

THE SPIDER FAUNA OF THE IRRIGATED RICE ECOSYSTEM IN CENTRAL KERALA, INDIA ACROSS DIFFERENT ELEVATIONAL RANGES

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ABSTRACT. A survey of spiders associated with the irrigated rice ecosystem in central Kerala, India was conducted across different elevational ranges. Spiders were collected from rice fields of high ranges, midland and low land areas in two cropping seasons viz., June–September 2002 (Kanni Krishy) and October 2002–February 2003 (Makara Krishy) with a total of 144 hours of sampling time distributed across the two seasons. The sampling areas constituted Adimali and Marayoor of Idukki district (high range), Vannappuram of Idukki district and Kothamangalam of Ernakulam district (midland) and Parakkadavu and Piravom of Ernakulam district (lowland). Visual searching methods were used to sample the spider fauna from quadrats. A total of 1130 individuals belonging to 92 species, 47 genera and 16 families were recorded during the study period. Araneidae and Tetragnathidae were the dominant families and *Tetragnatha mandibulata* Walckenaer 1842 (Family Tetragnathidae) the most abundant species. Various diversity indices, as well as richness and Chao I estimator were used to analyze the possible effect of elevation on species occurrence; the results showed that species richness and diversity were the highest in Parakkadavu, which is a lowland area. In a cluster analysis the localities belonging to the same elevation were found to form separate groups. The species fell into seven feeding guilds. Orb weavers were dominant at all study sites.

Keywords: Araneae, central Kerala, diversity, elevational gradient.

Spiders are ubiquitous in terrestrial ecosystems and abundant in both natural and agricultural habitats (Turnbull 1973; Nyffeler & Benz 1987). They play an important role in regulating insect pests in agriculture ecosystems (Nyffeler & Benz 1987; Nyffeler et al. 1994; Sunderland 1999). Studies of Hamamura (1969), Sasaba et al. (1973), Gavarra & Raros (1973), Samal & Misra (1975), Kobayashi (1977), Chiu (1979), Holt et al. (1987) and Tanaka (1989) clearly described the role of spiders as predators in reducing insect pests

in rice fields. In India, studies on the population and abundance of the spider assemblages in agricultural crops are few. Some basic studies were carried out by Pathak & Saha (1999) and Bhattacharya (2000). Banerji et al. (1993) and Anbalagan & Narayanaswamy (1999) also analyzed the population fluctuation of spiders in paddy fields. However, these studies were mostly limited to the identification of spiders and investigation of the dominant spider species. In this paper, we document the araneofauna associated with the irrigated rice

(*Oryza sativa* L.) ecosystem in central Kerala, India, based on studies conducted during two crop seasons. We also attempted to compare the diversity and richness of spiders across different elevational ranges and to analyze the possible effect of elevation on species occurrence.

METHODS

Study Area.—The areas selected for the study belong to Ernakulam and Idukki districts in Central Kerala, India. Elevation in these two districts ranges from 0–2695 m above MSL. The sampling sites included Adimali (latitude 10° 5' N; longitude 77° 44' E; elevation 1100 m above MSL) and Marayoor (10° 5' N; 77° 4' E; 2100 m above MSL) of Idukki district in the high range; Kothamangalam of Ernakulam district (9° 58' N; 76° 34' E; 230 m above MSL) and Vannappuram of Idukki district (9° 54' N; 76° 43' E; 270 m above MSL) in midland; and Parakkadavu (11° 15' N; 75° 49' E; 11 m above MSL) and Piravom (9° 58' N; 76° 34' E; 30 m above MSL) of Ernakulam district in the lowland. Average annual rainfall in Ernakulam district is 343.2 cm with 139 rainy days. Temperature ranges from 20–35 °C. The western parts of Idukki district comprising the midland area experiences moderate climate, temperature varying between 21–27 °C with minimum seasonal variation. The eastern parts of the district located in the highland have a comparatively cold climate with temperature varying between minus 1–15 °C in November/January and 5–15 °C during March/April. The sampling units were selected at random in all the localities.

The rice ecosystem in central Kerala consists of two physically and morphologically distinct habitats; the rectangular shaped flooded fields vegetated mainly by the rice plants, and the surrounding bunds which harbor weeds. This mosaic system is connected with irrigation canals and ditches, while sump ponds, marshes and tanks serve as contiguous aquatic habitats. The rice fields are frequently disturbed by farming practices, i.e. tillage, irrigation, fertilization, crop establishment, weeding and pesticide application, and by natural phenomena such as rainfall and flooding. These disturbances result in extreme instability on a short time-scale during the crop cycle, but relative stability on a long time-scale (Wa-

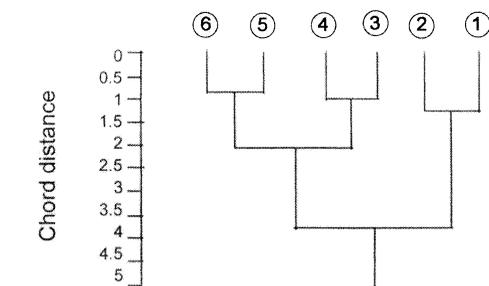


Figure 1.—Dendrogram for the cluster analysis of six sampling sites. 1 = Parakkadavu, 2 = Piravom, 3 = Vannappuram, 4 = Kothamangalam, 5 = Adimali, 6 = Marayoor.

tanabe & Roger 1985). Although rice is infested by a multitude of insect pests, the most destructive of them in central Kerala are the rice bug, *Leptocorisa acuta* (Thunberg); green leafhopper *Nephotettix virescens* (Distant) and brown planthopper, *Nilaparvata lugens* (Stal).

Study Time.—The study was carried out in two cropping seasons, viz. June–September 2002 (Kanni Krishy) and October 2002–February 2003 (Makara Krishy). A total of 144 hours were spent for sampling distributed across both cropping seasons.

Sampling.—Visual search was used for sampling in each selected study site. We spent one hour in each sampling unit on a fortnightly basis during each cropping season. Sampling was done from the same field during both seasons. A total of 24 hours were spent in each site across both cropping seasons, totaling 144 hours of sampling time. Spiders were collected from four quadrats (1 m x 1 m) placed at the four corners of a 10 m x 10 m area. Collections were done during early morning hours since it was observed that spider activity was the maximum at that time of day in the rice fields and the morning-dew-covered webs were easy to observe. The area around each plant was searched for possible webs and the plants were thoroughly examined for spiders from the bottom to the top. The spiders collected from each site every fortnight were preserved together in 70% ethyl alcohol with proper labeling of locality, date of collection and other notes of importance. The preserved specimens were counted under a stereo-zoom microscope (Leica-MS5). Spiders of all life stages were collected during sampling. The spiders were identified to the

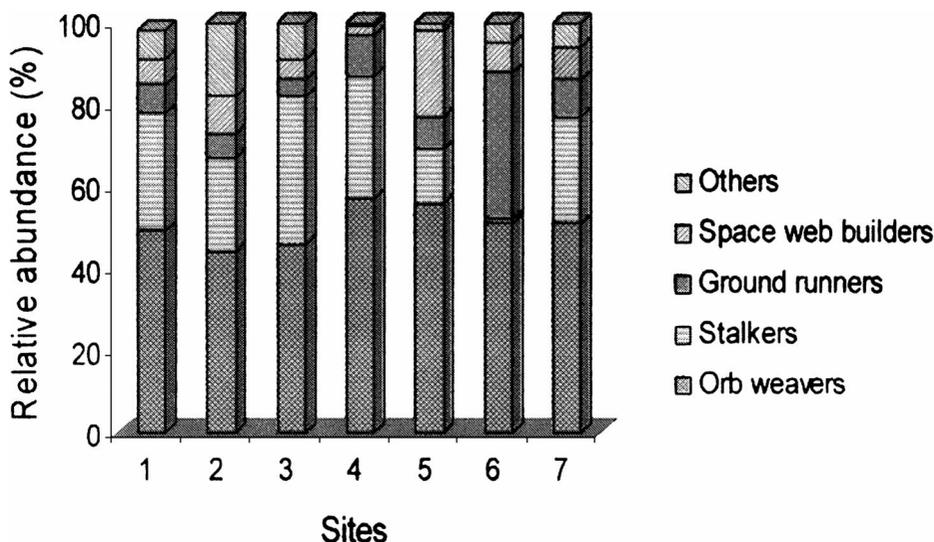


Figure 2.—Percentage of spider species by feeding guilds collected from irrigated rice ecosystem in central Kerala, India. 1 = Parakkadavu, 2 = Piravom, 3 = Vannappuram, 4 = Kothamangalam, 5 = Adimali, 6 = Marayoor, 7 = Total.

species level with the help of available literature (Tikader 1987; Barrion & Litsinger 1995) except the immature ones, which could be identified only to the generic level. Voucher specimens were deposited in a reference collection housed with the Arachnology Division, Dept. of Zoology, Sacred Heart College, Cochin, Kerala, India.

Data Analysis.—The diversity of spiders across different elevations were analyzed by widely used indices viz., the Shannon-Wiener index, which is sensitive to changes in the abundance of rare species in a community, and the Simpson index, which is sensitive to changes in the most abundant species in a community (Solow, 1993). Shannon-Wiener index is defined as:

$$H' = -\sum p_i \log p_i$$

where $p_i = n_i/N$ is the observed relative abundance of a particular species; n_i = the number of individuals of species i , and $N = \sum n_i$. The Simpson index is defined as:

$$D = \frac{\sum n_i(n_i - 1)}{N(N - 1)}$$

The results are given as 1-D.

The Margalef index, a species richness index, was computed based on the relationship between species richness (S) and total number

of individuals observed (N) which increases with increasing sample size. The Margalef index:

$$R1 = S - 1/\ln N.$$

The evenness index is a measure of how evenly species are distributed in a sample. When all species in a sample are equally abundant an evenness index will be at its maximum, decreasing towards zero as the relative abundance of the species diverge away from evenness. The modified Hill's ratio (E5) is the best evenness index, the least ambiguous, the most easily interpreted and is independent of the number of species in the sample (Ludwig & Reynolds 1988):

$$E5 = (1/D) - 1/e^{H'} - 1$$

where D = Simpson's index and H' = Shannon-Wiener index.

The Shannon-Wiener, Simpson, Margalef and Evenness (E5) indices were computed using the statistical software, SPDIVERS.BAS of Ludwig & Reynolds (1988).

The estimated species richness was calculated to determine whether or not the environment had been sufficiently sampled. The Chao 1 quantitative estimator (Chao 1984; Colwell & Coddington 1994) is calculated as:

$$S_{Chao1} = S_{obs} + (a^2/2b)$$

Table 1.—Total number of families, genera, and species composition of spiders sampled from different localities of central Kerala. 1 = Parakkadavu, 2 = Piravom, 3 = Vannappuram, 4 = Kothamangalam, 5 = Adimali, 6 = Marayoor.

Family	Genera	Species	Individuals	Localities					
				Lowland		Midland		Highland	
				1	2	3	4	5	6
Araneidae	11	25	132	9	5	13	12	13	9
Clubionidae	1	2	4	1	1			1	1
Eresidae	1	1	1				1		1
Filistatidae	1	1	1						
Gnaphosidae	1	1	2	1	1				
Hersiliidae	1	1	2	1			1		
Linyphiidae	1	1	59	1	1	1		1	1
Lycosidae	3	7	107	6	4	6	6	6	5
Miturgidae	1	1	2	1					
Oxyopidae	2	9	171	6	2	8	6	3	
Salticidae	10	14	115	10	3	5	10	5	
Sparassidae	1	1	1	1					
Tetragnathidae	4	16	437	12	4	10	13	13	7
Theridiidae	7	8	85	7	5	3	3	2	3
Thomisidae	1	2	4	2	1	1			
Uloboridae	1	2	7						1
Total	47	92	1130	58	27	47	54	44	28

where S_{obs} is the number of species observed; a is the number of singletons and b is the number of doubletons. The EstimateS program (Colwell 2000) was used to calculate the Chao 1.

The degree of association or similarity of the sampling sites was investigated using cluster analysis. The term “cluster analysis” encompasses a number of different classification algorithms (Faith 1991). It is a useful data reduction technique that can be helpful in identifying patterns and groupings of objects. The program CLUSTER.BAS (Ludwig & Reynolds 1988) was used for the cluster analysis of the data from different localities using the flexible strategy (Lance & Williams 1967) and chord distance, a measure of dissimilarity.

RESULTS

Distribution.—Spiders representing 16 families, 47 genera and 92 species were recorded during the study (Appendix 1). Table 1 is a summary of family composition. The sampling yielded a total of 1130 individuals. Some families were widely distributed throughout the study area while others were restricted to one or a few localities. The widely distributed families were Araneidae, Lycosidae, Tetragnathidae and Salticidae. Family

Araneidae was represented by 25 species belonging to 11 genera. However, the numerically dominant family was Tetragnathidae with a collection of 437 individuals belonging to 16 species and 4 genera. The numerically most abundant species was *Tetragnatha mandibulata* Walckenaer 1842 (Family Tetragnathidae) with a total of 109 individuals (Appendix 1). *T. javana* (Thorell 1890), *T. cochinensis* Gravely 1921, *Tetragnatha* sp., *Pardosa pseudoannulata* (Bösenberg & Strand 1906), *Pardosa* sp., *Lycosa tista* Tikader 1970, *Argiope* sp., and *Chrysso argyrodiformis* (Yaginuma 1952) were present at all study sites.

Diversity.—Diversity measurements did not vary considerably between sites across elevational gradients (Table 2) although the Parakkadavu site in the lowland recorded the highest Shannon-Wiener (3.49), Simpson (0.96), Margalef (6.83) and richness (58) values. The Evenness index E5 was the highest at Marayoor (0.90). The Chao 1 species richness estimator generated species richness values which were higher than the actual richness values. The highest value was observed at Parakkadavu (91.1), whereas the actual richness value at this site was 58.

Table 2.—Species diversity measures of spiders in rice ecosystem sampled from different localities in central Kerala. 1 = Parakkadavu, 2 = Piravom, 3 = Vannappuram, 4 = Kothamangalam, 5 = Adimali, 6 = Marayoor.

Diversity measures	Lowland		Midland		Highland	
	1	2	3	4	5	6
Shannon-Wiener index (H')	3.49	2.82	3.22	3.46	3.17	3.01
Simpson index (1-D)	0.96	0.92	0.93	0.95	0.93	0.94
Margalef index (R1)	6.83	3.92	6.00	6.71	5.73	4.21
Evenness index (E5)	0.86	0.85	0.84	0.87	0.84	0.90
Richness (S)	58	27	47	54	44	28
Chao 1	91.1	33.9	61.3	68.3	68.4	41.2

Cluster Analysis.—The pattern of clustering for the six localities is summarized in the dendrogram in Fig. 1. The species level analysis revealed two main clusters. The first cluster included four sites; Vannappuram and Kothamangalam (mid land) and Adimali and Marayoor (high land). At a chord distance of approximately 2.5, two groups emerged from this cluster. The first group was formed of the two high land sites while the second group included the two mid land sites. The second cluster was occupied by the remaining two low land sites, Parakkadavu and Piravom.

Guild Structure Analysis.—The spiders sampled belong to seven different foraging guilds (Uetz et al. 1999). These guilds are orb weavers, stalkers, ground runners, space web builders, sheet web builders, foliage runners, and ambushers (Fig. 2). Even though substrata for anchoring the webs are limited in rice fields compared to other terrestrial habitats, the orb weavers dominated in all the locations constituting 51% of the total collection. Stalkers were also seen in abundance (26%). Ground runners and space web builders were represented by 9% and 8%, respectively. Space web builders, foliage runners, and ambushers were less common in the study area.

DISCUSSION

The sixteen spider families recorded from the rice fields of Central Kerala represent 37% of the families reported from the country (Tikader 1987). A total of 92 spider species were reported from the rice ecosystem of central Kerala using two identification keys. Use of only two keys provided by Tikader (1987) and Barrion & Litsinger (1995) is justified as they are sufficient to identify spiders found in peninsular India. In a similar study, Bambarade-

niya & Edirisinghe (2001) have documented 60 species of spiders from an irrigated rice field ecosystem in Sri Lanka. Other works in Southeast Asia include that of Heong et al. (1991) recording 46 species of predators including bugs and spiders in Philippine rice fields and Barrion & Litsinger (1995) recording about 342 species of spiders from rice fields in the Philippines and other Southeast Asian countries. The observation that Araneidae and Tetragnathidae are the largest families is in conformity with the findings of Bambaradeniya & Edirisinghe (2001) in the rice fields of Sri Lanka. The dominance of tetragnathid spiders in the rice ecosystem of central Kerala might be expected as this wet habitat provides the congenial habitat for this family.

An analysis of various diversity indices across different elevations yielded only minimal differences in most of the indices used. This suggests that the effect of elevation on the diversity of spiders is not very drastic in the rice ecosystems of central Kerala. Nonetheless, Parakkadavu, which is a lowland area, exhibited more overall species richness and diversity. There are many environmental factors that affect species diversity. Some of these factors include seasonality, spatial heterogeneity, competition, predation, habitat type, environmental stability and productivity (Rosenzweig 1995). In terrestrial environments, a decrease in species richness with elevation and latitude is a common phenomenon. High elevation communities almost invariably occupy smaller areas than lowlands and they will usually be more isolated from similar communities than lowland sites. The effects of area and isolation are certain to contribute to the decrease in species richness with

elevation (Townsend et al. 2002). This explains the high overall species richness and diversity of Parakkadavu in comparison with other sites selected for the study. In addition, at Parakkadavu, rice cultivation is practiced in a cyclical way between polycultures of bananas and vegetables. This practice will provide enough shelter for spiders in different seasons. However, reasons for the low diversity indices recorded in the other lowland site, Piravom, need to be determined. One reason could be the practice of monoculture prevailing in this locality.

From the dendrogram, it is evident that the localities belonging to the same elevation formed one group in the cluster analysis. The midland and high range sites were found to be similar in the occurrence of species. Clustering revealed that the two low land sites behaved as a separate entity from the rest of the sites in species composition. This trend was predictable also because the distance between the mid and high land sites were less than that between the mid and low land sites.

The maximum number of species estimated by Chao 1 quantitative estimator showed wide deviations from the observed number of species. Chao 1 is an abundance-based estimator, so the number of times a species is present in a sample set has a significant effect on the number of species estimated to be present. This explains why Chao 1 gave a larger estimate of the overall species richness in the selected sites. Also, the presence of singletons and doubletons caused the Chao 1 to behave erratically. High relative percentages of singletons and doubletons during a sampling period indicate low abundance with Chao 1 (Fassbender 2002). The difference in estimated and observed numbers of species using Chao 1 reveals that the sampling efforts used were inadequate to reveal the true species diversity at the sites and indicates the necessity to conduct more intensive studies with modification of sampling techniques, viz. including extended sampling time, sampling during different time periods of the day, etc.

The most common explanation for the observed pattern of spider guild structure is the nature of the host crop, including its structural diversity, microenvironment, or the level of disturbance. Ample observations and more recent experimental evidence suggest that habitat structure maintains a diverse spider as-

semblage (Uetz 1991) and may be critical to successful insect pest suppression. The structural complexity may determine the guild composition of a crop's spider fauna and indirectly influence the level of herbivore damage.

The rice ecosystem of central Kerala has a diverse spider community and further research is indicated to evolve a better understanding of their ecology. These studies should include exploring other factors which are important in influencing spider diversity and richness in this agroecosystem, viz. effects of insecticides, availability of prey species, intra- and interspecific competition, surrounding habitats and climatic factors.

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Appendix 1.—Abundance data (total catches of two seasons) for spiders of rice ecosystem of central Kerala. 1 = Parakkadavu, 2 = Piravom, 3 = Vannappuram, 4 = Kothamangalam, 5 = Adimali, 6 = Marayoor.

Species name	Localities						Total
	Lowland		Midland		Highland		
	1	2	3	4	5	6	
Family Araneidae							
<i>Araneus</i> sp.	8	2	3	8			21
<i>Araneus bilunifer</i> Pocock 1900	1						1
<i>Araneus ellipticus</i> (Tikader & Bal 1981)			1		3	1	5
<i>Argiope</i> sp.	2	2	1	3	1	2	11
<i>Argiope aemula</i> (Walckenaer 1842)		3	2	1	1	1	8
<i>Argiope anasuja</i> Thorell 1887			3				3
<i>Argiope catenulata</i> (Doleschall 1859)	3		1	1	3	2	10
<i>Argiope pulchella</i> Thorell 1881			1	2	1		4
<i>Chorizopes</i> sp.				1			1
<i>Cyclosa</i> sp.		1				3	4
<i>Cyclosa bifida</i> (Doleschall 1859)						1	1
<i>Cyclosa fissicauda</i> Simon 1889			1		1		2
<i>Cyrtarachne</i> sp.	1						1
<i>Cyrtophora</i> sp.	3	1		5	2		11
<i>Cyrtophora citricola</i> (Forskål 1775)					1		1
<i>Eriovixia</i> sp.				4			4
<i>Eriovixia laglaizei</i> (Simon 1877)				3			3
<i>Eriovixia excelsa</i> (Simon 1889)				2	1	2	5
<i>Gasteracantha geminata</i> (Fabricius 1798)			2		1	3	6
<i>Gibbaranea bituberculata</i> (Walckenaer 1802)	2						2
<i>Neoscona</i> sp.	6		3	7	4		20
<i>Neoscona bengalensis</i> Tikader & Bal 1981					1		1
<i>Neoscona molemensis</i> Tikader & Bal 1981			1	1	1	1	4
<i>Neoscona vigilans</i> (Blackwall 1865)			1				1
<i>Zygiella</i> sp.	1		1				2
Family Clubionidae							
<i>Clubiona</i> sp.	1	1					2
<i>Clubiona drassodes</i> O. P. Cambridge 1874					1	1	2
Family Eresidae							
<i>Stegodyphus sarasinorum</i> Karsch 1891						1	1
Family Filistatidae							
<i>Pritha</i> sp.				1			1
Family Gnaphosidae							
<i>Gnaphosa</i> sp.	1	1					2
Family Hersiliidae							
<i>Hersilia savignyi</i> Lucas 1836	1			1			2
Family Linyphiidae							
<i>Linyphia</i> sp.	22	16	16		2	3	59
Family Lycosidae							
<i>Hippasa</i> sp.		1	2	2	2	3	10
<i>Lycosa</i> sp.	6	2	2	8	1	7	26
<i>Lycosa tista</i> Tikader 1970	1		1	1	1		4
<i>Pardosa</i> sp.	2	2	2	2	1	2	11
<i>Pardosa pseudoannulata</i> (Bösenberg & Strand 1906)	1	1	1	3	1	8	15
<i>Pardosa minuta</i> Tikader & Malhotra 1976	1						1
<i>Pardosa sumatrana</i> (Thorell 1890)	11		1	8	9	11	40
Family Miturgidae							
<i>Cheiracanthium melanostomum</i> (Thorell 1895)	2						2
Family Oxyopidae							
<i>Oxyopes</i> sp.	22	6	36	12	3		79
<i>Oxyopes ashae</i> Gajbe 1999	11		8	8	4		31

Appendix 1.—Continued.

Species name	Localities						Total
	Lowland		Midland		Highland		
	1	2	3	4	5	6	
<i>Oxyopes bharatae</i> Gajbe 1999			1	1			2
<i>Oxyopes sakuntalae</i> Tikader 1970			3				3
<i>Oxyopes shweta</i> Tikader 1970			1	4			7
<i>Oxyopes sitae</i> Tikader 1970			1				2
<i>Oxyopes sunandae</i> Tikader 1970	11		13	9			33
<i>Peucetia</i> sp.				2			2
<i>Peucetia viridana</i> (Stoliczka 1869)	2	4	5		1		12
Family Salticidae							
<i>Bavia</i> sp.	1			1			2
<i>Bianor</i> sp.	6		1	1			8
<i>Hasarius adansoni</i> (Audouin 1826)	4						4
<i>Hyllus</i> sp.	6		1	3	2		12
<i>Myrmarachne orientales</i> Tikader 1973	1			1			2
<i>Phintella</i> sp.			2				2
<i>Phintella vittata</i> (C. L. Koch 1846)		2		2	3		7
<i>Plexippus</i> sp.	2	1	2	4	3		12
<i>Plexippus paykulli</i> (Audouin 1826)	1			4			5
<i>Plexippus petersi</i> (Karsch 1878)	18	10	2	15	6		51
<i>Telamonia</i> sp.					1		1
<i>Telamonia dimidiata</i> (Simon 1899)	1			2			3
<i>Thiania</i> sp.				1			1
<i>Thyene</i> sp.	5						5
Family Sparassidae							
<i>Heteropoda venatoria</i> (Linnaeus 1767)	1						1
Family Tetragnathidae							
<i>Dyschiriognatha dentata</i> Zhu & Wen 1978	6			1	2	1	10
<i>Leucauge</i> sp.	7		3	2	3		15
<i>Leucauge bituberculata</i> Baert 1987	1		1	1	1		4
<i>Leucauge celebesiana</i> (Walckenaer 1842)		2		1	1		4
<i>Leucauge decorata</i> (Blackwall 1864)					2	6	8
<i>Leucauge pondae</i> Tikader 1970	13		2	11	4		30
<i>Tetragnatha andamanensis</i> Tikader 1977	18		6	8	3	1	36
<i>Tetragnatha ceylonica</i> O. P. Cambridge 1869	4		12	1	4		21
<i>Tetragnatha cochinchinensis</i> Gravely 1921	12	9	17	4	6	1	49
<i>Tetragnatha fletcheri</i> Gravely 1921						4	4
<i>Tetragnatha javana</i> (Thorell 1890)	19	11	8	12	8	7	65
<i>Tetragnatha mandibulata</i> Walckenaer 1842	32	12	10	36	19		109
<i>Tetragnatha maxillosa</i> Thorell 1895	1		2	1	1		5
<i>Tetragnatha</i> sp.	16		9	14	26	6	71
<i>Tetragnatha vermiformis</i> Emerton 1884	4						4
<i>Tylorida culta</i> (O. P. Cambridge 1869)				2			2
Family Theridiidae							
<i>Achaearanea</i> sp.		2	2	2	22		28
<i>Achaearanea durgae</i> Tikader 1970	2						2
<i>Argyrodes</i> sp.	1			1		1	3
<i>Chryso argyrodiformis</i> (Yaginuma 1952)	9	1	7		16	4	37
<i>Dipoena</i> sp.	1	1					2
<i>Phycosoma martinae</i> (Roberts 1983)	1	1					2
<i>Theridion</i> sp.	4	3		1		1	9
<i>Theridula</i> sp.	1		1				2
Family Thomisidae							
<i>Thomisus</i> sp.	1	1	1				3
<i>Thomisus andamanensis</i> Tikader 1980	1						1
Family Uloboridae							
<i>Uloborus</i> sp.				2		1	3
<i>Uloborus danolius</i> Tikader 1969				4			4
Total	325	99	203	238	180	85	1130