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Caption: Stripe-backed Weasel *Mustela strigidorsa*. Medium—digital, Software—procreate, Device—iPad + Apple pencil © Dhanush Shetty.

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COMMUNICATION

Diversity of spiders (Arachnida: Araneae) and the impact of pruning in Indian sandalwood plantations from Karnataka, India

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Abstract: Indian sandalwood *Santalum album* L. plantations in Karnataka were surveyed to study the diversity and abundance of spider fauna. A total of 1,244 individuals belonging to 56 spider species in 40 genera under 14 families were recorded in the sandalwood plantations. Among the spider families recorded, Araneidae was the most dominant with 15 species in nine genera followed by Salticidae with 13 species in 10 genera, Thomisidae with seven species in four genera, Oxyopidae with four species in three genera, Uloboridae with four species in a genus, and Theridiidae by three species each under three genera. Lycosidae and Sparassidae are represented by two species under two genera each. The families Cheiracanthiidae, Clubionidae, Hersiliidae, Philodromidae, and Pholcidae are represented by a species each. The pruning of sandalwood revealed a significant negative effect on the occurrence and distribution of spiders.

Keywords: Ambushers, Araneidae, guild, Orb web, pruning, Salticidae, *Santalum album*, spider fauna, stalkers, Thomisidae, Uloboridae.

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Author contributions: SP—carried out the field survey, collection, identification of spiders, analysis of data and prepared the manuscript. RS—guided and assisted Ms. Padma, in every step like, designing and execution of the work and finalizing the manuscript.

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सत्यमेव जयते

INTRODUCTION

Spiders are air-breathing carnivorous arthropods and are distributed ubiquitously in the globe except for Antarctica and have adapted to all known ecological environments except air and open sea (Foelix 1996). They are important ecological indicators, used to monitor warning signs for the environment at the earliest and as a biological control agent, since its assemblages have the ability to limit the population growth of arthropod pests and other natural enemies. Spiders are one of the known successful groups of natural predators occupying the agricultural ecosystems, and as efficient predators, they are able to suppress populations of major insect pests (Marc & Canard 1997). Therefore, relatively higher spider abundance has been considered a requirement for pest control in agricultural systems (Young & Edwards 1990; Carter & Rypstra 1995; Sunderland & Samu 2000).

Globally, spiders include about 49,368 described species in 4,215 genera under 129 families (World Spider Catalog 2021). In India, 1,875 species under 478 genera in 61 families are known (Caleb & Sankaran 2021). Considering the importance of spiders in integrated pest management strategy, the present study aimed to understand the spider diversity and distribution in sandalwood plantations of Karnataka and assess the impact of pruning of sandalwood in the distribution of spiders.

MATERIALS AND METHODS

Study area and sampling methods

An extensive survey was done in sandalwood plantations aged 2–6 years growing in different agro-forestry systems in Karnataka (Table 1, Figure 1) for a period of three years from June 2017–May 2020 and sampling was done between 0930 h to 1130 h. Active searching method of spiders was adopted and handpicked. Spiders were observed from each corner of the plant, from all the branches, flowers, fruits, and even from the ground. Spiders were photographed in their natural habitat and studied under a stereozoom microscope (Nikon SMZ 1500). The information of collection data such as place, date of collection, habitat, the colouration of spider and name of the collector were recorded. The specimens were preserved in vials with 70% ethyl alcohol and deposited in the Department of Entomology, IWST campus. Spiders were identified based on key morphological features provided by Tikader (1987), taxonomic articles available in the World Spider Catalog (2021), diagnostic drawings available in Metzner (2021), and with the help of taxonomic experts. Most of the adult spiders were identified to species level and others to genus level.

Impact of pruning on spider density

To assess the impact of pruning of sandalwood on the diversity and abundance of spiders, a study was undertaken in 2–3 years old plantations of both unpruned and pruned sandalwood during November 2019–January 2020 about 10 hectare in Kolar District, Karnataka. For this purpose, five 50 x 50 m blocks each in pruned and unpruned plantations were marked and from each block, spiders were collected from five trees at random. In unpruned trees, three different habitats (upper, middle, and lower canopies) tree stand were considered and three branches in each canopy were randomly selected for spider collection, the number of arboreal spiders in each tree was counted. In pruned trees, data was collected adopting the same methodology but only from the top canopy as the middle and the lower canopies were lost due to pruning. Three observations were taken at monthly intervals and the data analysed. From the data, comparison was

Table 1. List of Sandalwood plantation localities in Karnataka.

	District	Place/Village-Taluk	Latitude (N), Longitude (E)
1	Bangalore	Institute of wood science and technology, Malleshwaram	13.011361, 77.570444
		Environmental Management & Policy Research Institute, Doresanipalya	12.899250, 77.592222
2	Chikballapura	Bagepalli	13.803028, 77.804528
3	Chikkamagaluru	Bikkaemanae	13.260722, 75.764361
		Sevapura – Tarikere	13.703556, 75.824500
4	Chamarajanagar	Arepalya – Kollegal Taluk	12.083861, 77.102889
		Vadegere – Yelanduru Taluk	12.039444, 77.093667
		Chikkaluru – Kollegal Taluk	12.196972, 77.282778
5	Kollar	Agara – Yeldur Taluk	13.057528, 78.432389
		Kenchanahalli – Mulbagal Taluk	13.205889, 78.446194
		Mudiyanuru – Mulbagal Taluk	13.228306, 78.315972
6	Kopal	Kushtagi	15.759944, 76.196694
7	Tumkur	Timmanahalli – Chikkanayakanahalli Taluk	13.391167, 77.199611
		Bijavara – Madhugiri Taluk	13.677056, 77.236444

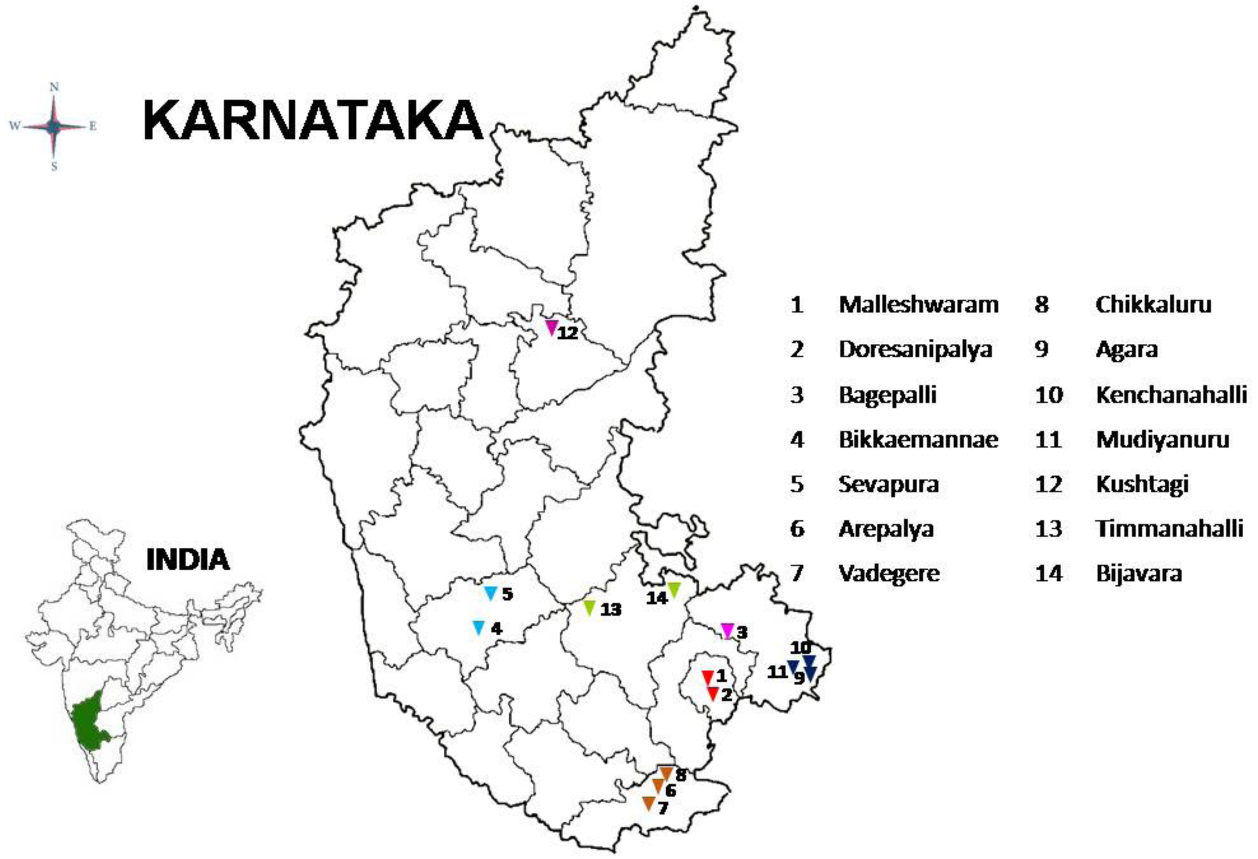

Figure 1. Map of Sandalwood plantations in Karnataka

made between the total spiders collected in unpruned and pruned plantations as well as between the spiders collected only from the top canopy of both the type of plantations by performing one-tailed ANOVA.

Guild classification

Depending upon the foraging strategies of spiders, they were categorised into eight different ecological guild structures namely, stalkers, ambushers, foliage runners, ground runners, sheet web-builders, tangle weavers, orb weavers, and space web-builders (Uetz et al 1999).

RESULTS

A total of 1,244 individuals of the 56 species of spiders in 40 genera under 14 families (Table 2) were collected and identified (Table 3) from the surveyed sandalwood plantations. Out of the 56 species (Figure 2), the family Araneidae (27%) is the most dominant in terms of species diversity with 15 species in nine genera followed by Salticidae (25%) with 13 species in 10 genera, Thomisidae (13%) with seven species in four genera, Oxyopidae (7%) with four species in three genera, and Uloboridae (7%) with four species in a single genus. Theridiidae (5%) is represented by three species under three genera and Lycosidae & Sparassidae (3%) with two species in two genera each. The families Cheiracanthiidae, Clubionidae, Hersiliidae Philodromidae, and Pholcidae (2%) are represented by a species each. In terms of the number of individuals collected, the dominant family was Salticidae with a collection of 366 individuals followed by Araneidae with 350 individuals. Among the species, *Telamonia dimidiata* was found to be more abundant with a total of 73 individuals followed by *Myrmaplata plataleoides*, *Menemerus bivittatus*, *Meotipa sahyadri*, and *Thomisus andamanensis*.

The spiders inhabiting the sandalwood plantation fall under eight ecological guilds based on their foraging mode (Figure 3). The majority of the observed spider families belong to 'orb-weavers' category with 36% dominance, followed by stalkers (30%), ambushers

Table 2. Diversity and abundance of spiders in sandalwood plantations.

	Families	Genus	Species	Individuals
1	Araneidae	9	15	350
2	Cheiracanthiidae	1	1	17
3	Clubionidae	1	1	15
4	Hersiliidae	1	1	17
5	Lycosidae	2	2	44
6	Oxyopidae	2	4	57
7	Philodromidae	1	1	13
8	Pholcidae	1	1	12
9	Salticidae	11	13	366
10	Sparassidae	1	1	37
11	Tetragnathidae	1	1	16
12	Theridiidae	2	3	78
13	Thomisidae	5	8	161
14	Uloboridae	1	4	74

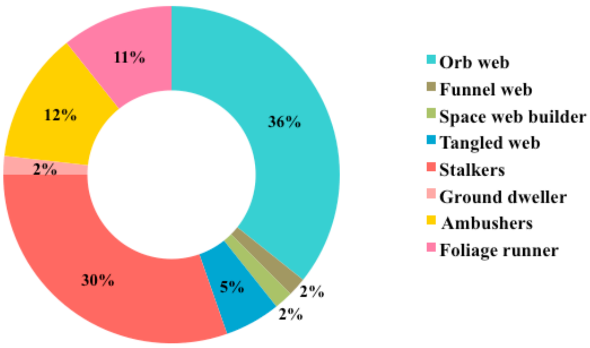

Figure 3. Guilds of spiders from sandalwood plantations.

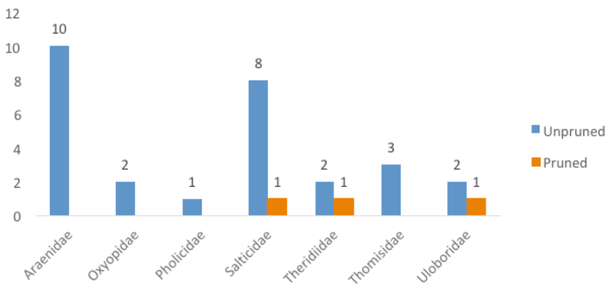

Figure 4. Comparison of spider density (or abundance) in unpruned and pruned plantations of sandalwood.

(12%), foliage runners (11%), tangled web (5%), and 2% each by ground dwellers, funnel web builders, and space web building spiders.

In the observations from around 10 hectare, unpruned

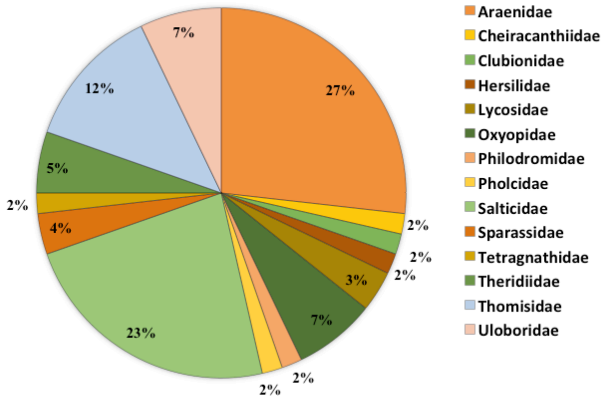

Figure 2. Details of spider families found in sandalwood plantations.

(Image 43) and pruned (Image 44) sandalwood, a total of 149 individuals belonging to 28 species under seven families and 11 individuals belonging to three species under three families were recorded, respectively. The number of spiders collected in unpruned sandalwood trees from upper, middle, and lower were 45 individuals in 11 species, 63 individuals in 21 species, and 44 individuals in 11 species, respectively. In the pruned sandalwood trees, the lower and the middle canopy was lost due to pruning and the number of spiders collected from upper canopy was only 17 individuals of three species (Figure 4). The one-way ANOVA result showed a significant difference in the overall level of diversity and abundance of spiders in pruned and unpruned sandalwood trees, F (1, 28)= 171.61, p <0.001. Also, a significant difference was seen in the upper canopy of unpruned and pruned sandalwood, F (1, 28)= 12.55, p= 0.0014. Thus, the above result indicates that the interaction of vertical branches and denser vegetation was significant and affected the composition and abundance of spiders.

DISCUSSION

The present survey is preliminary and the first dealing with spider diversity in sandalwood-based agroforestry ecosystems. Caleb & Sankaran (2021) reported 1,875 species under 478 genera in 61 families in India out of which 56 species in 40 genera under 14 families were found breeding in sandalwood plantations. This represents 2.986% and 21.95% of the total species and families, respectively, recorded in India. The number of families recorded is as high as in other biomes of India. Sandeep et al. (2020) reported 43 species of spiders under 23 families from 21 different fruit crops in Punjab. The

Table 3. Checklist of spiders in sandalwood plantations.

Family		Species
Araneidae	1	*Arachnura melanura* Simon, 1867 (Image 1)
	2	*Araneus mitificus* (Simon, 1886) (Image 2)
	3	*Araneus* sp.
	4	*Argiope anasuja* Thorell, 1887 (Image 3)
	5	*Argiope pulchella* Thorell, 1881 (Image 4)
	6	*Cyclosa insulana* (Costa, 1834) (Image 5)
	7	*Cyrtophora cicatrosa* (Stoliczka, 1869) (Image 6)
	8	*Cyrtophora citricola* (Forsskål, 1775) (Image 7)
	9	*Eriovixia laglaizei* (Simon, 1877) (Image 8)
	10	*Gasteracantha geminata* (Fabricius, 1798) (Image 9)
	11	*Neoscona bengalensis* Tikader & Bal, 1981 (Image 10)
	12	*Neoscona mukerjei* Tikader, 1980 (Image 11)
	13	*Neoscona nautica* (L.Koch, 1875)
	14	*Neoscona punctigera* (Doleschall, 857) (Image 12)
	15	*Nephila pilipes* (Fabricius, 1793) (Image 13)
Cheiracanthiidae	16	*Cheiracanthium* sp. (Image 14)
Clubionidae	17	*Clubiona* sp.
Hersiliidae	18	*Hersilia savignyi* Lucas, 1836 (Image 15)
Lycosidae	19	*Hippasa agelenoides* (Simon, 1884) (Image 16)
	20	*Pardosa peudoanulata* (Bösenberg & Strand, 1906) (Image 17)
Oxyopidae	21	*Hamadruas* sp. (Image 18)
	22	*Oxyopes javanus* Thorell, 1887
	23	*Oxyopes* sp. (Image 19)
	24	*Peucetia viridana* (Stoliczka, 1869) (Image 20)
Philodromidae	25	*Thanatus* sp.
Pholcidae	26	*Crossopriza lyoni* (Blackwall, 1867)
Salticidae	27	*Brettus cingulatus* Thorell, 1895 (Image 21)
	28	*Carrhotus viduus* C.L. Koch, 1846
	29	*Epeus indicus* Prószyński, 1992 (Image 22)
	30	*Hasarius adansoni* (Audouin, 1826)
	31	*Hyllus semicupreus* (Simon, 1885) (Image 23)
	32	*Menemerus bivittatus* (Dufour, 1831)
	33	*Myrmaplata plataleoides* (O.P. Cambridge, 1869) (Image 24)
	34	*Plexippus petersi* (Karsch, 1878)
	35	*Plexippus paykulli* (Audouin, 1826) (Image 25)
	36	*Rhene flavicomans* Simon, 1902 (Image 26)
	37	*Rhene flavigera* (C.L. Koch, 1846) (Image 27)
	38	*Rhene* sp.
	39	*Telamonia dimidiata* (Simon, 1899) (Image 28)
Sparassidae	40	*Heteropoda venatoria* (Linnaeus, 1767) (Image 29)
	41	*Olios milletti* (Pocock, 1901) (Image 30)
Tetragnathidae	42	*Opadometa fastigata* (Simon, 1877) (Image 31)
Theridiidae	43	*Meotipa sahyadri* Kulkarni, Vartak, Deshpande & Halali, 2017 (Image 32)
	44	*Nihonhimea mundula* (L.Koch, 1872) (Image 33)
	45	*Parasteatoda* sp.
Thomisidae	46	*Loxobates* sp. (Image 34)
	47	*Misumena* sp. (Image 35)
	48	*Thomisus andamanensis* Tikader, 1980 (Image 36)
	49	*Thomisus bulani* Tikader, 1960
	50	*Thomisus lobosus* Tikader, 1965 (Image 37)
	51	*Thomisus projectus* Tikader, 1960 (Image 38)
	52	*Tmarus* sp.
Uloboridae	53	*Uloborus* sp. 1 (Image 39)
	54	*Uloborus* sp. 2 (Image 40)
	55	*Uloborus* sp. 3 (Image 41)
	56	*Uloborus* sp. 4 (Image 42)

difference in spider fauna can be related to different time frames and methods of collection. Even environmental factors like the type of vegetation, seasonality, spatial heterogeneity, predation, prey occurrence etc. can affect species diversity (Riechert & Bishop 1990) and spiders are extremely sensitive to small changes in the habitat structure, complexity, and microclimate characteristics. Their abundance and distribution may vary from one geographic area to another (Downie et al. 1999). Spiders are polyphagous, feed on a variety of available prey even on the egg, larva/nymph, as well as adult stages of insects (Sandeep et al. 2020). Predatory spiders found breeding in the sandalwood-based agroforestry ecosystems serve as a source of successive predation against pests of sandalwood.

Most spiders exhibit excellent colouration and protective camouflage. The ant mimicking spider *M. plataleoides* and *Hersilia savignyi* resemble the bark of trees. Thomisid spiders commonly called ambushers which are "sit and wait" type of prey hunting spiders, sit on the flowers and have attractive colouration similar to the flower in which they hide. In contrast to this *Hippasa agelenoides* construct funnels/tunnels? in ground strata, hide at the small end and rush out and grab the prey (Pooja et al. 2019). Further, the difference in spider fauna is based on the vertical segregation of the foraging heights. Some spiders might prefer living in the uppermost parts of the plant, like *Nephila pilipes* and *Gasteracantha geminata*, while a few spiders like *Pardosa pseudoannulata* and *H. agelenoides* are usually found on the ground.

Arboreal spider assemblages assessed by the abundance-based measure showed a significant difference between unpruned and pruned sandalwood. Even the upper canopy inhabiting spiders were significantly less in pruned than unpruned sandalwood; this might be due to non-availability of nutritional resources and required breeding resources in the pruned trees. Pruning of sandalwood was found to have adverse effects on the diversity and abundance of spiders. Unpruned sandalwood is not only healthy, the lateral branches support erectness of the main stem and protect the tree from adverse conditions like high winds, rainstorms, and intense sunlight. It also supports the survival and existence of diverse living organisms including spiders. The presence of lateral branches increase the probability of dispersal of spiders by ballooning; also the canopy provides a conducive environment to hide from its own predators and in successful predation on prey. Pruned plants devoid of lower lateral branches having flatter branches with shorter vertical spread might increase the exposure of spiders to visually foraging predators (e.g., birds), it also narrows their habitat and the availability of natural food resources by decreasing the occurrence of prey, thus it negatively correlated with spider densities. In a given habitat, the biomass of vegetation and prey availability were the best predictions of spider abundance (Halaj et al. 1998). Rypstra (1986) documented a strong positive relationship between the diversity of web-building spiders and vegetation structural diversity across several habitats. It corroborated the dominance of orb-weaving spiders in unpruned sandalwood and enlightens the importance of branches and the natural growth of sandalwood for the occurrence of web-building spiders. Web-building spiders are stationary predators that wait for prey to approach near them. Their abundance is directly related to the physical architecture of the vegetation (Greenstone 1984). The chance of their occurrence in pruned trees is almost eliminated except fora few species of Uloboridae with a fewer number of individuals. Also, the pruned trees are susceptible to harsh wind effects and rainstorms, making them unsuitable for web-building spiders. Similarly, the occurrence of stalkers the second dominant guild, which actively jump over the prey for feeding, is directly related to the prey availability and shaded environment which hides them from other larger predators (Pooja et al. 2019). This is applicable to the rest of the spiders and their abundance. Many earlier studies confirmed that the diversity and complexity of the vegetation positively affects the abundance of spiders (Sudhikumar et al. 2005; Orguri et al. 2014; Ossamy et al. 2016).

Sundararaj et al. (2018) documented more species of insect pests and natural enemies from more diversified areas of sandalwood cultivation but with less severity of the infestations and not having requirement of the insecticidal application. Also, the plant diversity regulates insect herbivore populations by favouring the abundance and efficacy of associated natural enemies (Altieri & Letourneau 1984). Due to the pruning of sandalwood trees, the mobile ecosystem service providers like pollinators do not get a conducive environment for making their colonies and in combination with extensive applications of agrochemicals have a negative effect on the foraging ability and lifespan of pollinators and their resilience which leads to a colossal loss of pollination and apiculture (Sundararaj et al. 2020). Agroforestry practices enhance habitat diversification, increase soil productivity, support native fauna in agricultural landscapes and more resilience towards pests (Torres et al. 2015). The presence of fringe areas


Image 1. *Arachnura melanura*


Image 2. *Araneus mitificus*


Image 3. *Argiope anasuja*


Image 4. *Argiope pulchella*


Image 5. *Cyclosa insulana*


Image 6. *Cyrtophora cicatrosa*


Image 7. *Cyrtophora citricola*


Image 8. *Eriovixia laglaizei*


Image 9. *Gasteracantha geminata*


Image 10. *Neoscona bengalensis*


Image 11. *Neoscona mukerjei*


Image 12. *Neoscona punctigera*


Image 13. *Nephila pilipes*


Image 14. *Cheiracanthium* sp.


Image 15. *Hersilia savignyi*


Image 16. *Hippasa agelenoides*


Image 17. *Pardosa pseudoannulata*

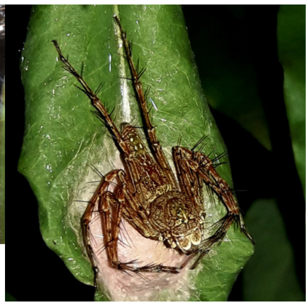
Image 18. *Hamadruas* sp.


Image 19. *Oxyopes* sp.


Image 20. *Peucetia viridana*


Image 21. *Brettus cingulatus*


Image 22. *Epeus indicus*


Image 23. *Hyllus semicupreus*


Image 24. *Myrmaplata plataleoides*


Image 25. *Plexippus paykulli*


Image 26. *Rhene flavicomans*


Image 27. *Rhene flavigera*


Image 28. *Telamonia dimidiata*


Image 29. *Heteropoda venatoria*


Image 30. *Olios milleti*


Image 31. *Opadometa fastigata*


Image 32. *Meotipa sahyadri*

Image 33. *Nihonhimea mundula*

Image 34. *Loxobates* sp.

Image 35. *Misumena* sp.

Image 36. *Thomisus andamanensis*

Image 37. *Thomisus lobosus*

Image 38. *Thomisus projectus*

Image 39. *Uloborus* sp. 1

Image 40. *Uloborus* sp. 2

Image 41. *Uloborus* sp. 3

Image 42. *Uloborus* sp. 4

of natural undisturbed vegetation is probably crucial in the maintenance of such a healthy predatory complex (Lalnunsangi et al. 2014). Sundararaj et al. (2019) commented that the increase in incidence of stem borer is of great concern as it causes very extensive and serious damage in perennial trees like sandalwood. Once they are infested with stem borer, it paves way for the infestation of decay fungi and such infestation is carried throughout the life of sandalwood, resulting in more than one third loss of heartwood. Similarly, the wound caused by the pruning will serve as the entry point of decay fungi and other bio-deteriorating agents leading to colossal damage of wood in the standing trees. Many other reports also corroborate the concept of habitat diversification, heterogeneity, and un-pruning of plants for the balanced co-existence of pests and their natural enemies thus regulating the adverse effects of pests on the plantations (Scheidler 1990; Coddington & Levi 1991; Whitmore et al. 2002; Tews et al. 2004; Buchholz & Schroder 2013; Sattler et al. 2021).

CONCLUSION

Sandalwood plantations support diversity of spider fauna and they play an active role in regulating the population of phytophagous insects. The pruning of sandalwood shows an adverse effect on the diversity and abundance of spiders. Hence it is recommended not to do pruning or do the pruning only in unavoidable situations. This will increases the habitat and nutritional resources of natural enemies like spiders and facilitate to keep pest populations under control.

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Image 43. Unpruned Sandalwood tree.

Image 44. Pruned Sandalwood tree.

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