushing 2001; Koh 2000). Due to lack of available identification keys for many families and the time required for conventional taxonomic work, a morphospecies approach was used to classify spiders. This approach has been found to be effective for poorly known and species-rich taxa such as spiders and other invertebrates (Oliver & Beattie 1996; Krell 2004). Voucher specimens of each spider species collected are deposited at Wildlife Institute of India, Dehradun and Arachnida Section, Zoological Survey of India, Kolkata.

Statistical analysis.- To assess how differences in species abundance might influence the species diversity (and thus community structure), we examined how the numbers of rare and common species varied among fire regimes. We interpreted rarity in two different ways: (1) species were considered rare if they were unique to particular levels of sampling (i.e., present in a single replicate of a sampling level regardless of abundance) or (2) species were considered rare if they occurred as singletons (abundance 1) or doubletons (abundance 2) within any particular sampling level. An important distinction between singletons and unique species is that singletons (or doubletons) can occur multiple times at a given same spatial scale if the abundance of a species is 1 (or 2) within replicates at any particular sampling level. Four sampling intervals representing pre-burn- (October-November), burn- (January- February), post-burn 1- (April-May) and late-season burn (July-August) over a year, were used to examine the effects of prescription burning from single- and multiple-burned sites on the spider community and grassland habitat. For each sampling method, spider abundance was assessed, and diversity, evenness, and richness calculated for each of the three treatments (single-burned, repeated- burned, and unburned controls). Diversity was calculated using the Shannon index, which utilizes the number of spiders in a taxa and the total number of spiders in a sample (Magurran 1988). Evenness was calculated using Pielou's index, which incorporates the Shannon diversity calculation and number of taxa in the sample (Magurran 1988). We used repeated measures ANOVA to compare the richness and abundance of grassland spiders among fire regimes and possible interactions between fire regime and season treatments.

Abundance data were $\log(x+1)$ transformed when necessary to meet assumptions of normality and homogeneity of variances. We tested for differences in community composition and guild composition between the three fire regimes using non-metric multidimensional scaling and Analysis of Similarities (ANOSIM, 999 permutations) using PRIMER software (Clarke & Warwick 1994). The Bray Curtis similarity index was used to calculate the similarity matrices (Clarke & Green 1988). All data were $\log(x+1)$ transformed and standardized to down weight the contribution of abundant species (by conversion to relative abundances) before the calculation of the similarity matrices (Clarke & Gorley 2001). Canonical correspondence analysis (CCA) (ter Braak 1986) was used to investigate the relationship between the sites based on the composition of their spider assemblages, and to determine how the assemblages responded to gradients in habitat variables. Indicator species analysis (Dufrene & Legendre 1997) was used to determine those spider species characteristics of certain treatment types. This analysis considers species found exclusively in a single treatment type to be perfect indicators of that habitat, and would receive an indicator value of 100. 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 & Grace 2002). PCOrd (McCune & Mefford 1999) was used for this analysis.

RESULTS

Species richness and diversity.- A total of 8272 individuals were collected during the entire sampling period, represents 198 species belonging to 74 genera and 27 families. Of all species captured, 96% found on the unburnt sites, while single fire and repeated fire represents 59% and 19% respectively. Burning, including both single and multiple-burns, caused 75 % reduction in spider abundance. Mean number of species and individuals significantly varied across fire regimes (Fig.1). Shannon index and evenness also showed significant differences between sites affected by different fire regimes (Fig.1). Rare species were a substantial component of the spider assemblage within each fire regime (Table 1). Because many singletons also represent unique species to a given sampling level, turnover in rare species appeared to influence the diversity estimates for species richness. Among the species collected, 49 species found unique to the unburnt sites; 20 and 12 species were observed at the single and repeated fire sites.

Effect of Season and Burning Phase.- The interaction between season and treatment sites showed that seasons had no significant effect on treatment sites for species abundance (Table 2), while in contrast, species richness of treatment sites varied across seasons. Species richness of burn and post burn time periods in fire treatments were clearly

different from the pre-burn period (Fig.2). This was especially true in post burn 2 period. Unburnt and burnt treatment experienced decrease in post burn 1 period followed by an increase in post burn 2 period. Mean species number considerably increased in burnt treatments at post burn 2 period in compare with the unburnt treatments.

Comparison of species composition between sites and fire regimes.- When the species were arranged to reflect their distribution across sites and treatments, a substantial proportion (59%) of species (117) was common to all three treatment groups. However differences in the overall spider composition were observed between the three fire regimes was found significant (Global $R = 0.62$, $P = 0.01$), while maximum dissimilarity of 79% was among unburnt and repeated fire regime (Table 2).

Community response to fire regime.- Broad assemblages of species with responses to burning disturbance displayed in the form of a biplot derived from the canonical correspondence analysis (CCA). The results of the CCA are shown in Fig. 3. The arrows depict the relative influence of the habitat variables on the composition of the spider assemblage, with the line length relative to the other variables, rather than an absolute degree of influence (ter Braak & Verdenschot 1995). Unburnt sites were characterized by high grass cover and litter cover as well as litter depth. Due to the correlation between variables (York 1999) these sites were also characterized by high soil moisture and ambient humidity level, a greater number of grass species. Burnt sites were characterized by less cover at ground and high soil temperature. Percentage grass cover and bare mineral soil were the only statistically significant variables and were found to have significant influence on the species composition between unburnt and burnt sites. Other environmental variables made only a minor (and non-significant) contribution to the observed differences in spider species composition. The first axis of the CCA explained the most variance in the data, while axes 2 explained relatively little and failed the Monte-Carlo test at the 0.05 level (Table 3). Indicator species analysis revealed species closely associated with fire regimes (Table 4). Most of the indicator species were found in the unburnt plots in compare to treatment compartments. Only one spider species could be considered indicator of the repeated burnt treatment, *Haplodrassus* sp.01, a hunting spider belongs family to Gnaphosidae. In contrast, 6 species were indicators of the unburnt sites, and 5 for the single fire treatment.

Community Structure.- Based on hunting methods and web building types from literature (Uetz et al. 1999; Höfer & Brescovits 2001), combined with field observations, we grouped the spider families into following six major guilds: 1) Orb weavers: Araneidae, Tetragnathidae; 2) Space and Sheet web weavers: Barychelidae, Dictynidae, Hahniidae, and Theridiidae; 3) Ground runners: Desidae, Gnaphosidae, Lycosidae and

Oonopidae; 4) Stalkers: Oxyopidae, Pisauridae, and Salticidae; 5) Funnel web weavers: Agelenidae, Clubionidae, Corinnidae, Dipluridae, Sparassidae, Miturigidae, and Thomisidae 6) Tangle web weavers: Linyphiidae and Theraphosidae. Relative abundances of different spider guilds showed significant differences by pair-wise ANOSIM tests (Table 5).

DISCUSSIONS

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. Ecological studies of arthropod assemblages in tall grasslands of India are surprisingly rare, considering the diversity of arthropods in the state in general and the importance of the Terai ecosystem. This is the first study which examined the impacts of fire management methods on the spider assemblage in the Terai Conservation Area. Fire caused an immediate decline in spider abundance and richness in both control (unburnt) and treatment plots (burnt, considering both single and repeated fire), however recovery was rapid and particularly in post burn 2 period, where species richness increased more than expected compared with the control plots. Several investigators have reported declined in spider numbers following burning of grasslands and prairies (Rice 1932; Riechert & Reeder 1972; Nagel 1973; Dunwiddie 1991). Grassland spider abundance at Terai found affected by repeated fire but not by season of burn.

In our study we found species strongly associated with particular fire regime and mean 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 our finding was interpreted for short duration scale. Nevertheless, species and guild composition not varied significantly between single and repeated fire sites, single fire sites comparatively hold high number of species and individuals as well as singletons and doubletons. Single fire qualified better considering prolonged time period allow recolonisation of spiders since aerial dispersal and colonization of neighbouring habitats are common phenomena among spiders (Bishop 1990; Bishop & Riechert 1990; Greenstone 1982, 1990). We found ground cover and soil temperature 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). 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. Studies found that burning generally acts as a sanitation procedure by removal or reduction of plant structure and litter (Ismail & Yarborough 1981). Based on Indicator species analysis we found species which were affected by fire, mostly belongs to Orb web weaver guild and species profited from fire, at large belongs to ground runner guild and family Gnaphosidae and Lycosidae. Niwa & Peck (2002) studied the influence of prescribed fire on spiders in conifer stands in Oregon and found, in agreement with the present study, that Gnaphosidae and Lycosidae were more numerous at burned sites. This pattern suggest abundance level dynamics of family Gnaphosidae and Lycosidae, belongs to ground runner guild, presumably resistant to fire dynamics and had rapid recolonisation at post fire phase. Our results indicate that spider assemblages at Terai grassland were influenced by fire event of whether or not fire occurs at all, but importantly the frequency of fire, operates at different fire regime, till the end of post burn season. This markedly necessitates thinking at adaptive management paradigm to adopt annual control patch burning, i.e. single fire treatment, and may facilitate multitaxa conservation approach through landscape level experiment.

ACKNOWLEDGMENTS

We are thankful to Mr. P.R. Sinha, Director, Prof. V.B. Mathur, Dean, and Prof. P.K. Mathur, Wildlife Institute of India for necessary support to carry out this study. We are thankful to Uttar Pradesh Forest Department for their unstinting help in the field and permission to carry out the study. We are thankful to Dr. B.K. Biswas, Zoological Survey of India, for helping in identification of spiders. We would like to express our special thanks to Dr. Bruce G Marcot, Dr. Yash Veer Bhatnagar and Dr. Kailash Chandra for their useful comments on the manuscript.

LITERATURE CITED

- Andersen, A.N. 1999.** Fire management in northern Australia: beyond command-and-control. *Australian Biologist* (12): 63-70.
- Bishop, L. & Riechert, S.E. 1990.** Spider colonization of agro ecosystems: Mode and source. *Environmental Entomology* (19): 1738-1745.
- Bishop, L. 1990.** Meteorological aspects of spider ballooning. *Environmental Entomology* (19): 1381-1388.
- Bradstock, R.A., Williams, J.E. & Gill, A.M. 2002.** Flammable Australia: The Fire Regimes and Biodiversity of a Continent. Cambridge University Press, Cambridge.
- Brennan, K.E.C., Ashby, L., Majer, J.D., Moir, M.L. & Koch, J.M. 2006.** Simplifying assessment of forest management practices for invertebrates: How effective are higher taxon and habitat surrogates for spiders following prescribed burning? *Forest Ecology and Management* (231): 138-154.

- Buffington, J.D. 1967.** Soil arthropod populations of the New Jersey Pine Barrens as affected by fire. *Annals of the Entomological Society of America* (60): 530-535.
- Bultman, T.L. & Uetz, G.W. 1982.** Abundance and community structure of forest floor spiders following litter manipulation. *Oecologia* (55): 34-41.
- Churchill, T.B. 1997.** Spiders as ecological indicators: an overview for Australia. *Memoirs of Museum Victoria* (56): 331-337.
- Churchill, T.B. & Arthur, J. 1999.** Measuring spider richness. Effects of different sampling methods and spatial and temporal scales. *Journal of Insect Conservation* (3): 287-295.
- Clarke, K.R. & Gorley, R.N. 2001.** PRIMER v5: User Manual/ Tutorial. Primer-E Ltd, Plymouth.
- Clarke, K.R. & Green, R.H. 1988.** Statistical design and analysis for a 'biological effects' study. *Marine Ecology Progress Series* (46): 213-226.
- Clarke, K.R. & Warwick, R.M. 1994.** Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Plymouth Marine Laboratory, Plymouth.
- Cushing, P.E. 2001.** Colorado spider survey. Denver Museum of Nature and Science, Denver.
- Dufrene, M. & Legendre, P. 1997.** Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monograph* (67): 53-73.
- Dunwiddie, P.W. 1991.** Comparisons of aboveground arthropods in burned, mowed and untreated sites in sandplain grasslands on Nantucket Island. *The American Midland Naturalist* (125): 206-212.
- Greenstone, M.H. 1982.** Ballooning frequency and habitat predictability in two wolf spider species (Lycosidae: *Pardosa*). *Florida Entomology* (65): 83-89.
- Greenstone, M.H. 1990.** Meteorological determinants of spider ballooning: the roles of thermals versus the vertical wind speed gradient in becoming airborne. *Oecologia* (84): 164-168.
- Haimi, J., Fritze, H. & Moilanen, P. 2000.** Response of soil decomposer animals to wood-ash fertilization and burning in a coniferous forest stand. *Forest Ecology and Management* (129): 53-61.
- Höfer, H. & Brescovit, A.D. 2001.** Spider and guild structure of a Neotropical spider assemblage (Araneae) from Reserva Duck, Amazonas, Brazil. *Andrias* (15): 99-119.
- Ismail, A.A. & Yarborough, D.E. 1981.** A comparison between flail mowing and burning for pruning lowbush blueberries. *HortScience* (16): 318-319.
- Koh, J.K.H. 2000.** A guide to common Singapore spiders. Singapore Science Centre, Singapore.
- Krell, F. 2004.** Parataxonomy vs. taxonomy in biodiversity studies—pitfalls and applicability of morpho-species sorting. *Biodiversity Conservation* (13): 795-812.
- Kumar, H., Mathur, P.K., Lehmkuhl, J.F., Khati, D.V.S., De, R. & Longwah, W. 2002.** In: Management of Forests in India for Biological diversity and Productivity: A New Perspective, Terai Conservation Area (TCA). WII-USDA Forest Service Collaborative Project Report, Wildlife Institute of India, Dehradun.

- Lawrence, K.L. & Wise, D.H. 2000.** Spider predation on forest-floor Collembola and evidence for indirect effects on decomposition. *Pedobiologia* (44): 33-39.
- Lawrence, K.L. & Wise, D.H. 2004.** Unexpected indirect effect of spiders on the rate of litter disappearance in a deciduous forest. *Pedobiologia* (48): 149-157.
- Lehmkuhl, J.F. 1994.** A Classification of Sub-tropical Riverine Grassland and Forest Associations in Chitwan National Park, Nepal. *Vegetatio* (111): 29-43.
- Lehmkuhl, J.F. 2000.** The organisation and Human Use of Terai Riverine Grasslands in the Royal Chitwan National Park, Nepal. In: *Grassland Ecology and Management in Protected Areas of Nepal*. Eds. Richard, C., K. Basnet, J.P. Sah & Y. Raut. *Grasslands of Terai Protected Areas* (2): 37-90.
- Magurran, A.E. 1988.** *Ecological diversity and its measurement*. Chapman and Hall.
- Malanson, G.P. 1987.** Diversity, stability, and resilience: effects of fire regime. In: *The role of fire in ecological systems*. Academic Publishing, Dordrecht, The Netherlands. Ed. L. Trabaud. 49-63pp.
- Mathur, P.K. 2000.** Status of Research and Monitoring in Protected Areas of Indian Terai – An Overview In: *Grassland Ecology and Management in Protected Areas of Nepal*. Eds. Richard, C., K. Basnet, J.P. Sah & Y. Raut. *Grasslands of Terai Protected Areas* (2): 16-29.
- McCune, B. & Mefford, M.J. 1999.** PC-ORD. *Multivariate Analysis of Ecological Data*. Version 4.0. MjM Software, Gleneden Beach, Oregon.
- McCune, B. & Grace, J. B. 2002.** *Analysis of Ecological Communities*. MJM Software Design, Gleneden Beach, Oregon.
- Merrett, P. 1976.** Changes in the ground-living spider fauna after heathland fires in Dorset. *The Bulletin of the British Arachnological Society* (3): 214-221.
- Mitchell, R.G. 1990.** Effects of prescribed fire on insect pests. In: *Natural and Prescribed Fires in Pacific Northwest Forests*. Oregon State University Press, Eds. Corvallis Walstad, J.D., Radosevich, S.R. & Sandberg, D.V. 111-121pp.
- Moretti, M., Conedera, M., Duelli, P. & Edwards, P.J. 2002.** The effects of wildfire on ground-active spiders in deciduous forests on the Swiss southern slope of the Alps. *Journal of Applied Ecology* (39): 321-336.
- Nagel, H.G. 1973.** Effect of spring prairie burning on herbivorous and non-herbivorous arthropod populations. *Journal of the Kansas Entomological Society* (46): 485- 496.
- Niwa, C.G. & Peck, R.W. 2002.** Influence of prescribed fire on carabid beetle (Carabidae) and spider (Araneae) assemblages in forest litter in south western Oregon. *Environmental Entomology* (31): 785-796.
- Oliver, I. & Beattie, A.J. 1996.** Invertebrate morphospecies as surrogates for species: a case study. *Conservation Biology* (1): 99-109.
- Peet, N.B., Watkinson, A.R., Bell, D.J. & Brown, K. 1997.** *The Management of tall grasslands for the conservation of biodiversity and sustainable utilization*. Scientific and Management Report, University of East Anglia, Norwich. 2.1 Section.
- Peet, N.B., Watkinson, A.R. Bell, D.J. & Kattel, B.J. 1999a.** Plant Diversity in the Threatened Sub-Tropical Grasslands of Nepal. *Biological Conservation* (88): 193-206.

Peet, N.B., Watkinson, A.R., Bell, D.J. & Sharma, U.R. 1999b. The Conservation Management of *Imperata cylindrica* Grasslands in Nepal with Fire and Cutting: An Experimental Approach. *Journal of Applied Ecology* (36): 374-387.

Peet, N.B., Bell, D.J. & Watkinson, A.R. 2000. In: Managing the Terai Grasslands in Nepal: Recent Research and Future Priorities. Proceedings of Workshop held in Royal Bardia National Park, Nepal. *Grasslands of Terai Protected Areas* (2): 30-36.

Pocock, R.I. 1900. The fauna of British India, including Ceylon and Burma. Arachnida, Taylor and Francis, London.

Rice, L.A. 1932. Effects of fire on prairie animal communities. *Ecology* (13): 392-401.

Riechert, S.E. & Reeder, W.G. 1972. Effects of fire on spider distribution in southwestern Wisconsin prairies, In Proc. 2nd Midwest Prairie Conference. University of Wisconsin, Madison Ed. J. Zimmerman. 73-90pp.

Skerl, K. & Gillespie, R. 1999. Spiders in conservation: tools, targets and other topics. *Journal of Insect Conservation* (3): 249-250.

Spence, J.R. & Niemela, J.K. 1994. Sampling carabid assemblages with pitfall traps: the madness and the method. *Canadian Entomology* 126 (3): 881-894.

ter Braak, C.J.F. 1986. Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology* (67): 1167-79.

ter Braak C.J.F. & Verdonschot P.F.M. 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Science* (57): 255-89.

Tikader, B.K. 1982. Fauna of India: spider (Araneidae and Gnaphosidae). Government of India.

Tikader, B.K. 1987. Handbook Indian Spiders. Zoological Survey of India, Calcutta, India.

Uetz, G.W. 1991. Habitat structure and spider foraging. In: *Habitat Structure: The Physical Arrangement of Objects in Space*. Chapman & Hall, London, New York. Eds. S. S. Bell, E. D. McCoy & H. R. Mushinsky. 325-348pp.

Uetz, G.W., Halaj, J. & Cady, B.A. 1999. Guild structure of spiders in major crops. *Journal of Arachnology* (27): 270-280.

Wegge, P., Janwali, S.R., Storaas, T. & Odden, M. 2000. In: *Grasslands and Large Mammals Conservation in the Lowland Terai. A Preliminary Synthesis Based on Field Research Conducted in Royal Bardia National Park, Nepal*. Eds. Richard, C., K. Basnet, J.P. Sha & Y. Raut. *Grasslands of Terai Protected Areas* (2): 50-57.

York, A. 1999. Long-term effects of repeated prescribed burning on forest invertebrates: management implications for the conservation of biodiversity. *Australia's Biodiversity-Responses to Fire. Biodiversity Technical Series* (1): 181-266.

Parameter	Study sites (fire regimes)		
	Unburnt (n=80)	Single fire (n=40)	Repeated fire (n=40)
Total no. of species	192	118	38
Singleton species	51	19	10
Doubleton species	6	7	4
Unique species	49	20	12

Table 1. Number of total species, singleton, doubleton, and unique species represented contrasting forms of rarity at sampled sites of different fire regime.

Parameter	Seasons		Sites		Seasons x Sites	
	F	<i>p</i>	F	<i>p</i>	F	<i>p</i>
(a) Species abundance	15.45	0.025	29.12	0.012	0.64	0.589
(b) Species richness	16.31	0.23	0.52	0.524	7.75	0.000

Table 2. Results of repeated measures ANOVA tests comparing species abundance (a), and species richness (b) between different season and treatment sites.

Parameter	Axis 1	Axis 2
Eigenvalue	0.135*	0.079
% of variance explained	4.9	2.9
Cumulative % variance explained	4.9	7.7
Pearson Correlation, Spp-Envt*	0.858*	0.724*

Table 3. Results from the Canonical correspondence analysis (CCA) of spider assemblage in Terai Grassland. Monte Carlo randomization test, 998 runs *P < 0.001.

Habitat variables	Axis 1	Axis 2
Soil pH	-0.93	-0.09
Soil moisture	-0.93	-0.05
Soil temperature	0.76*	-0.05
Ambient humidity	-0.4	-0.57
Number of grass species	-0.77	-0.29
Proportion litter cover	-0.9	-0.08
Proportion grass cover	-0.71	-0.67
Proportion bare ground	0.80*	-0.11
Litter depth	-0.79	-0.29

Correlations and biplot scores for 9 habitat variables

Parameter	Species	Sites	Value (IV)	Guild
Species affected by fire	<i>Leucauge celebesiana</i>	Unburnt	56	Orb-weavers
	<i>Leucauge</i> sp. 1		57	Orb-weavers
	<i>Pardosa kupupa</i>		60	Ground runners
	<i>Telemonia</i> sp. 1		60.1	Stalkers
	<i>Achaearanea</i> sp. 1		62	Space web builders
	<i>Leucauge decorata</i>		80.3	Orb-weavers
Species profit from fire	<i>Plexippus</i> sp.1	Single fire	38.1	Stalkers
	<i>Clubiona</i> sp. 2		17.8	Funnel- weavers
	<i>Haplodrassus bengalensis</i>		20.6	Ground runners
	<i>Zelotes</i> sp. 1		17.6	Ground runners
	<i>Drassodes luridus</i>		13.1	Ground runners
Exclusive species of burnt sites	<i>Haplodrassus</i> sp. 1	Repeated fire	24	Ground runners

Table 4. Results of Indicator Species Analysis (after Dufrene & Legendra 1997), computing indicator value coefficient and showing species associated with particular fire regimes and of those which respective guilds were assigned.

Comparison	Species composition		Guild composition	
	R	<i>p</i>	R	<i>p</i>
Among Fire regimes				
Global R	0.62	0.01	0.81	0.01
Unburnt vs. Single fire	0.696	0.012	0.869	0.01
Unburnt vs. Repeated fire	0.791	0.014	0.944	0.01
Single fire vs. Repeated fire	0.036	4.3	0.209	0.10

Table 5. Results of pair-wise ANOSIM tests comparing spider species and guild compositions between different fire regimes.

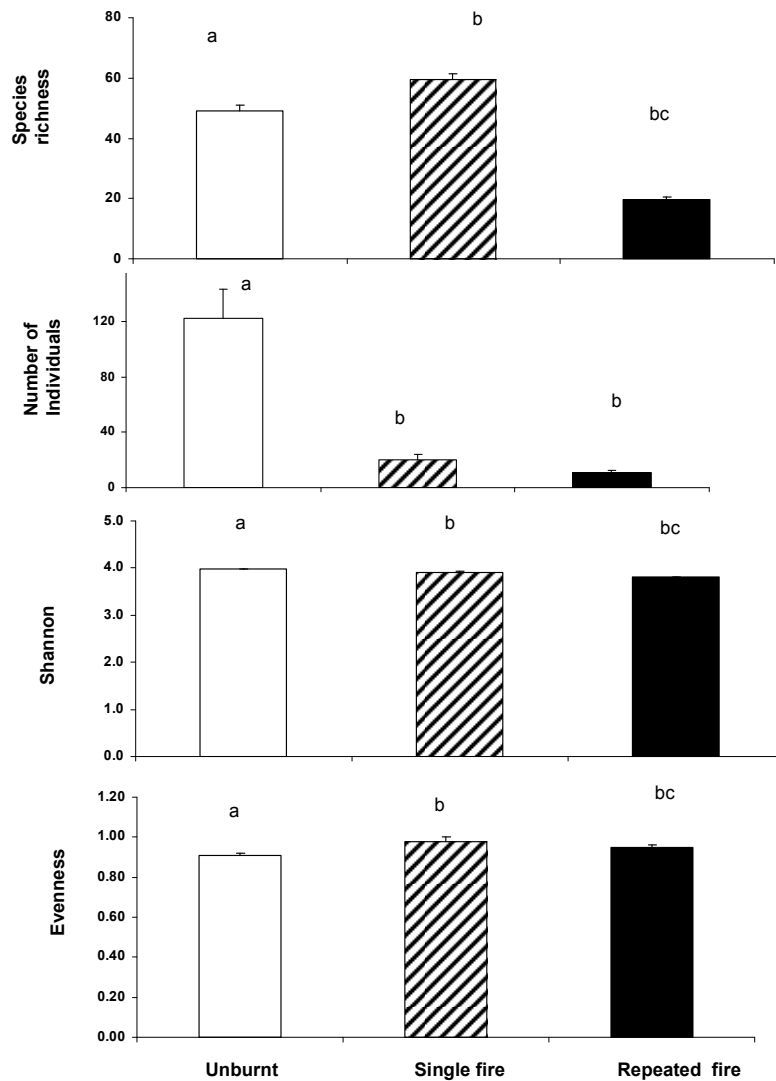


Fig. 1. Mean number of species and of individuals (+S.E.) and diversity (mean ± variance) in each study site grouped in classes of number of fires. Bars with different letters are significantly different. The number of individuals does not differ significantly between single and repeated fire. Significantly more species were collected in single burnt sites.

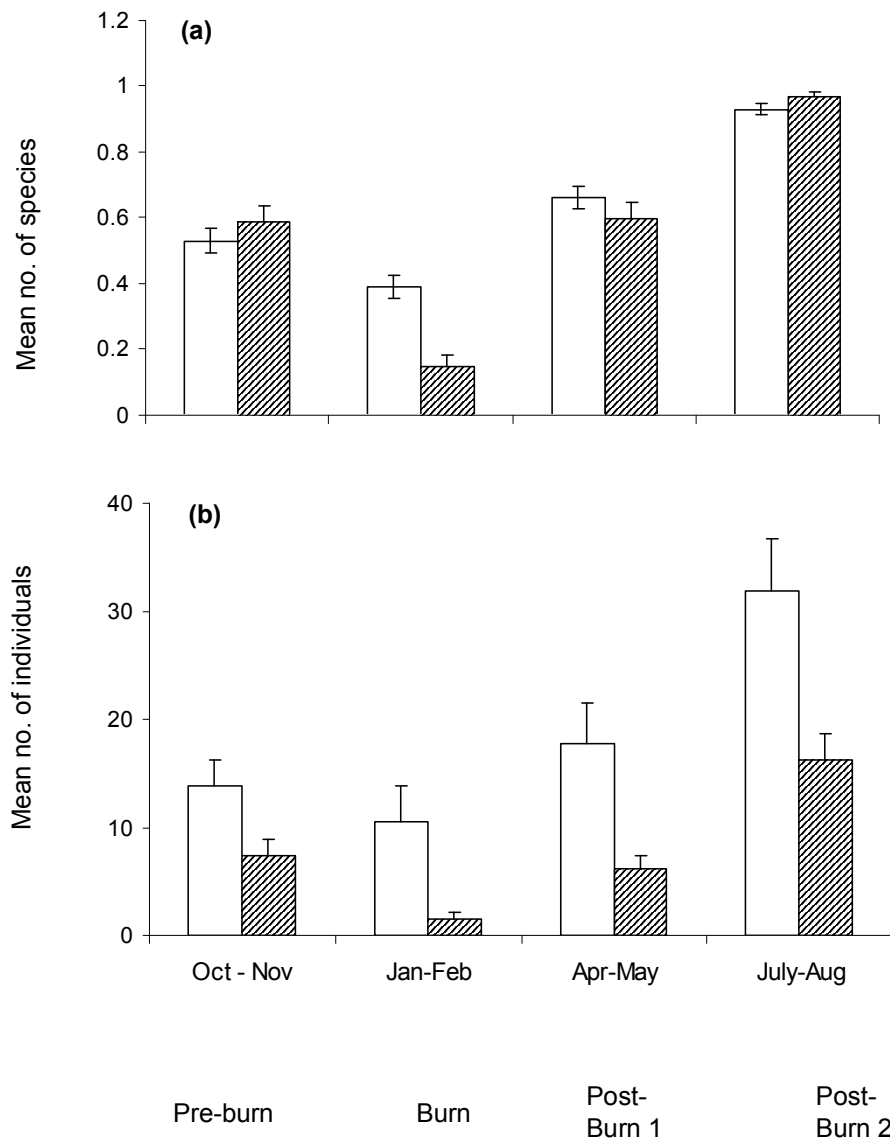


Fig. 2. Mean number of **(a)** species and **(b)** individuals of spider for each fire regime during pre-burn, burn, post-burn 1 and post-burn 2 periods. Open bars, are unburnt and lined bars are burnt treatments. Error bars are +1 SE.

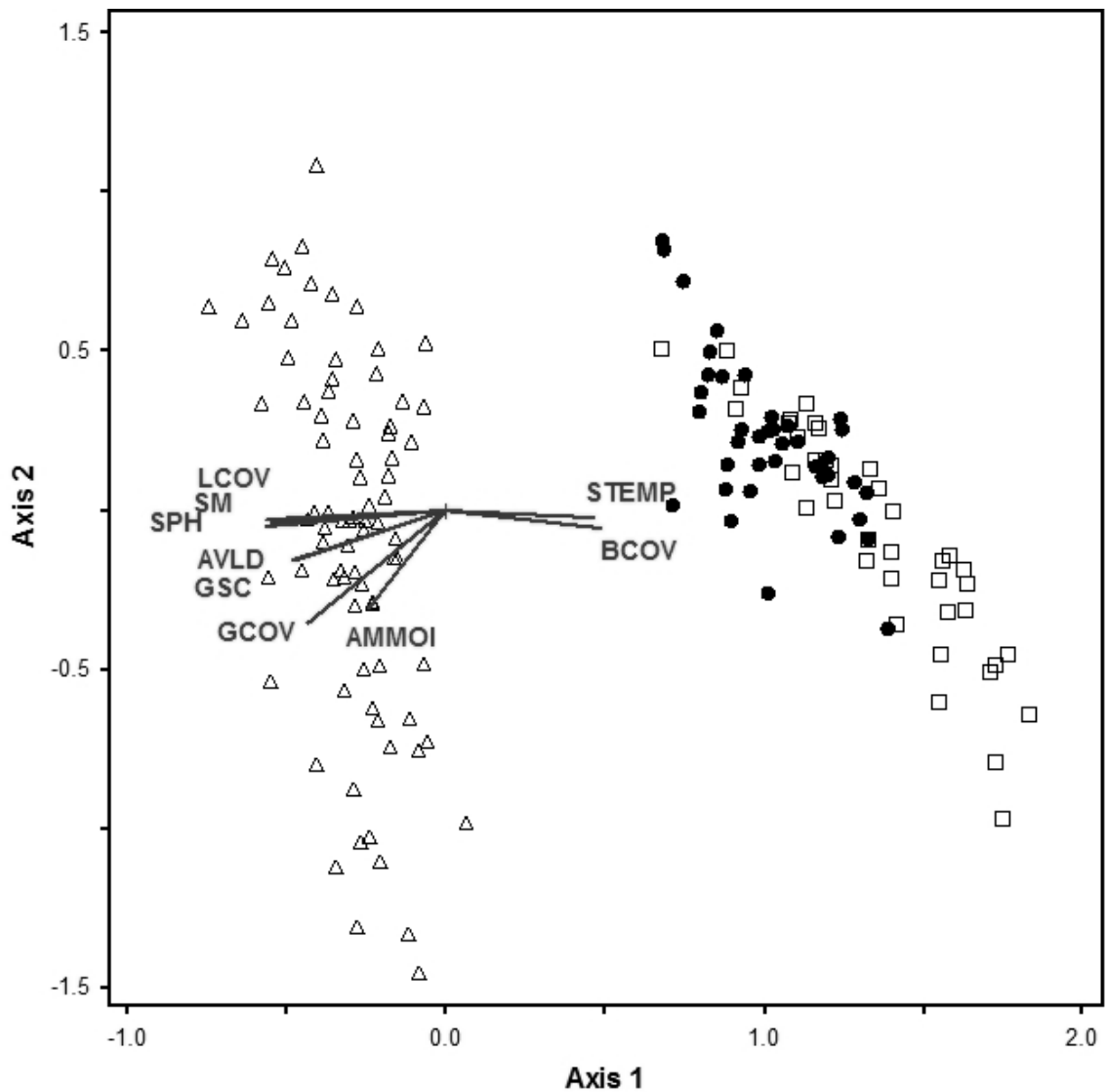


Fig. 3. Biplot from the Canonical Correspondence Analysis (CCA) ordination of spider assemblage. Points represent subplots (unburnt sites, open triangle; single fire sites, closed circle; repeated fire sites, open square) and vectors (arrows) represent habitat variables. The length of the arrow signifies the relative contribution of that variable to the species composition, while the direction signifies its contribution to the differences between treatments.

Appendix. - Abundance data (total catches of four seasons and two collection methods) for spiders of Terai Conservation Area.

Family	Species Name	Unburnt (n = 80)	Single fire (n= 40)	Repeated fire (n = 40)
Agelenidae	<i>Agelena</i> sp. 1	55	34	0
Araneidae	<i>Arachnura melanura</i> Simon 1867	7	0	0
	<i>Araneus bilunifer</i> Pocock 1900	8	1	0
	<i>Araneus</i> sp. 1	45	13	0
	<i>Argiope anasuja</i> Thorell 1887	3	0	0
	<i>Argiope pulchella</i> Thorell 1881	1	0	0
	<i>Cryptophora</i> sp. 1	27	2	0
	<i>Cryptophora</i> sp. 2	38	8	0
	<i>Cyclosa confraga</i> (Thorell 1892)	1	0	0
	<i>Cyclosa mulmeinensis</i> (Thorell 1887)	6	10	0
	<i>Cyclosa simoni</i> Tikader 1982	8	0	0
	<i>Cyclosa</i> sp. 1	1	0	0
	<i>Cyclosa</i> sp. 2	1	0	0
	<i>Cyrtophora citricola</i> (Forskål 1775)	1	0	0
	<i>Cyrtophora ksudra</i> Sherriffs 1928	4	4	0
	<i>Cyrtophora</i> sp. 3	1	0	0
	<i>Cyrtophora jabalpurensis</i> Gajbe & Gajbe 1999	10	1	0
	<i>Eriovixia excelsa</i> (Simon 1889)	5	0	0
	<i>Eriovixia laglaizei</i> (Simon 1877)	6	0	0
	<i>Gasteracantha</i> sp. 1	1	0	0
	<i>Gasteracantha dalyi</i> Pocock 1900	8	0	0
	<i>Gasteracantha geminata</i> (Fabricius 1798)	1	0	0
	<i>Gasteracantha hasselti</i> C.L.Koch 1837	4	0	0
	<i>Gea corbetti</i> Tikader 1982	1	0	0
	<i>Gea</i> sp. 1	11	0	0
	<i>Larinia</i> sp. 1	1	0	0
	<i>Larinia</i> sp. 2	1	0	0
	<i>Neoscona biswasi</i> Bhandari & Gajbe 2001	11	2	0
	<i>Neoscona mukerjei</i> Tikader 1980	2	0	0
	<i>Neoscona odites</i> Simon 1906	1	0	0
	<i>Neoscona theisi</i> (Walckenaer 1842)	3	0	0
	<i>Neoscona vigilans</i> (Blackwall 1865)	1	0	0
	<i>Nephila pilipes</i> (Fabricius 1793)	1	1	0
	<i>Parawixia dehaanii</i> (Doleschall 1859)	12	0	0
	<i>Parawixia</i> sp. 1	1	0	0
	<i>Poltya</i> sp. 1	9	0	0

	<i>Zygiella indica</i> O.P.Cambridge 1902	1	0	0
	<i>Zygellia</i> sp. 1	7	0	0
Barychelidae	<i>Sason robustum</i> O.P.Cambridge 1883	5	1	0
	<i>Sasonichus sullivanii</i> Pocock 1900	6	1	0
Clubionidae	<i>Clubiona boxaensis</i> Biswas & Biswas 1992	7	1	0
	<i>Clubiona deletrix</i> O.P.Cambridge 1885	7	1	0
	<i>Clubiona filicata</i> O.P.Cambridge 1874	7	6	0
	<i>Clubiona</i> sp. 1	7	2	0
	<i>Clubiona</i> sp. 2	0	11	0
Corinnidae	<i>Oedignatha indica</i> Reddy & Patel 1993	80	23	9
	<i>Oedignatha</i> sp. 1	27	4	8
	<i>Oedignatha</i> sp. 2	9	0	0
	<i>Trachelas himalayensis</i> Biswas 1993	5	0	1
Desidae	<i>Desis inermis</i> Gravely 1927	11	1	0
	<i>Desis</i> sp. 1	32	7	0
Dictynidae	<i>Dictyna albida</i> O.P.Cambridge 1885	49	21	10
	<i>Dictyna turbida</i> Simon 1905	9	0	0
Dipluridae	<i>Indothele rothi</i> Coyle 1905	21	4	0
Gnaphosidae	<i>Drassodes gangeticus</i> Tikader & Gajbe 1975	2	0	0
	<i>Drassodes luridus</i> O.P.Cambridge 1874	0	9	0
	<i>Drassodes parvidens</i> Caporiacco 1934	51	40	149
	<i>Gnaphosa</i> sp. 1	74	47	5
	<i>Gnaphosa stoliczka</i> O.P.Cambridge 1885	31	11	5
	<i>Gnaphosa kailana</i> Tikader 1966	2	0	0
	<i>Haplodrassus bengalensis</i> Gajbe 1992	0	25	0
	<i>Haplodrassus</i> sp. 1	0	0	213
	<i>Haplodrassus</i> sp. 2	3	0	23
	<i>Herpyllus</i> sp. 1	2	8	0
	<i>Ladissa</i> sp. 1	1	3	0
	<i>Zelotes</i> sp. 1	1	16	0
Hahniidae	<i>Hahnia mridulae</i> Tikader 1970	34	3	2
	<i>Hahnia</i> sp. 1	2	7	0
	<i>Hahnia</i> sp. 1	1	0	0
	<i>Neoantistea maxima</i> Caporiacco 1934	33	5	0
	<i>Scotosipilus</i> sp. 1	5	1	0
Linyphiidae	<i>Erigone rohtangensis</i> Tikader 1981	28	5	0
	<i>Linyphia</i> sp. 1	40	28	0
	<i>Linyphia</i> sp. 2	18	15	0
	<i>Linyphia</i> sp. 3	14	5	0
	<i>Linyphia</i> sp. 4	5	1	0

	<i>Linyphia</i> sp. 5	32	29	0
	<i>Linyphia</i> sp. 6	15	3	0
	<i>Linyphia</i> sp. 7	14	3	0
	<i>Linyphia</i> sp. 8	42	9	0
	<i>Linyphia</i> sp. 9	11	1	0
	<i>Linyphia</i> sp. 10	1	1	0
	<i>Linyphia</i> sp. 11	1	1	0
	<i>Linyphia</i> sp. 12	23	2	0
	<i>Linyphia</i> sp. 13	9	13	0
	<i>Linyphia</i> sp. 14	25	5	0
	<i>Linyphia</i> sp. 15	1	0	0
	<i>Linyphia</i> sp. 16	7	0	0
	<i>Linyphia</i> sp. 17	5	0	0
	<i>Oedothorax globiceps</i> Thaler 1987	48	19	12
	<i>Oedothorax</i> sp. 1	39	14	16
	<i>Oedothorax</i> sp. 2	1	0	0
Lycosidae	<i>Arctosa indica</i> Tikader & Malhotra 1980	58	40	65
	<i>Arctosa</i> sp. 1	3	1	0
	<i>Arctosa</i> sp. 2	25	8	13
	<i>Arctosa</i> sp. 3	27	10	3
	<i>Arctosa</i> sp. 4	1	1	0
	<i>Hippasa pisaurina</i> Pocock 1900	231	227	44
	<i>Hippasa</i> sp. 1	102	58	23
	<i>Hippasa</i> sp. 2	181	179	60
	<i>Hippasa</i> sp. 3	183	144	60
	<i>Pardosa birmanica</i> Simon 1884	241	143	50
	<i>Pardosa minuta</i> Tikader & Malhotra 1976	89	30	25
	<i>Pardosa</i> sp. 1	218	166	108
	<i>Pardosa</i> sp. 2	98	64	34
	<i>Pardosa kupupa</i> Tikader 1970	151	0	0
	<i>Trochosa himalayensis</i> Tikader & Malhotra 1980	76	35	39
	<i>Trochosa</i> sp. 1	1	159	40
	<i>Trochosa</i> sp. 2	0	1	0
Miturigidae	<i>Cheiracanthium adjacens</i> O.P.Cambridge 1885	33	16	20
Oonopidae	<i>Oonopidae</i> sp. 1	1	0	0
	<i>Oonopidae</i> sp. 2	6	0	0
	<i>Oonopidae</i> sp. 3	83	21	20
Oxyopidae	<i>Oxyopes birmanicus</i> Thorell 1887	21	9	0
	<i>Oxyopes elongatus</i> Biswas et al. 1996	65	16	0

	<i>Oxyopes shweta</i> Tikader 1970	41	14	0
	<i>Oxyopes</i> sp. 1	57	4	4
	<i>Peucetia</i> sp. 1	8	0	0
	<i>Peucetia</i> sp. 2	9	1	0
Philodromidae	<i>Philodromus</i> sp. 1	4	0	0
Pholcidae	<i>Artema</i> sp. 1	1	0	0
	<i>Crossopriza lyoni</i> (Blackwall 1867)	1	0	0
Pisauridae	<i>Pisaura decorata</i> Patel & Reddy 1990	28	16	0
	<i>Pisaura</i> sp. 1	57	3	4
	<i>Pisaura</i> sp. 2	19	4	0
Salticidae	<i>Marpissa</i> sp. 1	26	53	15
	<i>Myrmarachne</i> sp. 1	190	170	150
	<i>Myrmarachne</i> sp. 2	1	0	0
	<i>Myrmarachne</i> sp. 3	1	1	0
	<i>Myrmarachne</i> sp. 4	1	0	0
	<i>Phintella</i> sp. 1	13	3	2
	<i>Plexippus paykulli</i> (Audouin 1826)	62	62	40
	<i>Plexippus</i> sp. 1	0	53	0
	<i>Rhene</i> sp. 1	1	0	0
	<i>Rhene</i> sp. 2	1	1	0
	<i>Rhene</i> sp. 3	4	1	0
	<i>Rhene</i> sp. 4	5	1	0
	<i>Telemonia</i> sp. 1	53	0	0
Sparassidae	<i>Heteropoda fabrei</i> Simon 1885	1	0	0
	<i>Heteropoda venatoria</i> (Linnaeus 1767)	29	10	1
	<i>Heteropodidae buxa</i> Saha, Biswas & Raychaudhuri 1995	25	7	0
	<i>Olios tikaderi</i> Kundu, Biswas & Raychaudhuri 1999	1	0	0
Tetrablemmidae	<i>Tetrablemma</i> sp. 1	1	0	0
Tetragnathidae	<i>Leucauge celebesiana</i> (Walckenaer 1842)	58	0	0
	<i>Leucauge decorata</i> (Blackwall 1864)	55	0	0
	<i>Leucauge</i> sp. 1	38	0	0
	<i>Meta</i> sp. 1	1	0	0
	<i>Tetragnatha chamberlini</i> Gajbe 2004	27	3	1
	<i>Tylorida ventralis</i> (Thorell 1877)	1	6	2
	<i>Tylorida</i> sp. 1	5	0	0
Theraphosidae	<i>Chilobrachys</i> sp. 1	15	1	0
Theridiidae	<i>Achaeearanea budana</i> Tikader 1970	36	2	0
	<i>Achaeearanea</i> sp. 1	78	0	0
	<i>Achaeearanea</i> sp. 2	5	0	0

	<i>Achaearana triangularis</i> Patel 2003	58	7	0
	<i>Argyrodes cyrtophore</i> Tikader 1963	6	5	0
	<i>Argyrodes fissifrons</i> Thorell 1891	1	0	0
	<i>Argyrodes</i> sp. 1	6	2	0
	<i>Argyrodes</i> sp. 2	8	2	0
	<i>Argyrodes</i> sp. 3	1	0	0
	<i>Argyrodes</i> sp. 4	1	1	0
	<i>Chryso picturata</i> Simon 1895	9	18	0
	<i>Chryso</i> sp. 1	26	10	0
	<i>Chryso</i> sp. 2	2	0	0
	<i>Theridion</i> sp. 1	1	0	0
	<i>Theridion</i> sp. 2	1	0	0
	<i>Theridion</i> sp. 3	35	19	9
	<i>Theridion</i> sp. 4	1	0	0
	<i>Theridion</i> sp. 5	5	0	0
	<i>Theridion</i> sp. 6	26	8	0
	<i>Theridion</i> sp. 7	35	4	0
	<i>Theridion</i> sp. 8	31	25	0
	<i>Theridion</i> sp. 9	9	1	0
	<i>Theridion</i> sp. 10	3	0	0
	<i>Theridion</i> sp. 11	38	10	0
Thomisidae	<i>Diaea subdola</i> O. P. Cambridge 1885	30	5	2
	<i>Misumena indra</i> Tikader 1963	60	7	0
	<i>Misumena mridulai</i> Tikader 1962	19	3	0
	<i>Ozyptila manii</i> Tikader 1961	31	4	0
	<i>Ozyptila</i> sp. 1	11	1	0
	<i>Runcinia affinis</i> Simon 1897	12	6	0
	<i>Runcinia</i> sp 1	12	4	0
	<i>Thomisus pugilis</i> Stoliczka 1869	1	0	0
	<i>Thomisus</i> sp. 1	3	3	0
	<i>Thomisus</i> sp. 2	3	0	0
	<i>Thomisus</i> sp. 3	5	1	0
	<i>Thomisus</i> sp. 4	5	0	0
	<i>Thomisus</i> sp. 5	1	0	0
	<i>Thomisus</i> sp. 6	4	0	0
	<i>Thomisus</i> sp. 7	10	3	0
	<i>Thomisus</i> sp. 8	1	0	0
	<i>Thomisus</i> sp. 9	3	3	0
	<i>Thomisus</i> sp. 10	8	4	0
Uloboridae	<i>Uloborus danolius</i> Tikader 1969	1	0	0

	<i>Uloborus</i> sp. 1	1	0	0
	<i>Uloborus</i> sp. 2	1	0	0
	<i>Uloborus</i> sp. 3	1	0	0
Zodariidae	<i>Lutica</i> sp. 1	10	0	0