DISTRIBUTION OF SPIDERS IN MALAYSIA WITH SPECIAL EMPHASIS OF THE SYSTEMATICS AND ECOLOGY OF THE ORB-WEB SPIDER (ARANEAE: TETRAGNATHIDAE)

MUHAMMAD DZULHELMI BIN MUHAMMAD NASIR

FACULTY OF SCIENCES
UNIVERSITY OF MALAYA
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MUHAMMAD DZULHELMI BIN MUHAMMAD NASIR

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Name of Candidate: Muhammad Dzulhelmi Bin Muhammad Nasir

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Field of Study: Ecology and Biodiversity

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ABSTRACT

This study aimed to determine the diversity and distribution of spider species that can be found in selected locations on the west coast of Peninsular Malaysia. This study also aimed to determine the systematics and ecology of tetragnathid species in Malaysia. To document the spider diversity, specimens were collected from 11 selected locations from Peninsular Malaysia. Then, samplings of tetragnathid species that build orb-web were conducted in ten selected localities that represented ten habitat types in Malaysia. These samplings were conducted between January 2012 and December 2013. From the total number of spider species recorded in Peninsular Malaysia, additional 219 species including 70 newly recorded species were managed to be compiled. This documentation added up to a total of 644 spider species currently recorded in Peninsular Malaysia. From the specimens' collection, only 44.12% of tetragnathid species were collected out of total number of tetragnathid species recorded in Malaysia. This included 15 recognized species and three newly described species (i.e. *Leucauge sabahan*, *Opadometa kuchingensis* and *O. sarawakensis*). From the morphological diagnoses, this study identified that *Leucauge* and *Opadometa* species share many similar features, as well as in *Mesida* and *Tylorida*, although the members from the genus *Tetragnatha* is considered very distinct morphologically. The 14 morphological characters selected were useful for constructing the data matrix, dichotomous keys and diagnoses of tetragnathid species found in this country. The phylogenetic trees reconstructed using mitochondria-encoded cytochrome oxidase I (COI) and nuclear-encoded 18S rRNA (18S) genes of Malaysian tetragnathid species produced almost identical tree topologies with minor differences. The tree topologies corroborate with the internal relationship hypothesis of the family Tetragnathidae. They form two distinct lineages that are relative to subfamily Leucauginae and Tetragnathinae which is coherent with morphological characteristics. Both genes were useful in resolving the monophyletic relationships of tetragnathid species. However, the COI gene was more informative than 18S gene in resolving intra- and inter-specific relationships of tetragnathid species found in Malaysia. Meanwhile, web characteristics of twelve species from four genera (*Leucauge*, *Mesida*, *Tetragnatha* and *Tylorida*) occurring in Malaysia were investigated. Principal component analysis revealed that some tetragnathid species that coexist within the same habitat formed two close clustering in the PCA plots. Other tetragnathid species formed two separate clusters in the PCA plots due to wide variations in their web characteristics. Web-sizes and web-sites in relation to the heights from ground were the most important variables in the web characteristics. This finding suggests that tetragnathid spiders exhibit niche partitioning and their web characteristics determine the web placement in a particular habitat type. Orb-web spiders select and build their first orb-webs as early as during the juvenile stage. The relationships between the morphology and web characteristics of four tetragnathid species (*Leucauge argentina*, *L. celebesiana*, *Mesida gemmea* and *Tylorida ventralis*) was conducted. The morphological characters showed strong correlation with web sizes. However, no correlation was found between morphological characteristics and the number of spirals, number of radii, web angles and web-sites of the four tetragnathid species. Factors that reflect web characteristics of different body sizes are likely to be influenced by environmental factors. Changes of other web characteristics could be a response to the requirements of a particular situation within the habitat types. The information obtained from this present study will give an insight for other spider studies worldwide and particularly in Malaysia.

ABSTRAK

Kajian ini bertujuan untuk menentukan kepelbagaian dan taburan spesies labah-labah yang boleh ditemui di lokasi terpilih di sebelah barat Semenanjung Malaysia. Kajian ini juga bertujuan untuk menentukan sistematik dan ekologi spesies tetragnathid di Malaysia. Untuk mendokumentasikan kepelbagaian spesies labah-labah, specimen dikutip dari 11 lokasi terpilih di Semenanjung Malaysia. Tambahan pula, persampelan spesies tetragnathid yang membina sarang-bulat telah dijalankan di sepuluh kawasan terpilih yang mewakili sepuluh jenis habitat yang terdapat di Malaysia. Pensampelan ini telah dijalankan antara Januari 2012 dan December 2013. Daripada jumlah spesies labah-labah yang pernah direkodkan di Semenanjung Malaysia, sebanyak 219 spesies termasuk 70 rekod baru telah berjaya didokumentasikan. Hasil daripada pendokumentasian ini telah menjumlahkan sebanyak 644 spesies labah-labah yang telah direkodkan di Semenanjung Malaysia. Daripada pensampelan ini, sebanyak 44.12% spesies tetragnathid telah berjaya ditemui daripada jumlah bilangan spesies yang telah direkodkan di Malaysia. Ini termasuk 15 spesies yang telah diperihalkan dan tiga spesies baru (*Leucauge sabahan*, *Opadometa kuchingensis* dan *O. sarawakensis*). Dari diagnosis morfologi, kajian ini telah mengenal pasti bahawa spesies *Leucauge* dan *Opadometa* berkongsi banyak ciri-ciri yang sama, sebagaimana juga spesies *Mesida* dan *Tylorida*, manakala spesies *Tetragnatha* dianggap sangat berbeza. Empat belas ciri-ciri morfologi yang telah dipilih adalah sangat berguna dalam membina matriks data, kekunci dikotomi, untuk mendiagnosis spesies tetragnathid yang terdapat di negara ini. Hubungan filogenetik spesies tetragnathid Malaysia menggunakan gen separa mitokondria (COI) dan gen nuklear (18S) menghasilkan topologi pohon yang hampir sama dengan perbezaan yang sedikit. Topologi pohon ini telah menguatkan hipotesis hubungan dalam famili Tetragnathidae, yang membentuk dua kelompok salasilah berbeza relatif kepada subfamili Leucauginae dan Tetragnathinae yang koheren dengan ciri-ciri morfologi. Kedua-dua gen adalah berguna dalam menyelesaikan hubungan monofiletik spesies tetragnathid. Walau bagaimanapun, gen COI adalah lebih bermaklumat daripada gen 18S dalam menyelesaikan hubungan dalam dan antara spesies tetragnathid yang terdapat di Malaysia. Sementara itu, ciri-ciri sarang-bulat daripada 12 spesies dan empat genera (*Leucauge*, *Mesida*, *Tetragnatha* dan *Tylorida*) yang terdapat di Malaysia telah dikaji. Analisis komponen principal mendapati bahawa beberapa spesies tetragnathid yang wujud dalam habitat sama membentuk kelompok dekat, manakala spesies lain mempunyai variasi yang lebih luas dari segi ciri-ciri sarang-bulat. Saiz dan keletakan sarang-bulat yang berkaitan dengan ketinggian dari tanah merupakan pembolehubah yang paling penting dalam pembinaan sarang-bulat. Hasil penemuan ini menunjukkan bahawa spesies tetragnathid mempamerkan pembahagian nic dan ciri-ciri sarang-bulat menentukan lokasi sarang tersebut pada suatu habitat. Labah-labah bersarang-bulat memilih dan membina sarang pertama mereka seawal pada peringkat juvenil. Hubungan antara morfologi dan ciri-ciri sarang-bulat empat spesies tetragnathid (*Leucauge argentina*, *L. celebesiana*, *Mesida gemmea* dan *Tylorida ventralis*) telah dilaksanakan. Terdapat korelasi antara morfologi dengan saiz sarang-bulat. Walau bagaimanapun, tiada korelasi yang didapati antara morfologi dengan bilangan lingkaran, bilangan jejari, sudut sarang-bulat dan keletakan sarang-bulat untuk keempat-empat spesies tetragnathid. Faktor yang menggambarkan sarang-bulat dari saiz badan yang berbeza mungkin dipengaruhi oleh faktor persekitaran. Manakala, perubahan ciri-ciri sarang-bulat mungkin juga dipengaruhi oleh keperluan pada situasi tertentu mengikut jenis habitatnya. Maklumat yang diperolehi hasil daripada kajian ini akan menjadi pencetus kepada kajian spesies labah-labah lain yang terdapat di seluruh dunia dan Malaysia.

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&	and
♂	Male
♀	Female
%	Percent
^{o}C	Degree Celsius
µL	Microliter
ALE	Anterior lateral eyes
AME	Anterior median eyes
a.s.l.	Above sea level
BI	Bayesian inference
bp	Basepair
cm	Centimeter
cm^{2}	Square centimeter
COI	Cytochrome c oxidase subunit I
DNA	Deoxyribonucleic acid
et al.	et alia (and others)
GPS	Global positioning system
i.e.	id est (that is)
K2P	Kimura's two-parameter
m	Meter
mm	Millimeter
MCMC	Markov chain monte carlo
ML	Maximum likelihood
MP	Maximum parsimony
mtDNA	Mitochondrial deoxyribonucleic acid
N	Number of individuals
NJ	Neighbour-joining
NP	National Park
NR	Nature Reserve
PCA	Principal component analysis
PCR	Polymerase chain reaction
PLE	Posterior lateral eyes
PME	Posterior median eyes
rRNA	Ribosomal ribonucleic acid
SEM	Scanning electron microscope
sp.	Species (singular)
spp.	Species (plural)
TBR	Tree bisection reconnection

CHAPTER 1

GENERAL INTRODUCTION

1.1 SCOPES OF STUDY

Spiders are the largest group in the order Arachnida and comprise of more than 46,000 species from 114 families and 3988 genera worldwide (World Spider Catalog, 2016). They are known as successful predator groups and have wide spread terrestrial distributions from agriculture farms, forests, caves and human settlements. Spiders are good indicators of environmental changes in ecosystems, pest control and as natural prey and predators (Greenstone & Sunderland, 1999). However, very little attention had been given to this group due to lack of research interests (Grinang, 2004; Dzulhelmi *et al.*, 2014a).

A very limited research had been carried out on the natural history aspects of spider species in this country. To name a few, some research notes for *Heteropoda* species (i.e. Airame & Sierwald, 2000) and *Thiania* species (i.e. Jackson, 1986) were obtained from field observations, while studies on the diet preferences for *Heteropoda* species (i.e. Lau *et al.*, 2012), *Evarcha flavocinta* and *Plexippus petersi* (i.e. Maimusa *et al.*, 2012b), *Paracyrba wanlessi* (Jackson *et al.*, 2014) were performed in the laboratory. However, there is scarce information on the natural history of spider species found in this country.

In the meantime, studies in Malaysia had documented spider diversity in dipterocarp forests (i.e. Floren & Deelemen-Reinhold, 2005), secondary forests (i.e. Noraina, 1999), mangrove forests (i.e. Norma-Rashid *et al.,* 2009), limestone forests (Grinang, 2004) botanical gardens (i.e. Dzulhelmi & Norma-Rashid, 2014) and oil palm plantations (i.e. Wan-Azizi, 2008). Meanwhile, the spiders' roles in agriculture ecosystem in Malaysia were discussed in other literatures (e.g. Wood, 2002; Maimusa *et al*., 2012a; Norma-Rashid *et al*., 2014).

For the last two decades, many newly described species were collected from Malaysia (i.e. Platnick *et al*., 1997; Edmunds & Proszynski, 2001; Schwendinger, 2003; Zhang *et al*., 2003; Rheims & Brescovit, 2004; Zhang *et al*., 2006; Ono & Hashim, 2008; Eichenberger & Kranz-Baltensperger, 2011; Kranz-Baltensperger, 2012; Lin *et al*., 2012). From the recorded species, there are approximately 644 spider species in Peninsular Malaysia (Norma-Rashid & Li, 2009; Dzulhelmi *et al.*, 2014a), 307 species in Sarawak state (Koh *et al.*, 2013) and 222 species in Sabah state (Dzulhelmi *et al.*, 2014b). However, Deeleman-Reinhold (2001) mentioned that nearly 80% of spider species in this tropical region have not been described. Therefore, there could be indeed a high probability of discovering new species in the country.

Due to the scarcity of information, it is necessary to design and explore the spider group of this country. Hence, the present study chooses family Tetragnathidae, the orb-web spiders that may serve as potential key in understanding the spider group in this country (see Chapter 2). Tetragnathid spiders are diverse in the tropical and subtropical ecosystems. They occur in various habitat types ranging from cave entrances, tree buttresses, gardens, shrubs, near water vegetations and foliage in forests (Murphy & Murphy, 2000). Some tetragnathid species were considered as habitat specialists (e.g. Gillespie, 1987a; Aiken & Coyle, 2000; Koh & Ming, 2013) while others are considered as habitat generalist. This raises the question whether some Malaysian tetragnathid species are confined to certain habitat types. However, the information on the diversity and distribution of tetragnathid species within a particular habitat is scarce. Therefore, the investigation of tetragnathid species from various habitats in this country is required.

Molecular tool is an alternative approach that can provide a better understanding of intra- and interspecific relationships of different spider species. A recent study by Alvarez-Padilla & Hormiga (2011) had performed the phylogenetic tree reconstruction of the tetragnathid species using DNA sequences obtained from different parts of the world. The inference was made based on the morphological and behavioural characters (Alvarez-Padilla & Hormiga, 2011) in relation to the genetic data. However, most of the DNA sequences obtained from tetragnathid species are scarce in this country. Very few DNA sequences of spiders from this country were available in the GenBank (e.g. Benjamin *et al*., 2008; Muslimin *et al*., 2015). Meanwhile, comparison of several markers showed that particular genetic markers were more reliable for taxonomic purposes (e.g. Fang *et al*., 2000; Astrin *et al*., 2006). However, in some spider species, the application of desired genetic markers might be restricted due to difficulty in obtaining the compatible target DNA (e.g. Alvarez-Padilla, 2008). Hence, the search for the most informative genetic markers to delineate tetragnathid species found in this country is necessary.

Generally, tetragnathid species construct orb-webs which may differ in web characters, while some species within the group do not construct orb-webs. These sit-and-wait predators would choose quality locations, construct significant orb-webs that lure considerable diversity and density of prey. Different tetragnathid species live at different habitat types and the requirement of each species differs. Previous studies have discussed the placement of webs in relation to various factors i.e. prey type (e.g. Henaut *et al*., 2006; Tahir *et al*., 2010), wind disturbance (e.g. Liao *et al*., 2009) and vegetation structure (e.g. Richardson & Hanks, 2009). In addition, the relationships between certain web characteristics and prey size (e.g. Eberhard, 1988; Herberstein & Heiling *et al*., 1998) or body size (e.g. Richardson & Hanks, 2009; Tahir *et al*., 2010; Tahir *et al*., 2012) have been previously studied. Their studies mostly relate the web characteristics as an independent variable. Yet, there is very limited information on relationships between web characteristics and body sizes or the orb-web placement of tetragnathid species found in this country.

1.2 SIGNIFICANCE OF STUDY

The species richness provides great advantages for Malaysian researchers to study the spider group. As the spider fauna in this country is the least known, very little attention has been given to studying this group. Initiation to studying spider not only provides useful baseline information, it could also assist in other aspects of research interest. This study focuses on one family (i.e. Tetragnathidae) that builds orb-webs, together with several other aspects which include taxonomy, phylogeny and behavioural ecology of tetragnathid species. The findings obtained from this study would provide beneficial data for spider taxonomists, behavioural ecologists, molecular biologists and other relevant parties of interest.

1.3 HYPOTHESES

This study hypothesized that:

(1) Tetragnathid species are habitat dependent.

(2) Relationship of Malaysian tetragnathid species can be resolved using both COI and 18S genetic markers based on morphological characteristics.

(3) Combination of several web characteristics affects the placement of webs and will indirectly attain niche partitioning despite their life stages i.e. sub-adults and adults.

(4) If the morphology and web characteristics are not correlated, the variability of web characteristics could probably be influenced by environmental factors instead of morphological characteristics.

1.4 AIMS AND OBJECTIVES

The main objectives of this study were to:

(1) Document the diversity and distribution of spider species in selected localities in Peninsular Malaysia.

(2) Perform systematic studies of tetragnathid species in ten selected localities in Malaysia.

(3) Determine the genetic marker compatibility for Malaysian tetragnathid species using mitochondrial (COI) and nuclear (18S) DNA genes.

(4) Examine the relationships between web characteristics variables that determine niche partitioning of selected tetragnathid species

(5) Investigate the relationships between spider morphology and web characteristics of selected tetragnathid species.

CHAPTER 2

LITERATURE REVIEW

2.1 DISTRIBUTION

The distribution records of the tetragnathid species that had been recorded in South East Asian countries were based on the following literatures: Laos (Jager, 2007; Jager & Praxaysombath, 2009; Jager & Praxaysombath, 2011; Jager *et al*., 2012), Malaysia (Norma-Rashid & Li, 2009a; Norma-Rashid *et al*., 2009b; Koh *et al*., 2013; Dzulhelmi *et al*., 2014a; Dzulhelmi *et al*., 2014b), Singapore (Koh, 1989; Song *et al*., 2002), Brunei (Koh & Ming, 2013) and Philippines (Barrion & Litsinger, 1995). Other sources on distributional records for countries such as Myanmar, Vietnam, Thailand and Indonesia were available from books (Murphy & Murphy, 2000) and online database (World Spider Catalog 2016). In the contrary, some tetragnathid species were only recorded in a single locality in the respective country. For instance, species such as *Tetragnatha annamitica* and *T. tonkina* were only recorded in Vietnam, while *Dolichognatha albida* was only recorded in Thailand. Other species include *Glenognatha tangi*, *Leucauge leprosa*, *L. ditissima*, *Meta birmanica*, *Pachygnatha vorax*, *Prolochus longiceps*, *Tetragnatha baculiferens*, *T. hamata*, *T. jejuna*, *T. moulmeinensis* and *Timonoe argenteozonata* were recorded in Myanmar (Murphy & Murphy 2000). Moreover, species such as *Guizygiella guangxiensis*, *G. melanocrania*, *Leucauge xiuying*, *L. zizhong* and *Tetragnatha geniculata* have only been recorded in Laos (Jager & Praxaysombath, 2011).

Due to expansive taxonomy studies in Indonesia and Philippines, many tetragnathid species were described and recorded from the two countries. They include species such as

Dolichognatha deelemanae, *D. incanescens*, *D. mandibularis*, *Leucauge conifer*, *L. hasselti*, *L. quadripenicillata*, *L. scalaris*, *L. stictopyga*, *L. superba*, *L. vibrabunda*, *Mesida pumila*, *Meta montana*, *Mitoscelis aculeata*, *Neoprolochus jacobsoni*, *Tetragnatha Anguilla*, *T. flagellans*, *T. gracillima*, *T. klossi*, *T. nepaeformis* and *T. pulchella* in Indonesia (Murphy & Murphy 2000; World Spider Catalog 2016). Species such as *Dyschiriognatha hawigtenera*, *Leucauge bontoc*, *L. parangscipinia*, *L. mahabascapea*, *L. tredecimguttata*, *Mesida matinika*, *M. realensis*, *Meta baywanga*, *M. tiniktirika*, *Pachygnatha* ochongipina, *Tetragnatha desaguni*, *T. iwahigensis*, *T. IIavaca* and *T. okumae* were reported only in the Philippines (Barrion & Litsinger 1995; Murphy & Murphy 2000; World Spider Catalog 2016). Meanwhile, some species from the genera that have been recorded in other South East Asian countries such as *Dolichognatha*, *Glenognatha*, *Guizygiella*, *Meta*, *Mitoscelis*, *Neoprolochus*, *Pachygnatha*, *Prolochus* and *Timonoe* had never been reported in Malaysia. This similarities and differences may reflect the actual distribution though it may probably pertain to the lack of spider taxonomic studies in this country. Summary on the tetragnathid species recorded in South East Asian countries were retrieved from literatures (Table 2.1).

Table 2.1: Occurrence of tetragnathid species in South East Asia countries.

No	Species	VT	CB	TH	MY	LS	MS	SG	IN	BR	PH
1.	*Dolichognatha albida*			+							
2.	*D. deelemanae*								+		
3.	*D. incanescens*								+		
4.	*D. mandibularis*								+		
5.	*Dyschiriognatha bedoti*						+				
6.	*D. hawigtenera*										+
7.	*Glenognatha dentata*	+			+						+

8.	*G. tangi*				+						
9.	*Guizygiella guangxiensis*					+					
10.	*G. melanocrania*					+					
11.	*G. nadleri*	+				+					
12.	*Leucauge argentina*						+	+	+	+	+
13.	*L. bontoc*										+
14.	*L. celebesiana*					+	+	+	+	+	+
15.	*L. conifera*								+		
16.	*L. decorata*			+	+	+	+	+	+	+	+
17.	*L. ditissima*				+						
18.	*L. fibulata*							+	+		
19.	*L. granulata*						+		+		
20.	*L. hasselti*								+		
21.	*L. iraray*								+		+
22.	*L. leprosa*				+						
23.	*L. longula*				+				+		
24.	*L. macrochoera*				+				+		
25.	*L. mahabascapea*										+
26.	*L. parangscipinia*										+
27.	*L. quadrifasciata*						+		+		
28.	*L. quadripenicillata*								+		
29.	*L. scalaris*								+		
30.	*L. stictopyga*								+		
31.	*L. superba*								+		
32.	*L. tessellata*	+			+	+	+				
33.	*L. tredecimguttata*										+
34.	*L. vibrabunda*								+		
35.	*L. xiuying*					+					
36.	*L. zizhong*					+					
37.	*Mesida gemmea*				+		+	+	+		
38.	*M. matinika*										+
39.	*M. pumila*								+		

40.	*M. realensis*										+
41.	*M. yini*					+	+				
42.	*Meta baywanga*										+
43.	*M. birmanica*				+						
44.	*M. montana*								+		
45.	*M. tiniktirika*										+
46.	*Mitoscelis aculeata*								+		
47.	*Neoprolochus jacobsoni*								+		
48.	*Opadometa fastigata*			+	+			+	+		+
49.	*O. grata*				+	+	+	+	+	+	
50.	*Orsinome phrygiana*			+	+		+		+		
51.	*O. vethi*				+	+	+		+	+	
52.	*Pachygnatha ochongipina*										+
53.	*P. vorax*				+						
54.	*Prolochus longiceps*			+	+						
55.	*Tetragnatha anguilla*								+		
56.	*T. annamitica*	+									
57.	*T. baculiferens*				+						
58.	*Tetragnatha ceylonica*					+	+				+
59.	*T. chauliodus*				+		+	+			
60.	*T. desaguni*										+
61.	*T. flagellans*								+		
62.	*T. geniculata*					+					
63.	*T. gracillima*								+		
64.	*T. gressitti*						+				
65.	*T. hamata*				+						
66.	*T. hasselti*			+	+	+	+	+	+	+	
67.	*T. hirashimai*						+	+			
68.	*T. isidis*						+		+		
69.	*T. iwahigensis*										+
70.	*T. javana*	+	+			+	+		+		+
71.	*T. jejuna*				+						

72.	*T. josephi*				+		+	+		+	
73.	*T. klossi*								+		
74.	*T. lauta*					+	+				
75.	*T. lineatula*						+		+		
76.	*T. IIavaca*										+
77.	*T. mandibulata*	+		+	+	+	+	+	+		+
78.	*T. marginata*				+				+		
79.	*T. maxillosa*	+	+	+	+	+	+	+	+	+	+
80.	*T. moulmeinensis*				+						
81.	*T. nepaeformis*								+		
82.	*T. nitens*	+		+			+		+		+
83.	*T. novia*			+			+				
84.	*T. okumae*										+
85.	*T. pinicola*					+	+				
86.	*T. puella*				+				+		
87.	*T. pulchella*								+		
88.	*T. praedonia*					+	+				
89.	*T. serra*			+			+	+	+		+
90.	*T. tonkina*	+									
91.	*T. vermiformis*			+	+		+				+
92.	*T. virescens*	+	+	+		+	+		+		+
93.	*Timonoe argenteozonata*				+						
94.	*Tylorida striata*	+		+		+	+	+	+	+	
95.	*T. tianlin*					+	+				
96.	*T. ventralis*	+			+	+	+	+	+	+	

VT: Vietnam, CM: Cambodia, TH: Thailand, MY: Myanmar, LS: Laos, MS: Malaysia, SG: Singapore, IN: Indonesia, BR: Brunei, PH: Philippines.

2.2 HABITATS

It is quite difficult to categorize the tetragnathid species according to habitat due to their ability to adapt in a wide variety of habitat types. However, some information could be obtained in order to determine the habitat where some genera could be found. For instance, many *Meta* species (i.e. *M. bourneti, M. dolloff, M. menardi*) were found in dark places such as caves (Levi, 1980). Yet, few species such as *M. reticuloides* did not live in caves (Yoshida & Shinkai, 1993). The North American and some Japanese *Metleucauge* species (i.e. *M. chikunii*) made their webs above streams (Yoshida & Shinkai, 1993) while *Orsinome* species were reported near valleys and shrubs that were close to streams (Jager & Praxaysombath, 2009; Jager & Praxaysombath, 2011). The *Leucauge* and *Opadometa* had been recorded along rivers, roads (Alvarez-Padilla, 2008) and shrubs in gardens (Dzulhelmi & Norma-Rashid, 2014). Meanwhile, *Mesida* and *Tylorida* could be found at lower shrubs and at cave entrances (Jager & Praxaysombath, 2011). Additionally, *Tetragnatha* species were usually associated with water bodies such as streams and ponds, but some *Tetragnatha* species had also been observed on the roofs of huts, in front of caves (Jager & Praxaysombath, 2009), and even in the forests at upper elevations 1000 a.s.l (Dzulhelmi *et al*., 2014a).

Some species were considered habitat specialists, to name a few; *T. elongata* in riparian forests (Gillespie, 1987a), *T. straminea* in non-forested wetlands, *T. viridis* in conifers (Aiken & Coyle, 2000) and *T. josephi* in mangroves (Koh & Ming, 2013). Tetragnathid species that are aquatic habitat dependent would suffer dehydration if they could not reach water resources (Gillespie, 1987a). It is influenced by temperature and relative humidity.

Meanwhile, some *Tetragnatha* species from the genus *Dolichognatha* were found near tree buttresses and tree roots (Alvarez-Padilla, 2008), *Glenognatha* at the ground of marshes, wastelands and near meadows (Levi, 1980). *Pachygnatha* were found at moist areas on the grounds and *Mallometa* were found on tree trunks (Alvarez-Padilla, 2008). Thus, habitat generalists of tetragnathid species tend to occupy broader geographical ranges than habitat specialists.

2.3 TAXONOMY

The family Tetragnathidae was initially recognized as a separate family that included the genera *Tetragnatha* and *Pachygnatha* (Menge, 1866). On a later date, it was recognized as a subfamily Tetragnathinae under the family Argiopidae, consisted of seven other groups: Azileae, Cyatholipeae, Diphyeae, Meteae, Nesticeae, Tetragnatheae and Pachygnatheae (Simon, 1894). After that, Tetragnathidae was raised to a family ranking with two subfamilies; the subfamily Tetragnathinae which included the Tetragnatheae and Pachygnatheae, and the subfamily Metinae which included Azileae, Diphyeae and Meteae (Bonnet, 1956). Later, there were many classification group exchanges within the family Tetragnathidae and Araneidae (Alvarez-Padilla, 2008). For instance, the family Tetragnathidae formerly included Tetragnathinae (Roewer, 1942); Tetragnathinae and Nephilinae (Kaston, 1948); Tetragnathinae and Metinae (Locket *et al*., 1974). Then, Levi (1980) grouped Araneidae and Tetragnathidae as one family, though the later study separated Araneidae and Tetragnathidae as independent families (Levi, 1986). The family Tetragnathidae was formed by three subfamilies, i.e. Tetragnathinae, Metinae and

Nephilinae (Levi, 1986; Hormiga *et al*., 1995); or Tetragnathinae and Metinae (Kuntner, 2005; Kuntner, 2006).

The subfamily Leucauginae which consists of the genera *Dyschiriognatha*, *Leucauge, Mesida*, *Opadometa*, *Orsinome* and *Tylorida* (Murphy & Murphy, 2000) had been recorded in many South East Asian countries. The species within these genera are widely known as they had been described in many literatures. The genus *Leucauge* had never been the subject in taxonomic revision, although at least 60% of new species descriptions had been based on single sex (Dimitrov & Hormiga, 2010). Some *Leucauge* species were very common and well-known, and were given the common name "orchard spider" which was referring to *L. venusta* (Dimitrov & Hormiga, 2010), while others species had been synonymized due to similar morphological characters but with some variations in the genitalia (Levi, 2008).

Species within the genus *Opadometa* were established based on the *Leucauge* species which have dense brushes of hair on tibia IV. There are currently two *Opadometa* species, namely *O. grata* and *O. fastigata*, but both species were believed to be conspecific (Murphy & Murphy, 2000; Koh & Ming, 2013). Such discrepancy was a consequence of morphology descriptions of both species by using only one individual from each sex. Difficulty in finding the rare and cryptic male individuals made verification hard to be accomplished.

Tanikawa (2001) identified that the genus *Mesida* was closely related to the genus *Tylorida*. On the other hand, Alvarez-Padilla (2008) found that the genus *Mesida* to be closely related to the genus *Leucauge* and *Opadometa*. Yet, the taxonomy of the genus *Mesida* (e.g. Barrion & Litsinger, 1995; Zhu *et al*., 2003) had never been revised. Meanwhile, the genus *Tylorida* was established based on a male specimen of *T. striata* in which the holotype depository details were unknown (Alvarez-Padilla & Hormiga, 2011).

There are two species, namely *T. striata* and *T. ventralis* from the genus *Tylorida* that are commonly known and have wide distribution. Although the Japanese *Tylorida* (Tanikawa, 2004) and Chinese *Tylorida* species (Zhu *et al*., 2002) had been revised, new *Tylorida* species were being discovered and described (e.g. Kulkarni, 2014; Kulkarni & Lewis, 2015). Morphological characters had shown that the genus *Tylorida* was very closely related to the genus *Orsinome* (e.g. Zhu *et al*., 2003). However, there was no taxonomic revision made between the two genera (Kulkarni, 2014).

The subfamily Tetragnathinae consists of the genus *Cyrtognatha*, *Dolichognatha*, *Glenognatha*, *Pachygnatha* and *Tetragnatha* (Murphy & Murphy, 2000; Alvarez-Padilla, 2008). Hormiga *et al*. (1995) reported that *Glenognatha* was sister to the genus *Pachygnatha*. The taxonomy of *Dolichognatha* and *Glenognatha* had never revised. On the contrary, revision was made to the genus *Cyrtognatha (*Dimitrov & Hormiga, 2011) that concluded the genus *Cyrtognatha* as sister to *Tetragnatha*. The *Tetragnatha* is a large genus comprising of many long-bodied spider species that have long fangs and chelicerae, long cephalothorax, abdomens and legs, with worldwide distributions. This genus had been given considerable attention in which several taxonomy keys were available for *Tetragnatha* species from the Australasian region (Okuma, 1987), Asian region (Okuma, 1988), Hawaii (Gillespie, 1991; Gillespie, 2002; Gillespie, 2003a), Society Island (Gillespie, 2003b) and Marquesan Island (Gillespie, 2003c). There was not much information regarding the species from the genus *Dolichognatha* and *Pachygnatha* in South East Asia region despite their occurrence within particular countries (Barrion & Litsinger, 1995; Koh & Ming, 2013). Currently, the only available taxonomic key to tetragnathid species occurring in South East Asia was from the Philippines (Barrion & Litsinger, 1995).

The subfamily Metinae included the genus *Meta*, *Metleucauge* (Murphy & Murphy, 2000), *Mollometa*, *Nanometa* (Alvarez-Padilla, 2008). The genus *Mallometa* was confined to Chile while the genus *Nanometa* was restricted to Australia (World Spider Catalog, 2014). The taxonomic status of the genus *Metleucauge* had been revised for both American and Asian species (Levi, 1980; Tanikawa, 1992; Tanikawa & Chang, 1997). Recently, Alvarez-Padilla (2008) found that the genus *Metleucauge* was a sister to the large clade of the subfamily Leucaugines. Then again, the taxonomy of the genus *Meta* had been revised for American (Levi, 1980) and European (Marusik, 1986; Marusik & Koponen, 1992) species. *Meta* is either a sister clade to *Chrysometa* and *Metellina* (Hormiga *et al*., 1995) or a sister clade to *Dolichognatha* and *Metellina* (Alvarez-Padilla, 2008). On the other hand, there were a few genera that had also been recorded within the South East Asian regions. For instance, the genus *Guizygiella* had been placed under Tetragnathidae (e.g. Jager, 2007; Koh *et al*., 2013), but a few arachnologists were still classifying *Guizygiella* species under Zygiellidae (Wunderlich, 2004). To date, the placement of this genus remains uncertain.

2.4 PHYLOGENY

Molecular genetic information had been rapidly gaining support as it was quantifiable and provided discrete taxonomic characters that could often be standardized over a wide range of taxa and allowed rapid uniform analysis (Astrin *et al*., 2006). Molecular approaches had been used to identify closely related species (Franzini *et al*., 2013). The genital characteristics that most taxonomists relied on could be misleading due to polymorphism in some spider species (Huber & Gonzalez, 2001; Jocque, 2002). For instance, there were considerable variations in genitalia for some tetragnathid species such as *Mesida yini*, *Opadometa grata* (Jager & Praxaysombath, 2009), *Orsinome vethi* (Jager, 2007), *Tylorida tianlin* and *Tylorida ventralis* (Jager & Praxaysombath, 2009).

In most cases, phylogenetic analyses of tetragnathid species and their relatives relied on morphological and behavioural data whereas molecular work had been lacking (Alvarez-Padilla *et al.*, 2009). Although many new tetragnathid species had been discovered for the last few decades, taxonomic reclassification often took part without molecular support. Several studies on the phylogenetic relationships of tetragnathid species (i.e. Levi, 1980; Hormiga *et al*., 1995; Pan *et al*., 2004; Blackledge *et al*., 2009) had observed the stability on the relationships between tetragnathid species using morphological and molecular data (Alvarez-Padilla *et al*., 2009; Dimitrov & Hormiga, 2011). These studies proposed that the family Tetragnathidae has either three subfamilies (Leucauginae, Metinae, Tetragnathinae) within the 'Nanometa clade' (Alvarez-Padilla *et al*., 2009), or four subfamilies (Diphiinae, Leucauginae, Metinae, Tetragnathinae) within the 'Nanometa clade' (Dimitrov & Hormiga, 2011). The subfamily Diphiinae was only recovered as a tetragnathid lineage but the subfamily Metinae varied (Dimitrov & Hormiga, 2011). Due to inconsistency in resolving the taxonomic status of some groups using the morphological characters, the use of spider DNA could be very useful in resolving inter and intra specific relationships among the groups within the family Tetragnathidae.

2.5 WEB CHARACTERISTICS

If all orb-web spiders were the descendents of the orb-web building ancestors, some major aspects of orb-web construction behaviours appeared to have arisen independently from different evolutionary lineages (Eberhard, 1990a). Comparison had been made on the early stage orb-web construction of *L. mariana* with other uloborid and nephilid species (Eberhard, 1990b). Eberhard (1990b) highlighted the needs to determine the web-building behaviours before one could distinguish between different groups of spiders. Behavioural character coding was inevitably a very subjective decision and the limited data on the early stages of orb-web construction made it difficult to determine the criteria (Eberhard, 1990b).

The tetragnathids are recognized for their orb-webs with an open-hub, with many variations in the web characteristics. For instance, *Meta menardi* and *M. reticuloides* constructed orb-webs with an open-hub, but some webs of *M. menardi* had free sector zones in which spirals were not span (Yoshida & Shinkai, 1993). Adult *Pachygnatha* species did not build webs although they did during juvenile stage (Alvarez-Padilla, 2008). *Tetragnatha* species construct webs with variations in web characteristics in which some species build close-hubs, some with open-hubs and some with variations in the web characters. A few observations had been performed on the factors that determine the variations in these web characteristics. For instance, the spaces between temporary spirals loop were larger in the lower sectors of 45^o webs than in the upper sectors of the orb-webs of *Leucauge mariana* (Eberhard, 1987). Although the natural and experimental results showed that gravity influenced the temporary spirals initiation sites, Eberhard (1987) concluded that the differences in spacing between temporary spiral loops of *L. mariana* might be due to both gravity effect and differences in web characteristics. However, there was not much that can be conclude due to lack of information on web building behaviours in other tetragnathid species.

2.6 FORAGING-BEHAVIOURS

Orb-web spiders are sit-and-wait predators that construct their webs in a way to capture their prey. They did not invest energy or time in search of their prey, and were capable to survive long periods of starvation by reducing their metabolic and respiration rates (Scharf *et al*., 2011). The orb-webs served as a device to capture suitable prey sizes and types, including mobile and large prey that was difficult to capture (Scharf *et al*., 2011). In order to obtain the food sources, many orb-web spiders have unique strategies to lure their prey to their webs. The orb-web spiders could increase their captive efficiency by modifying web sizes and characteristics or relocating their webs to other more profitable web sites through life experience (Scharf *et al*., 2011). Different factors that influence the web characteristics of different tetragnathid species may include spider maturity, competitions, predation risks and prey types within that particular habitat. However, there was no guaranteed optimal web-site at any given time because placing a web at a specific site required continual trial and error procedures (Gillespie, 1987a).

Several studies had shown that tetragnathid species altered their web construction in relation to their body sizes (e.g. Henaut *et al*., 2006; Tahir *et al*., 2010). For instance, the *Leucauge decorata* constructed their webs at different sizes and heights but always maintained the basic web characteristics i.e. number of radii, number of spirals and mesh sizes (Tahir *et al*., 2010). Three groups of *Leucauge venusta* that differed in body sizes showed differences in web heights but maintained the web sizes and number of radii (Henaut *et al*., 2006). Some tetragnathid spiders use other means to attract their prey rather than altering the web characteristics. For instance, numerous brightly colored web- or non-web builder spiders were regarded as diurnal predators. Evidence had shown that the body coloration of *Leucauge magnifica* which was bright and colorful with low-contrast coloration functioned as visual lure to attract insects (Tso *et al*., 2006). The body of *L. magnifica* is not covered with bright and high-contrast colorations to avoid being falsely recognized by the prey as danger. Apart from that, it also reduced the predation risks by other visual predators on the spider itself (Tso *et al*., 2006; Tso *et al*., 2007).

On the contrary, some tetragnathid species tend to live in colonies and aggregate their orb-webs. The benefits of aggregating their orb-webs included decrease in silk investment, increased accessibility to areas of high prey availability that was not reachable by solitary web-building spiders and increased prey capture efficiency from the ‘ricochet effect’ (Salomon *et al*., 2010). Aggregation with a higher number of spider individuals also decreased attack by predatory wasps, through early vibration warnings from the web communities (Uetz *et al*., 2002). Salomon *et al*. (2010) observed that larger spiders tend to live at higher stratification in the social organization within the colonies than the smaller size spiders. Smaller individuals constructed webs after the larger individuals had completed their webs (Jakob *et al*., 1998) although some instars did not own any web within the social organization and they normally lived as floaters at the edge of the webs (Salomon *et al*., 2010). Each individual maintains its territory within the colony. If an intruder of conspecifics tried to approach the resident of *Leucauge* sp. web, a member would shake the web until the intruder fell off or would fight with the intruder to protect its web (Salomon *et al*., 2010). On the other hand, *L. mariana* aggregated among adults only during the dry seasons and then lived solitarily in rest of the year (Salomon *et al*., 2010). Furthermore, *Tetragnatha elongata* which aggregated their webs with conspecifics responded to prey and conspecific density according to the ‘risk-sensitive’ foraging theory (Gillespie, 1987b). When the captured prey availability was compatible to the number of colony members, *T. elongata* performed significant reduction in web-building activity and higher inter-individual tolerance (Gillespie, 1987b). If the density of *T. elongata* was low, silk sharing is unlikely to occur as individual would not come into contact with other individuals’ silk (Gillespie, 1987b). Likewise, if the prey density was low, *T. elongata* would subsequently construct larger orb-webs and became more aggressive towards their conspecifics (Gillespie, 1987b).

Meanwhile, some spider species practice cohabitation with different spider species, probably due to lack of reliable web-sites to overcome environmental disturbance. The advantages of cohabitation in spider species are that they reduce the cost of silk production, protection from extreme environmental conditions and disturbance. This also allows accessibility for these spiders to high abundance of preys by occupying open space (Proctor, 1992). As the webs of *Cyrtophora moluccensis* are very strong, some *Leucauge* species attach their threads to the webs to support and utilize them as scaffolds of their own webs (Proctor, 1992).

2.7 PREDATORY-BEHAVIOURS

Each tetragnathid species responded differently in its method of immobilizing their prey which might be related to the type of prey, number of aciniform glands and web characteristics (Yoshida, 2000). For instance, *Leucauge magnifica*, *Meta reticuloides*, *M. japonica* and *Tetragnatha praedonia* immobilized larger and/or dangerous prey such as millipedes, damselflies and winged ants by wrapping (Yoshida, 1989; Yoshida & Shinkai, 1993; Yoshida, 1990; Yoshida, 2000). As less silk was used for prey-immobilization by the tetragnatids than the araneids species, some prey managed to escape from the cocoon of silks (Yoshida, 2000). Meanwhile, *Metleucauge kompirensis*, *M. yaginumai* and *M. yunohamensis* immobilized their prey by only biting without wrapping it (Yoshida, 1989). This could probably been that whether *Metleucauge* species had lost their habit of immobilization by wrapping, or they were specialized and only captured weak and non-dangerous flying insects such as midges and nematocerous mayflies as their food source (Yoshida, 1989; Yoshida, 2000). It appeared that none-prey-wrapping type was one of the predatory behaviours of *Metleucauge* species (Yoshida, 1989). On the other hand, attack wrapping and carrying without biting the prey at the capture area is a unique attack sequence that was found only in *M. menardi* (Yoshida & Shinkai, 1993), which could be an adaptation by many *Meta* species living in dark area in caves (Levi, 1980).

Meanwhile, most orb-web spiders are able to capture a diverse and profitable array of prey types depending on the web-sites. For example, the *Leucauge decorata* and *Opadometa grata* are known to target *Aedes albopictus* (Diptera: Culicidae) mosquitoes as their preferred food in cemeteries and rubber plantations (Sulaiman *et al*., 1996). Then again, Diptera, Hymenoptera and Lepidoptera were the main prey captured in the colonial webs of *Leucauge* sp (Salomon *et al*., 2010). Although *Leucauge* sp. lives in colonies, captured prey was consumed individually without sharing between individuals (Salomon *et al*., 2010). Meanwhile, *Leucauge mariana* positioned its leg on the open-hub that was used as a launching platform to obtain information from vibrations produced when the prey hit the web, thus it increased the attacking time (Briceno & Eberhard, 2011). Some species such as the male *T. elongata* sometimes stole profitable prey items from the female's web (Danielson-Francois *et al*., 2002). To some extent, jumping spiders such as *Telamonia* species and *Portia fimbriata* predated on other orb-web spiders such as *T. ventralis* (Preston-Mafham & Cahill, 2000). Then again, rather than depending on their webs to capture profitable prey, some spider species have the ability to attract specific prey group. For example, moths were the *L. magnifica*'s prey of choice at night because nocturnal moths were attracted to the abdominal yellow stripes of *L. magnifica* that resembled the signal color of food resources of the moths (Tso *et al*., 2007). The differences in predatory behaviours of tetragnathid species showed a remarkable predatory strategy that should be examined and discussed to obtain a better understanding of tetragnathid species in this oriental region.

2.8 NICHE PARTITIONING

Differences in space utilization and tolerance to environment condition result in niche partitioning in orb-web spiders (Olive, 1980, Nyffeler, 1999). Orb-web spiders construct webs at stratified vertical sites to achieve niche partition (Tahir *et al*., 2012). For instance, *Leucauge decorata* and *Tetragnatha javana* construct orb-webs with distinct characteristics (i.e. distance from ground, web-size, mesh-size) to achieve niche partitioning (Tahir *et al*., 2012). Individuals occupying higher stratification are usually larger than the ones at lower stratification (Henaut *et al*., 2006; Tahir *et al*., 2010) such as in *Leucauge decorata* and *L. venusta*. However, this only occurs among conspecifics. In co-existence with other orb-web spider species, a species may built its web higher than other orb-web spider species which are larger in body sizes, as in *Tetragnatha javana* (Tahir *et al*., 2012). In addition, most orb-web spiders have generalist diets which usually utilize any available prey in ratio to their own body size. For instance, *Tetragnatha extensa* construct its orb-web 50-200 cm above ground and trapped flying insects at more than 97% of its total prey (Nyffeler & Benz, 1989).

Meanwhile, *Meta segmentata* constructs its orb-web between 0-150 cm in which flying insects were about 67% of its total prey while the 33% of its diets consists of other non-flying arthropods (Nyffeler & Benz, 1989). When two orb-web spider species niches overlapped in close cave environment, *Metellina merianae* used the typical orb-web hunting strategy while *Meta menardi* (Novak *et al*., 2010) and *M. japonica* combined orb-web hunting and off-web hunting strategies to optimize their prey types and to increase foraging success (Yoshida & Shinkai, 1993; Novak *et al*., 2010). Hence, different orb-web spiders can co-exist within the same habitat if they construct orb-webs with different architecture, stratified vertical web placement and consume different types of prey.

2.9 COURTSHIPS

Most spider species are solitary, and will remain together for a short period of time until the courtship and copulation events occurred. The male spiders might spend few hours to several days mate-guarding a penultimate female that was about to make the final moult to sexual maturity (Preston-Mafham & Cahill, 2000). This mate-guarding is known as ‘suitor phenomenon’ or ‘cohabitation’ which is an adaptive state for several reasons. The first male to mate with the virgin female spiders would be able to deposit his sperm, and thus giving this first-male sperm priority to associate with the new spiderlings. As female spiders were extremely aggressive towards their sexual partners, mating with the newly-matured females in ‘weak and supple’ conditions just after the final moult would give the male the advantage to avoid any retaliation from the females (Preston-Mafham & Cahill, 2000).

For example, right after the female *L. nigrovittata*’s final moult, it would perform a body-jerking display as an invitation to lure the male spiders for courtship (Preston-Mafham & Cahill, 2000). Courtship will be repeated by the pairs with several break intervals until reaching a stage when the female retreats as the male spider approaches (Preston-Mafham & Cahill, 2000). As the male approaches only when the female gives a signal, the male would not be considered as taking an advantage on the ‘weak and supple’ female condition (Preston-Mafham & Cahill, 2000).

Male spiders spread their lifetime reproductivity outputs among many female as possible during their life span. A pair of *T. ventralis* was observed to mate and had inserted the palps more than hundred times. The courtship was reportedly to have lasted for at least 10 hours during day-light. This is an act that support the first-male sperm priority theory (Preston-Mafham & Cahill, 2000). As finding female spiders to mate was challenging, this mechanism was crucial for the male spiders because rival males could overcome the first-male sperm priority (Preston-Mafham & Cahill, 2000).

Sexual dimorphism in spiders is very common in females weighing multiple times more than the males. There are some hypotheses suggested to the reproductive roles of male and female spider. Head (1995) stated that a larger size female was favored because it has a higher reproductive potential. Nonetheless, factors responsible for the smaller size of males was still far from clear (Moya-Larano *et al*., 2007). A recent gravity hypothesis stated that size is inversely proportional to moving speed on a vertical direction (Moya-Larano *et al*., 2002). The advantage of having small sizes among males was that they are able to reach the females that built their webs at higher vegetations at faster speed (Moya-Larano *et al*., 2002). However, there was negative relationship between the climbing speed and body mass for *L. venusta* (Moya-Larano *et al*., 2007).

When a male *Tetragnatha elongata* is assessing a potential mate from the edge of its web, it would choose heavier female as cue due to poor vision (Danielson-Francois *et al*., 2002). Heavier females indicated that the females were closer to oviposition (Danielson-Francois *et al*., 2002).

The male *T. elongata* would position itself at the edge of the female's web and tap the silk strands for few seconds (Danielson-Francois *et al*., 2002). It would pause and wait for the female to respond (Danielson-Francois *et al*., 2002). Once the female *T. elongata* pulses rhythmically, the male would approach the female. Both individuals would spread their chelicerae and fangs apart and interlock their chelicerae fangs for mating (Danielson-Francois *et al*., 2002). *T. extensa* presented its jaw open to welcome the male, and vibrates the web rapidly if the male spider was not welcomed (Preston-Mafham & Cahill, 2000). Male spiders would compete for the female and the winning male would immediately mate with the female (Danielson-Francois *et al*., 2002). Female *T. elongata* would sometimes eat the male *T. elongata* at some point (Danielson-Francois *et al*., 2002), although it was rarely reported.

Female *L. mariana* controlled the copulation with different males before and after courtship occurred (Eberhard & Huber, 1998). When the male and female were consent for courtship, the female would aid the male in the copulatory plug formation (Aisenberg & Eberhard, 2009). The male *L. mariana* demonstrated two courtship behaviours during copulation; 1) rhythmic pushing on the female's leg with his front legs; 2) repeated short insertions with his genitalia. It would then be followed with corporation by the female in copulatory plug formation (Aisenberg & Eberhard, 2009). The female would add a clear liquid to the small blobs of white paste that had been deposited by the male on her genital plate to form a mixture (Eberhard & Huber, 1998). However, if the female *L. mariana* had been plugged by another male, the rival male that intended to mate would only succeed if the former plug was successfully displaced or broken (Mendez & Eberhard, 2014).

The large and fecund females of *Meta segmentata* positioned their webs in aggregation with high quality habitats, while smaller female individuals lived alone in lower quality habitat sites (Ruberstein, 1987). Before the mating period, several *M. segmentata* males could be found at the corners of the females' webs. However, only one dominant male would compete for the female by chasing the other males away (Ruberstein, 1987). Then, moderate-size male would take high risk to mate with larger female in aggregation, while small-size male would mate with females monogamously in poor quality web sites to achieve higher reproductive success rate (Ruberstein, 1987). Hence, body sizes of both male and female *M. segmentata* spider are very important to determine their mating and reproductive success.

2.10 PARASITISM

Spider behaviours could also be influenced by the parasitoids. The spider *Plesiometa argyra* performed a highly stereotypic construction behaviour and constructed a unique "cocoon web" that was particularly well designed to support the parasitoid wasp *Hymenoepimecis argyraphaga* (Family: Ichneumonidae) larva cocoons (Eberhard, 2001). Initially, a female wasp would attack the *P. argyra* that was resting at the center of an orb-web and sting the host to temporal paralysis. Then, it would glue an egg to the spider's abdomen (Eberhard, 2001). At this stage, the host's movements showed no signs of weaknesses after the attack (Eberhard, 2000). When the larva grew, it would start to feed by sucking the haemolymph through small holes that it made on the spider's abdomen (Eberhard, 2001). When the second instar of the wasp emerged, it would induce the host *P. argyra* to construct a "cocoon web" before it would kill and consume the host (Eberhard, 2000). The mechanism by which the wasp larva was able to induce web construction behaviour in the spider host involved a fast-acting chemical reaction with effects gradually manifested (Eberhard, 2001).

CHAPTER 3

DISTRIBUTION OF SPIDERS FROM THE WEST COAST OF PENINSULAR MALAYSIA

3.1 INTRODUCTION

Spider fauna are consistently being documented in Southeast Asia but the spider fauna for Peninsular Malaysia is poorly investigated. The first checklist for spiders of Peninsular Malaysia recorded 425 species from 42 families and 238 genera (Norma-Rashid & Li, 2009) which provided a general guideline for researchers to investigate the spider fauna of Peninsular Malaysia. Later, quite a number of new records and descriptions of new species from various spider groups have emerged. These data has contributed to spider species for peninsular Malaysia, though the information was scattered. Nonetheless, Song *et al.*, (2002) has listed the diversity of spider fauna in other Southeast Asia.

Recently, inventories on the spider fauna for Laos with newly described species have been increasing rapidly (Jager, 2007; Jager & Praxaysombath, 2009; Jager & Praxaysombath, 2011). Such positive inventories are needed to expand the knowledge on the spider fauna of Southeast Asia. During our field survey to document the spider fauna on the west coast of peninsular Malaysia, we encountered many common spider species that were easily found and collected but may have been overlooked, therefore not recorded in the previous checklist (i.e. Norma-Rashid & Li, 2009). This paper provides spider fauna records which were mainly focusing on the west coast of Peninsular Malaysia. The compilation of recorded spider species from available literatures that were not listed in the previous checklist was also included.

3.2 MATERIALS AND METHODS

3.2.1 STUDY SITES

Specimens examined were collected from 11 field expeditions conducted between January 2012 through December 2013 in the following locations and habitats on the west coast of peninsular Malaysia based on accessibility and facilities (Figure 3.1). These localities comprise of different habitat types including (1) lowland dipterocarp forest (2) hill dipterocarp forest (3) montane oak forest (4) lower montane forest (5) mangrove forest (6) botanical garden (7) agriculture plantation and (8) human settlements (Table 3.1).

Penang National Park (5^{o}26’16” N, 100^{o}17’27” E), located on the island, is situated about 22 km from George Town, Pulau Pinang. This park covers about 1181 hectares of forest and 1381 hectares of wetlands. It is one of the smallest national parks in Malaysia. The sampling survey was conducted at the lowland dipterocarp forest along the maintrail to Kerachut Beach.

Penang Hill or Bukit Bendera (5^{o}26’1” N, 100^{o}15’60” E) is located about 6 km from George Town, Pulau Pinang. This hill resort temperatures usually range from 20-27^{o}C with the summit highest point reaches up to 833 meters above sea level. The most common forest type is the hill dipterocarp forest with some montane oak forest at higher altitude. The sampling survey was conducted at the hill dipterocarp forest along the maintrail to the summit.

Lekir Agriculture Center (4^{o}8’10” N, 100^{o}43’41” E) is located approximately 20 km from Seri Manjung, Perak. This agriculture center offers opportunity for the locals to learn fruit and vegetable planting in the land provided. It is organized by the Perak Agriculture Department. The sampling survey was conducted within the vicinity of the agriculture center.

Manjung Residential Area (4°11’45” N, 100°39’53” E) is located in Seri Manjung, Perak. The residential area is situtated inland at approximately 2 km from the main town. There are few fragmented patch of bushes and other trees such as rambutan, mango and coconuts surrounding the area. Sampling survey was conducted at the housing area.

Cameron Highlands (4°30’42” N, 101°28’42” E) is situated at approximately 200 km from Kuala Lumpur. Covering an area of 712 square kilometers, Cameron Highlands share its boundary with Pahang, Kelantan and Perak state. The mean temperature can rise up to 25°C during the day and can drop as low as 9°C at night. Although there is variety of forests at the area, the survey was conducted at the gardens near human settelements.

Fraser Hill Forest Reserve (3°43’7” N, 101°44’25” E) is situated about 104 km from Kuala Lumpur, and is located in Raub, Pahang. This hill resort has an average altitude of 1200 meters a.s.l., with the highest point rises at 1500 meters. The temperatures usually range between 22-28°C during the day and 16-20°C at night. This hill resort comprises of forest reserve covered with hills and montane forests. The sampling survey was conducted at the vicinity of the area.

Kuala Selangor Nature Park (3°20’16” N, 101°14’56” E) is situated approximately 60 km north of Kuala Lumpur in Kuala Selangor, Selangor. The park covers an estimation of 324 hectare of land comprising the coastal mangroves, secondary forests, a brackish water lake and coastal mudflats. This park plays an important role for coastal and riverine mangroves conservation. The sampling survey was conducted on the main trail, along the secondary forest.

Rimba Ilmu Botanical Garden (3°7’29” N, 101°39’12” E) is a 40-hectare botanical garden located within the main campus of University of Malaya in the city of Kuala Lumpur. There are more than a thousand species of plants from 500 genera and over 160 families that serve as an important conservatory for indigenous plants that can be found in this garden (Wong & Mustafa, 1997). The survey is conducted within the vicinity of the garden.

Ulu Gombak Field Study Centre (3^{o}22’60.1” N, 101^{o}47’20” E) is located 30 km from Kuala Lumpur. This forest reserve covers an area of 120 hectares of primary and secondary forests, and is surrounded by villages. The altitude ranges between 100 and 800 meters, with annual temperature of 26-27^{o}C. The sampling survey was conducted at the secondary forest within the vicinity of the forest reserve.

Taman Paku Pakis (2^{o}55’47”N, 101^{o}46’44” E) is a 20 hectare size botanical garden located within the main campus of Universiti Kebangsaan Malaysia. This garden was initiated in 1988 and was officially established in 1990. There are at least 150 species of fern species that is kept in this garden. The survey was conducted within the vicinity of the garden.

Kuala Pilah Rubber Plantation (2^{o}26’56” N, 102^{o}11’1” E) is a private land, located at Kuala Pilah, Negeri Sembilan. This rubber plantation is owned by the local villagers. There are many undergwoth shrubs at the plantation. The survey was conducted along the trail that is accessible and permitted by the owner.

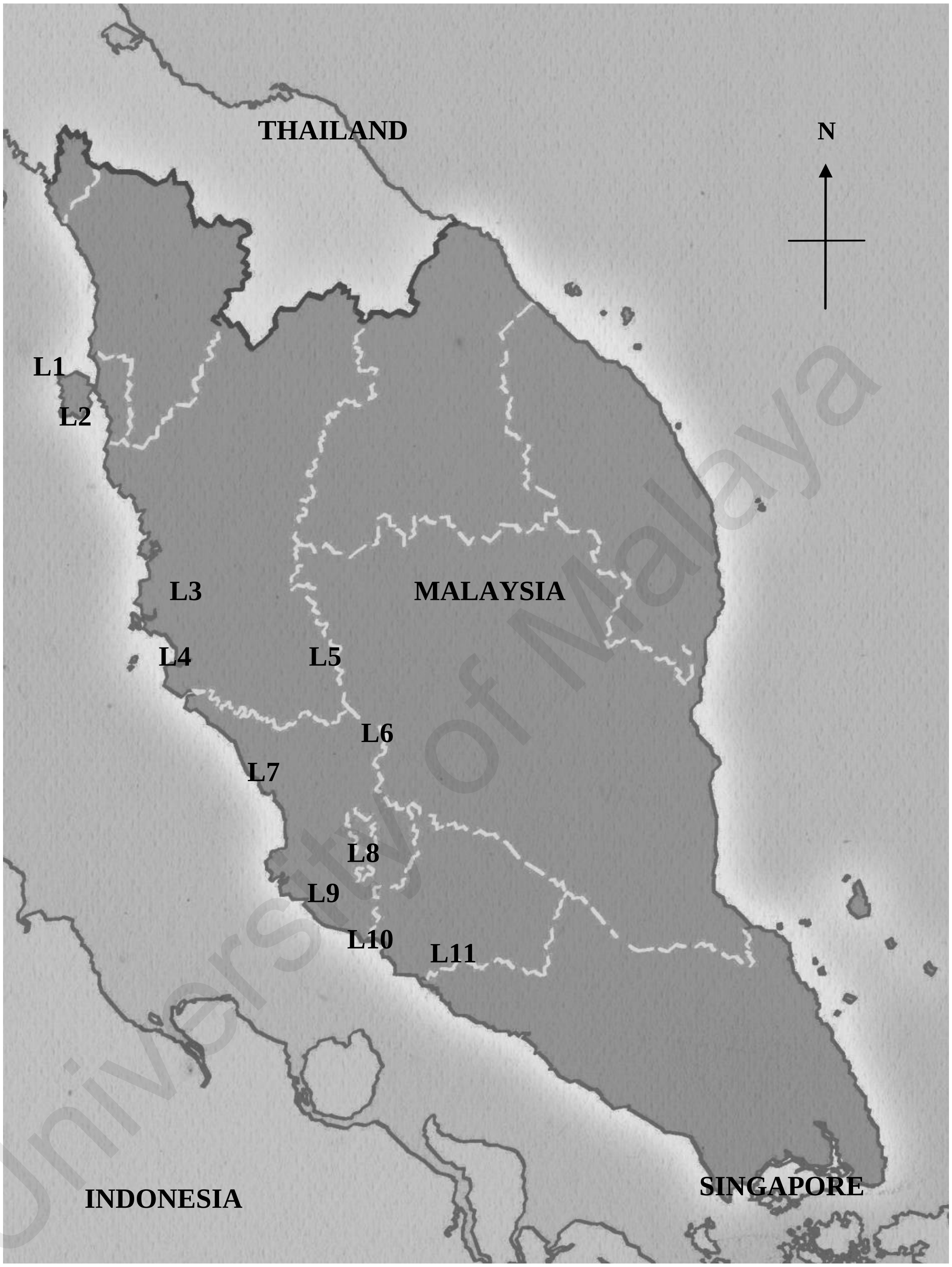

Figure 3.1: Map of Peninsular Malaysia. Sampling sites were indicated by the abbreviated letters.

Table 3.1: Sampling locations in Malaysia where the spider species were collected.

Code	Localities	Habitat types	Date
L1	Penang National Park, Balik Pulau	Lowland dipterocarp forest	9-11 October 2012
L2	Penang Hill, Air Itam	Hill dipterocarp forest (800m a.s.l.)	6-8 October 2012
L3	Lekir Agriculture Centre, Lekir	Agriculture farm	12-14 February 2013
L4	Manjung Residential Area, Seri Manjung	Human settlements	23-25 February 2013; 10-12 December 2013
L5	Cameron Highlands, Pahang	Lower montane forest (1100m a.s.l.)	25-27 January 2013
L6	Fraser Hill Forest Reserve, Raub	Hill forest (1200m a.s.l.)	23-27 September 2012
L7	Kuala Selangor Nature Park, Kuala Selangor	Mangrove forest	18-21 March 2013
L8	Rimba Ilmu Botanical Garden, Kuala Lumpur	Botanical garden	24-26 February 2012; 25-27 December 2012
L9	Ulu Gombak Field Study Centre, Gombak	Secondary forest	13-15 November 2012; 14-17 March 2013
L10	Taman Paku Pakis UKM, Bangi	Botanical garden	16-18 June 2012; 10-12 September 2012
L11	Kuala Pilah Rubber plantation, Kuala Pilah	Rubber plantation	17-19 November 2012

3.2.2 SPECIES IDENTIFICATION

Specimens were collected by hand and sweep-net during the day (0900-1200 h) and night (2000-2300 h). Specimens were stored in 75% ethanol. Male palps were observed under dissecting microscope and illustrated, while female genitalia were dissected, cleared in Potassium Hydroxide (KOH) and illustrated under microscope. Species identification was most notably done by using Barrion & Litsinger (1995), Song *et al.*, (1999), Murphy & Murphy (2000), Deeleman-Reinhold (2001), Sebastian & Peter (2009), Koh & Ming (2013) and other relevant literatures. The checklist is presented in alphabetical order and synonym names can be referred in World Spider Catalog (2016). The materials examined are presented in the list in the following order: specimen examined (if any), microhabitat found, period, collector(s), date, and location. The reference sequence is as follows: page number of the literature cited, figure, and photos or illustrations. In addition, published literature for spiders recorded in Peninsular Malaysia that were not listed by Norma-Rashid & Li (2009) included in this paper are presented in a table in the following sequence: Family, species name, page number (or figures/plates) of the mentioned species, and references for guidelines.

3.3 RESULTS

3.3.1 LIST OF SPIDER SPECIES COMPILED FROM PUBLISHED LITERATURES

A total of 149 spider species from 33 families and 95 genera were compiled from available literatures (Table 3.2). The family of Araneidae (26 species from 15 genera), Liocranidae (16 species from three genera) and Oonopidae (12 species from three genera) have the most number of species retrieved from published literatures. The family Barychelidae, Cithaeronidae, Dictynidae, Gnaposidae, Hahniidae, Linyphiidae, Mysmenidae, Ochyroceratidae, Philodromidae, Prodidomidae, Telemidae, Tetrablemmidae, Theraposidae and Theridiosomatidae were represented by a single species respectively.

Table 3.2: List of spiders of Peninsular Malaysia from published literatures.

Families	Species	Page number, References
Araneidae	*Anepsion maritatum* (Cambridge 1877)	p52, Koh & Ming (2013)
	Araneus anaspastus (Thorell 1892)	Wan-Azizi (2008)
	Araneus ancurus Zhu, Tu & Hu 1988	Wan-Azizi (2008)
	Araneus elongatus Yin, Wang & Xie 1989	Wan-Azizi (2008)
	Araneus mitificus (Simon 1886)	p40, Noraina (1999)
	Araneus neogeata (Thorell 1896)	Pl.12.5, Murphy & Murphy (2000)
	Argiope catenulata (Doleschall 1859)	p570, Barrion & Litsinger (1995)
	Argiope mangal Koh 1991	Pl.13.2, Murphy & Murphy (2000)
	Caerostris sumatrana Strand 1915	Pl.14.15,Murphy & Murphy (2000)
	Cyclosa centrodes (Thorell 1857)	Wan-Azizi (2008)
	Cyphalonotus selangor Dzulhelmi 2014	p5, Dzulhelmi *et al.*, (2014)
	Cyphalonotus sp.	Pl.17.6, Murphy & Murphy (2000)
	Cyrtophora cicatrosa (Stoliczka 1869)	p66, Koh & Ming (2013)
	Cyrtophora hainanensis Yin *et al.* 1990	Wan-Azizi (2008)
	Cyrtophora unicolor (Doleschall 1857)	p68, Koh & Ming (2013)
	Eriovixia laglaisei (Simon 1877)	Pl.15.1, Murphy & Murphy (2000)
	Gasteracantha crucigera Bradley 1877	p74, Koh & Ming (2013)
	Gasteracantha kuhli Koch 1837	p559, Barrion & Litsinger (1995)
	Gasteracantha mammosa Koch 1844	p34, Koh (1989)
	Gea subarmata Thorell 1890	P568, Barrion & Litsinger (1995)
	Hyposinga pygmaea (Sundevall 1831)	P611, Barrion & Litsinger (1995)
	Macracantha arcuata (Fabricius 1793)	p80, Koh & Ming (2013)
	Neoscona nautica (Koch 1875)	p12, Yong (2009a)
	Neoscona vigilans (Blackwall 1865)	p12, Yong (2009a)
	Parawixia dehaani (Doleschall 1859)	p40, Noraina (1999)

	Prasonica sp.	Wan-Azizi (2008)
Barychelidae	*Sason sundaicum* Schwendinger 2003	p203, Schwendinger (2003)
Cithaeronidae	*Cithaeron praedonius* Cambridge 1872	p83, Platnick & Gajbe (1994)
Clubionidae	*Clubiona analis* Thorell 1895	p132, Jager (2012)
	Clubiona concinna (Thorell 1887)	Pl.22.4, Murphy & Murphy (2000)
	Clubiona hystrix Berland 1938	p104, Deeleman-Reinhold (2001)
	Clubiona japonica Koch 1878	p122, Deeleman-Reinhold (2001)
	Clubiona meraukensis Chrysanthus 1967	p11, Norma-Rashid *et al.* (2009)
	Malamatidia bohorokensis Deeleman-Reinhold 2001	p193, Deeleman-Reinhold (2001)
	Nusatidia javana Simon 1896	p170, Deeleman-Reinhold (2001)
	Pristidia viridissima Deeleman-Reinhold 2001	p95, Koh & Ming (2013)
Corinnidae	*Copa* sp.	Pl.23.2, Murphy & Murphy (2000)
	Corinna gulosa (Thorell 1878)	p259, Deeleman-Reinhold (2001)
	Medmassa tigris Deeleman-Reinhold 1995	p102, Koh & Ming (2013)
	Sesieutes abruptus Dankittipakul & Deeleman-Reinhold 2013	p182, Dankittipakul and Deeleman-Reinhold (2013)
	Sesieutes apiculatus Dankittipakul & Deeleman-Reinhold 2013	p186, Dankittipakul and Deeleman-Reinhold (2013)
	Sesieutes bifidus Dankittipakul & Deeleman-Reinhold 2013	p184, Dankittipakul and Deeleman-Reinhold (2013)
	Sesieutes lucens Simon 1897	p178, Dankittipakul and Deeleman-Reinhold (2013)
	Sphecotypus birmanicus (Thorell 1897)	p333, Deeleman-Reinhold (2001)
Dictynidae	*Sudesna* sp.	Pl.20.8, Murphy & Murphy (2000)
Gnaposidae	*Urozelotes rusticus* (Koch 1872)	Pl.23.8, Murphy & Murphy (2000)
Hahniidae	*Alista* sp.	Pl.20.7, Murphy & Murphy (2000)
Linyphiidae	*Plectombolus* sp.	p123, Koh & Ming (2013)
Liocranidae	*Orthobula* sp.	p203, Murphy & Murphy (2000)
	Sphingius vivax (Thorell 1897)	p494, Deeleman-Reinhold (2001)
	Sphingius superbus Dankittipakul, Tavano & Singtripop 2011	p1, Dankittipakul *et al.,* (2011)
	Sphingius bifurcatus Dankittipakul, Tavano & Singtripop 2011	p1, Dankittipakul *et al.,* (2011)
	Sphingius spinosus Dankittipakul, Tavano & Singtripop 2011	p1, Dankittipakul *et al.,* (2011)
	Teutamus apiculatus Dankittipakul, Tavano & Singtripop 2012	p1705, Dankittipakul *et al.*, (2012
	Teutamus brachiatus Dankittipakul, Tavano & Singtripop 2012	p1703, Dankittipakul *et al.*, (2012)
	Teutamus calceolatus Dankittipakul, Tavano & Singtripop 2012	p1709, Dankittipakul *et al.*, (2012)
	Teutamus deelemanae Dankittipakul, Tavano & Singtripop 2012	p1725, Dankittipakul *et al.*, (2012)
	Teutamus globularis Dankittipakul, Tavano & Singtripop 2012	p1713, Dankittipakul *et al.*, (2012)
	Teutamus leptothecus Dankittipakul, Tavano & Singtripop 2012	p1723, Dankittipakul *et al.*, (2012)
	Teutamus lioneli Dankittipakul, Tavano & Singtripop 2012	p1707, Dankittipakul *et al.*, (2012)
	Teutamus politus (Thorell 1890)	p474, Deeleman-Reinhold (2001)
	Teutamus rama Dankittipakul, Tavano & Singtripop 2012	p1699, Dankittipakul *et al.*, (2012)
	Teutamus seculatus Dankittipakul, Tavano & Singtripop 2012	p1715, Dankittipakul *et al.*, (2012)
	Teutamus serrulatus Dankittipakul, Tavano & Singtripop 2012	p1701, Dankittipakul *et al.*, (2012)

Lycosidae	*Draposa tenasserimensis* (Thorell 1895)	p48, Kronestedt (2010)
	Draposa zhanjiangensis (Yin *et al*. 1995)	p49, Kronestedt (2010)
	Hippasa holmerae Thorell 1895	Pl.18.6, Murphy & Murphy (2000)
	Pardosa apostoli Barrion & Litsinger 1995	p52, Lau *et al.*, (2012)
	Pardosa pseudoannulata (Bosenberg & Strand 1906)	p371, Yong (2004)
Miturgidae	*Cheiracanthium insulanum* (Thorell 1878)	p229, Deeleman-Reinhold (2001)
	Cheiracanthium turiae Strand 1916	p235, Deeleman-Reinhold (2001)
Mysmenidae	*Maymena* sp.	p222, Murphy & Murphy (2000)
Nephilidae	*Nephila antipodiana* (Walckenaer 1842)	p20, Yong (2009b)
	Nephila kuhli Doleschall 1857	Pl.10.8, Murphy & Murphy (2000)
Ochyroceratidae	*Althepus spiralis* Li, Li & Jager 2014	p1, Li *et al.* (2014)
Oonopidae	*Gamasomorpha camelina* Simon 1893	Pl.6.1, Murphy & Murphy (2000)
	Gamasomorpha coniacris Eichenberger 2012	p27, Eichenberger *et al*., (2012)
	Gamasomorpha insomnia Eichenberger 2012	p19, Eichenberger *et al*., (2012)
	Gamasomorpha ophiria Eichenberger 2012	p21, Eichenberger *et al*., (2012)
	Gamasomorpha petoteca Eichenberger 2012	p13, Eichenberger *et al*., (2012)
	Gamasomorpha raya Eichenberger 2012	p30, Eichenberger *et al*., (2012)
	Gamasomorpha schmilingi Eichenberger 2012	p32, Eichenberger *et al*., (2012)
	Gamasomorpha squalens Eichenberger 2012	p23, Eichenberger *et al*., (2012)
	Ischnothyreus namo Kranz-Baltensperger 2012	p43, Kranz-Baltensperger (2012)
	Ischnothyreus tekek Kranz-Baltensperger 2012	p41, Kranz-Baltensperger (2012)
	Ischnothyreus tioman Kranz-Baltensperger 2012	p39, Kranz-Baltensperger (2012)
	Triculana bilingua Eichenberger & Kranz-Baltensperger 2011	p8, Eichenberger & Kranz-Baltensperger (2011)
Oxyopidae	*Hamataliwa floreni* Deeleman-Reinhold 2009	p144, Koh & Ming (2013)
	Tapponia micans Simon 1885	p147, Koh & Ming (2013)
Pisauridae	*Dolomedes mizhoanus* Kishida 1936	p11, Norma-Rashid *et al*., (2009)
	Nilus albocinctus (Doleschall 1859)	p164, Koh & Ming (2013)
Philodromidae	*Philodromus* sp.	p499, Dzulhelmi & Norma-Rashid (2014)
Pholcidae	*Belisana ketambe* Huber 2005	p53, Huber (2005)
	Crossopriza Iyoni (Blackwall 1867)	p153, Koh & Ming (2013)
	Pholcus phalangioides (Fuesslin 1775)	p37, Barrion & Litsinger (1995)
	Smeringopus pallidus (Blackwall 1858)	p11, Norma-Rashid *et al*., (2009)
	Uthina luzonica Simon 1893	p254, Murphy & Murphy (2000)
Prodidomidae	*Molycria voc* Deeleman-Reinhold 2001	p556, Deeleman-Reinhold (2001)
Psechridae	*Fecenia ochracea* (Doleschall 1859)	Pl.21.5, Murphy & Murphy (2000)
	Fecenia protensa Thorell 1891	p1, Bayer (2011)
	Psechrus libelti Kulczynski 1908	p169, Koh & Ming (2013)
Salticidae	*Artabrus erythrocephalus* (Koch 1846)	Pl.27.3, Murphy & Murphy (2000)
	Neon sumatranus Logunov 1998	p302, Zabka & Nentwig (2000)
	Pancorius magnus Zabka 1985	Pl.28.5, Murphy & Murphy (2000)
	Saaristattus tropicus Logunov & Azarkina 2008	p114, Logunov & Azarkina (2008)
	Simaetha sp.	Pl.29.7, Murphy & Murphy (2000)
	Sobasina sylvatica Edmund & Proszynski 2001	p142, Edmunds & Proszynski (2001)
	Stagetillus opaciceps Simon 1885	Pl.27.8, Murphy & Murphy (2000)
	Telamonia dimidiata (Simon 1899)	p98, Yong (2008)
	Telamonia elegans (Thorell 1887)	Pl.27.5, Murphy & Murphy (2000)
	Thiania demissa (Thorell 1892)	p554, Jackson (1986)

	Viciria pavesii Thorell 1877	p172, Maimusa (2012)
Scytodidae	*Scytodes lugubris* (Thorell 1887)	Pl.5.3, Murphy & Murphy (2000)
	Scytodes thoracica (Latreille 1802)	P37, Barrion & Litsinger (1995)
Sparassidae	*Gnathopalystes kochi* (Simon 1899)	P235, Koh & Ming (2013)
	Heteropoda davidbowie Jager 2008	p237, Koh & Ming (2013)
	Heteropoda garciai Barrion & Litsinger 1995	p52, Lau *et al*., (2012)
	Heteropoda tetrica Thorell 1897	p240, Koh & Ming (2013)
	Olios mahabangkawitus Barrion & Litsinger 1995	p52, Lau *et al*., (2012)
	Sinopoda forcipata (Karsch 1881)	p20, Jager (1999)
Telemidae	*Telema malaysiaensis* Wang & Li 2000	p1, Wang & Li (2010)
Tetrablemmidae	*Brignoliella besutensis* Lin, Li & Jager 2012	p55, Lin *et al*., (2012)
Tetragnathidae	*Tetragnatha ceylonica* Cambridge 1869	p513, Barrion & Litsinger (1995)
	Tetragnatha javana Thorell 1804	p494, Barrion & Litsinger (1995)
	Tetragnatha nitens (Audouin 1826)	p64, Gillespie (2003)
Theraposidae	*Psednocnemis* sp.	p1, West *et al*., (2012)
Theridiidae	*Anelosimus linda* Agnarsson & Zhang 2006	p32, Agnarsson & Zhang (2006)
	Argyrodes argentatus Pickard-Cambridge 1880	p20, Yong (2009b)
	Argyrodes flavescens (Pickard-Cambridge 1880)	p20, Yong (2009b)
	Ariamnes flagellum (Doleschall 1857)	Pl.9.5, Murphy & Murphy (2000)
	Dipoenura fimbriata Simon 1909	p281, Koh & Ming (2013)
	Euryopsis sp.	p408, Murphy & Murphy (2000)
	Meotipa impatiens Deeleman-Reinhold 2009	p289, Koh & Ming (2013)
	Nesticodes rufipes (Lucas 1846)	Pl.8.5, Murphy & Murphy (2000)
	Theridula caudata Saito, 1933	Pl.9.3, Murphy & Murphy (2000)
	Theridion zebrinum Zhu 1998	p297, Koh & Ming (2013)
Theridiosomatidae	*Epeirotypus dalong* Miller, Griswold & Yin 2009	p22, Miller *et al*., (2009)
Thomisidae	*Amyciaea lineatipes* Pickard-Cambridge 1901	p40, Noraina (1999)
	Barboropactus cinerascens (Doleschall 1859)	Pl.26.6, Murphy & Murphy (2000)
	Cebrenninus rugosus Simon 1887	p306, Koh & Ming (2013)
	Diaea sp.	p434, Murphy & Murphy (2000)
	Phrynarachne ceylonica (Cambridge 1884)	Pl.25.8, Murphy & Murphy (2000)
	Platythomisus octomaculatus (Koch 1845)	p314, Koh & Ming (2013)
Zodariidae	*Cryptothele* sp.	p333, Koh & Ming (2013)
	Malayozodarion hoiseni Ono & Hashim 2008	p49, Ono & Hashim (2008)
	Mallinella gombakensis Ono & Hashim 2008	p42, Ono & Hashim (2008)
	Mallinella maruyamai Ono & Hashim 2008	p44, Ono & Hashim (2008)
	Mallinella tumidifemoris Ono & Hashim 2008	p49, Ono & Hashim (2008)
	Storena sp.	p499, Dzulhelmi & Norma-Rashid (2014)

3.3.2 LIST OF NEW SPIDER RECORDS FROM PENINSULAR MALAYSIA

In the present study, a total of 70 spider species from 14 families, 58 genera were recorded for the first time in Peninsular Malaysia. Most of the species were from the family Araneidae (22 species from 16 genera), Salticidae (15 species from 13 genera) and family Theridiidae (seven species from five genera). Family Clubionidae, Gnaposidae, Linyphiidae, Pholcidae, Sparassidae and Zodariidae were represented by a single species each.

ARANEIDAE

1. *Araneus inustus* (Koch 1871)

Material examined: 6 female (LACP003), on leaves, night, DMN & MDN, 12.02.2013, L3.

Photo/Illustrations: Pl.15, Sebastian and Peter (1999)

2. *Argiope pulchella* Thorell 1881

Material examined: 1 female (KPRP010), construct orb-web between branches, night, DMN & SSNP, 18.11.2012, L11.

Photo/Illustrations: p267, fig.152C, Song *et al.* (1999)

3. *Chorizopes bengalensis* Tikader 1975

Material examined: 1 female (FH078), on shrubs, night, DMN & SSNP, 21.10.2012, L6.

Photo/Illustrations: p270, fig.155D, Song *et al.* (1999)

4. *Chorizopes dicavus* Yin *et al.* 1990

Material examined: 1 female (FH064), on shrubs, morning, DMN & SSNP, 21.10.2012, L6; 1 F (PH014), on shrubs, morning, DMN & SSNP, 10.10.2012, L2.

Photo/Illustrations: p270, 155E, Song *et al.* (1999)

5. *Cyclosa cucurbitoria* (Yin *et al.* 1990)

Material examined: 4 female (FH005), on shrubs, sweep net, morning, DMN & SSNP, 21.10.2012, L6.

Photo/Illustrations: p277, fig.160N, Song *et al.* (1999)

6. *Cyclosa dives* Simon 1877

Material examined: 2 female (TPP177), on leaves, morning, DMN, 18.06.2012, L10.

Photo/Illustrations: p277, fig160Q, Song *et al.* (1999)

7. *Cyclosa nigra* Yin *et al.* 1990

Material examined: 1 female (LACP006), on leaves, morning, DMN & MDN, 12.02.2013, L3; 1 F (FH073), on shrubs, night, DMN & SSNP, 21.10.2012, L6.

Photo/Illustrations: p278, fig.161H, Song *et al.* (1999)

8. *Cyrtarachne keralensis* Jose 2011

Material examined: 1 female (TPP085), on leaves, morning, DMN, 18.06.2012. L10

Photo/Illustrations: p324, Jose (2011)

9. *Cyrtophora cylindroides* (Walckenaer 1841)

Material examined: 1 female (PNP105), on shrubs, by sweep-net, morning, DMN & SSNP, 08.10.2012, L1.

Photo/Illustrations: p67, Koh and Ming (2013)

10. *Deione* sp.

Material examined: 1 female (PH241), on shrubs, by sweep-net, morning, DMN & SSNP, 10.10.2012, L2.

Photo/Illustrations: p90, Murphy and Murphy (2000)

11. *Eriovixia pseudocentrodes* (Bosenberg & Strand 1906)

Material examined: 2 female (RIBG047), on shrubs, night, DMN & SSNP, 25.02.2012, L8.

Photo/Illustrations: p71, Koh and Ming (2013)

12. *Gasteracantha clavigera* Giebel 1863

Material examined: 1 female (UG002), on leaves, night, DMN & SSNP, 25.02.2012, L9.

Photo/Illustrations: p73, Koh and Ming (2013)

13. *Heurodes porculus* (Simon 1877)

Material examined: 1 female (UG008), on shrubs, night, DMN & SSNP 14.03.2013, L9.

Photo/Illustrations: Pl.12.6, Murphy and Murphy (2000)

14. *Larinia phthisica* (Koch 1871)

Material examined: 1 female (RIBG247), construct orb-web between shrubs, night, DMN & SSNP, 25.02.2012, L8.

Photo/Illustrations: Pl.XIV.S78, Barrion and Litsinger (1995)

15. *Lipocrea fusiformis* (Thorell 1877)

Material examined: 2 female (LACP230), on shrubs, night, DMN & MDN, 14.02.2013, L3.

Photo/Illustrations: p79, Koh and Ming (2013)

16. *Mangora foliosa* Zhu & Yin 1997

Material examined: 1 female (UG149), on shrubs, by sweep-net, night, DMN & SSNP, 14.03.2013, L9.

Photo/Illustrations: p298, fig.174A, Song *et al.* (1999)

17. *Neoscona bengalensis* Tikader & Bal 1981

Material examined: 1 female (LACP124), construct orb-web between shrubs, night, DMN & MDN, 14.02.2013, L3.

Photo/Illustrations: Pl.13.7, Murphy and Murphy (2000)

18. *Neoscona punctigera* (Doleschall 1857)

Material examined: 2 female (FH117), construct orb-web between branches, night, 22.10.2012, L6.

Photo/Illustrations: p129, Murphy and Murphy (2000)

19. *Neoscona rumpfi* (Thorell 1887)

Material examined: 1 female (MRP064), construct orb-web between shrubs, night, DMN & MDN, 23.02.2013, L4.

Photo/Illustrations: p630, Barrion and Litsinger (1995)

20. *Neoscona theisi* Walckenaer 1841

Material examined: 5 female (LAC009), construct orb-web between shrubs, night, DMN & MDN, 14.02.2013, L3.

Photo/Illustrations: Pl.XV.S83, Barrion and Litsinger (1995)

21. *Pasilobus* sp.

Material examined: 1 female (RIBG470), on shrubs, daylight, DMN & SSNP, 14.02.2013, L3.

Photo/Illustrations: p124, Murphy and Murphy (2000)

22. *Singa perpolita* (Thorell 1892)

Material examined: 1 female (MRP255), on shrubs, night, DMN & MDN, 23.02.2013, L4.

Photo/Illustrations: p87, Koh and Ming (2013)

CLUBIONIDAE

23. *Clubiona krisisensis* Barrion & Litsinger 1995

Material examined: 2 female (FH070), on shrubs, by sweep-net, night, DMN & SSNP, 22.10.2012, L6; 1F (PH025), on shrubs, by sweep-net, morning, L2.

Photo/Illustrations: Pl.1.1, Deeleman-Reinhold (2001)

CORINNIDAE

24. *Aetius decollatus* O.P.-Cambridge 1896

Material examined: 1 female (PNP449), under rock, morning, DMN & SSNP, 20.12.2012, L8.

Photo/Illustrations: p335, Deeleman-Reinhold (2001)

25. *Apochinomma nitidum* (Thorell 1895)

Material examined: 1 male (MRP385), on leaves, night, DMN, 10.12.2013, L4.

Photo/Illustrations: p328, Deelemen-Reinhold (2001)

26. *Castianeira zetes* (Simon 1897)

Material examined: 1 female (KS289), on leaves, night, DMN & SSNP, 20.03.2013, L7.

Photo/Illustrations: P.47, Sebastian and Peter (2009)

27. *Medmassa insignis* Thorell 1890

Material examined: 1 female (UG134), on tree bark, night, DMN & TGG, 13.11.2012, L9.

Photo/Illustrations: p101, Koh and Ming (2013)

GNAPOSIDAE

28. *Hitobia yaginumai* Deeleman-Reinhold 2001

Material examined: 1 female (UG146), on shrubs, by sweep-net, night, DMN & SSNP, 20.03.2013, L9.

Photo/Illustrations: p512, Deeleman-Reinhold (2001)

LINYPHIIDAE

29. *Linyphia* sp.

Material examined: 1 female (UG159), under leaves, by sweep-net, night, DMN & TGG, 13.11.2012, L9.

Photo/Illustrations: Pl.58, Sebastian and Peter (1999)

OXYOPIDAE

30. *Hamadruas superba* (Thorell 1887)

Material examined: 1 female (TPP093), on leaves, morning, DMN, 12.09.2012, L10; 1F

(UG283), on leaves, night, DMN & TGG, 13.11.2012, L9.

Photo/Illustrations: p694, Deeleman-Reinhold (2009)

31. *Hamataliwa incompta* (Thorell 1895)

Material examined: 1 female (RIBG205), on shrubs, morning, DMN & SSNP, 20.12.2012, L8.

Photo/Illustrations: p145, Koh and Ming (2013)

PHOLCIDAE

32. *Pholcus gracillimus* Thorell 1890

Material examined: 1 male (PNP115), under leaves, by sweep-net, morning, DMN & SSNP, 08.10.2012, L1.

Photo/Illustrations: p250, Murphy and Murphy (2000)

SALTICIDAE

33. *Burmattus pococki* (Thorell 1895)

Material examined: 1 female (PNP101), under leaves, morning, DMN & SSNP, 08.10.2012, L1.

Photo/Illustrations: p177, Koh and Ming (2013)

34. *Cytaea oreophila* Simon 1902

Material examined: 1 female (TPP042), on leaves, morning, DMN, 12.09.2012, L10.

Photo/Illustrations: Pl.29.4, Murphy and Murphy (2000)

35. *Chrysilla lauta* Thorell 1887

Material examined: 1 female (LACP023), on leaves, morning, DMN & MDN, 12.02.2013, L3.

Photo/Illustrations: p103, Koh (1989)

36. *Epocilla calcarata* (Karsch 1880)

Material examined: 1 female (TPP109), on leaves, morning, DMN, 12.09.2012, L10.

Photo/Illustrations: p188, Koh and Ming (2013)

37. *Menemerus bivittatus* (Dufour 1831)

Material examined: 1 female (TPP150), on shrubs, morning, DMN, 12.09.2012, L10.

Photo/Illustrations: p110, Koh (1989)

38. *Myrmarachne plataleoides* (Cambridge 1869)

Material examined: 1 female (UG214) on shrubs, sweep net, morning, DMN & TGG, 13.11.2012, L9.

Photo/Illustrations: p132, Koh (1989)

39. *Pancorius thorelli* (Simon 1899)

Material examined: 1 female (TPP022), on leaves, morning, DMN, 10.09.2012, L10.

Photo/Illustrations: Pl.28.4, Murphy and Murphy (2000)

40. *Parabathippus macilentus* Thorell 1890

Material examined: 1 female (UG156), on shrubs, morning, DMN & SSNP 14.03.2013, L9.

Photo/Illustrations: p296, Murphy and Murphy (2000)

41. *Parabathippus petrae* (Proszynski and Deeleman-Reinhold 2012)

Material examined: 1 female (RIBG006), on shrubs, morning, DMN & SSNP, 25.12.2012, L8; 1 female (UG145), on shrubs, by sweep-net, morning, 13.11.2012, L9.

Photo/Illustrations: p208, Koh and Ming (2013)

42. *Plexippus petersi* (Karsch 1878)

Material examined: 1 female (MRP012), on shrubs, morning, DMN & MDN, 23.02.2013, L4.

Photo/Illustrations: p114, Koh (1989)

43. *Phintella bifurcilinea* (Bosenberg and Strand 1906)

Material examined: 1 female (RIBG019), on shrubs, morning, DMN & SSNP, 25.12.2012, L8.

Photo/Illustrations: p210, Koh and Ming (2013)

44. *Phintella debilis* (Thorell 1891)

Material examined: 1 female (RIBG201), on shrubs, morning, DMN & SSNP, 25.12.2012, L8.

Photo/Illustrations: p211, Koh and Ming (2013)

45. *Ptocasius montiformis* Song 1991

Material examined: 1 female (PNP110), on leaves, morning, DMN & SSNP, 08.10.2012, L1; 1 female (PH003), on leaves, by sweep-net, DMN & SSNP, morning, 10.10.2012, L2.

Photo/Illustrations: p557, 313T, Song *et al*. (1999)

46. *Uroballus peckhami* Zabka, 1985

Material examined: 1 female (UG143) on shrubs, morning, DMN & TGG, 13.11.2012, L9.

Photo/Illustrations: Koomen (unpublished)

47. *Viciria praemandibularis* (Hasselt 1893)

Material examined: 1 female (RIBG195) on shrubs, sweep net, morning, DMN & TGG, 11.11.2012, L9.

Photo/Illustrations: p230, Koh and Ming (2013)

SPARASSIDAE

48. *Heteropoda venatoria* (Linnaeus 1767)

Material examined: 1 female (UG204), on shrubs, night, DMN, & SSNP, 13.11.2012, L9.

Photo/Illustrations: p241, Koh and Ming (2013)

TETRAGNATHIDAE

49. *Mesida yini* Zhu, Song & Zhang 2003

Material examined: 3 female (TPP034), make web on shrubs, night, DMN & SSNP, 10.09.2012, L10.

Photo/Illustrations: p22, Jager and Proxaysombath (2011)

50. *Tetragnatha lauta* Yaginuma 1959

Material examined: 2 female (FH002), morning, grasses by lake side, DMN, 25.09.2012, L6.

Photo/Illustrations: p227, 127R, Song et al. (1999)

51. *Tetragnatha pinicola* Koch 1870

Material examined: 3 female (KS049), night, between tree branches, DMN & SSNP, 20.03.2013, L7.

Photo/Illustrations: p228, 128I, Song *et al.* (1999)

52. *Tetragnatha praedonia* Koch 1878

Material examined: 1 female (FH031), night, between tree branches, SSNP, 25.09.2012, L6.

Photo/Illustrations: p228, 128P, Song et al. (1999)

53. *Tylorida tianlin* Zhu, Song & Zhang

Material examined: 1 female (FH034), night, at hill slopes, SSNP, 25.09.2012, L6.

Photo/Illustrations: p9401, China Animal Group (2010)

THERIDIIDAE

54. *Chrysso argyrodiformis* (Yaginuma 1952)

Material examined: 2 female (FH074), on shrubs, night, by sweep-net, DMN & SSNP, 22.10.2012, L6.

Photo/Illustrations: Pl.147, Sebastian and Peter (2009)

55. *Chrysso octomaculata* (Bosenberg & Strand 1906)

Material examined: 2 female (RIBG188), under leaves, morning, by sweep-net, DMN & SSNP, 25.12.2012. L8.

Photo/Illustrations: p426, Barrion and Litsinger (1995)

56. *Latrodectus geometricus* Koch 1841

Material examined: 1 female (KPRP187), on shrubs, by sweep net, night, DMN & SSNP, 18.11.2012, L11.

Photo/Illustrations: p288, Koh and Ming (2013)

57. *Parasteatoda celsabdomina* (Zhu 1998)

Material examined: 4 female (KPRP187), on shrubs, night, by sweep-net, 18.11.2012, L11; 1 female (PNP102), on shrubs, by sweep-net, morning, 08.10.2012, L1.

Photo/Illustrations: p18, Jager and Proxaysombath (2011)

58. *Parasteatoda tapidariorum* (Koch 1841)

Material examined: 3 female (KPRP189), on shrubs, by sweep net, night, DMN & SSNP, 18.11.2012, L11.

Photo/Illustrations: p94, Howell and Jenkins (2004)

59. *Rhomphaea labiata* (Zhu & Song 1991)

Material examined: 1 female (KS288), under leaves, by sweep-net, night, DMN & SSNP, 20.03.2013, L7.

Photo/Illustrations: p295, Koh and Ming (2013)

60. *Theridion tubicola* Doleschall 1859

Material examined: 1 female (PNP103), on shrubs, by sweep-net, morning, DMN & SSNP, 09.10.2012, L1.

Photo/Illustrations: p398, Murphy and Murphy (2000)

THOMISIDAE

61. *Mastira bipunctata* Thorell 1891

Material examined: 1 female (RIBG193), on leaves, morning, DMN & SSNP, 25.12.2012, L8.

Photo/Illustrations: p310, Koh and Ming (2013)

62. *Massuria angulata* Thorell 1887

Material examined: 1 female (PH024), on shrubs, sweep net, morning, DMN & SSNP, 10.10.2012, L2.

Photo/Illustrations: p309, Koh and Ming (2013)

63. *Runcinia albostriata* Boesenberg & Strand 1906

Material examined: 1 female (LACP001), on shrubs, night, DMN & MDN, 12.02.2013, L3.

Photo/Illustrations: Pl.1.S6, Barrion and Litsinger (1995)

64. *Synema globosum* (Fabricius 1775)

Material examined: 1 female (PH028), on shrubs, by sweep-net, morning, DMN, 11.10.2012, L2; 1 female (PH028), on shrubs, by sweep-net, morning, DMN & SSNP, 10.10.2012, L2.

Photo/Illustrations: p499, 282J, Song *et al.* (1999)

65. *Tmarus orientalis* Schenkel 1963

Material examined: 1 female (UG282), on shrubs, night, DMN & SSNP 17.03.2013, L9.

Photo/Illustrations: p515, fig.283J, Song *et al.* (1999)

66. *Thomisus guangxicus* Song and Zhu 1995

Material examined: 1 male (CH003), on shrubs, morning, DMN, 27.01.2013, L5.

Photo/Illustrations: p499, 282F, Song *et al.* (1999)

67. *Xysticus nyingchiensis* Song & Zhu 1995

Material examined: 1 female (KS283), on shrubs, night, DMN & SSNP, 20.03.2013, L7.

Photo/Illustrations: P518, fig.286H, Song *et al.* (1999)

ULOBORIDAE

68. *Miagrammopes oblongus* Yoshida 1982

Material examined: 1 female (PNP119), on shrubs, by sweep-net, morning, DMN & SSNP, 08.10.2012, L1.

Photo/Illustrations: p326, Koh and Ming (2013)

69. *Uloborus plumipes* Lucas 1846

Material examined: 1 female (RIBG244), on leaves, morning, DMN & SSNP, 25.12.2012, L8.

Photo/Illustrations: p329, Koh and Ming (2013)

ZODARIIDAE

70. *Asceua gruezoi* Barrion & Litsinger 1992

Material examined: 1 male (TPP248), on tree bark, night, DMN, 11.09.2012, L10.

Photo/Illustrations: p308, Barrion and Litsinger (1995)

3.4 DISCUSSIONS

In the present study, a total of 70 spider species from 14 families, 58 genera were first time recorded from the west coast of Peninsular Malaysia. Additionally, 149 species from 33 families and 95 genera were compiled from available literatures. An estimated 66% increment for spider diversity recorded in this paper contributed to a much wider views for the spider diversity, and this should enhance others to explore and discover more of the spider fauna which still remain mysterious till today. The additional recorded species still does not reveal the accurate number of spider species occurred for this country since most of the newly recorded spider fauna from this study are likewise to be found in other Southeast Asian countries. Thus, it should be expected that many more species found in the neighboring countries might yet to be found in this country due to the same climate, topographies and habitat types. Therefore, it should also be expected that more spider species could be discovered for countries that have more tropical rainforests coverage with greater habitat variability and bigger land mass.

Documenting the spider fauna and providing the localities is very important especially when the species are specialize to certain microhabitats (Sial & Chaudhry, 2012) and very cryptic (e.g. *Cyphalonotus selangor*). Deeleman-Reinhold (2001) mentioned that nearly 80% of the spider species in this tropical region are still not described. The current constraint to determine the actual proportion of spider fauna for Malaysia is a very challenging task due to very limited spider studies in this country. There are many other unidentified spider specimens in our collection that demonstrates a crucial need for extensive collaboration from local and foreign arachnologists determining and describing many other undescribed species. Besides that, taxonomic revisions has transferred many species to different groups, and introducing new genera. This had led to many synonymous names erected for some particular genus and species when it is actually referring to the same spider (see World Spider Catalog, 2016). On the other hand, some type material species with descriptions were destroyed or lost during previous wars (Benjamin, 2001), or not formally stored for future references making it difficult to clarify the presence of the mentioned species within the region. As difficulties arises particularly during identification of spiders at species level, it is suggested that future work must provide live specimen photographs beside each illustration of genitalia for every species to avoid confusion. Additionally, taxonomic problems should be resolved (Sial & Chaudhry, 2012) and supported by phylogenetic work. In this way, inaccuracy of species identification, groupings could be tackled in the near future.

CHAPTER 4

SYSTEMATICS OF TETRAGNATHID SPIDERS IN MALAYSIA

4.1 INTRODUCTION

The long-jawed orb-weaver spiders belong to the family Tetragnathidae which contain at least 47 genera and 967 species worldwide (World Spider Catalog, 2016). There are three known subfamilies; they are Leucauginae Caporiacco 1955, Metinae Simon, 1894 and Tetragnathinae Menge 1866. The genus *Tetragnatha* Latreille, 1804 is the type genus of this family. The members of this family (Tetragnathidae) are very diverse in morphological and behavioural characteristics. Many of these characters are synapomorphic to the family Araneidae and Nephilidae (Griswold *et al*., 1998). The tetragnathid spiders differ from other families in their male pedipalps that have only one tegular apophysis, in anatomy of their spinneret spigots and also in their web building behaviours (Levi, 1986; Hormiga *et al*., 1995). Tetragnathids belong to the ecribellate families that have eight and three tarsal claws. The body sizes of these species range from small to large (2-23 mm). Their morphological features vary significantly within family and there are many species that do not exhibit the main tetragnathid morphological characters. Most male tetragnathids have observable large chelicerae which are usually armoured with numerous teeth and specialized cheliceral apophysis (Eberhard & Huber, 1998). The embolus and conductor are closely associated in the male palps. There are also conspicuous trichobothria on the fourth leg femurs and the lateral eyes are juxtaposed. While the majority of females in the tetragnathid genera have entelegyne genitalia, there is an exception for the subfamily

Tetragnathinae in which its members have secondary haplogyne (Alvarez-Padilla, 2008 and references therein).

Currently, there are six tetragnathid species from six genera in the state of Sarawak (Koh *et al*., 2013), 29 species from five genera in Malaysian peninsular (Norma-Rashid & Li, 2009; Dzulhelmi *et al*., 2014a) and four species from two genera in the state of Sabah (Dzulhelmi *et al*., 2014b). In comparison with the number of species recorded in the South East Asian countries such as Philippines (Barrion & Litsinger, 1995), Singapore (Koh, 1989; Song *et al*., 2002), Laos (Jager, 2007; Jager & Praxaysombath, 2009; Jager & Praxaysombath, 2011, Jager *et al*., 2012) and Brunei (Koh & Ming, 2013), there are still many tetragnathid species that had not been recorded in this country. Moreover, most countries in South East Asia including Malaysia have only provided lists of species names without taxonomic descriptions, keys to species and illustrations. This study aims to document the presence and distribution of tetragnathid species in selected localities in Malaysia. Taxonomic descriptions, diagnostic features for identification and dichotomous keys based on the collected tetragnathid species are also constructed.

4.2 MATERIALS AND METHODS

4.2.1 STUDY SITES

Sampling was conducted in 10 selected locations throughout Malaysia, which consisted of four localities in Peninsular, three in Sarawak and three in Sabah (Figure 4.1). These selected localities were chosen based on accessibility and facilities. As tetragnathid species were known to occur at various habitats, specimens were collected from different habitat types and gardens that represented (1) montane oak forest (2) mangrove forest (3) dipterocarp forest (4) heath forest (5) peat swamp forest (6) hill forest (7) secondary forest (8) long grasses and (9) forest fringe (Table 4.1).

Fraser Hill Forest Reserve (3^{o}43’7”N, 101^{o}44’25”E) is situated about 104 km from Kuala Lumpur, and is located in Raub, Pahang. This hill resort has an average altitude of 1200 meters a.s.l., with the highest point rises at 1500 meters. The temperatures usually range between 22-28^{o}C during the day and 16-20^{o}C at night. This hill resort comprises of forest reserve covered with hills and montane forests. The sampling survey was conducted at the the hill forests in the Pine Tree Hill, Abu Suradi and Hemmant Trail.

Kuala Selangor Nature Park (3^{o}20’16”N, 101^{o}14’56”E) is situated approximately 60 km north of Kuala Lumpur in Kuala Selangor, Selangor. The park covers an estimation of 324 hectare of land comprising the coastal mangroves, secondary forests, a brackish water lake and coastal mudflats. This park plays an important role for coastal and riverine mangroves conservation. The sampling survey was conducted on the main trail, along the secondary forest covered with strangling figs, mangrove ferns (*Acrostichum aureum*) and sea almond trees (*Terminalia cattapa*) (Harinder & Nagarajan 2010).

Ulu Gombak Field Studies Centre (3^{o}22’60’N, 101^{o}47’20”E) is located 30 km from Kuala Lumpur. This forest reserve covers an area of 120 hectares of primary and secondary forests, and is surrounded by villages. The altitude ranges between 100 and 800 meters, with annual temperature of 26-27^{o}C. The sampling survey was conducted at the secondary forest within the vicinity of the reserve.

The forest fringe (2^{o}55'47"N, 101^{o}46'44" E) stretches along the outer part of UKM Permanent Forest Reserve within the main campus of Universiti Kebangsaan Malaysia (UKM) in Bangi, Selangor. The forest reserve itself covers about 138 hectares of a recovering logged forest which is inclusive of ecological research area to safeguard and prevent further development of this green area (Salleh 1999). This fragmented forest harbors great value for research, recreation, education and conservation purposes. The sampling survey was conducted on shrubs and ferns along the outer part of UKM Permanent Forest Reserve.

Gunung Gading National Park (1^{o}41'27"N, 109^{o}50'45"E) is situated in the Lundu district, Sarawak. This park covers a total of 4196 hectares. The primary purpose of this park gazette was to provide a conservation zone for the protection of the biggest flower, Rafflesia (Sarawak Forestry 2006). The sampling survey was conducted in the dipterocarp forest along Gunung Gading Summit Trail.

Kubah National Park (1^{o}36'41"N, 110^{o}11'44"E) is located 22 km from Kuching city, in Sarawak. The park covers an area of 2230 ha surrounded by villages and small agricultural farm settings. There are five main vegetation types within the park which are inclusive of alluvial forests, mixed dipterocarp forests, heath forests, sub-montane forests and secondary forests (Hazebroek & Abang-Morshidi 2000). Sampling survey was conducted in the heath forest along the Main Trail.

Bako National Park (1^{o}41'08"N, 110^{o}26'10"E) is located about 40 km off northeast of Kuching city, Sarawak. This park covers an approximate of 2727 hectares of forests. This park provides one of the most threatened primates, the Proboscis monkey (*Nasalis* *larvatus*). Therefore, it becomes one of the most visited national parks in Sarawak. Major forest types within this park include beach forests, mangrove forests, peat swamp forests, heath forests, mixed dipterocarp forests, cliff vegetation and grassland vegetation (Hazebroek & Abang-Morshidi 2000). The sampling survey was conducted at Ulu Assam trail in the peat swamp forest.

Crocker Range National Park Headquarters (5°58’05”N, 116°08’02”E) is situated 15 km from Keningau city, in Sabah. This park is located at highland of 850 to 1000 meters, with temperature range between 18°C and 26°C (Anonymous 2016). The major forests type covers are lowland, hill and montane forest. The sampling survey was conducted at long grasses near the Crocker Nature Center.

Mesilau National Park (6°02’05”N, 116°54’01”E) is located at the southeast corner of the Mount Kinabalu at an altitude of 1950 meters, at Ranau, Sabah. The park is situated within the boundaries of the UNESCO World Heritage Site of Kinabalu National Park. This park is reported to be 17°C during the day and drops to 10°C at night. The forest type is covered mainly of oak and chestnut forests with large conifers (Anonymous 2012). The sampling survey was conducted along the Kogonon Trail.

Poring Hot spring Nature Reserve (6°02’35”N, 116°42’07”E) is located amidst the foothill of Mount Kinabalu near Ranau, Sabah. It is one of the nature reserves for tourism industry which offers accommodation such as chalets and hostels, butterfly center, orchid conservation center, tropical garden with an animal rehabilitation farm, hot pools and canopy walkways. The sampling survey was conducted along the main trail in the undergrowth shrubs of the lowland dipterocarp forest.

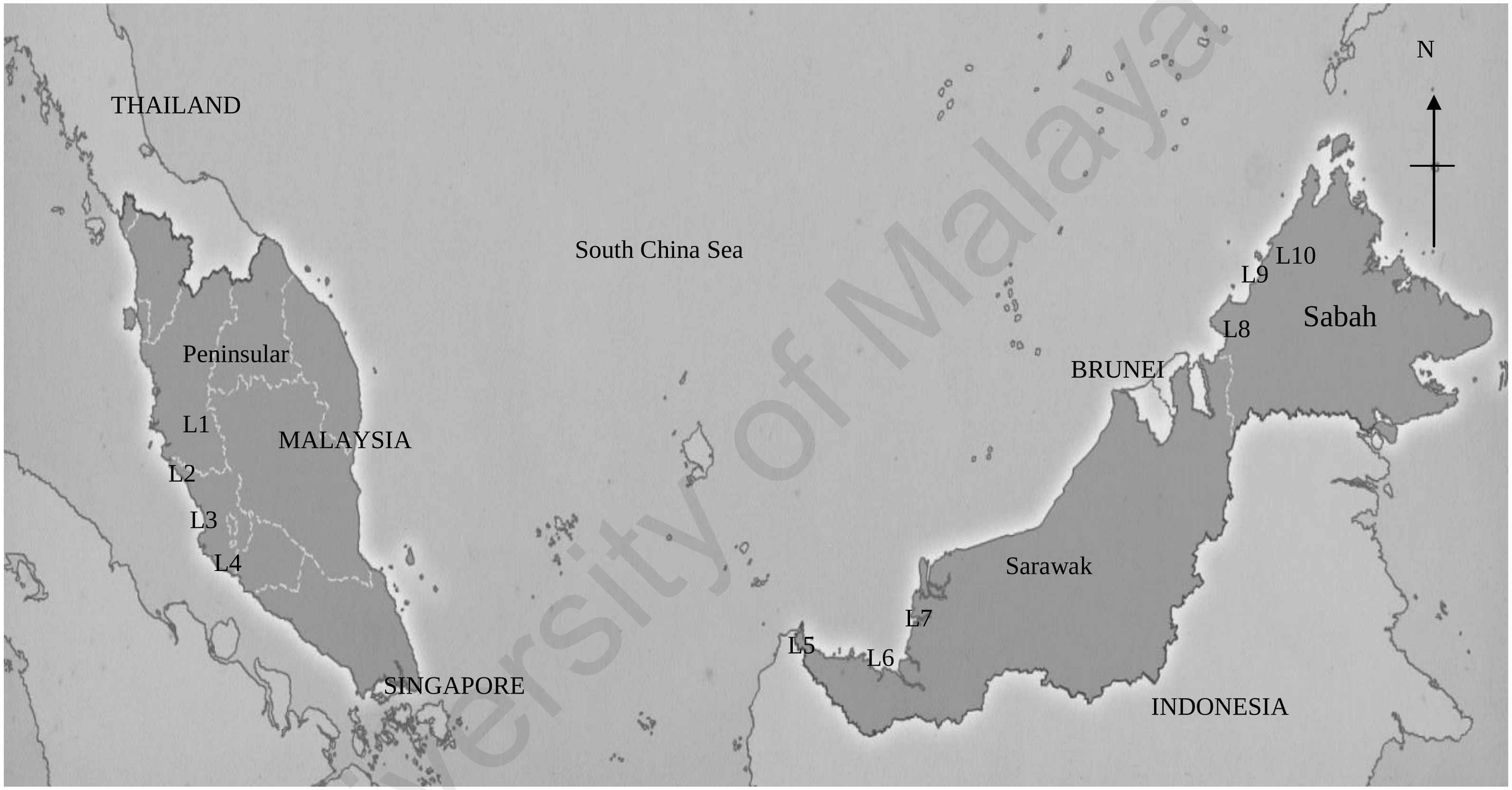

Figure 4.1: Map of Malaysia. Sampling sites were indicated by the abbreviated letters.

Table 4.1: Sampling locations in Malaysia where tetragnathid spiders were collected.

Code	Localities	Habitat types	Date
L1	Fraser Hill Forest Reserve, Raub	Hill forest (1200m a.s.l)	23-27 September 2012
L2	Kuala Selangor Nature Park, Kuala Selangor	Mangrove forest	18-21 March 2013
L3	Ulu Gombak Field Studies Centre, Gombak	Secondary forest	14-17 March 2013
L4	UKM Permanent Forest Reserve, Bangi	Forest fringe	10-12 September 2012
L5	Gunung Gading National Park, Lundu	Dipterocarp forest	21-23 April 2013
L6	Kubah National Park, Matang	Heath forest	17-19 April 2013
L7	Bako National Park, Muara Tebas	Peat swamp forest	25-27 April 2013
L8	Crocker Range National Park Headquarters, Keningau	Long grasses (1000m a.s.l)	25-27 May 2013
L9	Mesilau National Park, Ranau	Montane oak forest (1950m a.s.l)	16-18 May 2013
L10	Poring Hot Spring Nature Reserve, Ranau,	Lowland dipterocarp forest	19-21 May 2013

4.2.2 SAMPLING

Tetragnathids species that build orb-webs were sampled manually during the day (1000-1400 hours) and at night (2000-0000 hours) between September 2012 and May 2013 for three consecutive days at each selected location. All specimens were stored in labeled vials containing 75% ethanol and brought back to the laboratory for species identification.

4.2.3 PROCESSING SPECIMENS

Each of the collected tetragnathid specimens was sorted according to morpho-species, photographed and measured. The morphological traits examined including the total length, carapace length, carapace width, abdomen length and leg I-II-III-IV were measured in millimeters (mm) using the Dinolite software. Selected representative of each species was illustrated under a microscope (Nikon SMZ-U, Japan).

For female specimens, the genitalia were dissected and cleared in Potassium Hydroxide (KOH) for illustration purposes. Meanwhile, the male specimens were processed according to the standard ethanol dehydration and acetone fixation procedure for scanning electron microscopy. The specimens were first pre-soaked in 2% aqueous Osmium Oxide (OsO_4) and left overnight at 4^oC. In the following day, the specimens were rinsed twice with distilled water (ddH_2O) for 15 minutes.

As the specimens had been stored in 70% ethanol, the dehydration steps were started by soaking the specimens for 15 minutes at 75% concentration, followed by 85% and 95%. At 100% ethanol concentration, the soaking was repeated twice. After the dehydration steps were completed, the specimens were fixed by soaking in mixtures of ethanol (EtOH) and acetone (C_3H_6O) at 3:1, 1:1 and 1:3 ratios for 15 minutes in each concentration. The processes were followed by soaking the specimens in absolute C_3H_6O for 1 hour, with 3 times changing in every 20 minutes interval. Then, the specimens were sent for critical point drying and left overnight in vacuum desiccators. Prepared specimens were mounted on a stub and sputter-coated with gold palladium (AuPd) before viewing under scanning electron microscope (Hitachi TM-1000, Japan).

4.2.4 SPECIES IDENTIFICATION

Each collected tetragnathid species was described and diagnosed using the anatomy features based on the closest species (Figure 4.3). Morphological characters being described have included the following features: (1) carapace (2) eyes (3) chelicerae (4) abdomen (5) legs (6) spinnerets and (7) genitalia. Comparison on fourteen selected morphological characters from the collected tetragnathid species were also used to plot data matrix. In addition, the dichotomous keys for female spiders were constructed down to the species level for each genus, using the most distinctive morphological characters that were observable under a 50x dissecting microscope (AmScope, USA). Species identification was performed according to the morphology descriptions of *Leucauge* and *Opadometa* (Yoshida, 2009; Dzulhelmi *et al*., 2015), *Mesida* (Jager & Praxaxsombath, 2011), *Tylorida* (Tanikawa, 2004; Jager & Praxaysombath, 2009; Kulkarni, 2014) and *Tetragnatha* (Okuma, 1987; Okuma, 1988) and were supported by additional references (Barrion & Litsinger, 1995; Song *et al*., 1999; Murphy & Murphy, 2000; Lau *et al*., 2011; Koh & Ming, 2013; Dzulhelmi & Suriyanti, 2015).

The terminologies of the chelicerae of female *Tetragnatha* species were numbered from the distal end as U1-U*n* on the promargin and L1-L*n* on the retromargin (Gillespie,

1991) (Figure 4.2). For the males, the cheliceral armatures of *Tetragnatha* species were adopted from Okuma (1987) and Gillespie (1991) as follows:

a : An apophysis, used for locking the female’s fang during courtship

Gu : Guide tooth of upper row, a small distal tubercle on the promargin

G1 : Guide tooth of lower row, the first major tooth on retromargin

T : The second largest tooth on the promargin

rsu : The upper row of small teeth, the remaining proximal teeth on the promargin

s1 : A tooth which usually slopes towards the base of the segment in the male of some species, the first major tooth on the promargin

AX1 : An auxiliary guide tooth of lower row, present in some species, a small distal tubercle on the retromargin

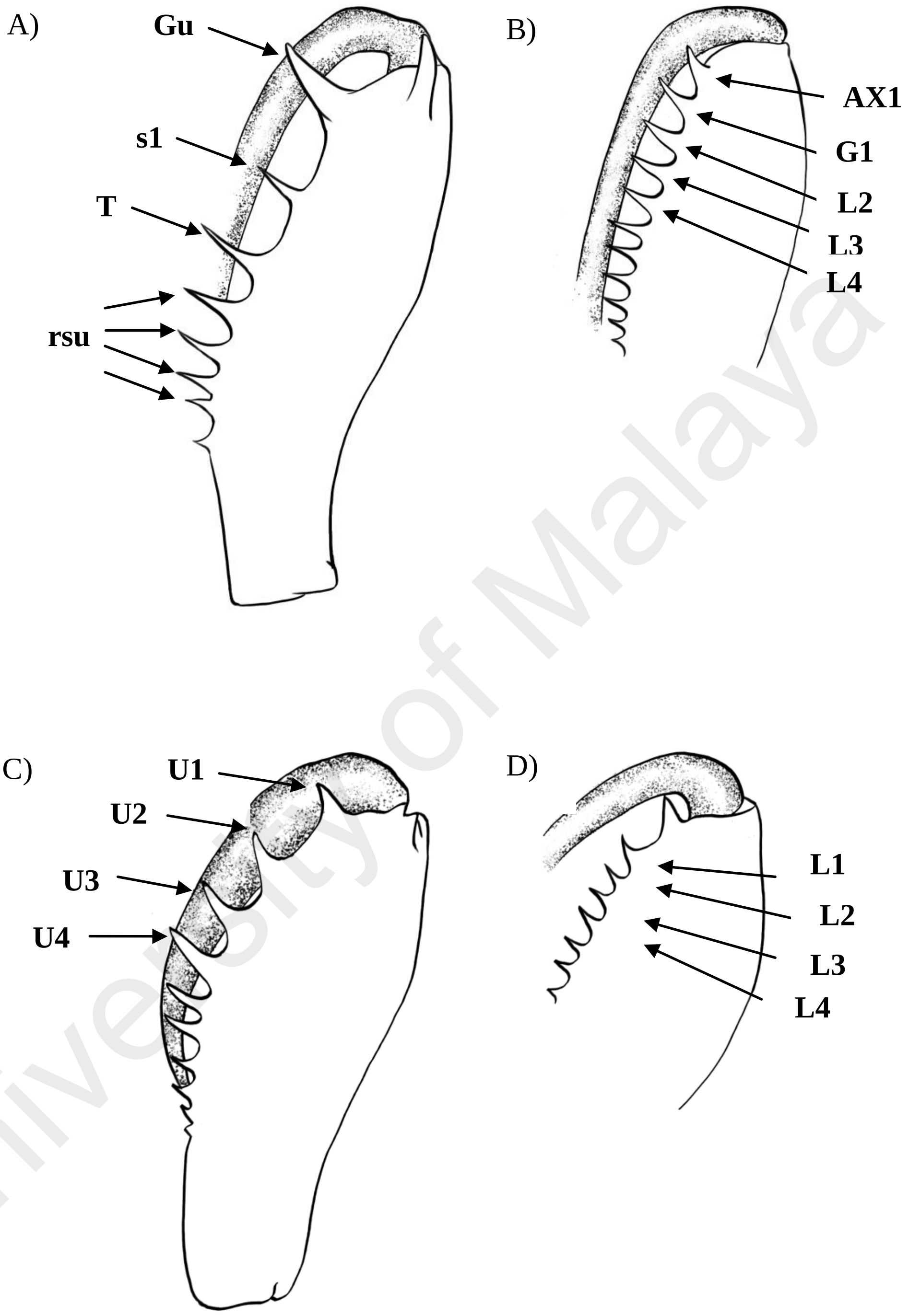

Figure 4.2: Terminologies for cheliceral armatures of *Tetragnatha* species. Male: (A) Promargin of right chelicerae (B) Retromargin of left chelicerae; Female: (C) Promargin of right chelicerae (D) Retromargin of left chelicerae.

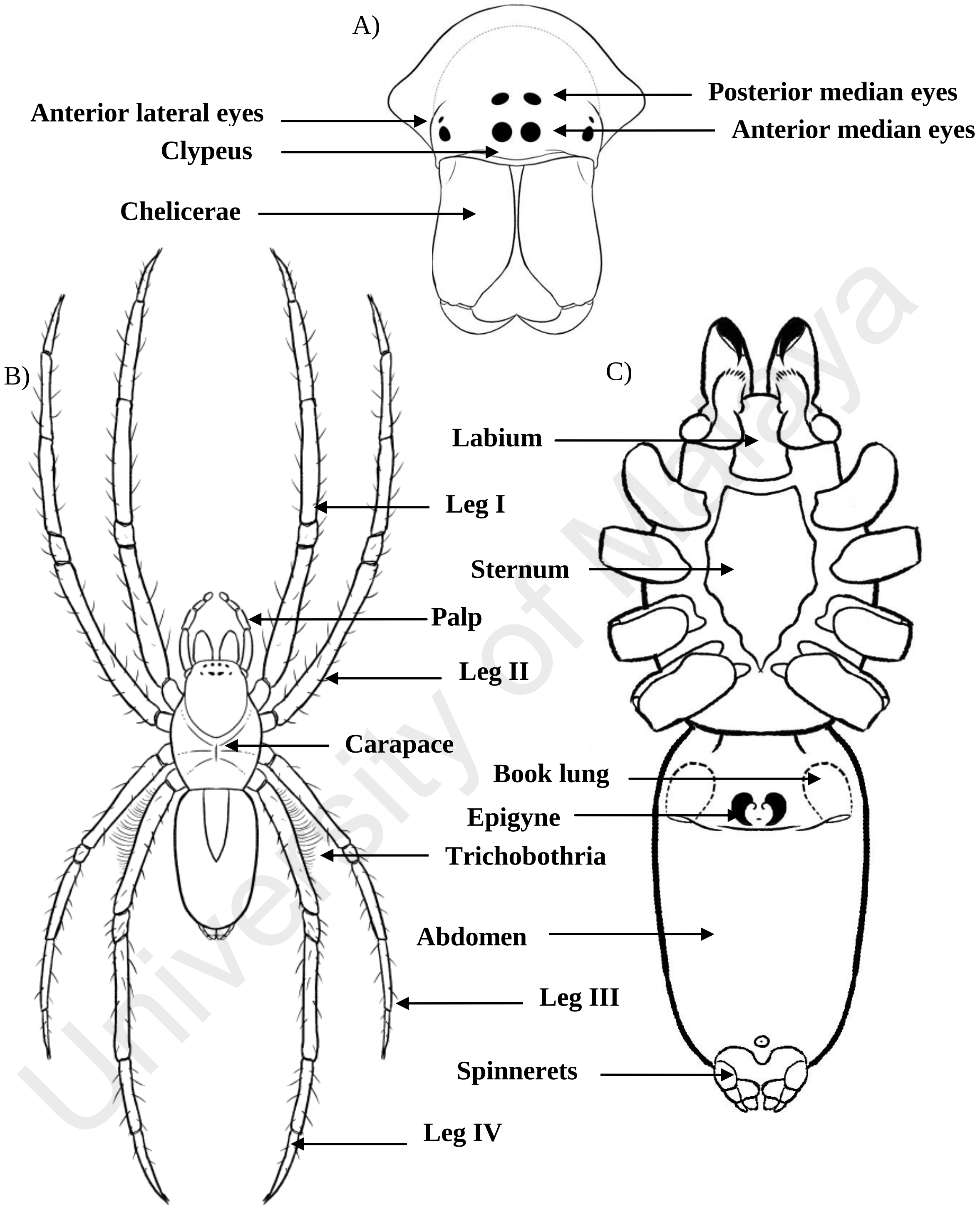

Figure 4.3: General external anatomy of spider. (A) Face, frontal view (B) Body, dorsal view (C) Body, ventral view.

4.3 RESULTS

4.3.1 DISTRIBUTION OF TETRAGNATHID SPECIES IN MALAYSIA

Out of 34 tetragnathid species from seven genera that are known in this country, a total of 18 tetragnathid species from five genera of tetragnathid spiders that construct orb-web were collected (Table 4.2). This included 15 recognized species with three newly described species from Sarawak (Table 4.3). From the reported total number of species recorded, only 44.12% of tetragnathid species were collected. From the current study, a total of 190 individuals that were sampled included 17 males (8.95%) and 173 females (91.05%), with a total of 115 adults (60.52%) and 75 sub-adults (39.75%). The most common species collected in descending order were, *Mesida gemmea* with 31 individuals (16.31%), *Leucauge argentina* with 27 individuals (14.21%), *L. celebesiana* with 27 individuals (14.21%) and *T. ventralis* with 26 individuals (13.68%) while other tetragnathid species collected were less than 20 individuals (10.52%). In addition, *Leucauge tessellata*, *Opadometa sarawakensis*, *Tetragnatha hasselti* and *T. lauta* were collected with less than three individuals (1.58%) respectively.

From 10 selected localities, Fraser Hill Forest Reserve, Kubah National Park, Poring Hot Spring Nature Reserve and Crocker Range National Park recorded at least five tetragnathid species found within the sites. Fraser Hill Forest Reserve recorded four out of five *Tetragnatha* species, while the other three localities recorded three *Leucauge* species within the selected localities. In term of the tetrangathid species distribution, *L. celebesiana* and *T. ventralis* were found within at least five selected localities, while seven species namely *L. decorata*, *L. liui*, *L. tessellata*, *Opadometa kuchingensis*, *O. sarawakensis*, *Tylorida tianlin*, *Tetragnatha hasselti*, *T. lauta*, *T. maxillosa* and *T. pinicola* were represented in only one locality.

Table 4.2: Occurrence of tetragnathid species in selected study sites in Malaysia.

Species	UG	KS	FH	UKM	GNP	BNP	KNP	PHS	CRP	MR
L. argentina	-	-	-	-	+	-	+	+	+	-
L. celebesiana	-	-	+	-	-	-	+	+	+	+
L. decorata	-	-	-	-	-	-	-	-	+	-
L. liui	-	-	-	-	-	-	-	-	-	+
L. sabahan	-	-	-	-	+	-	+	+	-	-
L. tessellata	+	-	-	-	-	-	-	-	-	-
M. gemmea	+	-	-	-	+	-	+	+	-	-
M. yini	-	-	-	+	-	-	-	-	-	+
O. kuchingensis	-	-	-	-	-	+	-	-	-	-
O. sarawakensis	-	-	-	-	-	+	-	-	-	-
T. ceylonica	-	-	+	-	-	-	+	-	+	-
T. hasselti	-	-	+	-	-	-	-	-	-	-
T. lauta	-	-	+	-	-	-	-	-	-	-
T. maxillosa	-	-	+	-	-	-	-	-	-	-
T. pinicola	-	+	-	-	-	-	-	-	-	-
T. striata	-	-	-	+	-	-	-	-	+	-
T. tianlin	-	-	-	-	-	-	-	-	-	+
T. ventralis	+	+	+	+	-	+	-	+	-	-

UG: Ulu Gombak Field Studies Centre, KS: Kuala Selangor Nature Park, FH: Fraser Hill Forest Reserve, UKM: Forest fringe within Universiti Kebangsaan Malaysia, GNP: Gunung Gading National Park, BNP: Bako National Park, KNP: Kubah National Park, PHS: Poring Hot Spring Nature Reserve, CRP: Crocker Range National Park, MR: Mesilau National Park; +: present; - : absent.

Table 4.3: Summary contrast on the tetragnathid species number from specific region to the present study.

Genus	[1]Worldwide	[2]Southeast Asia	[3]Malaysia	Present study
Dyschiriognatha	5	2	1	0
Leucauge	160	13	8	5 + 1 NS
Mesida	13	4	2	2
Opadometa	2	2	1	2 NS
Tylorida	10	3	2	2
Tetragnatha	326	21	13	5
Orsinome	17	2	2	0
Total	528	45	31	18

NS: New species; References for the number of tetragnathid species, 1: World Spider Catalog (2016), 2: Barrion & Litsinger (1995), Murphy & Murphy (2000), Song *et al*. (2002), Jager (2007), Jager & Praxaysombath (2009; 2011), Koh *et al*. (2013), 3: Norma-Rashid & Li (2009), Dzulhelmi *et al*. (2014a), Dzulhelmi *et al*. (2014b).

4.3.2 SYSTEMATICS OF TETRAGNATHID SPECIES IN MALAYSIA

Closest species for comparison, illustration or photographs, synonymous names, distributions, habitats were summarized for the tetragnathid species captured in this study and were obtained from available literatures as stated. Fourteen selected morphological characters were used to diagnose the tetragnathid species collected in the present study (Table 4.4) and the result is summarized in the form of data matrix (Table 4.5). The following abbreviations are used throughout the chapter: anterior lateral eyes (ALE), anterior median eyes (AME), posterior lateral eyes (PLE) and posterior median eyes (PME).

Meanwhile, the numbers of female adult tetragnathid species representing each species collected in this study were very limited for most species. For female adults, three species (i.e. *Leucauge argentina*, *Mesida gemmea* and *Tylorida ventralis*) were collected with more than 10 individuals, seven species collected were between five to nine individuals while eight species were only represented with three or fewer individuals respectively. The female adult measurements are displayed accordingly (Table 4.6).

Table 4.4: Morphological characters used for the data matrix.

No	0	1	2
1	CL / TL (<40%)	CL / TL (>40%)	X
2	Single row trichobothria	double row trichobothria	NO trichobothria
3	Abdomen round or oval	Abdomen elongated	Abdomen others
4	Abdomen vertical	Abdomen horizontal	X
5	Ratio CL/AL (< 50%)	CL/AL (> 50%)	X
6	NO spines on legs	Short spines (1x leg width)	Long spines (>1x leg width)
7	NO dense hairs on leg IV	YES dense hairs on leg IV	X
8	Lateral eyes continued	Lateral eyes well separated	X
9	PME-PME > AME-AME	PME-PME < AME-AME	PME-PME = AME-AME
10	Diameter PME < AME	Diameter PME > AME	Diameter PME=AME
11	Clypeus (< 2 times AME)	Clypeus (> 2 times AME)	Clypeus (=2 times AME
12	Short chelicerae	medium chelicerae	Long chelicerae
13	Max size (6 mm)	Max size (9 mm)	Max size (>10 mm)
14	Monomorphism	Dimorphism	X

AL: Abdomen length; CL: carapace length; CW: carapace width; TL: total length; ALE: anterior lateral eyes; AME: anterior median eyes; PLE: posterior lateral eyes; PME: posterior median eyes.

Table 4.5: Data matrix for tetragnathid species in Malaysia.

No.	Species / Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	*L. argentina*	1	1	0	0	1	1	0	0	0	1	0	0	0	0
2.	*L. celebesiana*	0	1	1	1	1	2	0	0	0	2	0	0	2	0
3.	*L. decorata*	0	1	1	1	1	1	0	0	0	1	0	0	1	0
4.	*L. liui*	0	1	0	1	1	1	0	0	2	1	0	0	0	0
5.	*L. sabahan*	1	1	0	1	1	1	1	0	0	0	0	0	1	?
6.	*L. tessellata*	1	1	1	1	1	2	1	0	0	2	0	0	1	?
7.	*M. gemmea*	1	1	1	1	1	1	0	1	2	0	0	0	1	0
8.	*M. yini*	1	1	0	1	1	2	0	1	2	2	0	0	0	0
9.	*O. kuchingensis*	1	1	1	1	1	1	1	0	1	2	0	0	1	?
10.	*O. sarawakensis*	0	1	2	0	0	1	1	0	1	0	0	0	1	?
11.	*T. ceylonica*	0	2	1	1	1	1	0	0	0	1	0	1	2	1
12.	*T. hasselti*	0	2	1	1	0	1	0	1	1	1	0	2	1	1
13.	*T. lauta*	0	2	1	1	1	0	0	0	0	1	0	1	0	1
14.	*T. maxillosa*	0	2	1	1	1	1	0	0	0	1	0	2	2	1
15.	*T. pinicola*	0	2	1	1	0	2	0	0	0	1	0	1	1	1
16.	*T. striata*	1	0	2	0	1	2	0	1	0	1	1	0	0	0
17.	*T. tianlin*	1	0	0	1	1	2	0	1	2	0	0	0	0	1
18.	*T. ventralis*	0	0	1	1	1	2	0	1	1	1	0	0	1	0

Table 4.6: Range (mean) measurements on the morphological characteristics of adult females for tetragnathid species.

No.	Species	N	TL	CL	CW	AL
1.	*L. argentina*	14	3.421-4.204 (3.904)	1.481-1.836 (1.718)	1.338-1.631 (1.430)	2.121-3.710 (2.760)
2.	*L. celebesiana*	7	8.151-11.616 (10.181)	3.109-4.324 (3.667)	1.948-2.935 (2.544)	5.936-7.844 (6.931)
3.	*L. decorata*	8	6.526-9.771 (7.535)	2.251-3.311 (2.680)	1.297-2.305 (1.730)	4.370-6.461 (5.236)
4.	*L. liui*	5	4.192-4.650 (4.451)	1.536-1.806 (1.672)	1.047-1.348 (1.200)	2.380-3.141 (2.793)
5.	*L. sabahan*	3	5.660-7.237 (6.584)	2.771-2.906 (2.855)	1.961-2.165 (2.046)	3.142-4.547 (3.912)
6.	*L. tessellata*	2	5.554-6.874 (6.214)	2.298-2.911 (2.605)	1.757-2.013 (1.885)	3.424-4.204 (3.814)
7.	*M. gemmea*	12	3.430-5.394 (4.324)	1.406-2.196 (1.803)	1.003-1.444 (1.248)	2.143-3.598 (2.635)
8.	*M. yini*	5	3.024-4.014 (3.552)	1.321-1.634 (1.470)	1.001-1.364 (1.199)	1.432-2.948 (2.195)
9.	*O. kuchingensis*	2	5.332-8.226 (6.779)	2.167-3.873 (3.021)	1.937-2.559 (2.248)	3.127-4.535 (3.831)
10.	*O. sarawakensis*	1	9.051	3.570	2.543	8.572
11.	*T. ceylonica*	3	6.021-7.593 (6.928)	2.516-2.764 (2.524)	1.244-1.879 (1.577)	4.041-5.089 (4.646)
12.	*T. hasselti*	2	6.789-8.789 (7.789)	2.530-3.086 (2.808)	1.516-1.647 (1.582)	5.198-6.664 (5.931)
13.	*T. lauta*	1	4.462	2.511	2.032	3.254
14.	*T. maxillosa*	3	7.640-10.359 (9.306)	2.673-3.054 (2.923)	1.496-1.669 (1.601)	4.619-7.603 (6.583)
15.	*T. pinicola*	6	7.226-8.480 (8.027)	2.650-3.212 (2.886)	1.681-1.888 (1.788)	5.736-6.331 (5.935)
16.	*T. striata*	5	3.274- 4.475 (3.921)	1.393-1.881 (1.717)	1.129-1.455 (1.303)	1.858-3.116 (2.676)
17.	*T. tianlin*	5	4.037-5.590 (5.014)	1.723-2.251 (2.035)	1.406-1.699 (1.531)	2.409-3.431 (3.075)
18.	*T. ventralis*	14	4.796-7.501 (5.746)	1.144-2.827 (2.190)	1.053-2.037 (1.621)	2.382-5.021 (3.513)

N: number of individuals; TL: total length; CL: carapace length; CW: carapace width; AL: Abdomen length.

Table 4.6 (cont.): Range (mean) measurements on the morphological characteristics of adult females for tetragnathid species.

No.	Species	N	Leg I	Leg II	Leg III	Leg IV
1.	*L. argentina*	14	6.566-8.799 (7.636)	4.586-6.498 (5.519)	2.994-4.167 (3.365)	4.035-5.819 (4.832)
2.	*L. celebesiana*	7	15.477-36.971 (24.055)	9.863-19.321 (16.777)	6.021-10.929 (8.070)	11.511-16.271 (14.800)
3.	*L. decorata*	8	11.294-29.295 (16.139)	8.636-21.599 (12.003)	4.666-8.692 (5.851)	7.972-14.897 (10.365)
4.	*L. liui*	5	8.004-10.894 (9.207)	5.248-7.410 (6.260)	2.132-3.687 (3.074)	4.063-6.161 (5.223)
5.	*L. sabahan*	3	21.471-22.163 (21.905)	15.192-16.023 (15.537)	6.466-7.057 (6.846)	14.363-14.792 (14.577)
6.	*L. tessellata*	2	13.955-15.577 (14.766)	9.406-14.193 (11.800)	5.687-6.466 (6.077)	9.338-11.572 (10.455)
7.	*M. gemmea*	12	11.354-14.998 (13.498)	6.607-9.682 (8.264)	3.393-3.994 (3.761)	5.453-7.779 (6.382)
8.	*M. yini*	5	8.564-10.966 (9.325)	4.858-7.011 (5.884)	2.362-3.301 (2.891)	4.428-5.253 (4.826)
9.	*O. kuchingensis*	2	12.807-17.878 (15.343)	10.221-12.833 (11.527)	5.945-8.677 (7.311)	9.976-11.887 (10.932)
10.	*O. sarawakensis*	1	17.36	16.03	8.33	14.63
11.	*T. ceylonica*	3	15.272-21.171 (19.073)	8.406-11.154 (10.067)	4.535-6.532 (5.699)	8.071-12.827 (10.990)
12.	*T. hasselti*	2	23.692-24.423 (24.058)	15.718-15.729 (15.724)	7.106-7.258 (7.182)	15.142-15.212 (15.177)
13.	*T. lauta*	1	17.912	7.576	4.374	8.715
14.	*T. maxillosa*	3	26.144-28.568 (27.172)	13.247-15.172 (14.430)	5.954-8.052 (7.070)	15.832-16.703 (16.241)
15.	*T. pinicola*	6	20.815-27.611 (25.458)	10.966-14.146 (12.565)	4.856-7.061 (6.160)	13.738-15.146 (14.596)
16.	*T. striata*	5	10.143-14.826 (12.975)	6.334-8.211 (7.338)	2.881-4.088 (3.486)	5.599-7.045 (6.424)
17.	*T. tianlin*	5	9.341-17.752 (13.377)	4.871-9.156 (7.042)	2.869-4.229 (3.705)	5.254-7.112 (6.350)
18.	*T. ventralis*	14	8.102-20.606 (15.795)	4.885-11.973 (9.059)	3.266-5.538 (4.497)	4.385-9.993 (7.426)

N: number of individuals.

TETRAGNATHIDAE Menge, 1866

Long jawed orb-weavers

Cephalothorax longer than wide; eight eyes in two transverse rows, lateral eyes contiguous or apart; sternum longer than wide; Maxillae long; labium longer than wide or wider than long; Chelicerae variable, short, medium or long and well developed; long legs, slender, with or without spines, leg I usually the longest and leg III the shortest, three tarsal claw; Abdomen variable in size and shape, elongated, cylindrical, rounded or oval; Spinnerets similar in size; no cribellum; epigynum simple or complex, with unsclerotized genital plate, flat, a depression without ventral projection; Male palp without median apophysis, having palpal tibia coned-shaped, longer than wide.

LEUCAUGE White, 1841

The genus *Leucauge* is characterized by the two rows of long feathered trichobothria on femur IV ectal surface. There are at least 160 recognized species that can be found in tropical and subtropical region in the world (World Spider Catalog, 2016) with at least 13 species that are found in the South East Asian countries: *L. bontoc* (Barrion and Litsinger, 1995), *L. iraray* (Barrion and Litsinger, 1995), *L. mahabascapea* (Barrion and Litsinger, 1995), *L. parangscipinia* (Barrion and Litsinger, 1995), *L. xiuying* (Zhu, Song and Zhang, 2003), *L. zizhong* (Zhu, Song and Zhang, 2003) including 7 species that had been recorded for Malaysia: *L. argentina* (Hasselt 1882), *L. celebesiana* (Walckenaer 1841), *L. decorata* (Blackwall 1864), *L. fibulata* (Thorell, 1892), *L. granulata* (Walckenaer, 1841), *L. quadrifasciata* (Thorell, 1890), *L. tessellata* (Thorell 1887) (Norma-Rashid & Li, 2009; Dzulhelmi *et al*., 2014a). The present study collected six species which are *L. argentina*, *L. celebesiana*, *L. decorata*, *L. liui*, *L. sabahan* and *L. tessellata*.

Key to the *Leucauge* species

1. Dense brush hairs on tibia IV present……………………………..……………….......2

   Dense brush of hairs on tibia IV absent………………………...……………………...3

2. Abdomen elongated, PME diameter more than AME……………………..…*L. tessellata*

   Abdomen oval, PME diameter less than AME………………………….……*L. sabahan*

3. Adult body size 5 mm or less, abdomen not elongated.....………................................. 4

   Adult body size 6 mm or more, abdomen elongated……………………..……………5

4. Abdomen upright vertically, distance between PME-PME more than AME-AME……………………………………………………………………… *L. argentina*

   Abdomen oval, distance between PME-PME less than AME-AME……………....*L. liui*

5. Abdomen has posterior end extended beyond the spinneret.……….……..…*L. decorata*

   Abdomen does not have posterior end extended beyond the spinneret...….*L. celebesiana*

Leucauge argentina (Hasselt 1882)

Figure 4.4: *Leucauge argentina* (♀).

Closest species for comparison: *L. bontoc* (Barrion & Litsinger 1995); *L. crucinota* (Boesenberg & Strand 1906); *L. xiuying* Zhu, Song & Zhang 2003

Diagnosis: (1) *L. argentina* has oblongate abdomen with four small shoulder humps while *L. bontoc* has elongate abdomen with swollen shoulder humps (2) Clypeus height of *L. argentina* is shorter compared to clypeus height of *L. bontoc* (3) *L. argentina* had epigynum with broad, apically truncate scape while *L. bontoc* has epigynum with longer than wide scape (Barrion & Litsinger, 1995) (4) *L. argentina* has oval shape abdomen much closer to square-like while *L. crucinota* and *L. xiuying* has oval shape abdomen which is much rounded-like shape.

Illustrations / photographs: Figure 4.4; p543, Barrion & Litsinger (1995); p126, Tso & Tanikawa (2000); p255, Koh and Ming (2013)

Synonymy: *Theridion argentinum* (Hasselt 1882); *Argyroepeira argentina* (Thorell 1890); *Argyroepeira argentina* (Workman 1896); *Leucauge argentina* (Barrion & Litsinger 1995); *Leucauge argentina* (Tso & Tanikawa 2000); *Leucauge argentina* (Zhu, Song & Zhang 2003)

Distributions: Brunei, Singapore, Indonesia, Philippines, Malaysia, Taiwan (Koh & Ming, 2013; World Spider Catalog, 2016)

Habitats: lower vegetation (Koh & Ming 2013), grasses at slope in forests, heath forest, lowland dipterocarp forest, lower montane forest

Materials examined: 16 adults (2♂, 14♀) and 11 sub-adults (11♀) from L5, L6, L8 and L10

Description**:** Paratype male (GNP048M). **Carapace**: carapace yellowish-brown in colour, carapace is longer than it is wide (approximately 34% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area, the heart-shape sternum is dark-brown in colour and it is longer than it is wide in length, there is a light-brown colour line along the center of carapace from the eyes toward the abdomen, with lots of thorn-like along both side of the carapace edge. **Eyes**: eye measurements: diameters AME 0.06, ALE 0.06, PME 0.08, PLE 0.06; inter-distances AME-AME 0.06, AME-ALE 0.10, PME-PME 0.08, PME-PLE 0.08, PLE-PLE 0.01, AME-PME 0.08; clypeus high 0.06; lateral eyes loosely contiguous or almost so, eight eyes in two slightly recurved rows, PME size slightly smaller than AME, distance between PME-PME greater than between AME-AME, PME size one times distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME eye size, distance between AME-ALE are about one times the AME eye size, distance between AME-PME are similar to the distance between PME-PME, clypeus height one times the

AME size. **Chelicerae**: promargin with 4 teeth, retromargin with 4 teeth. **Abdomen**: abdomen vertically oblong, but does not overhang carapace, humps on dorsal abdomen, brown in colour with some white, yellow and black marking patterns on top side of the abdomen, black markings covering the bottom side of the abdomen. **Spinnerets**: tip of spinnerets pointing straight downward. **Legs**: legs formula I-II-IV-III, legs are yellowish-green in colour with dark-brown annulations, legs with short spines which are one time leg width, leg similar colour to carapace, trichobothria two times femur IV width; Leg I: femur with 6-8 spines, tibia I with 6-8 spines, Leg II: femur II with 4-6 spines, tibia II with 4-6 spines, Leg III: femur III with 4-6 spines, tibia III with 4-6 spines, Leg IV: femur IV with 4-6 spines, tibia IV with 4-6 spines, two rows of long trichobothria covering more than one-third of the prolateral femur IV. **Palp**: Illustrated on p126, Tso & Tanikawa (2000).

Description**:** Paratype female (PHS001). **Carapace**: carapace yellowish-brown in colour, carapace is longer than it is wide (approximately 34% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area, the heart-shape sternum is dark-brown in colour and it is longer than it is wide in length, there is a light-brown colour line along the center of carapace from the eyes toward the abdomen, with lots of thorn-like along both side of the carapace edge. **Eyes**: eye measurements: diameters AME 0.08, ALE 0.08, PME 0.10, PLE 0.08; inter-distances AME-AME 0.08, AME-ALE 0.12, PME-PME 0.10, PME-PLE 0.10, PLE-PLE 0.02, AME-PME 0.10; clypeus high 0.08; lateral eyes loosely contiguous or almost so, eight eyes in two slightly recurved rows, PME size slightly smaller than AME, distance between PME-PME greater than between AME-AME, PME size one times distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME eye size, distance between AME-ALE are about one times the AME eye size, distance between AME-PME are similar to the distance between PME-PME, clypeus height one times the

AME size. **Chelicerae**: promargin with 4 teeth, retromargin with 4 teeth. **Abdomen**: abdomen vertically oblong, but does not overhang carapace, humps on dorsal abdomen, brown in colour with some white, yellow and black marking patterns on top side of the abdomen, black markings covering the bottom side of the abdomen. **Spinnerets**: tip of spinnerets pointing straight downward. **Legs**: legs formula I-II-IV-III, legs are yellowish-green in colour with dark-brown annulations, legs with short spines which are one time leg width, leg similar colour to carapace, trichobothria two times femur IV width; Leg I: femur with 8-10 spines, tibia I with 8-10 spines, Leg II: femur II with 6-8 spines, tibia II with 6-8 spines, Leg III: femur III with 6-8 spines, tibia III with 6-8 spines, Leg IV: femur IV with 6-8 spines, tibia IV with 6-8 spines, two rows of long trichobothria covering more than one-third of the prolateral femur IV. **Epigyne**: Illustrated on p543, Barrion & Litsinger (1995).

Leucauge celebesiana (Walckenaer 1841)

Closest species for comparison: *L. blanda* (Koch, 1877) and *L. decorata* (Blackwall, 1864) (Yoshida, 2009)

Diagnosis: (1) *L. celebesiana* has cephalic area that is higher than thoracic area while *L. decorata* has a rather elevated to a V-shape appearance (2) *L. celebesiana* has an abdomen end that does not exceed the spinneret while *L. decorata* has round tip end of the abdomen which strongly exceeds the spinnerets (3) *L. celebesiana* has elongated abdomen with rounded at both end while *L. blanda* has abdomen with more rectangular-like end (4) *L. celebesiana* do not have two black spots on the shoulder of the abdomen which is present on *L. blanda*.

Illustrations / photographs: p546, Barrion & Litsinger (1995); p256, Koh & Ming (2013)

Synonymy: *Tetragnatha celebesiana* (Walckenaer, 1841); *Epeira nigro-trivittata* (Doleschall, 1859); *Meta celebesiana* (Simon, 1885a); *Meta nigrotrivittata* (Thorell, 1890); *Argyroepeira nigrotrivittata* (Thorell, 1890a; Simon, 1894a); *Argyroepeira celebesiana* (Simon, 1894a); *Leucauge nigrotrivittata* (Simon, 1905); *Leucauge retracta* (Chamberlin, 1924a); *Leucauge veterascens* (Chamberlin, 1924a); *Leucauge magnifica* (Yaginuma, 1954; Lee, 1966; Yin 1966; Hikichi, 1977; Song, 1980; Hu, 1984); *Leucauge tuberculata* (Song, Zhu and Chen, 1999)

Distributions: India, Sri Lanka, China, Japan, Taiwan, Korea, Indonesia, Laos, Myanmar, Philippines, Brunei, Malaysia, New Guinea

Habitats: damp places (e.g. edge of waterfalls), among grasses in open areas at forest fringe (Koh & Ming, 2013), lower montane forest, heath forest, dipterocarp forest

Materials examined: 9 adults (2♂, 7♀) and 18 sub-adults (1♂, 17♀), from L1, L6, L8 and L10

Description: Paratype male (CRP001). **Carapace**: Carapace orange in colour, carapace is longer than it is wide (approximately 31% longer than wide (Figure 4.5B), cephalic area markedly narrower and higher than thoracic area (Figure 4.5C), cephalic area depressed smoothly to thoracic area, the heart-shape sternum is slightly longer than it is wide in length (Figure 4.5D), longitudinal fovea in deep groove, two pit present. **Eyes**: diameters AME 0.10, ALE 0.12, PME 0.15, PLE 0.12; inter-distances AME-AME 0.10, AME-ALE 0.27, PME-PME 0.12, PME-PLE 0.23, PLE-PLE 0.07, AME-PME 0.08; clypeus high 0.20; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE slightly recurved while PE straight, PME slightly larger than AME, distance between PME-PME greater than between AME-AME, PME size one times the distance between them, AME size one times the distance between them, distance between PME-PLE are slightly more than one time the PME eye size, distance between AME and ALE are about two times the AME eye size, distance between AME-PME are slightly shorter than distance between AME-AME, clypeus height one and a half times the AME size (Figure 4.5A). **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: abdomen elongated and rounded at both end, the abdomen does not overhang the carapace, the abdomen has lateral side which are yellow and black in colour, multiple black and white band on dorsal abdomen, and two yellow horizontal bands on ventral abdomen. **Spinnerets**: Spinnerets at ventral tip of the abdomen, tip of spinneret facing downward and does not exceed end of abdomen. **Legs**: legs formula I-II-IV-III, legs are orange in colour with black annulations, legs with long spines which are two times leg width, Leg I: femur I with 8-10 spines, tibia I with 8-10 spines; leg II: femur II with 8-10 spines, tibia II with 8-10 spines; leg III: femur III with 4-6 spines, tibia III with 4-6 spines; leg IV: femur IV with 6-8 spines, tibia IV with 6-8 spines, two rows of long trichobothria covering about half of prolateral femur IV. **Palp**: As shown in Figure 4.5E & Figure 4.5F, illustrated on Figure 122I, p219, Song *et al*. (1999).

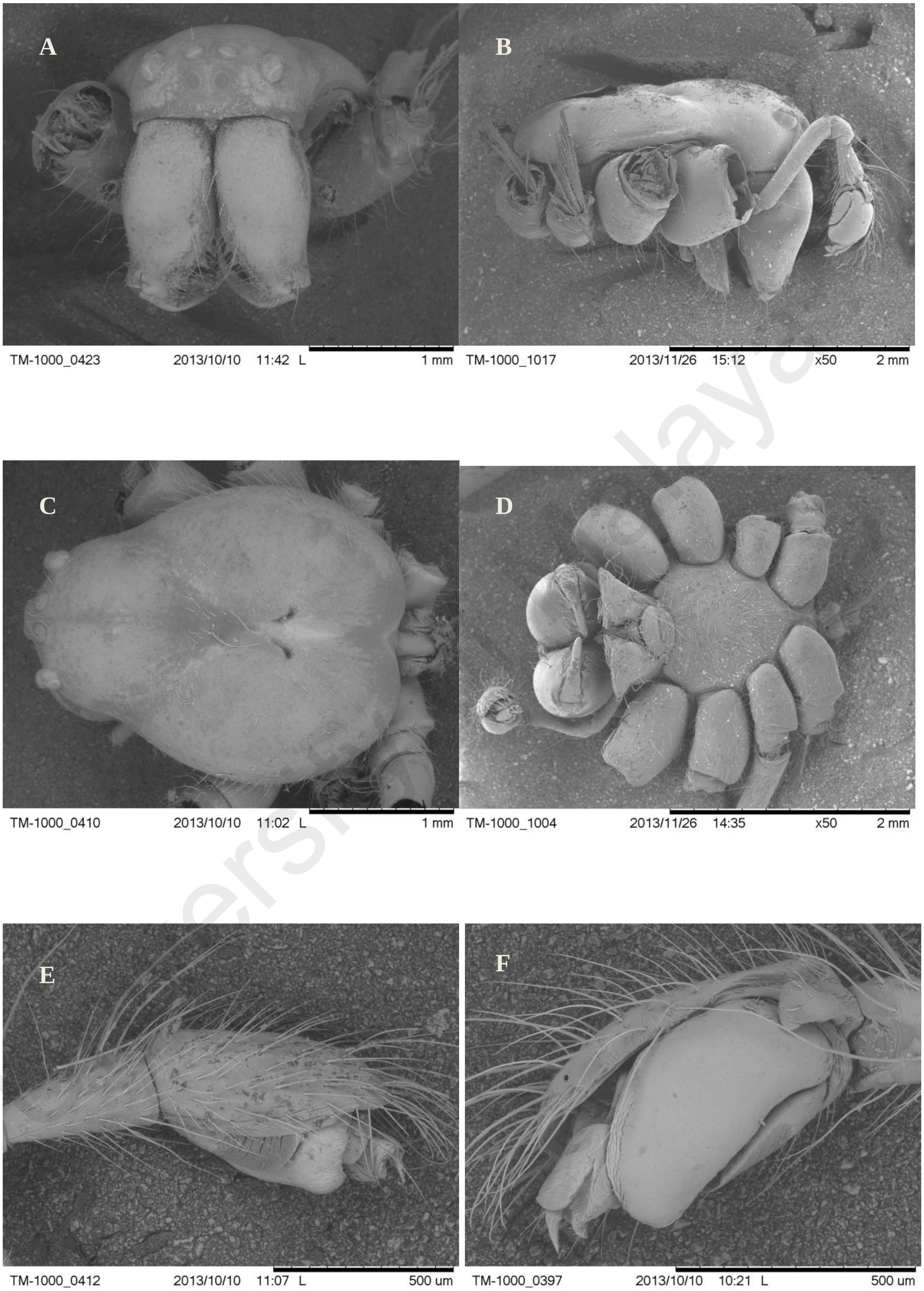

Figure 4.5: *Leucauge celebesiana* (♂). Eye pattern: (A) frontal view; carapace: (B) lateral view, (C) dorsal view, (D) ventral view; palp: (E) retrolateral view, (F) ventral view.

Description: Paratype female. **Carapace**: carapace orange in colour, carapace is longer than it is wide (approximately 48% longer than wide), cephalic area markedly narrower and higher than thoracic area, the heart-shape sternum is longer than wide in length, cephalic area depressed smoothly to thoracic area, longitudinal fovea in deep groove, two pit present. **Eyes**: diameters AME 0.10, ALE 0.12, PME 0.10, PLE 0.14; inter-distances AME-AME 0.10, AME-ALE 0.28, PME-PME 0.12, PME-PLE 0.26, PLE-PLE 0.06, AME-PME 0.08; clypeus high 0.21; Lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE slightly recurved while PE straight, PME slightly bigger than AME, distance between PME-PME slightly greater than between AME-AME, PME size one times the distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME eye size, clypeus height one and a half times the AME size, distance between AME-PME are slightly shorter than distance between AME-AME. **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: elongated abdomen are rounded at both end and do not overhang the carapace, lateral side are yellow and black in colour, multiple black and white band on dorsal abdomen, two yellow horizontal band on ventral abdomen. **Spinnerets**: spinnerets at ventral tip of the abdomen, tip of spinneret facing downward and do not exceed end of abdomen. **Legs**: legs formula I-II-IV-III, legs are orange in colour with black annulations, legs with long spines which are two times leg width, leg I: femur I with 8-10 spines, tibia I with 8-10 spines; leg II: femur II with 6-8 spines, tibia II with 6-8 spines; Leg III: femur III with 4-6 spines, tibia III with 4-6 spines; leg IV: femur IV with 6-8 spines, tibia IV with 6-8 spines, two rows of long trichobothria covering about half of prolateral femur IV. **Epigyne**: transverse C-shaped, longer than wide scape with truncated end, posterior epigynal margin straight, anterior bulge distinct and lateral margins nearly parallel-sided (Barrion & Litsinger, 1995), illustrated on Figure 121M, p218, Song *et al*. (1999).

Leucauge decorata (Blackwall 1864)

Figure 4.6: *Leucauge decorata* (♀).

Closest species for comparison: *L. subblanda* (Bosenberg & Strand, 1906), *L. blanda* (Koch, 1877) and *L. decorata* (Blackwall, 1864) (Yoshida, 2009), *Leucauge zizhong* (Zhu, Song & Zhang, 2003)

Diagnosis: (1) *L. decorata* has elongated abdomen with median depression while *L. celebesiana* has moderate elongated abdomen but without median depression from side view (Barrion & Litsinger, 1995) (2) *L. decorata* has a round tip end of the abdomen which strongly exceeds the spinnerets while the *L. celebesiana* and *L. blanda* has an abdomen end that does not exceed the spinnerets. (3) *L. decorata* has more elongated shape abdomen with an end tip abdomen exceeding the spinnerets much greater while *L. zizhong* has more oval shape abdomen with an end tip of abdomen that exceeds the spinnerets much lesser.

Illustrations / photographs: Figure 4.6; p538, Barrion & Litsinger (1995); p257 Koh & Ming (2013)

Synonymy: *Tetragnatha decorata* (Blackwall, 1864b; Cambridge, 1869); *Nephila angustata* (Stoliczka, 1869), *Meta decorata* (Koch, 1872a), *Argyroepeira celebesiana* (Workman, 1896)

Distributions: Australia, Hong Kong, Taiwan, China, Malaysia, Indonesia, Singapore, Laos, Myanmar, Thailand, Brunei, New Guinea, Bangladesh, Sri Lanka, India, Pakistan (Tahir *et al*., 2010), Paleotropical

Habitats: grasses and low shrubs in shaded and moist environment (Koh and Ming, 2013), lower montane forest

Materials examined: 9 adults (1♂, 8♀) and 4 sub-adults (4♀) from L8

Description: Paratype male (CRP005). **Carapace**: carapace orange in colour, carapace is longer than it is wide (approximately 25% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area, the heart-shape sternum is similar in colour to the carapace and it is longer than wide in length. **Eyes**: diameters AME 0.10, ALE 0.10, PME 0.12, PLE 0.10; inter-distances AME-AME 0.10, AME-ALE 0.18, PME-PME 0.12, PME-PLE 0.18, PLE-PLE 0.02, AME-PME 0.12,; clypeus high 0.15; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE strongly recurved, PE recurved, PME size slightly larger than AME, distance between PME-PME greater than between AME-AME, PME size one times the distance between them, AME size one times the distance between them, distance between PME-PLE are about two time the PME eye size, distance between AME-ALE are about two times the AME eye size, distance between AME-PME about the distance between PME-PME, clypeus height one and a half times the AME size. **Chelicerae**: promargin with 3 teeth, retromargin with 4 teeth. **Abdomen**: elongated abdomen is round at both end and does not overhang the carapace, the end tip of the abdomen exceed the abdomen, dorsal abdomen with black spot on the shoulder and near end tip, abdomen brown in colour with silvery pattern markings, black colour at the tip end. **Spinnerets**: spinnerets at ventral tip of the abdomen, tip of spinnerets pointed downward and do not exceed the abdomen. **Legs**: legs formula I-II-IV-III, legs are orange in colour with black annulations, legs with short spines which are one time leg width, Leg I: femur I with 1-3 spines, tibia I with 1-3 spines; Leg II: femur II with 1-3 spines, tibia II with 1-3 spines; Leg III: femur III with 4-6 spines, tibia III with 4-6 spines; Leg IV: femur IV with 1-3 spines, tibia IV with 1-3 spines, two rows of long trichobothria covering more than one-third of the prolateral femur IV. **Palp**: paracymbium apically curved upward, that produce an obliquely truncate tip as viewed dorsally, lanceolate embolus (Barrion & Litsinger, 1995). Illustrated on Figure 122E, p219, Song *et al.* (1999).

Description: Paratype female (CRP002). **Carapace**: carapace orange in colour, carapace is longer than it is wide (approximately 25% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area, the heart-shape sternum is similar in colour to the carapace and it is longer than wide in length. **Eyes**: diameters AME 0.10, ALE 0.10, PME 0.12, PLE 0.10; inter-distances AME-AME 0.10, AME-ALE 0.18, PME-PME 0.12, PME-PLE 0.18, PLE-PLE 0.02, AME-PME 0.12,; clypeus high 0.15; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE strongly recurved, PE recurved, PME size slightly larger than AME, distance between PME-PME greater than between AME-AME, PME size one times the distance between them, AME size one times the distance between them, distance between PME-PLE are about two time the PME eye size, distance between AME-ALE are about two times the AME eye size, distance between AME-PME about the distance between PME-PME, clypeus height one and a half times the AME size. **Chelicerae**: promargin with 3 teeth, retromargin with 4 teeth. **Abdomen**: elongated abdomen is round at both end and does not overhang the carapace, the end tip of the abdomen exceed the abdomen, dorsal abdomen with black spot on the shoulder and near end tip, abdomen brown in colour with silvery pattern markings, black colour at the tip end. **Spinnerets**: spinnerets at ventral tip of the abdomen, tip of spinnerets pointed downward and do not exceed the abdomen. **Legs**: legs formula I-II-IV-III, legs are orange in colour with black annulations, legs with short spines which are one time leg width, Leg I: femur I with 1-3 spines, tibia I with 1-3 spines; Leg II: femur II with 1-3 spines, tibia II with 1-3 spines; Leg III: femur III with 4-6 spines, tibia III with 4-6 spines; Leg IV: femur IV with 1-3 spines, tibia IV with 1-3 spines, two rows of long trichobothria covering more than one-third of the prolateral femur IV. **Epigyne:** median scape moderately broad and truncate towards tips, narrowed basally, and constricted at midhalf (Barrion & Litsinger, 1995), illustrated on Figure 121H, p218, Song *et al.* (1999).

Leucauge liui Zhu, Song & Zhang 2003

Closest species for comparison: *L. subgemmea* Bosenberg & Strand 1906

Diagnosis: Description and illustration for *L. subgemmea* is not accessible for comparison with *L. liui*.

Illustrations / photographs: p14, Yoshida (2009); p9486, Anonymous (2011)

Synonymy: none.

Distributions: China, Taiwan

Habitats: lower montane forest

Materials examined: 7 adults (2♂, 5♀) from L8

Descriptions: Paratype male (MR045). **Carapace**: carapace dark-yellow in colour, carapace is longer than it is wide (approximately 40% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area lower in height to thoracic area, the heart-shape sternum is wider than it is long in length, no fovea in shallow groove, two pit absent. **Eyes**: diameters AME 0.05, ALE 0.05, PME 0.07, PLE 0.05; inter-distances AME-AME 0.05, AME-ALE 0.07, PME-PME 0.05, PME-PLE 0.07, PLE-PLE 0.03, AME-PME 0.07; clypeus high 0.05; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE recurved, PE procurved, PME size greater than AME, distance between PME-PME similar to between AME-AME, PME size almost one times the distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME size, distance between AME-PME are about one time the PME size, clypeus height about one times the AME size. **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: abdomen is rounded and does not overhang carapace, it has a light yellow patch on ventral side, dark brown band along the centre of the abdomen towards the spinnerets, few black spots near the end part of the abdomen, silvery on dorsal covering other parts of abdomen. **Spinnerets**: Two black dots on left and right side of spinnerets, spinnerets pointing downwards and does not exceed abdomen end. **Legs**: legs formula I-II-IV-III, femurs are yellow in colour while other leg parts are brown in colour with no annulations, legs with short spines which are one time leg width, leg I: femur I with 4-6 spines, tibia I with 4-6 spines; leg II: femur II with 4-6 spines, tibia II with 4-6 spines; leg III: femur III with 4-6 spines, tibia III with 4-6 spines; leg IV: femur IV with 4-6 spines, tibia IV with 4-6 spines, two rows of long trichobothria covering two third of prolateral femur IV. **Palp**: Illustrated on p14, Yoshida (2009).

Descriptions: Paratype female (MR031). **Carapace**: carapace dark-yellow in colour, carapace is longer than it is wide (approximately 34% longer than wide) (Figure 4.7A), cephalic area markedly narrower than thoracic area, cephalic area lower in height to thoracic area, the sternum is wider than it is long in length (Figure 4.7B), no fovea in shallow groove, two pit absent. **Eyes**: diameters AME 0.05, ALE 0.05, PME 0.07, PLE 0.05; inter-distances AME-AME 0.05, AME-ALE 0.07, PME-PME 0.05, PME-PLE 0.07, PLE-PLE 0.03, AME-PME 0.07; clypeus high 0.05; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE recurved, PE procurved, PME size larger than AME, distance between PME-PME similar to AME-AME, PME size almost one time the distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME size, distance between AME-PME are about one time the PME size, clypeus height about one times the AME size (Figure 4.7D). **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: round-shape abdomen does not overhang carapace, the abdomen has light yellow patch on ventral side, a dark brown band along the centre of abdomen towards the spinneret, few black spots near the end part of the abdomen, silvery on dorsal covering other parts of abdomen (Figure 4.7C). **Spinnerets**: Two black dots on left and right side of spinnerets, spinneret pointing downwards, and does not exceed abdomen end. **Legs**: legs formula I-II-IV-III, femurs are yellow in colour while other leg parts are brown in colour with no annulations, legs with short spines which are one time leg width, leg I: femur I with 4-6 spines, tibia I with 4-6 spines; leg II: femur II with 4-6 spines, tibia II with 4-6 spines; leg III: femur III with 4-6 spines, tibia III with 4-6 spines; leg IV: femur IV with 4-6 spines, tibia IV with 4-6 spines, two rows of long trichobothria covering two third of prolateral femur IV, trichobothria one time femur IV width. **Epigyne:** Epigynum with two shallow depressions (Figure 4.7E; Figure 4.7F; Yoshida, 2009), illustrated on p14, Yoshida (2009).

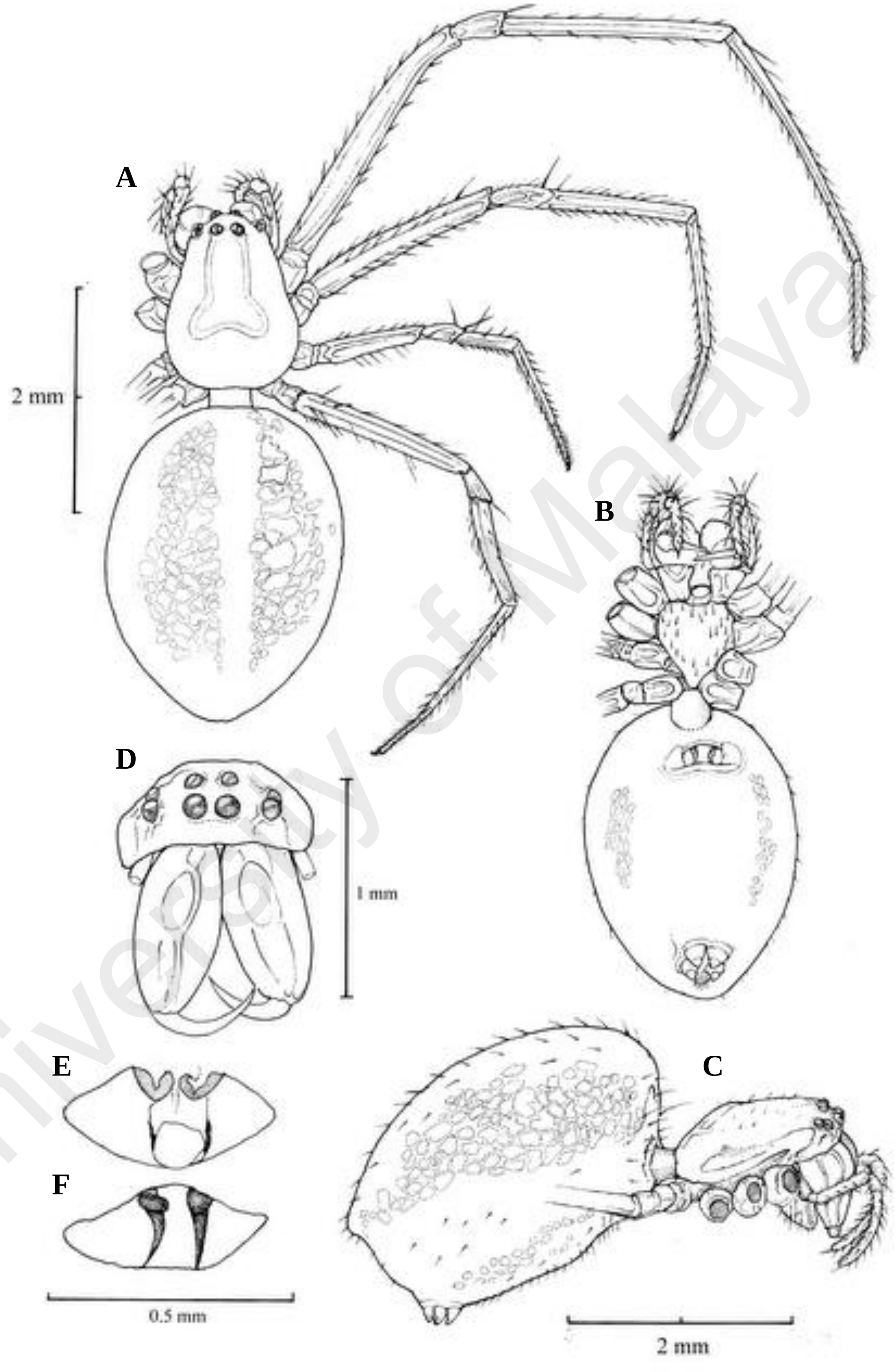

Figure 4.7: *Leucauge liui* (♀). Body: (A) dorsal view, (B) ventral view, (C) lateral view; eye pattern: (D) frontal view; epigyne: (E) ventral view (outer), (F) dorsal view (internal).

Leucauge sabahan Dzulhelmi sp. nov.

Etymology: The specific name is a noun, referring to the location where the holotype was collected.

Closest species for comparison: *L. tessellata* (Thorell, 1887) and *L. taiwanica* (Yoshida, 2009)

Diagnosis: (1) The *L. sabahan* has oval-shaped abdomen while *L. tessellata* has elongated-shape abdomen. (2) The *L. sabahan* abdomen does not overhang the carapace, and does not extend posteriorly above the spinnerets as in *L. taiwanica*. (3) The abdomen of *L. sabahan* has a leaf-like shape pattern, with no pairs of anterior and posterior black spots that differed significantly to the abdomen patterns and coloration of *L. taiwanica*.

Illustrations / photographs: Figure 4.8; p804, Dzulhelmi *et al*., (2016)

Synonymy: none.

Distributions: Malaysia

Habitats: heath forests, dipterocarp forests

Materials examined: 3 adults (3♀) and 3 sub-adults (3♀) from L5, L6 and L10

Description: Holotype Female (GNP036). **Carapace:** carapace orange-brown in colour, carapace is longer than it is wide (approximately 33% longer than wide) (Figure 4.8A; Figure 4.8B), cephalic area markedly narrower in the thoracic area, the heart-shape sternum is similar color to the carapace and it is slightly wider than it is long in length (Figure 4.8E). **Eyes:** diameters AME 0.15, ALE 0.10, PME 0.13, PLE 0.10; inter-distances AME-AME 0.11, AME-ALE 0.28, PME-PME 0.13, PME-PLE 0.28, PLE-PLE 0.05, AME-PME 0.15; clypeus high 0.15; lateral eyes loosely contiguous or almost so, eight eyes in two slightly recurved rows, PME slightly smaller than AME, distance between PME-PME greater than between AME-AME, PME size about one times the distance between them, AME size one time the distance between them, distance between PME-PLE are about twice the PME eye size, clypeus height one times the AME size (Figure 4.8D); **Chelicerae**: promargin with 3 teeth, retromargin with 4 teeth. **Abdomen**: oval-shaped abdomen that do not overhang carapace, the abdomen is light-brown where the dorsal abdomen is covered with leaf patterns of silver pigments, two silvery line markings on the ventral abdomen (Figure 4.8C). **Spinnerets**: spinnerets at ventral tip of abdomen, tip of spinnerets facing downward and exceed end of abdomen (Figure 4.8F). **Legs**: legs formula I-II-IV-III, legs are darker-brown in colour with black annulations, legs with short spines which are one time leg width, Leg I: femur with 8-10 spines, tibia I with 1-3 spines, Leg II: femur II with 6-8 spines, tibia II with 6-8 spines, Leg III: femur III with 6-8 spines, tibia III with 6-8 spines, Leg IV: femur IV with 6-8 spines, tibia IV with 6-8 spines, long dense brush of hairs covering more than one-third of the tibia, metatarsus IV has dense brush of hairs, two rows of long trichobothria covering more than one-third of the prolateral femur IV. **Epigyne**: simple and weakly sclerotized, spermathecae round in shape with short copulatory duct (Figure 4.8G; Figure 4.8H).

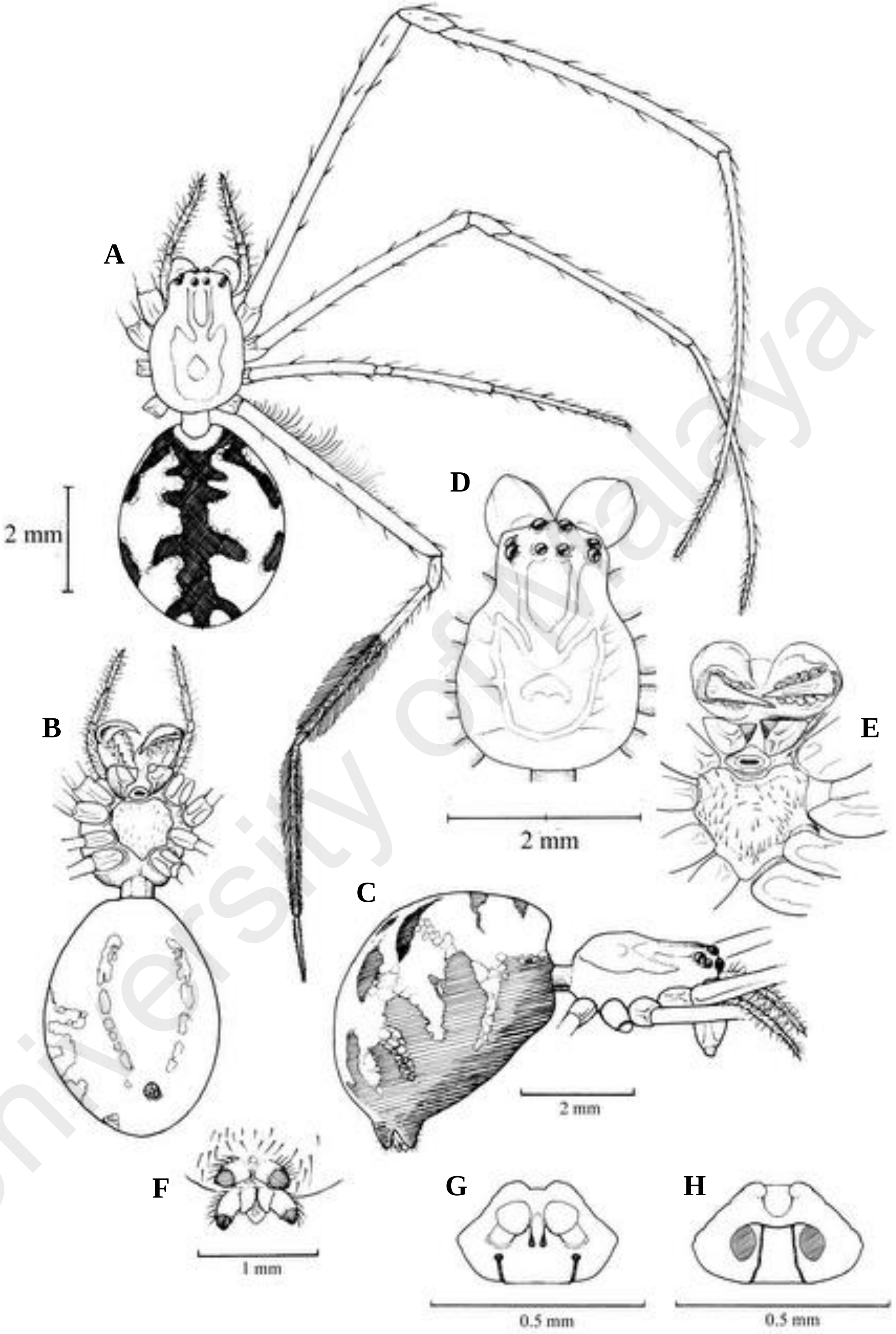

Figure 4.8: *Leucauge sabahan* (♀). Body: (A) dorsal view, (B) ventral view, (C) lateral view; eye pattern: (D) dorsal view; (E) sternum; (F) spinnerets; epigyne: (G) dorsal view (internal), (H) ventral view (outer).

Leucauge tessellata (Thorell 1887)

Figure 4.9: *Leucauge tessellata* (♀) (Photo: www.hkwildlife.net).

Closest species for comparison: *L. taiwanica* (Yoshida, 2009), *Opadometa fastigata* (Simon 1887)

Diagnosis: (1) *L. tessellata* has elongated-shape abdomen while *L. taiwanica* has oval-shape abdomen. (2) *L. tessellata* has variation in abdomen patterns which differed distinctly with *L. taiwanica* (3) *L. tessellata* has elongated-shape abdomen while *O. fastigata* has a pear-shape abdomen.

Illustrations / photographs: Figure 4.9; p127, Tso & Tanikawa (2000)

Synonymy: *Callinethis tessellata* (Thorell, 1887); *Argyroepeira tessellata* (Pocock, 1900), *Leucauge lygisma* (Wang, 1991a); *Leucauge termisticta* (Song & Zhu, 1992b; Chen 1997; Tso & Tanikawa 2000); *Leucauge nitella* (Zhu, Song & Zhang, 2003); *Leucauge subtessellata* (Zhu, Song & Zhang, 2003)

Distributions: India, China, Taiwan, Laos, Malaysia, Indonesia, Moluccas

Habitats: Secondary forest

Materials examined: 2 adults (2♀) from L3

Descriptions: Paratype female (UG003). **Carapace**: carapace is orange in colour, carapace is longer than it is wide (approximately 30% longer than wide), cephalic area markedly narrower and about same level in height to thoracic area, longitudinal fovea in deep groove, the heart-shape sternum is orange in colour and is longer than it is wide in length. **Eyes**: diameters AME 0.12, ALE 0.10, PME 0.12, PLE 0.10; inter-distances AME-AME 0.12, AME-ALE 0.28, PME-PME 0.16, PME-PLE 0.28, PLE-PLE 0.02, AME-PME 0.14; clypeus high 0.20; Lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE slightly recurved while PE straight, PME size is similar to AME, distance between PME-PME slightly greater than between AME-AME, PME size is shorter to the distance between them, AME size about one time the distance between them, distance between PME-PLE are greater than two times the PME eye size, distance between AME-PME slightly greater than distance between AME-AME, clypeus height one and a half times AME size. **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: elongated abdomen are rounded at both end and does not overhang the carapace, abdomen is brown in colour with silvery colour patterns. **Spinnerets**: Spinnerets at ventral tip of the abdomen, tip of spinnerets pointing downward and does not exceed end of abdomen, two black spots present near spinnerets. **Legs**: legs formula I-II-IV-III, legs are orange in colour with black annulations, legs with long spines which are one and a half times leg width, leg I: femur I with 6-8 spines, tibia I with 1-3 spines; leg II: femur II with 6-8 spines, tibia II with 1-3 spines; Leg III: femur III with 4-6 spines, tibia III with 4-6 spines; leg IV: femur IV with 4-6 spines, tibia IV with 4-6 spines, two rows of long trichobothria covering about half of prolateral femur IV, light brush hairs covering one third of tibia IV. **Epigyne**: Illustrated on p15, Yoshida, (2009).

MESIDA Kulczynski, 1911

The genus *Mesida* is characterized by the two rows of long feathered/ branched trichobothria on femur IV ectal surface (Alvarez-Padilla & Hormiga, 2011). There are 13 recognized species that can be found in the world with at least 4 species that can be found in South East Asian countries: *M. matinika* Barrion & Litsinger 1995, *M. realensis* Barrion & Litsinger 1995 including two species that had been recorded in Malaysia which are *M. gemmea* (Hasselt 1882) and *M. yini* Zhu, Song & Zhang 2003. The present study collected two species which are *M. gemmea* and *M. yini*.

Key to the *Mesida* species

1. Abdomen oval, PME similar size to AME...………………………………………*M. yini*

   Abdomen slightly elongated, PME diameter less than AME…………..……*M. gemmea*

Mesida gemmea (Hasselt 1882)

Figure 4.10: *Mesida gemmea* (♀).

Closest species for comparison: *M. matinika* Barrion & Litsinger, 1995; *M. realensis* Barrion & Litsinger, 1995; *M. yini* Zhu, Song & Zhang, 2003

Diagnosis: (1) *M. gemmea* has clypeus height more than one and a half times AME size while *M. matinika* has clypeus height less than one times AME size (2) *M. gemmea* have PME diameter less than AME while *M. yini* have PME diameter similar to AME (3) *M. gemmea* have elongated abdomen while *M. yini* have oval abdomen (4) *M. gemmea* has two black spot on the left and right side of spinnerets while *M. realensis* has a broad black spot on the posterolateral tip of abdomen (Barrion & Litsinger, 1995).

Illustrations / photographs: Figure 4.10; p128, Tso & Tanikawa (2000)

Synonymy: *Meta gemmea* Hasselt 1882, *Argyroepeira gemmea* Thorell 1895, *Leucauge gemmea* Simon 1905

Distributions: Malaysia, Myanmar, Laos, Indonesia, Taiwan

Habitats: heath forest, dipterocarp forest, secondary forest

Materials examined: 15 adults (3♂, 12♀) and 16 sub-adults (16♀) from L3, L5, L6 and L10

Descriptions: paratype male (KNP039). **Carapace**: carapace is yellowish in colour, longer than it is wide (approximately 41% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area similar in height to thoracic area, no fovea in shallow groove, two pit absent, sternum is longer than it is wide in length. **Eyes**: diameters AME 0.14, ALE 0.14, PME 0.12, PLE 0.14; inter-distances AME-AME 0.12, AME-ALE 0.16, PME-PME 0.12, PME-PLE 0.15, PLE-PLE 0.03, AME-PME 0.12; clypeus high 0.20; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE recurved, PE procurved, PME size smaller than AME, distance between PME-PME similar to AME-AME, AME size one times the distance between them, PME size one time the distance between them, AME size slightly larger than distance between them, distance between PME-PLE one time the PME size, distance between AME-PME are one time the PME size, all eyes are surrounded with black markings, clypeus height one and a half times the AME size. **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: elongated-shape abdomen does not overhang carapace, few black markings on the ventral abdomen, silvery on dorsal covering other parts of abdomen. **Spinnerets**: spinnerets pointing downwards and does not exceed abdomen end, two black dots on left and right side of spinnerets. **Legs**: legs formula I-II-IV-III, legs are yellowish in colour with light brown annulations, legs with short spines which are one time leg width, leg I: femur I with 1-3 spines, tibia I with 1-3 spines; leg II: femur II with 1-3 spines, tibia II with 1-3 spines; leg III: femur III with 1-3 spines, tibia III with 1-3 spines; leg IV: femur IV with 1-3 spines, tibia IV with 1-3 spines, two rows of long trichobothria covering two third of prolateral femur IV, trichobothria three time femur IV width. **Palp**: Illustrated on p128, Tso & Tanikawa (2000).

Descriptions: Paratype female (GNP034). **Carapace**: carapace is yellowish in colour, longer than it is wide (approximately 41% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area similar in height to thoracic area, no fovea in shallow groove, two pit absent, sternum is longer than it is wide in length. **Eyes**: diameters AME 0.14, ALE 0.14, PME 0.12, PLE 0.14; inter-distances AME-AME 0.12, AME-ALE 0.16, PME-PME 0.12, PME-PLE 0.15, PLE-PLE 0.03, AME-PME 0.12; clypeus high 0.20; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE recurved, PE procurved, PME size smaller than AME, distance between PME-PME similar to AME-AME, AME size one times the distance between them, PME size one time the distance between them, AME size slightly larger than distance between them, distance between PME-PLE are one time the PME size, distance between AME-PME are one time the PME size, all eyes are surrounded with black markings, clypeus height one and a half times the AME size (Figure 4.11A; Figure 4.11B). **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: elongated-shape abdomen does not overhang carapace, few black markings on the ventral abdomen, silvery on dorsal covering other parts of abdomen (Figure 4.11D; Figure 4.11E; Figure 4.11F). **Spinnerets**: spinnerets pointing downwards and does not exceed abdomen end, two black dots on left and right side of spinnerets. **Legs**: legs formula I-II-IV-III, legs are yellowish in colour with light brown annulations, legs with short spines which are one time leg width, leg I: femur I with 1-3 spines, tibia I with 1-3 spines; leg II: femur II with 1-3 spines, tibia II with 1-3 spines; leg III: femur III with 1-3 spines, tibia III with 1-3 spines; leg IV: femur IV with 1-3 spines, tibia IV with 1-3 spines, two rows of long trichobothria covering two third of prolateral femur IV, trichobothria three time femur IV width. **Epigyne:** As shown in Figure 4.11C, illustrated on p128, Tso & Tanikawa (2000).

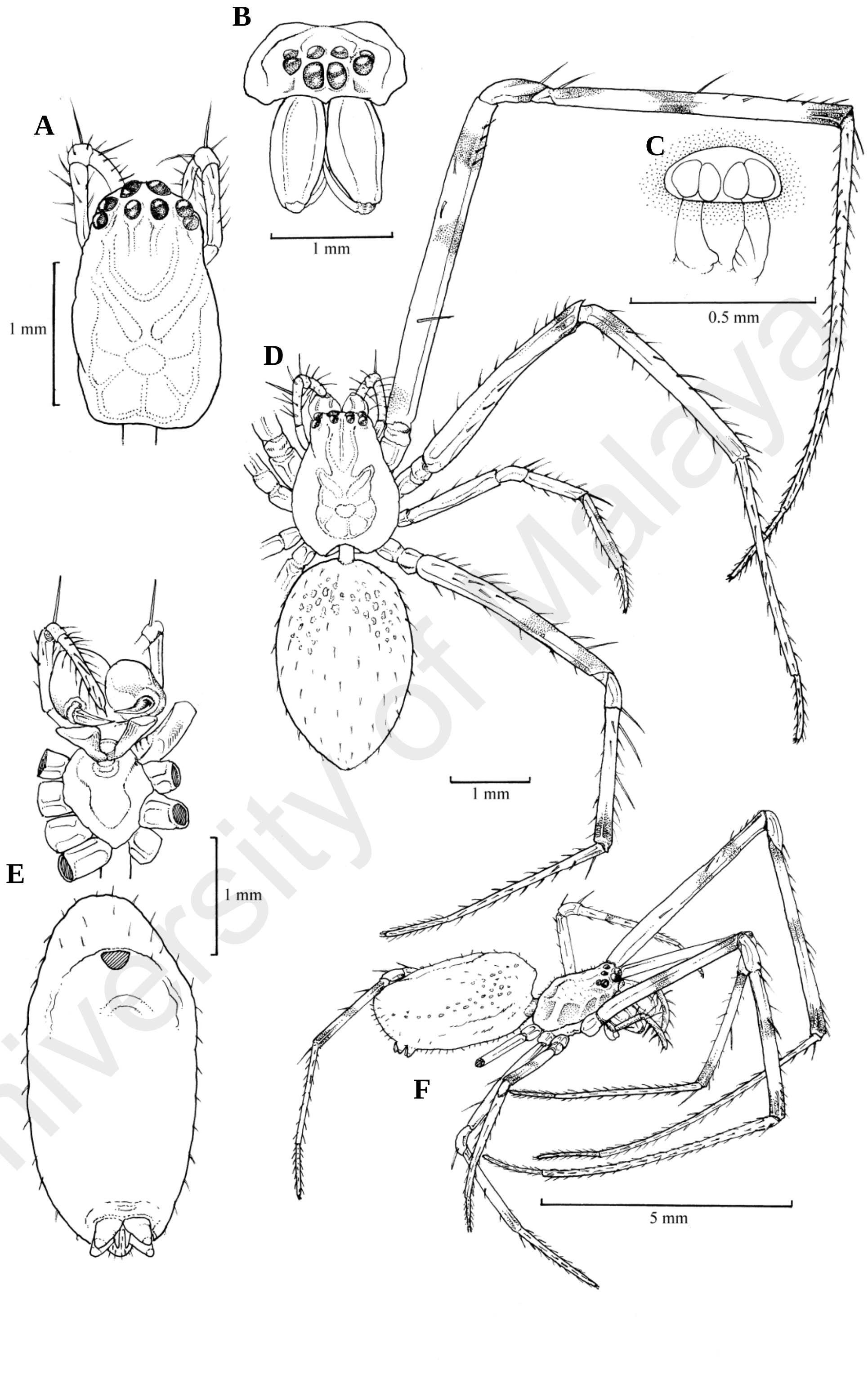

Figure 4.11: *Mesida gemmea* (♀). Eye pattern: (A) dorsal view, (B) frontal view; epigyne: (C) ventral view; body: (D) dorsal view, (E) ventral view, (F) lateral view.

Mesida yini Zhu, Song & Zhang, 2003

Closest species for comparison: *M. gemmea* (Hasselt 1882); *M. matinika* Barrion & Litsinger 1995; *M. yangbi* Zhu, Song & Zhang 2003

Diagnosis: (1) *M. yini* have PME diameter similar to AME while *M. gemmea* have PME diameter less than AME (2) *M. yini* have oval abdomen while *M. gemmea* have elongated abdomen. (3) *M. yini* has oval shape abdomen with two black spot on the left and right side of the spinnerets while *M. matinika* has elongated abdomen with two black spots on each side of the middle dorsal of the abdomen (Barrion & Litsinger, 1995) (4) *M. yini* has one or two pair of black markings on the dorsal end of the abdomen while *M. yangbi* has three pairs of black markings on the dorsal end of the abdomen (5) *M. yini* has shorter and broader intromittent ducts while *M yangbi* has longer and narrower intromittent ducts (Jager & Praxaysombath, 2011).

Illustrations / photographs: p9494, Anonymous (2011); p21, Jager & Praxaysombath (2011)

Synonymy: none.

Distributions: Malaysia, Laos, China

Habitats: forest fringe

Materials examined: 1 adults (1♂, 5♀) from L4

Descriptions: Paratype male (UKM039M). **Carapace**: carapace is orange in colour, carapace is longer than it is wide, (approximately 16.53% longer than wide), cephalic area markedly narrower and about the same height to thoracic area, cephalic area almost even in height to thoracic area (Figure 4.12B; Figure 4.12C), sternum wider than longer, two pit absent, sternum is heart shape and longer than it is wide in length (Figure 4.12D). **Eyes**: diameters AME 0.14, ALE 0.14, PME 0.14, PLE 0.14; inter-distances AME-AME 0.14,

AME-ALE 0.12, PME-PME 0.14, PME-PLE 0.12, PLE-PLE 0.03, AME-PME 0.14; clypeus high 0.08; Lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE very recurved while PE straight, PME almost similar to AME, distance between PME-PME shorter than between AME-AME, PME size one time the distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME eye size, distance between AME-PME is similar to distance between AME-AME and PME-PME, AME and LE are surrounded with black markings, clypeus height about half times the AME size (Figure 4.12A). **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: the abdomen is oval in shape and does not overhang the carapace, the abdomen is orange with yellow in colour on the dorsal, four black dots marking at the end of dorsal abdomen. **Spinnerets**: Spinneret exceed end of abdomen, tip of spinneret facing downward, two black dot markings on the left and right of the spinnerets. **Legs**: legs formula I-II-IV-III, legs are orange in colour with no annulations, legs with long spines which are two times leg width, leg I: femur I with 1-3 spines, tibia I with 1-3 spines; leg II: femur II with 1-3 spines, tibia II with 1-3 spines; leg III: femur III with 1-3 spines, tibia III with 1-3 spines; leg IV: femur IV with 1-3 spines, tibia IV with 1-3 spines, two row of trichobothria covering about half or prolateral femur IV. **Palp**: As shown in Figure 4.12E and Figure 4.12F, illustrated on p21, Jager & Praxaysombath (2011).

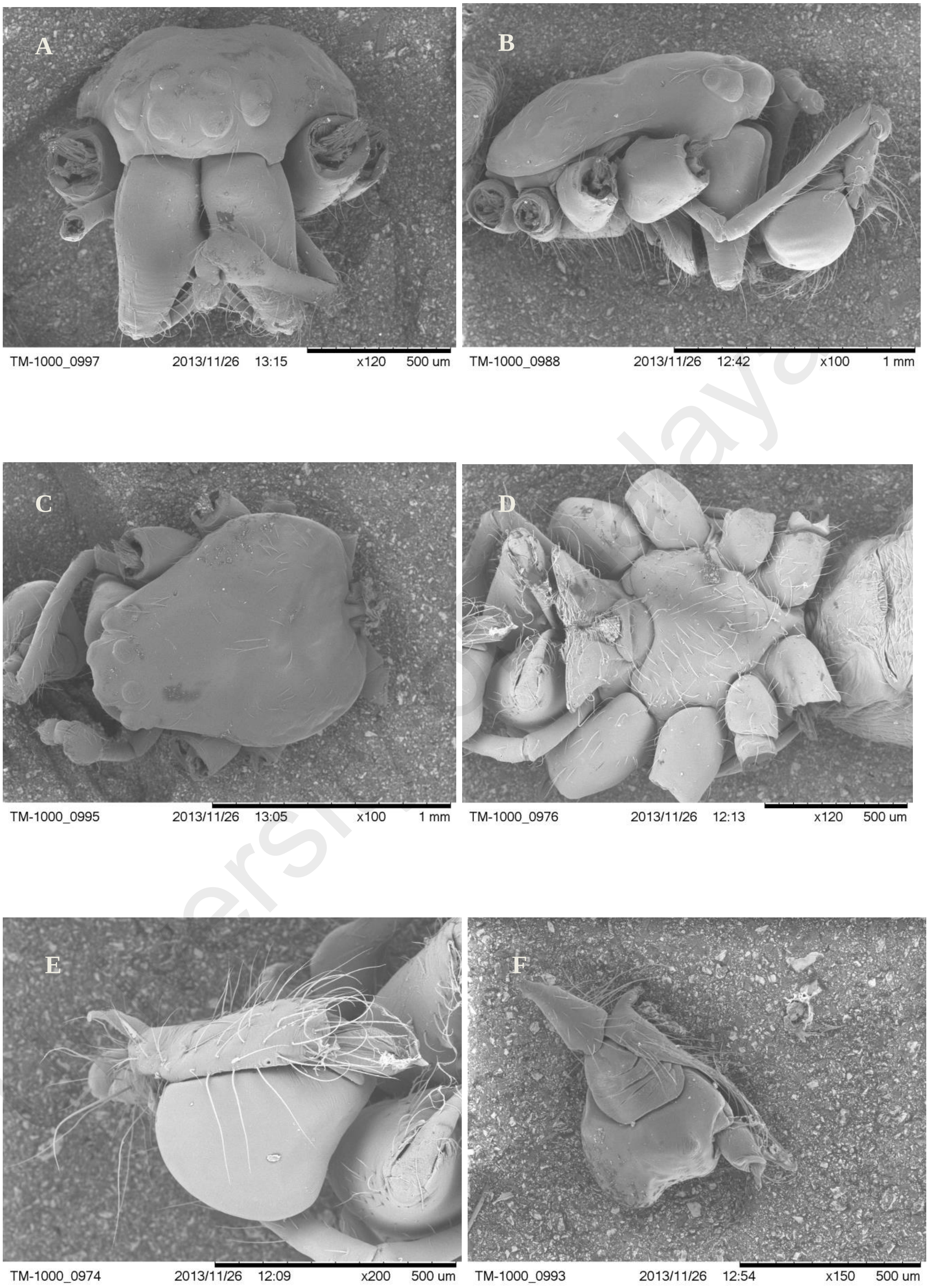

Figure 4.12: *Mesida yini* (♂). Eye pattern: (A) frontal view; carapace: (B) lateral view, (C) dorsal view, (D) ventral view; palp: (E) retrolateral view, (F) ventral view.

Descriptions: Paratype female (UKM031). **Carapace**: carapace is orange in colour, carapace is longer than it is wide, (approximately 16.53% longer than wide), cephalic area markedly narrower and about the same height to thoracic area, cephalic area almost even in height to thoracic area, sternum wider than longer, two pit absent, sternum is heart shape and longer than it is wide in length. **Eyes**: diameters AME 0.14, ALE 0.14, PME 0.14, PLE 0.14; inter-distances AME-AME 0.14, AME-ALE 0.12, PME-PME 0.14, PME-PLE 0.12, PLE-PLE 0.03, AME-PME 0.14; clypeus high 0.08; Lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE very recurved while PE straight, PME almost similar to AME, distance between PME-PME shorter than between AME-AME, PME size one time the distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME eye size, distance between AME-PME is similar to distance between AME-AME and PME-PME, AME and LE are surrounded with black markings, clypeus height about half times the AME size. **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: the abdomen is oval in shape and does not overhang the carapace, the abdomen is orange with yellow in colour on the dorsal, four black dots marking at the end of dorsal abdomen. **Spinnerets**: Spinneret exceed end of abdomen, tip of spinneret facing downward, two black dot markings on the left and right of the spinnerets. **Legs**: legs formula I-II-IV-III, legs are orange in colour with no annulations, legs with long spines which are two times leg width, leg I: femur I with 1-3 spines, tibia I with 1-3 spines; leg II: femur II with 1-3 spines, tibia II with 1-3 spines; leg III: femur III with 1-3 spines, tibia III with 1-3 spines; leg IV: femur IV with 1-3 spines, tibia IV with 1-3 spines, two row of trichobothria covering about half or prolateral femur IV. **Epigyne**: Illustrated on p21, Jager & Praxaysombath (2011).

OPADOMETA Archer, 1951

The genus *Opadometa* is characterized by the present of two rows of long trichobothria and dense brush hairs on femur IV. There are two recognized species and eight subspecies that can be found in tropical and region in the world with at least 2 species that are found in the South East Asian countries: *O. fastigata* (Simon, 1877) including one species that had been recorded in Malaysia which is *O. grata* (Guerin, 1838). The present study collected two newly described species which are *O. kuchingensis* sp. nov and *O. sarawakensis* sp. nov.

Key to the *Opadometa* species

1. Dense brush hairs present on the tibia I and IV..…………………………..…………..2
   Dense brush of hairs present only on tibia IV…..……………………….………*O. fastigata*

2. Oval abdomen that does not overhang the carapace, shorter copulatory duct..…………………………………………………………..…………..…..…*O. kuchingensis*
   Pear-shaped abdomen and strongly overhangs the carapace, copulatory ducts are more than half the spermathecae length……………………...……………...*O. sarawakensis*

Opadometa kuchingensis Dzulhelmi & Suriyanti sp. nov.

Etymology: The specific name is a noun, referring to the division in Sarawak where the holotype was collected.

Closest species for comparison: *Opadometa fastigata* (Simon 1887), *Opadometa sarawakensis* Dzulhelmi & Suriyanti 2015

Diagnosis: (1) The *O. kuchingensis* has an oval abdomen that does not overhang the carapace while *O. fastigata* and *O. sarawakensis* has a pear-shaped abdomen and strongly overhangs the carapace. (2) The *O. kuchingensis* and *O. sarawakensis* have dense brush hairs on tibia I and IV while *O. fastigata* has dense hairs on tibia IV only. (3) The *O. kuchingensis* have shorter copulatory duct while *O. sarawakensis* copulatory ducts are more than half the spermathecae length.

Illustrations / photographs: p105, Dzulhelmi *et al*. (2015)

Synonymy: none.

Distributions: Malaysia

Habitats: lowland dipterocarp forest

Materials examined: 2 adults (2♀) and 5 sub-adults (1♂, 4♀) from L7

Description: Holotype female (BNP005). **Carapace**: carapace light-brown in colour, carapace is longer than it is wide (approximately 51% longer than wide), cephalic area slightly narrower or nearly equal to thoracic area (Figure 4.13E), sternum is dark-brown in colour and is slightly longer than it is wide in length, 1.27 long, 1.24 (Figure 4.13D). **Eyes**: diameters AME 0.18, ALE 0.10, PME 0.18, PLE 0.10; inter-distances AME–AME 0.14, AME–ALE 0.43, PME–PME 0.11, PME–PLE 0.36, PLE–PLE 0.10, AME–PME 0.21; clypeus 0.21 high; lateral eyes loosely contiguous or almost so, eight eyes in slightly two recurved rows. PME slightly smaller than AME, distance between PME-PME slightly shorter than between AME-AME, PME size greater than distance between them, AME size one time the distance between them, distance between PME and PLE are about two times the PME eye size, clypeus height one time the AME size (Figure 4.13C). **Chelicerae**: Promargin with series of 4 teeth, retromargin with series of 3 teeth (Figure 4.13A; Figure 4.13B). **Abdomen**: Pear-shaped abdomen that do not overhang the carapace, light-orange abdomen colour with darker orange marking covering one third of the dorsal end of the abdomen, with black marking at the tip of the abdomen (Figure 4.13F). **Spinnerets**: Spinnerets at ventral tip of abdomen, tip of spinneret facing downward and does not exceed end of abdomen. **Legs**: legs formula I-II-IV-III, legs light-brown in colour with black annulations, legs with short spines which are one time leg width, Leg I: femur I with 3–5 spines, tibia I wit 3–4 spines, dense brush hairs covering more than one-third of the tibia, Leg II: femur II with 1–2 spines, tibia II with 3–4 spines, very few brush hairs covering more than one-third of the tibia, one row of short trichobothria covering half of retrolateral femur II, Leg III: femur III with 1–2 spines, tibia III with 3–4 spines, one row of short trichobothria covering more than two third of prolateral femur III; Leg IV: femur IV with 1–2 spines, tibia 4 with 3–4 spines, dense brush hairs covering more than one-third of the tibia, two rows of long trichobothria covering more than one third of the prolateral femur IV. **Epigyne**: Epigyne simple and weakly sclerotized, spermathecae ovate and mushroom-like in shape, copulatory duct shorter than spermathecae in length (Figure 4.13G; Figure 4.13H), illustrated on p105, Dzulhelmi *et al*. (2015).

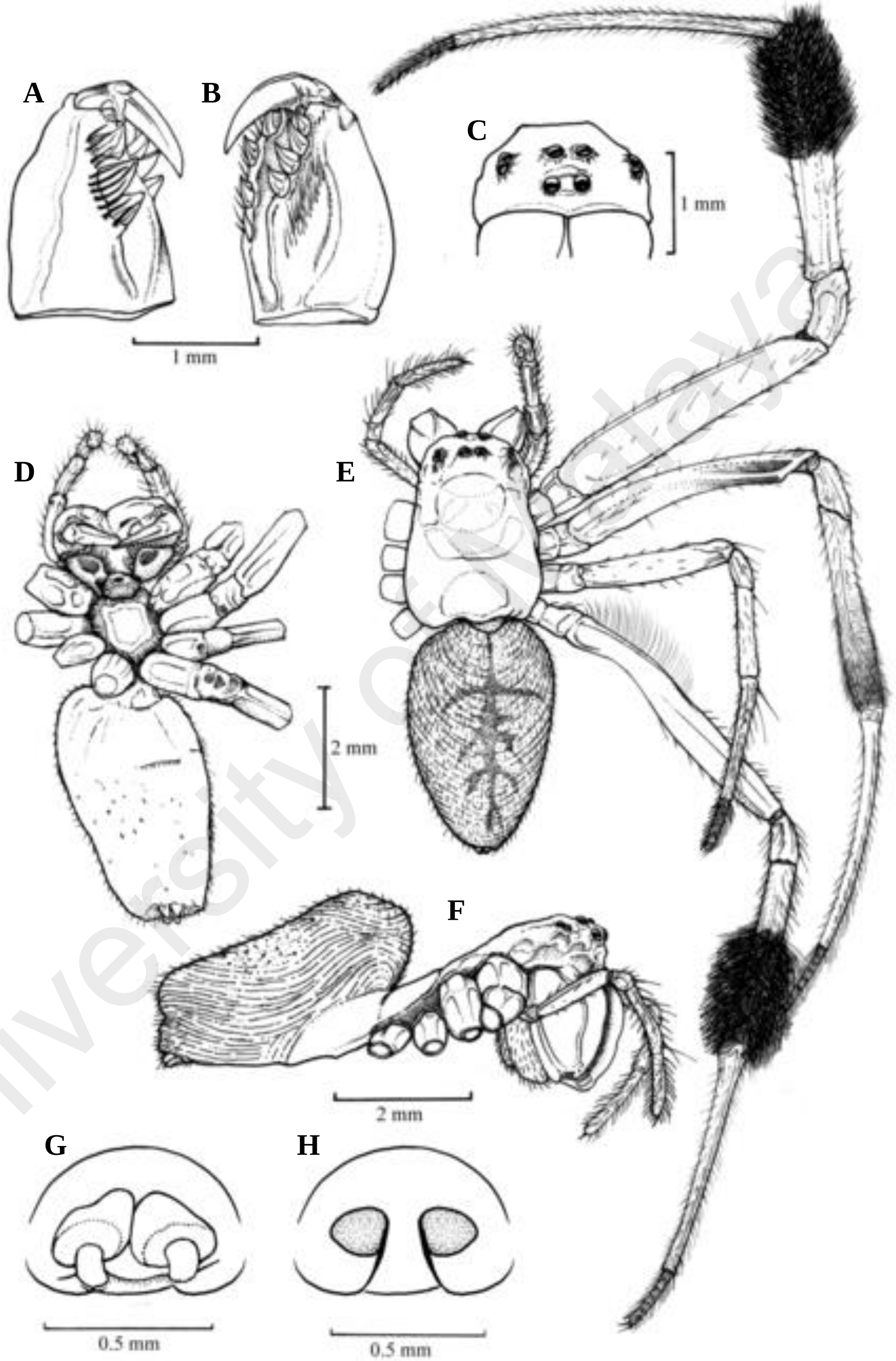

Figure 4.13: *Opadometa kuchingensis* (♀). Right teeth: (A) prolateral view, (B) ventral view; eye pattern: (C) frontal view; body: (D) ventral view, (E) dorsal view, (F) lateral view; epigyne: (G) dorsal view (internal), (H) ventral view (outer).

Opadometa sarawakensis Dzulhelmi & Suriyanti sp. nov

Etymology: The specific name is a noun, referring to the state of the location where the holotype was collected.

Closest species for comparison: *Opadometa fastigata* (Simon 1887), *Opadometa kuchingensis* Dzulhelmi & Suriyanti 2015

Diagnosis: (1) The *O. sarawakensis* has red oval patch on the dorsal abdomen while the blue colouration with black markings covering other part of the abdomen, while *O. fastigata* and *O. kuchingensis* has reddish-orange colouration. (2) The *O. sarawakensis* have dense brush hairs on tibia I and IV while *O. fastigata* has dense hairs on tibia IV only. (3) The spermathecae shape for *O. sarawakensis* is oblong as in bean-like shape, while *O. kuchingensis* are ovate as mushroom-like shape, and *O. grata* are rectangular-like in shape.

Illustrations / photographs: p259, Koh & Ming (2013); p104, Dzulhelmi *et al.* (2015).

Synonymy: none.

Distributions: Malaysia, Brunei

Habitats: Wooded areas and disturbed forest (Koh & Ming, 2013), lowland dipterocarp forest

Materials examined: 1 adult (1♀) from L7

Description: **Male**. Unknown. **Female**. Holotype (BNP003). **Carapace**: carapace dark-brown in colour, carapace is longer than it is wide (approximately 40% longer than wide), cephalic area markedly narrower than thoracic area, sternum is darker-brown in colour and it is slightly longer than wide in length (Figure 4.14C; Figure 4.14D). The thoracic area is wider and lower than the cephalic area. **Eyes:** Diameters AME 0.14, ALE 0.12, PME 0.13, PLE 0.12; inter-distances AME–AME 0.18, AME–ALE 0.47, PME–PME 0.15, PME–PLE 0.44, PLE-PLE 0.10, AME–PME 0.21; clypeus 0.15 high. Lateral eyes loosely contiguous or almost so, eight eyes slightly recurved in two rows (Figure 4.14A; Figure 4.14B), PME slightly smaller than AME, distance between PME-PME slightly shorter than between AME-AME, PME size about one time the distance between them, AME size about one time the distance between them, distance between PME and PLE are about three and a half times the PME eye size, clypeus height one time AME size. **Chelicerae**: Promargin with series of 4 teeth, retromargin with series of 4 teeth (Figure 4.14F; Figure 4.14G). **Abdomen**: Pear-shaped pointed forward abdomen that overhangs the carapace, blue colour covering the abdomen and some black markings on the abdomen with a red coloured oval patch at the middle part of the abdomen (Figure 4.14E). **Spinnerets**: Spinnerets at ventral tip of the abdomen, tip of spinneret facing downward and does not exceed end of abdomen. **Legs**: legs formula I-II-IV-III, legs are dark-brown in colour with black annulations, legs with short spines which are one time leg width, Leg I: femur I with 1-3 spines, tibia I with no spines, dense brush hairs covering more than one-third of the tibia; Leg II: femur II with no spines, tibia II with 3–4 spines, very few brush hairs covering more than one-third of the tibia, one row of long trichobothria covering one-third of retrolateral femur II; Leg III: femur III with 1–2 spines, tibia III with 3–4 spines, one row of short trichobothria covering more than two third of prolateral femur III; Leg IV: femur IV with 1–3 spines, tibia IV with 1–3 spines, thick brush hairs covering more than one-third of the tibia, two rows of long trichobothria covering more than two third of the prolateral femur IV. **Epigyne**: Simple and weakly sclerotized, spermathecae oblong and bean-like in shape, copulatory duct and spermathecae almost equal in length (Figure 4.14H; Figure 4.14I), illustrated on p104, Dzulhelmi *et al*. (2015).

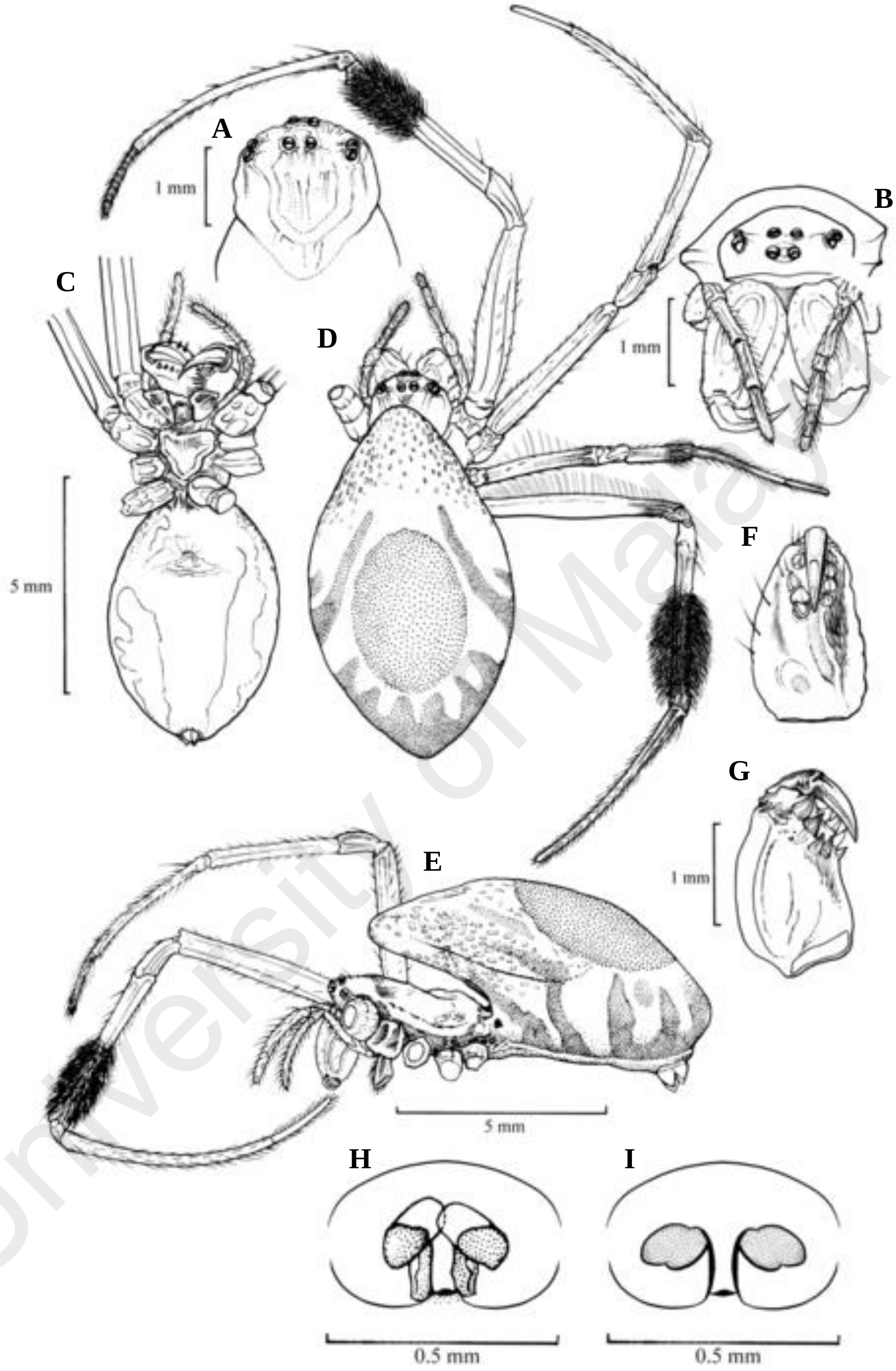

Figure 4.14: *Opadometa sarawakensis* (♀). Eye pattern: (A) dorsal view, (B) frontal view; body: (C) ventral view, (D) dorsal view, (E) lateral view; right teeth: (F) inner view, (G) lateral view; epigyne: (H) dorsal view (internal), (I) ventral view (outer).

TETRAGNATHA Latreille, 1804

The genus *Tetragnatha* is recognized by its long chelicerae, carapace and abdomen. There are 326 recognized species that can be found in the world. There are at least 21 recognized species that is found in the South East Asian countries: *T. desaguni* (Barrion & Litsinger, 1995), *T. geniculata* (Karsch, 1891), *T. iwahigensis* (Barrion & Litsinger, 1995), *T. lauta* (Yaginuma, 1959), *T. llavaca* (Barrion & Litsinger, 1995), *T. hirashimai* (Okuma, 1987), *T. okumae* (Barrion & Litsinger, 1995), *T. praedonia* (Koch, 1878) including 13 species that had been recorded in Malaysia: *T. ceylonica* (Cambridge, 1869), *T. chauliodus* (Thorell 1890), *T. hasselti* (Thorell, 1890), *T. isidis* (Simon 1880), *T. javana* (Thorell, 1804), *T. josephi* (Okuma 1988), *T. lineatula* (Roewer, 1942), *T. mandibulata* (Walckenaer 1842), *T. maxillosa* (Thorell 1895), *T. nitens* (Audouin, 1826), *T. serra* (Doleschall 1857), *T. vermiformis* (Emerton, 1884), *T. virescens* (Okuma, 1979) (Norma-Rashid & Li, 2009; Dzulhelmi *et al*., 2014a). The present study collected five species which are *T. ceylonica*, *T. hasselti*, *T. lauta*, *T. maxillosa* and *T. pinicola*.

Key to the *Tetragnatha* species

1. Long chelicerae…………………………….….…………..……….……………..2

   Short chelicerae…………………………………….…..……………..………..3

2. Lateral eyes continuous or almost so, abdomen and chelicerae ratio (<40%), legs with short spines...…..……………………………...………………….*T. maxillosa*

   Lateral eyes well separated, abdomen and chelicerae ratio (>40%), legs with long spines .....……………..…………………………………….....……..…*T. hasselti*

3. No spines on legs, adult body size (<7 mm)…………………………………*T. lauta*

   Spines on legs, adult body size (>7 mm)……………………………..……..…………4

4. Distance between PLE to PME not distinctly observe, abdomen and chelicerae ratio (<40%), long spines on legs (> 1x leg width)…………….………...…..…*T. pinicola*

   Distance between PLE to PME distinctly observe, abdomen and chelicerae ratio (>40%), Short spines on legs (1x leg width)………..…..…………..….*T. ceylonica*

Tetragnatha ceylonica Cambridge, 1869

Closest species for comparison: *T. virescens* Okuma 1979, *T. vermiformis* Emerton 1988

Diagnosis: (1) *T. ceylonica* had ALE-ALE closer than AME-AME while *T. vermiformis* and *T. virescens* have ALE-ALE more separated than the AME-AME (2) *T. ceylonica* had abdomen slightly wider at posterior end and narrows down as it reach the end of the abdomen while *T. vermiformis* and *T. virescens* had abdomen almost similar wide in length till the end.

Illustrations / photographs: Fig. 315, p512 Barrion & Litsinger (1995); p49, Okuma (1988)

Synonymy: *Meta gracilis* Stoliczka 1869, *T. latifrons* Thorell 1877, *T. fronto* Thorell 1890, *T. gracilis* (Pocock 1900; Merian 1911; Gravely 1921), *T. modesta* Hirst 1911, *T. eitapensis* (Strand 1913; Chrysanthus 1975)

Distributions: South East Asia, Africa, New Guinea, New Britain

Habitats: lower montane forest

Materials examined: 3 adults (3♀) and 2 sub-adults (2♀) from L1, L6 and L8

Descriptions: Paratype female (CRP032). **Carapace**: carapace longer than wide (approximately 47% longer than wide) (Figure 4.15C). **Eyes**: Lateral eyes loosely contiguous or almost so, distance between PME slightly greater than between AME, PME size smaller than distance between them, AME distinctly smaller than PME, distance between PLE to PME distinctly observe. **Chelicerae**: Chelicerae length shorter than carapace (chelicerae 60% length of carapace), promargin: series of 7 teeth, teeth length of U1 almost similar in length to U2, U1 contiguous to U2, U2 separated from U3 by 15% chelicerae length, U3 to U7 decreasing in size proximally, retromargin: series of 7 teeth, prominent tooth present, L1 almost similar in size to L2, L1 separated from L2 by 15% chelicerae length, L2 separated from L3 by 18% chelicerae length, L3-L7 decreasing in size proximally, chelicerae fang short approximately 71% length of base, tapering to smooth point at the end of U5 and L6 (Figure 4.15E; Figure 4.15F; Figure 4.15G). **Abdomen**: carapace length is 41% to abdomen, abdomen light brown on both side with black marking along dorsal and ventral abdomen to the spinnerets (Figure 4.15A; Figure 4.15B). **Spinnerets**: Spinneret at end tip of abdomen (not ventral), end point of spinneret exceed the tip of abdomen (Figure 4.15D). **Legs**: legs formula I-II-IV-III, legs without banded, legs with short spines which are one time leg width, Leg I: femur I with 6-8 spines, tibia I with 6-8 spines; Leg II: femur II with 4-6 spines, tibia II with 6-8 spines; Leg III: femur III with 3-4 spines, tibia III with 3-4 spines; Leg IV: femur IV with 3-4 spines, tibia IV with 5-7 spines. **Epigyne**: Illustrated on p512, Barrion & Litsinger (1995).

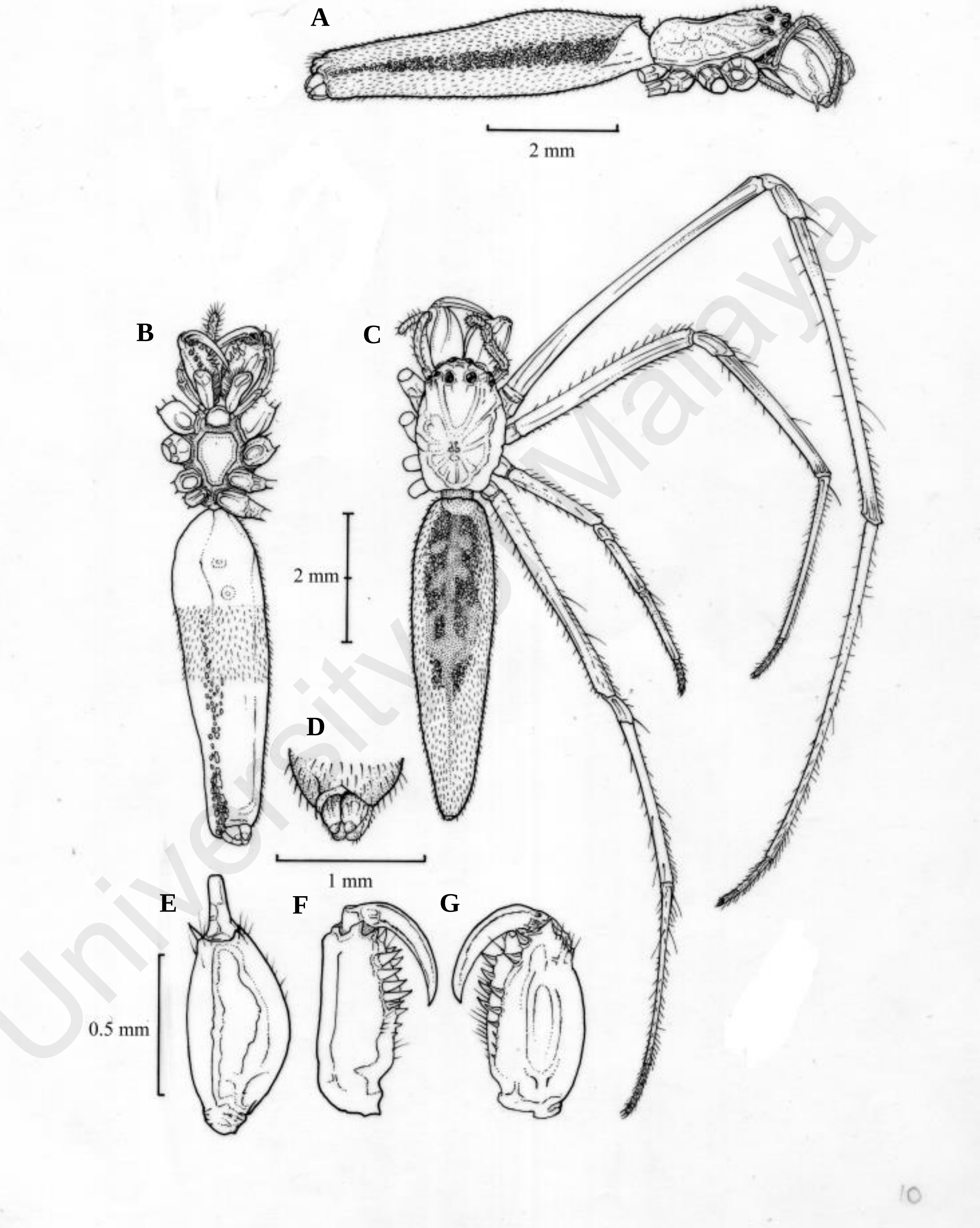

Figure 4.15: *Tetragnatha ceylonica* (♀). Body: (A) lateral view, (B) ventral view, (C) dorsal view; (D) spinnerets; right teeth: (E) lateral view, (F) ventral view, (G) dorsal view.

Tetragnatha hasselti Thorell, 1890

Closest species for comparison: *T. javana* (Thorell 1890); *T. mandibulata* Walckenaer 1841; *T. nitens* (Audouin 1826); *T. praedonia* Koch 1878; *T. serra* Doleschall 1857

Diagnosis: (1) *T. hasselti* has ALE-PLE distance slightly similar or more than AME-AME while *T. praedonia* has ALE-PLE slightly closer than AME-AME (2) The *T. serra* has a long (s) near the outer apex which is absent from this species. (3) The *T. mandibulata* has a very strong (AX1) and (G1), with present of (EX) which is absent from this species. (4) The *T. nitens* has a strong (EX) which is absent from this species. (5) The *T. javana* has a tail overhanging spinnerets which is absent from this species.

Illustrations / photographs: p263, Koh & Ming (2013)

Synonymy: *Tetragnatha aduncata* (Wang 1991)

Distributions: Malaysia, Brunei, Indonesia, Singapore, Laos, Myanmar, Thailand, Bangladesh, China

Habitats: among grasses near rice field, tree foliage along jungle edge (Koh & Ming, 2013), heath forest

Materials examined: 2 adults (2♀) from L6

Descriptions**:** Paratype female (KNP045). **Carapace**: carapace longer than wide (approximately 53% longer than wide), carapace fully orange colour. **Eyes**: Lateral eyes well separated, distance between PME slightly shorter than between AME, PME size about the same as distance between them, AME slightly smaller than PME (Figure 4.16C). **Chelicerae**: Chelicerae length shorter than carapace (chelicerae 48% length to carapace), promargin: series of 9 teeth, teeth length of U1 longer than U2, U1 separated from U2 by 8% chelicerae length, U2 separated from U3 by 21% chelicerae length, U3 separated from U4 by 8% chelicerae length, U5-U8 decrease in size proximally, retromargin: series of 9 teeth, prominent tooth absent, teeth length of L1 shorter than L2, L1 separated from L2 by 22% chelicerae length, L2 separated from L3 by 22% chelicerae length, L3 separated from L4 by 8% chelicerae length, L5-L8 decrease in size proximally, chelicerae fang short approximately 84% length of base, tapering to smooth point at end of U6 and L7 (Figure 4.16A; Figure 4.16B). **Abdomen**: carapace length is 38% to abdomen, End tip of abdomen exceed spinneret, orange colour abdomen (Figure 4.16D; Figure 4.16E; Figure 4.16F). **Spinnerets**: spinneret at ventral tip of abdomen, end point of spinneret not exceeding abdomen (Figure 4.16G). **Legs**: legs formula I-II-IV-III, legs without banded, legs with long spines which are one times leg width, leg hairs as long as spines, Leg I: femur I with 6-8 spines, tibia I with 6-8 spines; Leg II: femur II with 6-8 spines, tibia II with 6-8 spines; Leg III: femur III with 3-4 spines, tibia III with 3-4 spines; Leg IV: femur IV with 6-8 spines, tibia IV with 3-5 spines. **Epigyne**: Illustrated on Figure 126D, p226, Song *et al.* (1999).

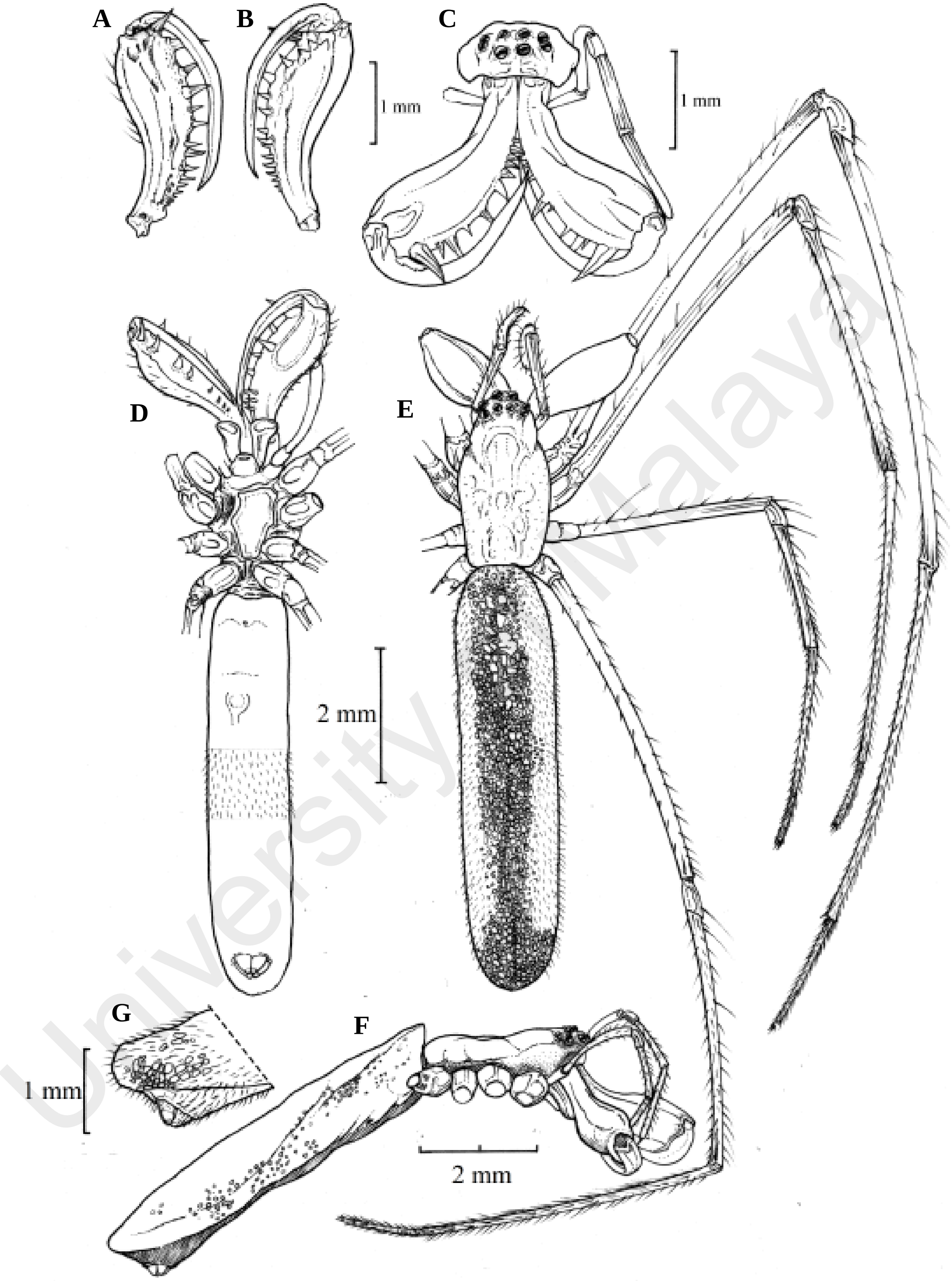

Figure 4.16: *Tetragnatha hasselti* (♀). Right teeth: (A) ventral view, (B) dorsal view; eye pattern: (C) frontal view; body: (D) ventral view, (E) dorsal view, (F) lateral view; spinnerets: (G) lateral view.

Tetragnatha lauta Yaginuma, 1959

Closest species for comparison: *T. pinicola* Koch 1870; *T. virescens* Okuma 1979, *T. vermiformis* Emerton 1988

Diagnosis: (1) *T. lauta* had ALE-ALE closer than AME-AME while *T. vermiformis* and *T. virescens* have ALE-ALE more separated than the AME-AME (2) The *T. lauta* does not have spines on legs while *T. pinicola* have long spines on legs.

Illustrations / photographs: Fig 127R-U, p227, Song *et al*. (1999)

Synonymy: none.

Distributions: Hong Kong, Taiwan, Japan, Malaysia, Laos, Korea, China

Habitats: Hill forest

Materials examined: 1 adult (1♀) from L1

Descriptions: Paratype female (FH002). **Carapace**: carapace longer than wide (approximately 75% longer than wide), brown carapace with yellow marking on the side of the carapace. **Eyes**: Lateral eyes loosely contiguous or almost so. Distance between PME slightly greater than between AME, PME size greater than distance between them (Figure 4.17A). **Chelicerae**: Chelicerae shorter than carapace (ratio: 1: 2) (chelicerae 50% length to carapace) (Figure 4.17B), Promargin: series of 7 teeth, teeth length of U1 shorter than U2, U1 separated from U2 by 14% chelicerae length, U2 to U7 decreasing in size proximally, U3 to U7 are smaller in size than U2, Retromargin: series of 8 teeth, prominent tooth present, teeth length of L1 longer than L2, L1 contiguous with L2, L2 to L8 about the same in size proximally, chelicerae fang short, approximately 85% length of base, tapering to smooth point at the end of U7 and L8 (Figure 4.17C; Figure 4.17D; Figure 4.17E). **Abdomen**: carapace (ratio 2.5:1.0), carapace length is 40% to abdomen, brown abdomen with yellow marking on the side and on dorsal of abdomen (Figure 4.17F; Figure 4.17G;

Figure 4.17H). **Spinnerets**: Spinnerets at ventral tip of abdomen, tip of spinneret exceed end point of abdomen (Figure 4.17I). **Legs**: legs formula I-II-IV-III, legs without banded, without spines on legs. **Epigyne**: Illustrated on Figure 126D, p226, Song *et al*. (1999).

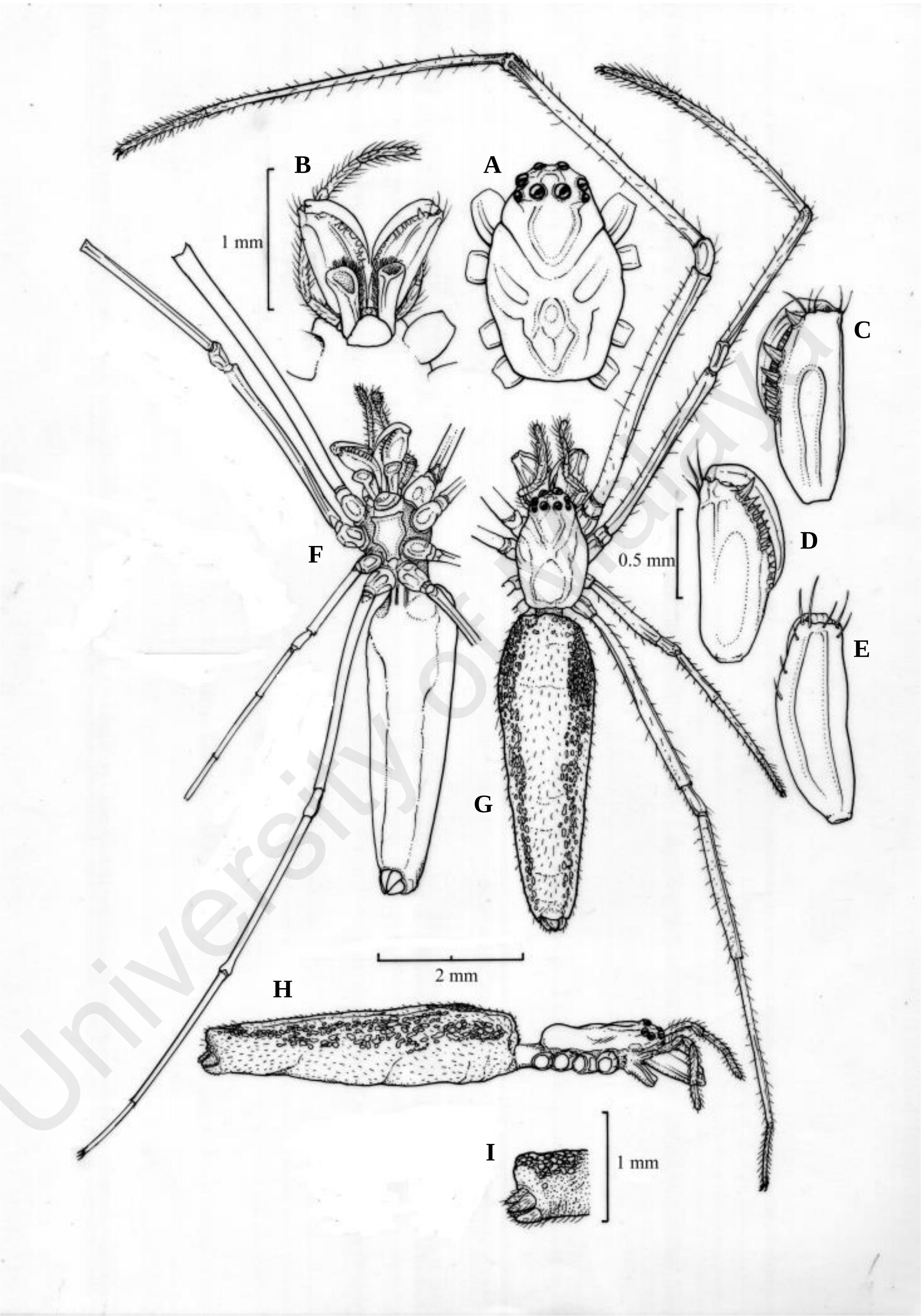

Figure 4.17: *Tetragnatha lauta* (♀). Eye pattern: (A) dorsal view; chelicerae: (B) ventral view; right teeth: (C) dorsal view, (D) ventral view, (E) lateral view; body: (F) ventral view, (G) dorsal view, (H) lateral view; spinnerets: (I) lateral view.

Tetragnatha maxillosa Thorell, 1895

Figure 4.18: *Tetragnatha maxillosa* (♀).

Closest species for comparison: *T. mandibulata* Walckenaer 1841, *T. nitens* (Audouin 1826)

Diagnosis: (1) *T. maxillosa* has PME size greater than distance between PME-PME while *T. mandibulata* has PME size smaller than distance between PME-PME (2) *T. maxillosa* have small and weak or absent AX1 while *T. mandibulata* and *T. nitens* have fang with strong AX1 and EX (Barrion & Litsinger, 1995).

Illustrations / photographs: Figure 4.18; p228, Figure 128A-D, (Song *et al*. 1999); p83 (Okuma, 1988)

Synonymy: *T. japonica* (Bosenberg & Strand 1906; Saito 1933; Lee 1966), *T. listeri* (Gravely 1921), *T. conformans* (Chamberlin, 1924a); *T. propioides* (Schenkel 1936), *T. cliens* (Yin 1976; Hu, 1984; Guo, 1985), *T. diensens* (Zhao, 1993)

Distributions: Malaysia, Thailand, Vietnam, Cambodia, Laos, Myanmar, Indonesia, Philippines, China, Taiwan, Japan, Korea, South Africa, Bangladesh, Sri Lanka, New Hebrides, New Guinea

Habitats: Hill forest

Materials examined: 4 adults (1♂, 3♀) and 2 sub-adults (2♀) from L1

Descriptions: Paratype male (FH005M). **Carapace**: carapace longer than wide (approximately 58% longer than wide), brown carapace. **Eyes**: Lateral eyes loosely contiguous or almost so, Distance between PME-PME slightly greater than between AME-AME, PME size greater than distance between them (Figure 4.19G; Figure 4.19H). **Chelicerae**: Chelicerae almost same length as carapace (97%), promargin: series of 7 teeth, length of 'a' is about 25% the length of chelicerae, Gu separated from s1 by 10% chelicerae length, distance between s1 and T approximately 15% chelicerae length, s1 approximately the equal in length to T, T separated from rsu1 by approximately 10% chelicerae length, rsu1 separated from other rsu by approximately 10% chelicerae length, 3 rsu teeth decreasing in size proximately, chelicerae fang short approximately 90% length of base, tapering to curve end point and exceed L8 and rsu (Figure 4.19A; Figure 4.19B). **Abdomen**: carapace length is 48% to abdomen, end point of abdomen exceed tip of spinnerets, yellow line marking on the abdomen dorsal (Figure 4.19D; Figure 4.19E; Figure 4.19F). **Spinnerets**: Spinnerets at ventral tip of abdomen (Figure 4.19I). **Legs**: legs formula I-II-IV-III, legs without banded, legs with short spines which are one time leg width, Leg I: femur I with 6-8 spines, tibia I with 4-6 spines; Leg II: femur II with 6-8 spines, tibia II with 4-6 spines; Leg III: femur III with 1-3 spines, tibia III with 1-3 spines; Leg IV: femur IV with 1-3 spines, tibia IV with 4-6 spines. **Palp**: As shown in Figure 4.19C, illustrated on p510, Barrion & Litsinger (1995).

Descriptions: Paratype female (FH005). **Carapace**: carapace longer than wide (approximately 74% longer than wide), brown carapace. **Eyes**: Lateral eyes loosely contiguous or almost so, Distance between PME-PME slightly greater than between AME-AME, PME size greater than distance between them (Figure 4.20H). **Chelicerae**: Chelicerae almost same length as carapace (97%) (Figure 4.20D), promargin: series of 7 teeth, teeth length of U1 shorter than U2, U1 separated from U2 by 33% chelicerae length, U2 to U7 decreasing in size proximally, presence of distinct tooth at upper part of chelicerae (beside U1), promargin teeth bigger than retromargin teeth, retromargin: series of 11 teeth, prominent tooth absent, L1 distinctly robust and longer than L2-L11, L1 separated from L2 by 7% chelicerae length, L2 to L11 decreasing in size proximally, chelicerae fang short approximately 75% length of base, tapering to smooth point at the end of U5 and L11 (Figure 4.20A; Figure 4.20B; Figure 4.20C). **Abdomen**: carapace length is 38% to abdomen, end point of abdomen exceed tip of spinneret, yellow line marking on the abdomen dorsal (Figure 4.20E; Figure 4.20F; Figure 4.20G). **Spinnerets**: Spinnerets at ventral tip of abdomen. **Legs**: legs formula I-II-IV-III, legs without banded, legs with short spines which are one time leg width, Leg I: femur I with 6-8 spines, tibia I with 4-6 spines; Leg II: femur II with 6-8 spines, tibia II with 4-6 spines; Leg III: femur III with 1-3 spines, tibia III with 1-3 spines; Leg IV: femur IV with 1-3 spines, tibia IV with 4-6 spines. **Epigyne**: Illustrated on p509, Barrion & Litsinger (1995).

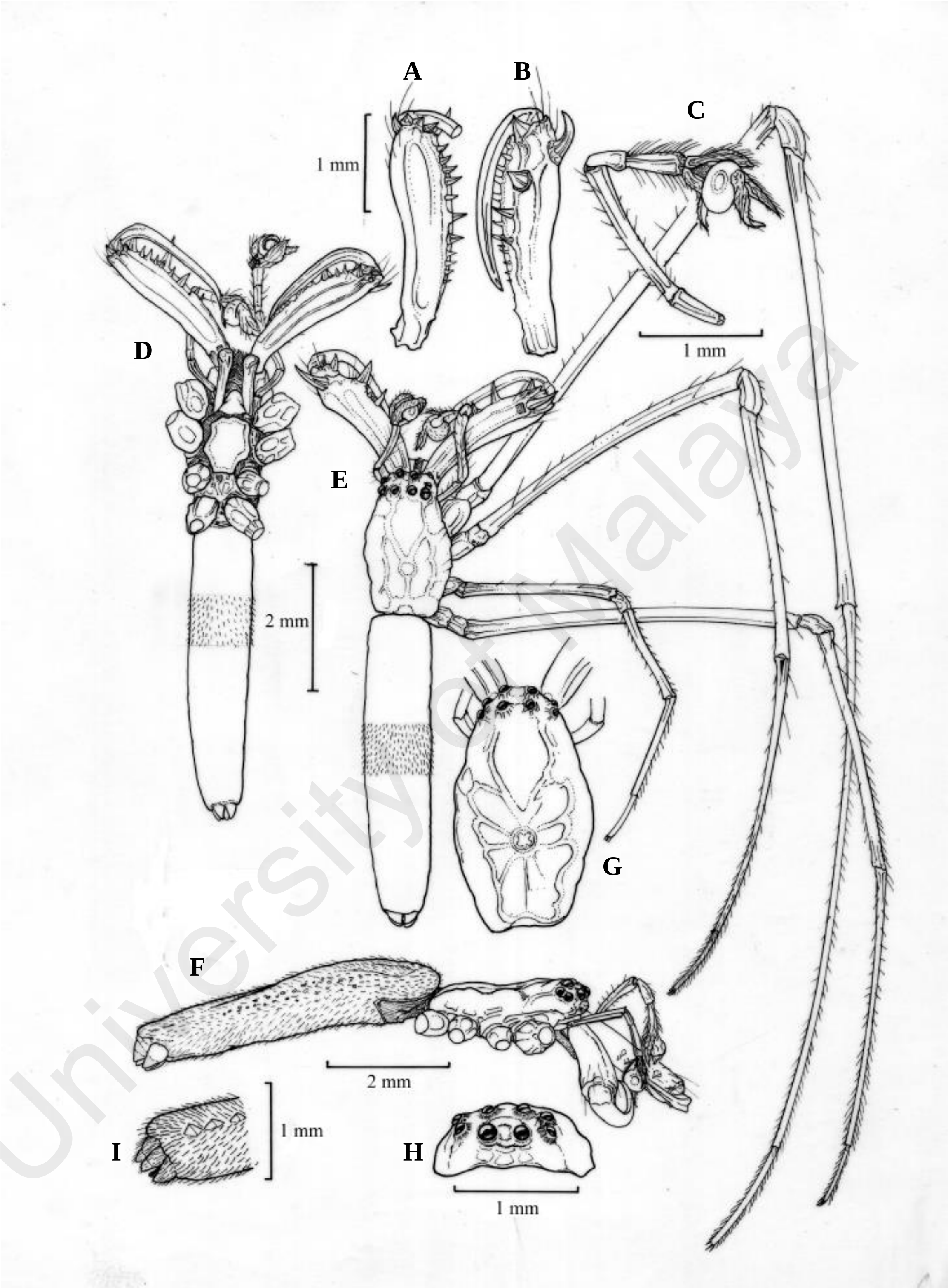

Figure 4.19: *Tetragnatha maxillosa* (♂). Right teeth: (A) ventral view, (B) dorsal view; left palp: (C) ventral view; body: (D) ventral view, (E) dorsal view, (F) lateral view; eye pattern: (G) dorsal view, (H) frontal view; spinnerets: (I) lateral view.

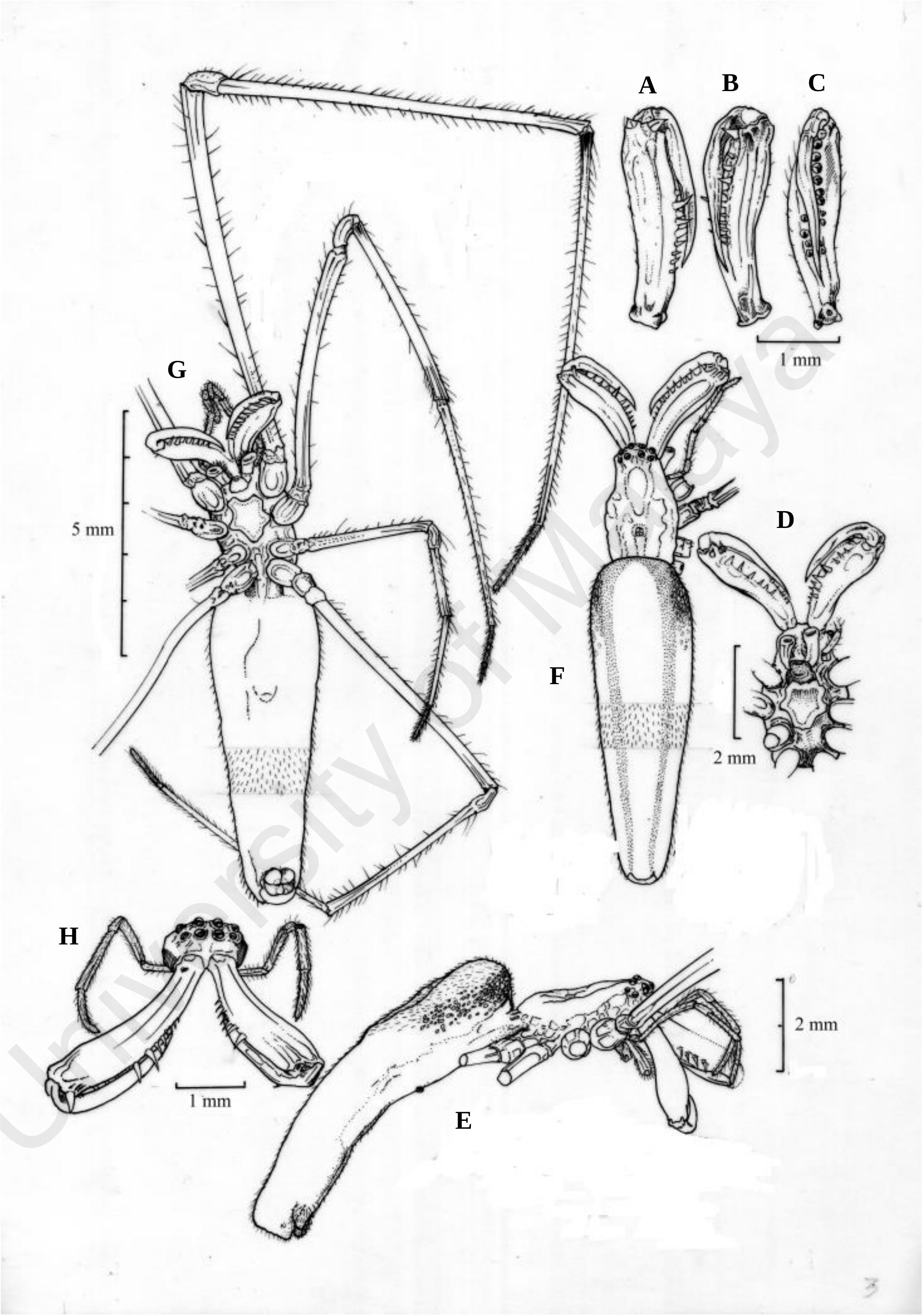

Figure 4.20: *Tetragnatha maxillosa* (♀). Left teeth: (A) dorsal view, (B) ventral view, (C) inner view; chelicerae: (D) ventral view; body: (E) lateral view, (F) dorsal view, (G) ventral view; eye pattern: (H) frontal view.

Tetragnatha pinicola Koch, 1870

Figure 4.21: *Tetragnatha pinicola* (♀).

Closest species for comparison: *T. squamata* Karsch 1879

Diagnosis: (1) *T. pinicola* has long abdomen compared to broad abdomen as in *T. squamata*.

Illustrations / photographs: Figure 4.21; Figure 128I-L, Song *et al*. (1999)

Synonymy: *Eugnatha picta* (Lendl 1886)

Distributions: Malaysia, China, Palearctic

Habitat: Mangrove forests

Materials examined: 7 adults (1♂, 6♀) and 4 sub-adults (4♀) from L2

Descriptions: Paratype male (KS036M). **Carapace**: carapace longer than wide (approximately 38% longer than wide), light brown; **Eyes**: Lateral eyes loosely contiguous or almost so, Distance between PME slightly greater than between AME, PME size smaller than distance between them, AME distinctly smaller than PME (Figure 4.22J; Figure

4.22K). **Chelicerae**: Chelicerae length shorter than carapace (chelicerae 88% length to carapace) (Figure 4.22C), promargin: series of 5 teeth, distance between Gu and s1 approximately 30% chelicerae length, distance between s1 and T approximately 26% chelicerae length, T largest teeth on promargin, rsu approximately equal in size, ‘a’ smaller than T, retromargin: series of 8 teeth, prominent tooth present, small AX1 and continuous to G1, G1 largest teeth on retromargin, L2-L6 decreasing in size proximally, chelicerae fang short approximately 89% length of base, tapering to curve end point and exceed L5 and rsu (Figure 4.22G; Figure 4.22H; Figure 4.22I). **Abdomen**: carapace length is 37% to abdomen, browner abdomen compared to its carapace; **Spinneret**: Spinneret at end tip of abdomen (not ventral), end point of spinneret exceed the tip of abdomen (Figure 4.22D; Figure 4.22E; Figure 4.22F). **Legs:** legs formula I-II-IV-III, legs without banded, legs with long spines which are two times leg width, Leg I: femur I with 6-8 spines, tibia I with 6-8 spines, Leg II: femur II with 6-8 spines, tibia II with 6-8 spines, Leg III: femur III with 1-3 spines, tibia III with 1-3 spines, Leg IV: femur IV with 1-3 spines, tibia IV with 5-7 spines. **Palp**: As shown in Figure 4.22A and Figure 4.22B, illustrated in Figure 126S, p226, Song *et al*. (1999).

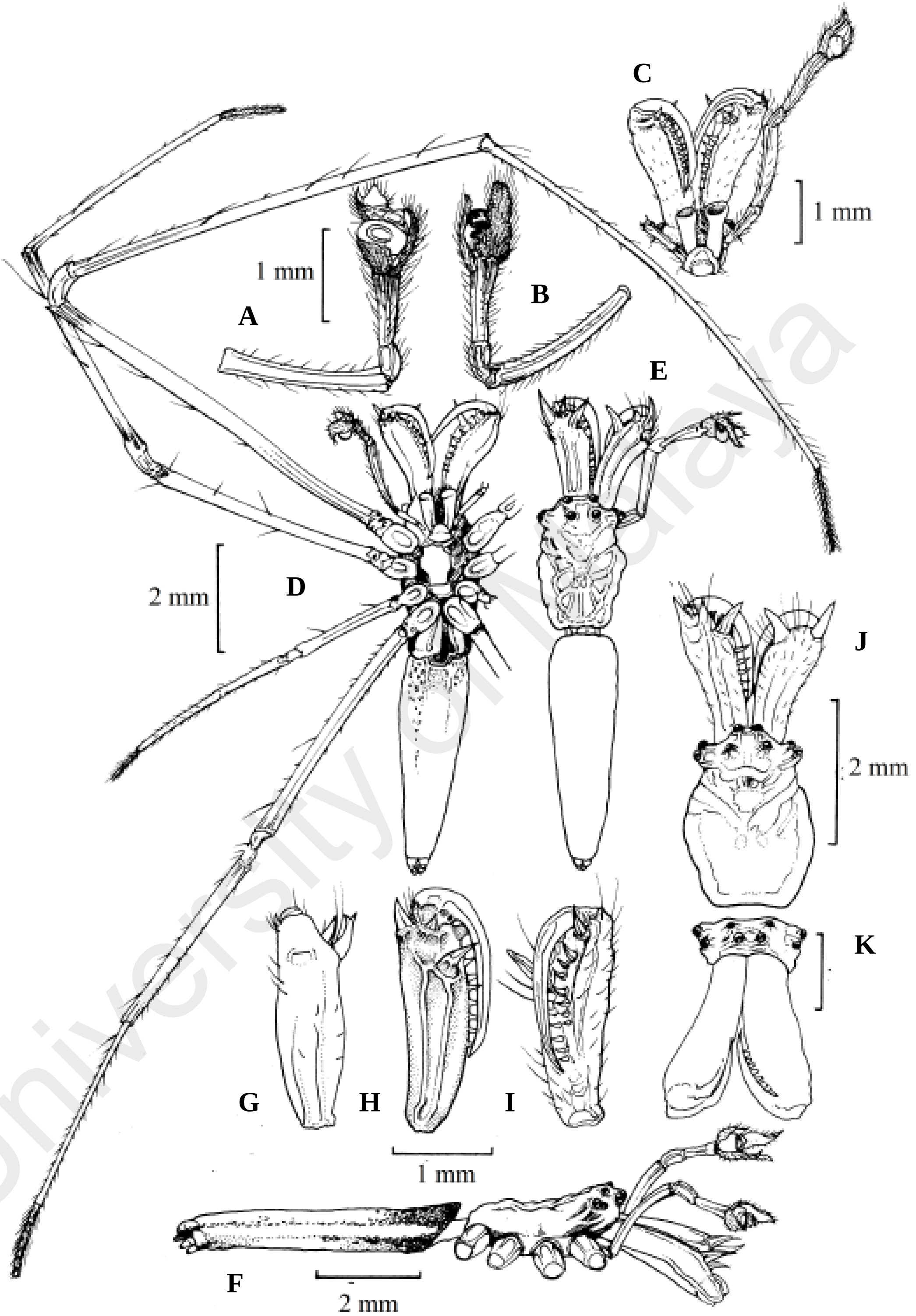

Figure 4.22: *Tetragnatha pinicola* (♂). Left palp: (A) ventral view (B) retrolateral view; chelicerae: (C) ventral view; body: (D) ventral view, (E) dorsal view, (F) lateral view; right teeth: (G) lateral view, (H) ventral view, (I) dorsal view; eye pattern: (J) dorsal view, (K) ventral view.

Descriptions: Paratype female (KS050). **Carapace**: carapace longer than wide (approximately 38% longer than wide), light brown (Figure 4.23D; Figure 4.23E). **Eyes**: Lateral eyes loosely contiguous or almost so, Distance between PME slightly greater than between AME, PME size smaller than distance between them, AME distinctly smaller than PME (Figure 4.23G). **Chelicerae**: Chelicerae length shorter than carapace (chelicerae 40% length to carapace), promargin: series of 7 teeth, teeth length of U1 almost similar in length to U2, U1 separated from U2 by 10% chelicerae length, U1-U7 about the same in size, retromargin: series of 7 teeth, prominent tooth present, L1 longer than L2, L1 contiguous to L2, L2 to L7 decrease in size proximally, chelicerae fang short approximately 63% length of base, tapering to smooth point at the end of U7 and L4 (Figure 4.23A; Figure 4.23B). **Abdomen**: carapace length is 37% to abdomen, browner abdomen compared to its carapace (Figure 4.23F). **Spinneret**: Spinneret at end tip of abdomen (not ventral), end point of spinneret exceed the tip of abdomen (Figure 4.23C). **Legs:** legs formula I-II-IV-III, legs without banded, legs with long spines which are two times leg width, Leg I: femur I with 6-8 spines, tibia I with 6-8 spines, Leg II: femur II with 6-8 spines, tibia II with 6-8 spines, Leg III: femur III with 1-3 spines, tibia III with 1-3 spines, Leg IV: femur IV with 1-3 spines, tibia IV with 5-7 spines. **Epigyne**: Illustrated on Figure 126F, p226, Song *et al*. (1999).

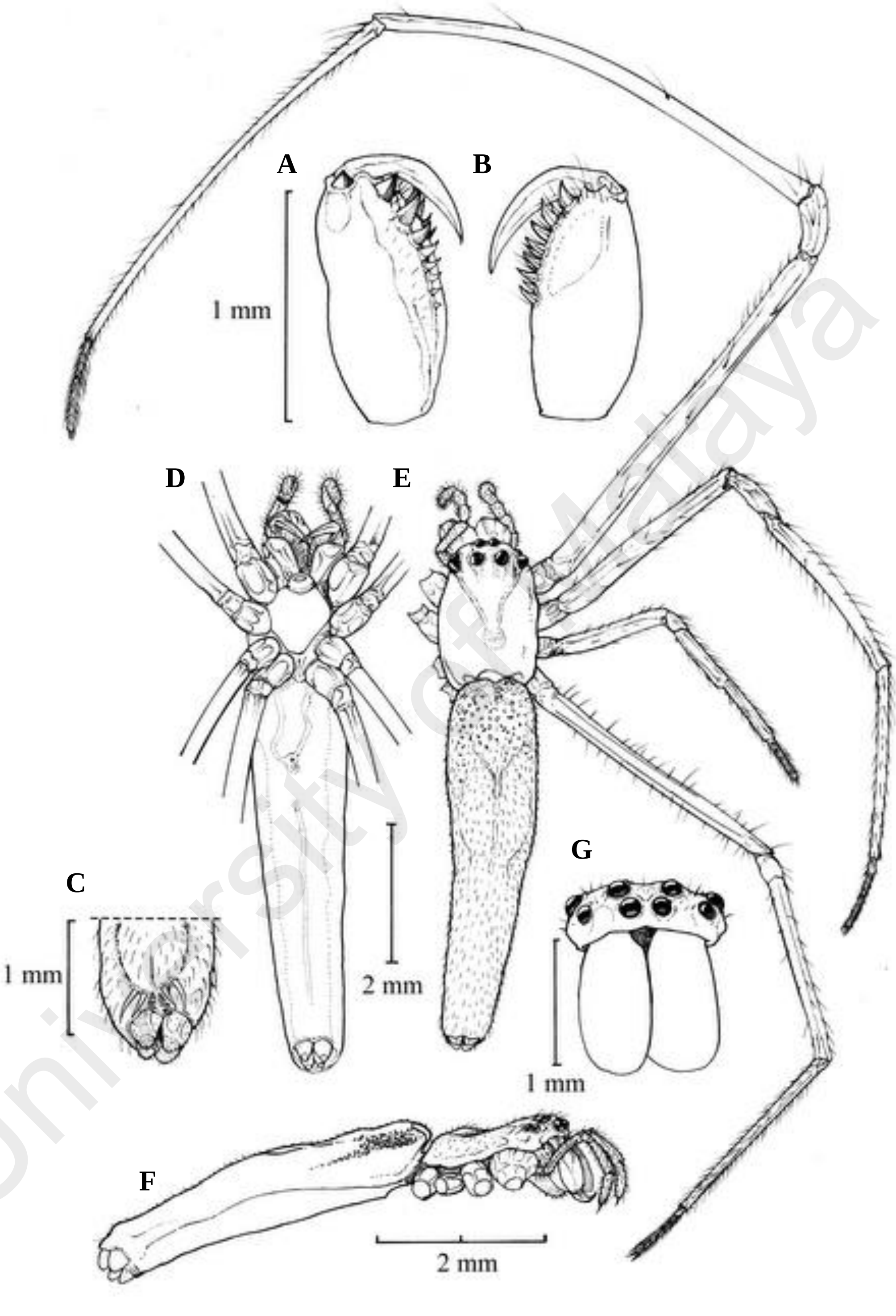

Figure 4.23: *Tetragnatha pinicola* (♀). Right teeth: (A) ventral view, (B) dorsal view; (C) spinnerets; body: (D) ventral view, (E) dorsal view, (F) lateral view; eye pattern: (G) frontal view.

TYLORIDA Simon, 1894

The genus *Tylorida* is characterized by the presence of **single** smooth trichobothria shaft on each femur I-IV (Barrion & Litsinger, 1995). There are 10 recognized species that can be found in the tropical region in the world (World Spider Catalog, 2016) with at least 3 species that had been recorded in the South East Asian countries: *T. tianlin* (Zhu, Song & Zhang, 2003) including 2 species that had been recorded from Malaysia which are *T. striata* (Thorell, 1877) and *T. ventralis* (Thorell, 1877). The present study collected three species which are *T. striata*, *T. tianlin* and *T. ventralis*.

Key to the *Tylorida* species

1. Abdomen elongated and triangular-like, adult body size 6 mm or more………*T. ventralis*
   Abdomen oval or square-like, adult body size less than 6 mm……………………….....2

2. PME diameter more than AME, clypeus height more than two times AME…….*T. striata*
   PME diameter less than AME, clypeus height less than two times AME……….*T. tianlin*

Tylorida striata Thorell, 1877

Figure 4.24: *Tylorida striata* (♀).

Closest species for comparison: *T. tianlin* Zhu, Song & Zhang 2003

Diagnosis: (1) *T. striata* have square-like shape abdomen while *T. tianlin* have oval shape abdomen (2) *T. striata* have clypeus height more than two times AME while *T. tianlin* have clypeus height less than two times AME.

Illustrations / photographs: Figure 4.24; p265, Koh & Ming (2013)

Synonymy: *Meta striata* (Thorell, 1877; Hasselt 1882); *Argyroepeira bigibba* (Thorell, 1887); *Argyroepeira striata* (Thorell, 1887; Workman & Workman, 1894); *Tylorida magniventer* (Bosenberg & Strand, 1906); *Sternospina concretipalpis* (Schmidt & Krause, 1993a); *Tylorida stellimicans* (Simon, 1885)

Distributions: Malaysia, Brunei, Indonesia, Laos, Myanmar, Singapore, Thailand, Vietnam, Philippines, New Guinea, China, Taiwan, Japan, Australia

Habitats: grassy areas in open areas, lowland dipterocarp forest, forest fringe

Specimens examined: 6 adults (1♂, 5♀) and 2 sub-adults (2♀) from L4 and L8

Descriptions: Paratype male (CRP040). **Carapace**: carapace is light-orange in colour, longer than it is wide (approximately 57% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area, two light-brown colour line along the center of carapace from the eyes toward the abdomen, the heart-shape sternum is light-brown in colour and it is longer than wide in length. **Eyes**: diameters AME 0.09, ALE 0.08, PME 0.09, PLE 0.08; inter-distances AME-AME 0.09, AME-ALE 0.09, PME-PME 0.11, PME-PLE 0.09, PLE-PLE 0.02, AME-PME 0.11; clypeus high 0.18; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE strongly recurved, PE recurved, PME size is similar to AME, AME surrounded with black colour marking, distance between PME-PME slightly greater than between AME-AME, PME size slightly shorter than the distance between them, AME size one times the distance between them, distance between PME-PLE are one time the PME eye size, distance between AME-ALE are one times the AME eye size, distance between AME-PME about the distance between PME-PME, clypeus height two times the AME size. **Abdomen**: square-like shape abdomen is upright and does not overhang carapace, abdomen is brown in colour with some silvery white marking patterns covering the abdomen. **Chelicerae**: promargin with 3 teeth, retromargin with 5 teeth. **Spinnerets**: tip of spinnerets pointing straight downward. **Legs**: legs formula I-II-IV-III, legs are yellowish-green in colour with no annulations, legs with long spines which are two times leg width, leg I: femur with 1-3 spines, tibia I with 6-8 spines, leg II: femur II with 1-3 spines, tibia II with 6-8 spines, leg III: femur III with 1-3 spines, tibia III with 6-8 spines, leg IV: femur IV with 1-3 spines, tibia IV with 6-8 spines. **Palp**: Palpal patella without macrosetae, palp femur is very long which is four times longer than its width, paracymbium shorter than half the cymbium length, curved and with the distal margin swollen, embolus base is longer than wide and is rectangular, spermathecae ducts with more than five coils and turns (Alvarez-Padilla, 2008), illustrated on p153, Tanikawa (2004).

Descriptions: Paratype female (UKM033). **Carapace**: carapace is light-orange in colour, longer than it is wide (approximately 38% longer than wide), two light-brown colour line along the center of carapace from the eyes toward the abdomen, cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area, the heart-shape sternum is light brown in colour and it is longer than it is wide in length. **Eyes**: diameters AME 0.09, ALE 0.08, PME 0.11, PLE 0.08; inter-distances AME-AME 0.07, AME-ALE 0.11, PME-PME 0.10, PME-PLE 0.12, PLE-PLE 0.02, AME-PME 0.12; clypeus high 0.18; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE strongly recurved, PE recurved, AME surrounded with black colour marking, PME size larger than PME, distance between PME greater than between AME, PME size one times the distance between them, AME size one times the distance between them, distance between PME-PLE are one time the PME eye size, distance between AME-ALE are one times the AME eye size, distance between AME-PME about the distance between PME-PME, clypeus height two times the AME size. **Abdomen**: square-like shape abdomen is upright and does not overhang carapace, the abdomen is brown in colour with some silvery white marking patterns covering the abdomen. **Chelicerae**: promargin with 3 teeth, retromargin with 5 teeth. **Spinnerets**: spinnerets pointing straight downward. **Legs**: legs formula I-II-IV-III, legs are yellowish-green in colour with no annulations, legs with long spines which are two times leg width, leg I: femur with 1-3 spines, tibia I with 6-8 spines, leg II: femur II with 1-3 spines, tibia II with 6-8 spines, leg III: femur III with 1-3 spines, tibia III with 6-8 spines, leg IV: femur IV with 1-3 spines, tibia IV with 6-8 spines. **Epigyne**: Spermathecae walls weakly sclerotized, copulatory and fertilization ducts coiled, but longer than the spermathecae length (Alvarez-Padilla, 2008), illustrated on p153, Tanikawa (2004).

Tylorida tianlin Zhu, Song & Zhang 2003

Closest species for comparison: *T. ventralis* (Thorell 1877)

Diagnosis: (1) *T. tianlin* AME diameter more than PME while *T. ventralis* have AME diameter less than PME (2) *T. tianlin* have oval abdomen while *T. ventralis* have triangular-like abdomen.

Illustrations / photographs: p9401, Anonymous (2011)

Synonymy: none.

Distributions: Malaysia, China, Laos

Habitats: montane oak forest, lowland dipterocarp forest, dipterocarp forest

Materials examined: 6 adults (1♂, 5♀) from L5, L9 and L10

Descriptions: Paratype male (MR035). **Carapace**: carapace is light-brown in colour, carapace is longer than it is wide (approximately 30% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area (Figure 4.25B; Figure 4.25C), no fovea in shallow groove, two pit absent, dark-brown colour line along the center of carapace from the eyes toward the abdomen, the heart-shape sternum is dark-brown in colour and is longer than it is wide in length (Figure 4.25D). **Eyes**: eye measurements: diameters AME 0.11, ALE 0.10, PME 0.10, PLE 0.10; inter-distances AME-AME 0.10, AME-ALE 0.10, PME-PME 0.10, PME-PLE 0.10, PLE-PLE 0.02, AME-PME 0.10; clypeus high 0.10; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE recurved, PE procurved, PME size slightly smaller than AME, distance between PME-PME similar to AME-AME, PME size one times the distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME size, distance between AME-PME are about one time the PME size, clypeus height about one times the AME size (Figure 4.25A). **Chelicerae**: promargin with 4 teeth, retromargin with 4 teeth. **Abdomen**: oval abdomen is elongated and does not overhang carapace, the abdomen is light-brown in colour, with black-markings on the dorsal at the half end of the abdomen. **Spinnerets**: spinnerets at ventral tip of abdomen, spinnerets pointing downward and exceed the end of the abdomen. **Legs**: legs formula I-II-IV-III, legs are light-brown in colour with dark-brown annulations, legs with long spines which are one and a half times leg width, Leg I: femur I with 1-3 spines, tibia I with 4-6 spines; Leg II: femur II with 1-3 spines, tibia II with 1-3 spines; Leg III: femur III with 1-3 spines, tibia III with 1-3 spines; Leg IV: femur IV with 4-6 spines, tibia IV with 4-6 spines. **Palp**: As shown in Figure 4.25E and Figure 4.25F, illustrated on p9401, Anonymous (2011).

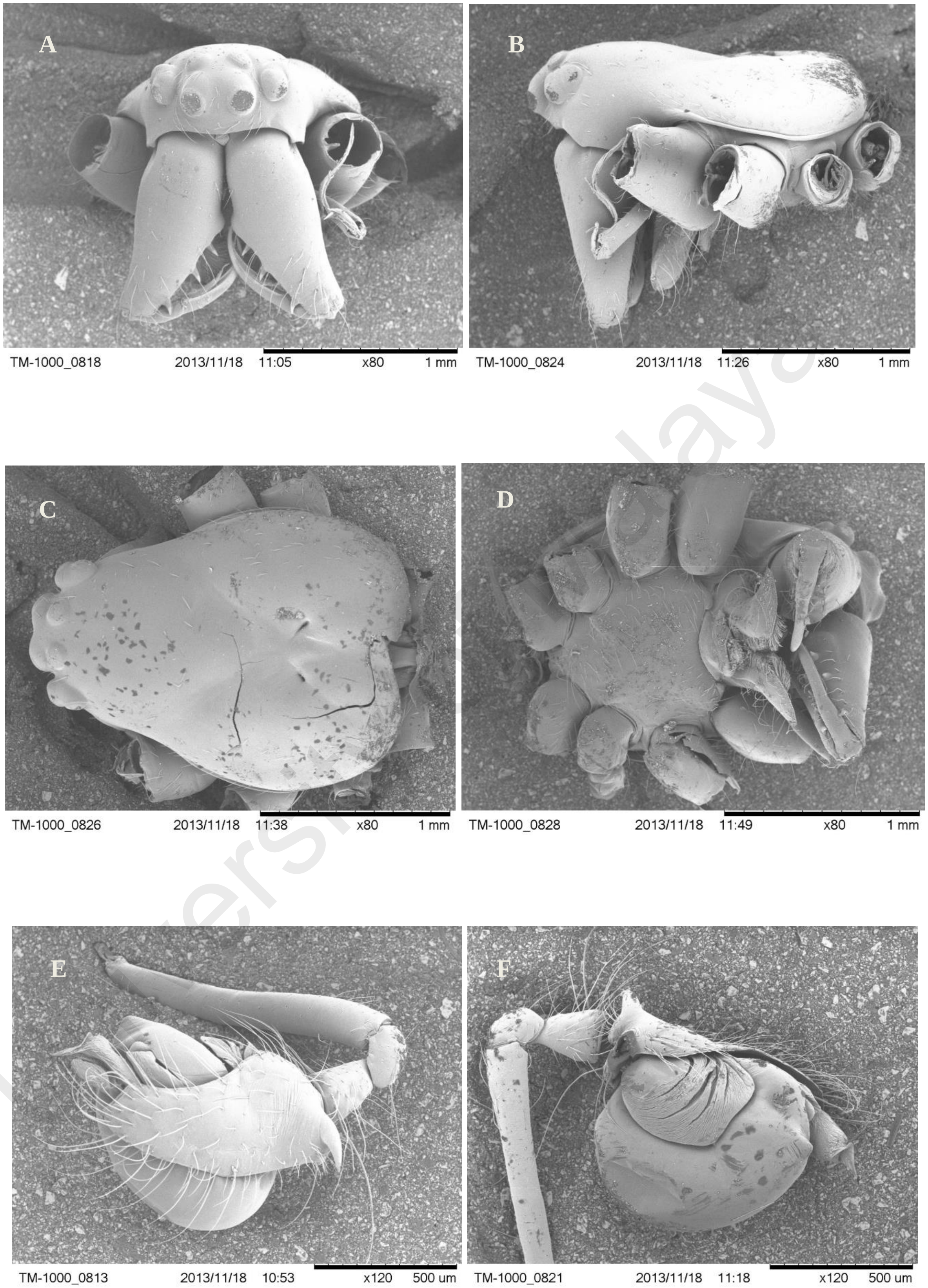

Figure 4.25: *Tylorida tianlin* (♂). Eye pattern: (A) frontal view; carapace: (B) lateral view, (C) dorsal view, (D) ventral view; palp: (E) retrolateral view, (F) ventral view.

Descriptions: Paratype female (MR036). **Carapace**: carapace is light-brown in colour, carapace is longer than it is wide (approximately 36% longer than wide), cephalic area markedly narrower than thoracic area, cephalic area higher in height to thoracic area, no fovea in shallow groove, two pit absent, dark-brown colour line along the center of carapace from the eyes toward the abdomen, the heart-shape sternum is dark-brown in colour and is longer than it is wide in length (Figure 4.26B; Figure 4.26C). **Eyes**: black markings surrounding the eyes, eye measurements: diameters AME 0.11, ALE 0.10, PME 0.10, PLE 0.10; inter-distances AME-AME 0.10, AME-ALE 0.10, PME-PME 0.10, PME-PLE 0.10, PLE-PLE 0.02, AME-PME 0.10; clypeus high 0.10; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE recurved, PE procurved, PME size is smaller than AME, distance between PME-PME similar to AME-AME, PME size one time the distance between them, AME size one times the distance between them, distance between PME-PLE are about one time the PME size, distance between AME-PME are about one time the PME size, clypeus height about one times the AME size (Figure 4.26A). **Chelicerae**: promargin with 4 teeth, retromargin with 4 teeth. **Abdomen**: oval abdomen is elongated and does not overhang carapace, the abdomen is light-brown in colour, with black-markings on the dorsal at the half end of the abdomen (Figure 4.26D; Figure 4.26E). **Spinnerets**: spinnerets at ventral tip of abdomen, spinnerets pointing downward and exceed the end of the abdomen. **Legs**: legs formula I-II-IV-III, legs are light-brown in colour with dark-brown annulations, legs with long spines which are one and a half times leg width, Leg I: femur I with 1-3 spines, tibia I with 4-6 spines; Leg II: femur II with 1-3 spines, tibia II with 1-3 spines; Leg III: femur III with 1-3 spines, tibia III with 1-3 spines; Leg IV: femur IV with 4-6 spines, tibia IV with 4-6 spines. **Epigyne**: Illustrated on p9401, Anonymous (2011).

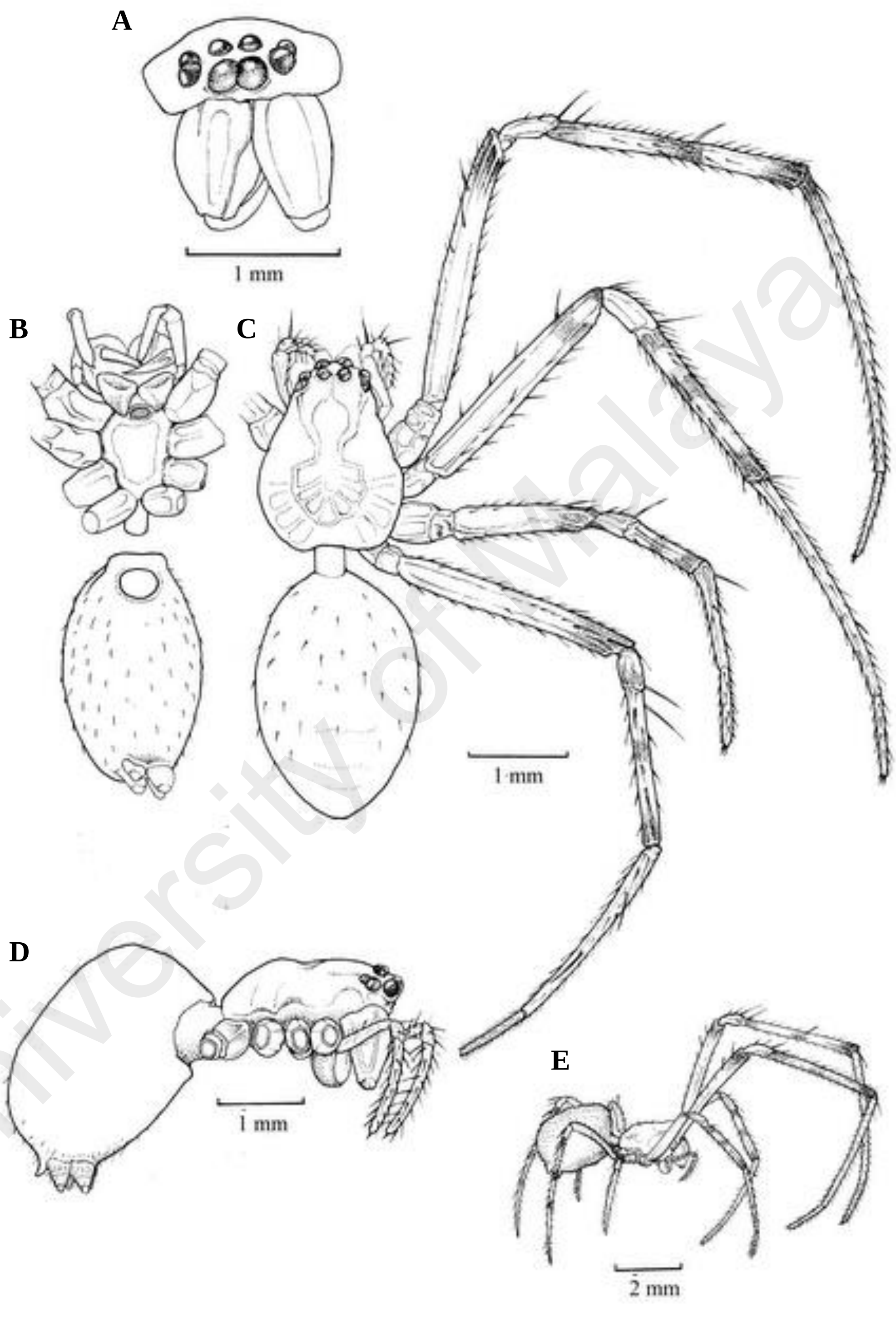

Figure 4.26: *Tylorida tianlin* (♀). Eye pattern: (A) frontal view; body: (B) ventral view, (C) dorsal view, (D) lateral view; abdomen: (E) lateral view.

Tylorida ventralis (Thorell, 1877)

Figure 4.27: *Tylorida ventralis* (♀).

Closest species for comparison: *T. cylindrata* (Wang 1991); *T. tianlin* Zhu, Song & Zhang 2003

Diagnosis: (1) *T. ventralis* have triangular-like abdomen while *T. tianlin* have oval abdomen. (2) *T. ventralis* have AME diameter less than PME while *T. tianlin* have AME diameter more than PME. (3) *T. ventralis* is twice smaller in total length than *T. cylindrata* (Tanikawa, 2004) (4) Male *T. ventralis* has conductor and embolus less projecting from cymbium than *T. cylindrata* (Tanikawa, 2004).

Illustrations / photographs: Figure 4.27; p266, Koh & Ming (2013)

Synonymy: *Meta ventralis* (Thorell, 1877); *Argyroepeira ventralis* (Thorell, 1887; Workman 1896); *Leucauge ventralis* (Pocock, 1904; Tikader, 1982a); *Anopas ventralis* (Archer, 1951a); *Leucauge sphenoida* (Wang, 1991a; Song, Zhu and Chen, 1999)

Distributions: Malaysia, Indonesia, Laos, Myanmar, Vietnam, Brunei, New Guinea, Sri Lanka, India, Taiwan, Japan, China

Habitat: heavily wooded garden (Koh & Ming, 2013), forest fringe, secondary forest, mangrove forest, hill forest, lowland dipterocarp forest

Specimens examined: 16 adults (2♂, 14♀) and 10 sub-adults (10♀) from L1, L2, L3, L4 and L7

Descriptions: Paratype male (UKM041). **Carapace**: carapace is light-brown in colour with dark brown marking vertically along the middle, connected to cephalic area which are covered in brown colour, carapace is longer than it is wide (approximately 32% longer than wide) (Figure 4.28B), cephalic area markedly narrower and about the same height to thoracic area, cephalic area almost even in height to thoracic area, longitudinal fovea in deep groove, two pit present (Figure 4.28C), the heart-shape sternum is dark-brown in colour and is slightly wider than it is long in length (Figure 4.28D). **Eyes**: eye measurements: diameters AME 0.12, ALE 0.12, PME 0.13, PLE 0.13; inter-distances AME-AME 0.13, AME-ALE 0.08, PME-PME 0.08, PME-PLE 0.06, PLE-PLE 0.01, AME-PME 0.13; clypeus high 0.16; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE and PE straight, PME size slightly larger than AME, distance between PME-PME shorter than between AME-AME, PME size one and a half time the distance between them, AME size one times the distance between them, distance between PME-PLE are about half time the PME size, distance between AME-PME are about the same distance to AME-AME, clypeus height about one times the AME size (Figure 4.28A). **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: elongated abdomen does not overhang the carapace, the ventral abdomen has vertical dark-brown line. **Spinnerets**: Spinnerets pointing backward and exceed the end of the abdomen, dark brown marking around the spinnerets. **Legs**: legs formula I-II-IV-III, legs are brown in colour with light-brown annulations, legs with long spines which are two times leg width, leg I: femur I with 6-8 spines, tibia I with 6-8 spines; leg II: femur II with 6-8 spines, tibia II with 6-8 spines; leg III: femur III with 4-6 spines, tibia III with 4-6 spines; leg IV: femur IV with 6-8 spines, tibia IV with 6-8 spines, two rows of short smooth trichobothria covering about half of prolateral femur IV, trichobothria one times femur IV width. **Palp**: Conductor and embolus less projecting from cymbium (Figure 4.28E; Figure 4.28F; Tanikawa, 2004), illustrated on p153, Tanikawa (2004).

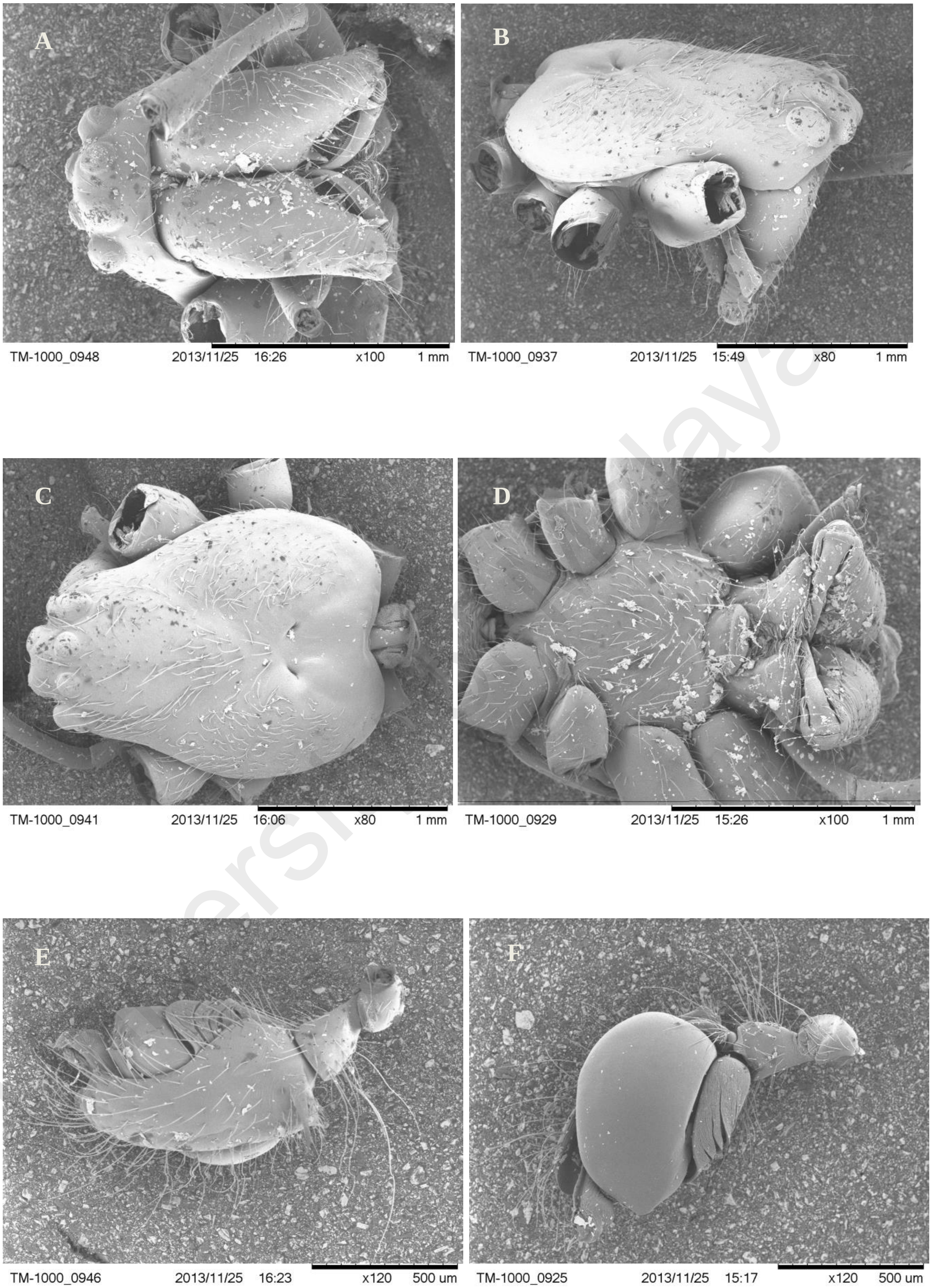

Figure 4.28: *Tylorida ventralis* (♂). Eye pattern: (A) frontal view; carapace: (B) lateral view, (C) dorsal view, (D) ventral view; palp: (E) retrolateral view, (F) ventral view.

Descriptions: Paratype female (KS053). **Carapace**: carapace is light-brown in colour with dark brown marking vertically along the middle, connected to cephalic area which are covered in brown colour, carapace is longer than it is wide (approximately 16% longer than wide), cephalic area markedly narrower and about the same height to thoracic area, cephalic area almost even in height to thoracic area, longitudinal fovea in deep groove, two pit present, carapace wider than abdomen, the heart-shape sternum is dark-brown in colour and slightly wider than it is long in length. **Eyes**: diameters AME 0.12, ALE 0.12, PME 0.13, PLE 0.13; inter-distances AME-AME 0.13, AME-ALE 0.08, PME-PME 0.08, PME-PLE 0.06, PLE-PLE 0.01, AME-PME 0.13; clypeus high 0.16; lateral eyes loosely contiguous or almost so, eight eyes in two rows, AE and PE straight, PME size slightly larger than AME, distance between PME-PME shorter than between AME-AME, PME size one and a half time the distance between them, AME size one times the distance between them, distance between PME-PLE are about half time the PME size, distance between AME-PME are about the same distance to AME-AME, clypeus height about one times the AME size. **Chelicerae**: promargin with 4 teeth; retromargin with 4 teeth. **Abdomen**: triangular-shape abdomen has hump at the end of the dorsal side of abdomen and do not overhang the carapace, vertical broad line dark-brown colour on the ventral side of abdomen. **Spinnerets**: Spinnerets pointing downward and does not exceed the end of the abdomen, dark brown marking around the spinnerets. **Legs**: legs formula I-II-IV-III, legs are brown in colour with light-brown annulations, legs with long spines which are two times leg width, leg I: femur I with 6-8 spines, tibia I with 6-8 spines; leg II: femur II with 6-8 spines, tibia II with 6-8 spines; leg III: femur III with 4-6 spines, tibia III with 4-6 spines; leg IV: femur IV with 6-8 spines, tibia IV with 6-8 spines, two rows of short smooth trichobothria covering about half of prolateral femur IV, trichobothria one time femur IV width. **Epigyne**: simple, less sclerotized, Illustrated on p153, Tanikawa (2004).

4.4 DISCUSSION

The tetragnathid spiders of Malaysia from the two largest states (Sabah and Sarawak) in Borneo were successfully compiled. Currently there are seven genera that had been recorded in Malaysia which include *Dyschiriognatha*, *Leucauge*, *Mesida*, *Opadometa*, *Orsinome*, *Tetragnatha* and *Tylorida* (Norma-Rashid & Li, 2009; Koh *et al*., 2013. However, some species from these genera were not managed to be recorded in the present study although they had been recorded elsewhere in Malaysia. For instance, *Dyschiriognatha* sp. had been recorded in Sarawak (Koh *et al*., 2013), while *Orsinome* sp. had been recorded in Peninsular Malaysia (Norma-Rashid & Li, 2009). Factors such as the microhabitat selection, web building behaviours and their cryptic lifestyles made it rather challenging to encounter some of these tetragnathid species. For example, *Dolichognatha* species build horizontal orb-webs with hanging debris suspended by vertical lines (Koh & Ming, 2013), near tree buttresses and roots near the ground (Alvarez-Padilla, 2008). Meanwhile, *Orsinome* species preferred building orb-webs on vegetation overhanging forest streams (Koh & Ming, 2013). This study only managed to document about 35% of total recorded *Tetragnatha* species in this country. Most *Tetragnatha* species occurred in moist environments, or near water reservoirs. Then again, within the South East Asian countries, *Orsinome phrygiana* and *Tetragnatha lineatula* had only been recorded in Peninsular Malaysia. Likewise, *Leucauge granulata* and *L. quadrifasciata* were only recorded in Peninsular Malaysia and Indonesia (Norma-Rashid & Li, 2009; World Spider Catalog, 2016). The poorly known species, *Dyschiriognatha bedoti* had only been recorded in Sarawak (Koh *et al*., 2013). However, there is no recent information with regards to these species, although Alvarez-Padilla (2008) noted that *L. granulata* was abundant in museum collections.

This study provides the dichotomous keys and data matrix comprising fourteen morphological characters that can be very useful to determine tetragnathid species. From the morphological diagnosis, this study identified that *Leucauge* and *Opadometa* species share many similar features, as well as in *Mesida* and *Tylorida*, although the members from the genus *Tetragnatha* is considered very distinct morphologically. The genus *Leucauge* and *Opadometa* were initially grouped together and was later separated (Archer, 1951). The synapomorphies of the genera *Leucauge* and *Opadometa* are that (1) the number of trichobothria on the femur of leg IV is more than 10 pairs (2) five chelicerae teeth on promargin and (3) epigynum is strongly sclerotized (Tanikawa, 2001). The main morphological characteristic that separates the genus *Opadometa* from other genera is the presence of dense brush of hair on the tibia of leg IV. However, there are several *Leucauge* species (i.e. *L. tessellata*, *L. taiwanica*) that also have dense brushes of hair on tibia IV (Yoshida, 2009). As the genus *Opadometa* had never been revised, Yoshida (2009) treated the *Opadometa* as *Leucauge*. From six *Leucauge* and two *Opadometa* species collected in the present study, four synapomorphies were identified in the former genera, (1) two rows of trichobothria on femur IV (2) lateral eyes continues (3) clypeus height is less than two times AME and (4) have short chelicerae. The only morphology that separates the genus *Leucauge* and *Opadometa* species is the distance between PME-PME and AME-AME.

The genus *Mesida* and *Tylorida* are very closely related and share many morphological characteristics. The synapomorphies for the genus *Mesida* and *Tylorida* are (1) the number of trichobothria is less than 10 pairs (2) female with four chelicerae teeth on promargin (3) epigynum is weakly sclerotized (Tanikawa, 2001) and (4) male chelicerae is proportionally larger than the female chelicerae (Alvarez-Padilla, 2008). Still, the only morphological characteristic that separates *Mesida* from *Tylorida* species is the presence of spur on anterior surface of the male chelicerae (Tanikawa, 2001). From the two *Mesida* and three *Tylorida* species collected in the present study, four synapomorphies were identified in both *Mesida* and *Tylorida* species, (1) ratio between carapace and abdomen length is more than 50% (2) absence of dense brush of hair on leg IV (3) lateral eyes well separated and (4) have short chelicerae. The only morphological characteristic that separates the species in the genus *Mesida* and *Tylorida* is the number of row of the trichobothria.

Based on the previous and present studies, different spider taxonomists use different sets of species for morphological comparison (e.g. Tanikawa, 2001; Alvarez-Padilla, 2008). This study has identified and suggested select morphological characters of the most similar tetragnathid species with the collected specimens for diagnoses. The information gathered in this study could also be used for other tetragnathid species found in other parts of South East Asian countries.

CHAPTER 5

PHYLOGENETICS RELATIONSHIPS OF TETRAGNATHID SPIDERS (ARANEAE, TETRAGNATHIDAE) IN MALAYSIA INFERRED FROM PARTIAL SEQUENCES OF THE COI AND 18S rRNA GENES

5.1 INTRODUCTION

The long-jawed, orb-weaver, spider family Tetragnathidae, contains 47 genera (World Spider Catalog, 2016) with at least 967 species throughout the world. There are three subfamilies, namely Leucauginae Caporiacco 1955, Metainae, and Tetragnathinae Menge, 1866. The genus *Tetragnatha* Latreille 1804, is the genus type of this family (Alvarez-Padilla *et al*., 2009). Members from this family are diverse in morphological and behavioural characteristics. Many of these characteristics are homoplasius to Araneidae and Nephilidae (Griswold *et al*., 1998; Alvarez-Padilla & Hormiga, 2011). The morphological features within the family vary significantly, and some are distinguishable from the typical tetragnathid morphology. The body lengths of tetragnathids range between 2-23 mm. The Tetragnathid spiders' choice of habitats in the tropical and subtropical ecosystems are highly diverse - including in low vegetation areas, in tree buttresses, at cave entrances, and near waterways (e.g. rivers, ponds) (Alvarez-Padilla, 2008; Dzulhelmi *et al.*, 2014a; Dzulhelmi *et al*., 2014b). However, some species have been found confined to specific habitats only (e.g. caves, mangroves) (Koh & Ming, 2013).

Malaysia is occupied by many tetragnathid species in the tropical rainforests of Southeast Asian countries (Barrion & Litsinger, 1995; Murphy & Murphy, 2000; Song *et al*., 2002; Jager, 2007; Jager & Praxaysombath, 2009; Jager & Praxaysombath, 2011; Jager *et al*., 2012; Koh & Ming, 2013). Currently, there are, reportedly, at least six genera, representing 34 species, in Malaysia. From these, six genera with 20 species are found in the Peninsular (Norma-Rashid & Li, 2009; Dzulhelmi *et al*., 2014a), eight genera with eight species in Sarawak (Koh *et al*. 2013), and two genera with four species in Sabah (Dzulhelmi *et al*., 2014b). Two known subfamilies, Leucauginae and Tetragnathinae, is also found in Malaysia. Leucauginae is characterized by specific modifications in the female genital system, such as a weakly sclerotized spermathecal wall (Alvarez-Padilla *et al*., 2009). This distinctively identifiable female physical characteristic has been extensively examined, and has been established to be confined to species from the genera *Leucauge*, *Opadometa, Mesida* and *Tylorida*. On the other hand, the Tetragnathinae's distinguishing characteristic is its lack of a sclerotized plate and fertilization ducts, where only the copulatory ducts are found to be present (Alvarez-Padilla *et al*., 2009). In Malaysia, *Tetragnatha* is the only genus represented in this subfamily.

The phylogenetic relationships of tetragnathid species from different parts of the world have been well-studied (i.e. Levi, 1980; Hormiga *et al*., 1995; Pan *et al*., 2004; Blackledge *et al*., 2009; Alvarez-Padilla *et al*., 2009; Dimitrov & Hormiga, 2011). The studies used combination sets of different markers to identify the relationships between the studied species. Unfortunately, until today, the genetic data on the Malaysian tetragnathid species is still unknown due to the absence of any record. Therefore, for the purpose of conducting this molecular study, with time and money as the constraining factors (Astrin *et al*., 2006), it is important to determine which single marker would be best suited to be used for taxonomic identification purposes (e.g. Fang *et al*., 2000; Astrin *et al*., 2006).

The objective of this study is to determine the genes compatibility for 17 Malaysian tetragnathid species, with special focus on delineating members of the subfamilies Leucauginae (*Leucauge*, *Opadometa*, *Mesida* and *Tylorida*) and Tetragnathinae

(*Tetragnatha*). The mitochondria-encoded cytochrome oxidase I (COI) and the nuclear-encoded 18S rRNA (18S) genes were analyzed independently, and the results were further cross-examined in association with morphological characteristics of the regional tetragnathid species. The genetic information derived from the results of this in-depth molecular level research could be highly useful for species identification and taxonomic verification purposes of the Malaysian tetragnathid.

5.2 MATERIALS AND METHODS

5.2.1 DNA EXTRACTION, POLYMERASE CHAIN REACTION AND SEQUENCING

Tetragnathid spiders collected were preserved in individual jars containing 70% ethanol and stored in -20°C for identification and DNA extraction respectively. Two or more legs (depending on spider size) were rinsed several times with distilled water and transferred into a 1.5 mL microcentrifuge tube containing lysis buffer. The legs were homogenized in liquid nitrogen for at least five minutes. Proteinase K was added and incubated overnight at 65^{o}C water bath. On the next day, Proteinase K was deactivated by heating the sample at 95^{o}C for 10 minutes. Genomic DNA was extracted using Qiagen DNeasy Tissue Kits according to the manufactured procedures.

5.2.2 AMPLIFICATION OF THE MITOCHONDRIAL COI GENE

The universal forward primer LCOI1490 (3’-GGTCAACAAATCATAAAGATATTGG-5’) and reverse primer HCOI2198 (3’-TAAACTTCAGGGTGACCAAAAAATCA-5’) (Alvarez-Padilla, 2008) were used to amplify the COI region. The initial denaturation of amplification was set at 94^{o}C for 2 minutes followed by 94^{o}C for 20 seconds, 50^{o}C for 35 seconds, 65^{o}C for 30 seconds for a total of 34 cycles, and final extension at 72^{o}C for 3 minutes. Amplification products were viewed on a pre-casted agarose gel with Ethidium Bromide under ultra-violet illumination. The products were sent for purification and sequencing at Genomics Bioscience and Technology Co. Ltd.

5.2.3 AMPLIFICATION OF THE NUCLEAR 18S GENE

Full length 18S region was amplified with the universal primer set 18Sa (3'-ATTAAAGTTGTTGCGGTTA-5') and 9r (3'-GATCCTTCCGCAGGTTCACCTAC-5') (Alvarez-Padilla, 2008). Total reaction volume of 50 µL consists of 10µL of dH_2O, 5µL for each primer, 25µL of master mix (Lucigen, USA) and 5µL of DNA template. 'Touchdown' condition for the PCR reaction was set at 94°C for 2 minutes as the initial denaturation, followed by 94°C for 20 seconds, 60°C for 35 seconds, 65°C for 30 seconds, for 13 cycles. The remaining 21 cycles were set at 94°C for 15 seconds, 48°C for 35 seconds, 65°C for 30 seconds and final extension at 72°C for 3 minutes.

5.2.4 MULTIPLE ALIGNMENT AND SEQUENCE ANALYSES

The electophoragrams of each forward and reverse sequence were checked manually and assembled using BioEdit Sequence Alignment Editor Version 7.0.5 (Hall, 2005). The reverse sequences were set to reverse complement, grouped together with the forward sequences, aligned together using the pairwise alignment (optimal GLOBAL alignment), mismatched base pairs were edited with accordance to the accompanying electrophoragrams and saved as FASTA files. Then, all 'cleaned' sequences for tetragnathid species with two out-group sequences obtained from genbank were saved as into one file in FASTA format. Multiple alignments of the sequences were performed using Clustal X version 1.81 (Thompson *et al.*, 1997) and saved in NEXUS format. The length of the COI and 18S sequences was 625 bp and 930 bp, respectively.

The COI and 18S rRNA sequences obtained from this study were deposited in the National Center for Biotechnology Information (NCBI) GenBank DNA sequence database

(Table 5.1). The Leucauginae subfamily was represented by the genera *Leucauge* (five out of six species), *Opadometa* (two out of three species), *Mesida* (two out of two species) and *Tylorida* (three out of four species). The Tetragnathinae subfamily was represented by the genus *Tetragnatha* (five out of 16 species). *Larinioides cornutus* and *Gasteracantha cancriformis* for COI, and *Gasteracantha kuhlii* and *Cyclosa conica* for 18S were used as outgroups (Table 5.1).

5.2.5 PHYLOGENETIC ANALYSES

Phylogenetic trees based on maximum parsimony (MP) and Maxinum Likelihood (ML) analyses were reconstructed using (PAUP) software version 4.0 (Swofford, 2003). For ML analysis, the best model was computed using Modeltest3.7 (Posada & Crandall, 1998). However, as PAUP was not able to obtain satisfactory result for ML analysis, the best model was then computed using PhyML 3.0 (Guindon *et al*., 2010). The phylogenetic trees suggested by Akaike Information Criterion (AIC) were reconstructed using HKY85 and GTR model for COI and 18S respectively. Pairwise genetic distance and NJ of both COI and 18S were performed using Kimura-two-parameter model. Full heuristic search was used for the MP analysis. The tree reliability was estimated by bootstrapping with 1000 replications of data sets for MP, and 100 replications for ML methods. Bayesian Inference (BI) analysis using four chains of Markov chain Monte Carlo (MCMC) with four hundred thousand, and six hundred and seventy five thousand MCMC generations was performed for COI and 18S respectively in MrBayes version 3.1.2 (Ronquist & Huelsenbeck, 2003).

i. The analysis for each respective method using the PAUP software was keyed as follows:

a. Neighbor-joining (NJ):

```
begin paup; log start file=NJ.log; outgroup 34 35; set criterion=distance increase=auto; dset
distance=K2P; NJ treefile=NJ.tre; set autoclose=yes; bootstrap nreps=1000 search=NJ
treefile=NJBt.tre; log stop; end
```

b. Maximum Parsimony (MP):

```
begin paup; log start file=MP.log; set criterion=parsimony; set autoclose=yes; set
storebrlens=yes; set root=outgroup; outgroup 34 35; set increase=auto; bootstrap
nreps=1000 treefile=ML.tree search=heuristic/ addseq=random nreps=10 swap=tbr hold=1;
savetrees from=1 to=1 file=COI/18S.cb.pa.tree.nex format=altnex brlens=yes
savebootp=nodelabels maxdecimals=0; end;
```

c. Genetic distance

```
Begin paup; dset distance=p; showdist; savedist format=nexus file=P_dist.nex; dset
distance=p; showdist; savedist format=onecolumn file=P_dist1.txt; end;
```

d. Maximum Likelihood (ML):

```
For COI: begin paup; log start file=ML.log; set autoclose=yes; set criterion=likelihood; set
root=outgroup; outgroup 34 35; set storebrlens=yes; set increase=auto; Lset  Base=(0.2762
0.0815 0.1706) Nst=2 TRatio=4.5831 Rates=gamma Shape=0.5107 Pinvar=0.4891;
```

```
bootstrap nreps=100 search=heuristic / addseq=random swap=tbr hold=1; savetrees from=1
to=1 file=COIML.cb.mlb.tree.nex format=altnex brlens=yes savebootp=nodelabels
MaxDecimals=0; log stop; end;
```

For 18S:

```
begin paup; log start file=ML.log; set autoclose=yes; set criterion=likelihood; set
root=outgroup; outgroup 34 35; set storebrlens=yes; set increase=auto; Lset Base=(0.2586
0.2200 0.2714) Nst=6 Rmat=(1.0000 2.0643 1.0000 1.0000 4.6308) Rates=gamma
Shape=0.6043 Pinvar=0.5402; bootstrap nreps=100 search=heuristic / addseq=random
swap=tbr hold=1; savetrees from=1 to=1 file=18SML.cb.mlb.tree.nex format=altnex
brlens=yes savebootp=nodelabels MaxDecimals=0; log stop; end;
```

ii. Executing Modeltest 3.7

The ‘modeltest3.7 folder’ was renamed as ‘modeltest3.7’ and copied into the new folder. Then, multiple sequence alignments that were saved as NEXUS were also copied into the new folder. The ‘COI/18S.nxs’ was executed in PAUP software respectively. Next, ‘modeltest3.7/paupblock/modelblockPAUPb10’ was executed in PAUP software. Once completed, a file named ‘model.scores’ was created inside ‘modeltest3.7>paupblock>model.scores’, and renamed as ‘COI/18S.scores’, copied and paste into the ‘modeltest3.7>bin’. The next step proceeded with the start ‘menu>all programs>accessories>command prompt’. When command prompt was opened, cd was typed, followed by drag-and-drop the ‘bin’ file onto the command prompt, deleted the “ ” marks and entered. After that, the command ‘modeltest3.7.win<COI/18S.scores>COI/18Sfinal.modeltest’ was typed and entered. This step had created the new file inside the bin file. Then, the COI/18Sfinal.modeltest was viewed using notepad. The suggested model test and values can viewed under ‘Akaike Information Criterion (AIC)’. Copy and paste the value of the following: Lset Base, Nst, Rmat, Rates=gamma, Shape, Pinvar.

iii. Bayesian analysis of phylogeny: MrBayes v3.2.2 x86

The present study used the Bayesian analysis of phylogeny (MrBayes) software version 3.2.2 to obtain the posterior probability (Ronquist & Huelsenbeck, 2003; Ronquist *et al*., 2005). The command using MrBayes software was keyed as follows:

Execute filename.nex; lset nst=6 rates=invgamma; mcmc ngen=20000 (**until reach less than 0.01**); sump burnin=0.25; sumt burnin=0.25

iv. Model selection using PhyML

The multiple sequence alignments that was saved as PHY with ‘selection criterion’ (Akaike Information Criterion) was uploaded online at automatic model selection (www.atgc-montpellier.fr/phyml/). Perform bootstrap at 100 was selected for ‘branch support’ criteria. The criterias of the ‘substitution model’ were selected as follows:

Substitution model: HKY85; Equilibrium frequencies: optimized; Transition/transversion ratio (DNA models): estimated; Proportion of invariable sites: 0.489; Number of substitution rate categories: 6; Gamma shape parameter: 0.510

Table 5.1: Seventeen tetragnathid species, localities, coordinates and GenBank accession numbers of specimens examined in this study

Species	Localities	Coordinates	COI	18S
Leucauge argentina	Penang National Park, Pulau Pinang	5°26’16”N; 100°17’27”E	KU836866	KU836900
	Poring Hot Spring Nature Reserve, Ranau	6°2’35”N, 116°42’7”E	KU836869	KU836901
	Kubah National Park, Kuching	1°36’41”N, 110°11’44”E	KU836868	KU836899
	Gunung Gading National Park, Kuching	1°41’27”N, 109°50’45”E	KU836867	KU836898
Leucauge celebesiana	Poring Hot Spring Nature Reserve, Ranau	6°2’35”N, 116°42’7”E	KU836871	KU836903
	Mesilau National Park, Ranau	6°02’5”N, 116°54’1”E	KU836872	KU836904
	Kubah National Park, Kuching	1°36’41”N, 110°11’44”E	KU836870	KU836902
Leucauge decorata	Crocker Range National Park, Keningau	5°58’5”N, 116°08’2”E	KU836874	KU836905
	Crocker Range National Park, Keningau	5°58’5”N, 116°08’2”E	KU836873	KU836906
Leucauge sp.	Gunung Gading National Park, Kuching	1°41’27”N, 109°50’45”E	KU836875	KU836907
Leucauge tessellata	Ulu Gombak Field Studies Centre, Gombak	3°22’60”N, 101°47’20”E	KU836876	KU836909
	Ulu Gombak Field Studies Centre, Gombak	3°22’60”N, 101°47’20”E	KU836877	KU836908
Opadometa grata	Rimba Ilmu Botanical Garden, Kuala Lumpur	3°7’29”N; 101°39’12”E	KU836883	KU836915
Opadometa kuchingensis	Bako National Park, Kuching	1°41’8”N, 110°26’10”E	KU836884	KU836916
	Bako National Park, Kuching	1°41’8”N, 110°26’10”E	KU836882	KU836914
Mesida gemmea	Kubah National Park, Kuching	1°36’41”N, 110°11’44”E	KU836879	KU836910
	Gunung Gading National Park, Lundu	1°41’27”N, 109°50’45”E	KU836878	-
	Ulu Gombak Field Studies Centre, Gombak	3°22’60”N, 101°47’20”E	-	KU836911
Mesida yini	Universiti Kebangsaan Malaysia, Bangi	2°55’47”N, 101°46’44”E	KU836880	KU836912
	Universiti Kebangsaan Malaysia, Bangi	2°55’47”N, 101°46’44”E	KU836881	KU836913
Tetragnatha hasselti	Kubah National Park, Sarawak	1°36’41”N, 110°11’44”E	KU836891	-
	Kubah National Park, Sarawak	1°36’41”N, 110°11’44”E	-	KU836924
Tetragnatha lauta	Fraser Hill Forest Reserve, Raub	3°43’7”N, 101°44’25”E	KU836892	KU836925
Tetragnatha maxillosa	Fraser Hill Forest Reserve, Raub	3°43’7”N, 101°44’25”E	KU836893	KU836926
	Fraser Hill Forest Reserve, Raub	3°43’7”N, 101°44’25”E	KU836894	KU836927
Tetragnatha pinicola	Kuala Selangor Nature Park, Kuala Selangor	3°20’16”N, 101°14’56”E	KU836895	KU836928
	Kuala Selangor Nature Park, Kuala Selangor	3°20’16”N, 101°14’56”E	KU836896	KU836929
Tetragnatha sp.	Bako National Park, Kuching	1°41’8”N, 110°26’10”E	KU836897	KU836930
[1]*Tylorida striata*	Naratiwat Province, Thailand	5°47’45”N, 101°50’4”E	EU003309	-
	Universiti Kebangsaan Malaysia, Bangi	2°55’47”N, 101°46’44”E	-	KU836919
Tylorida tianlin	Mesilau National Park, Ranau	6°02’5”N, 116°54’1”E	KU836885	KU836917
	Mesilau National Park, Ranau	6°02’5”N, 116°54’1”E	KU836886	KU836918
Tylorida ventralis	Universiti Kebangsaan Malaysia, Bangi	2°55’47”N, 101°46’44”E	KU836889	KU836923
	Universiti Kebangsaan Malaysia, Bangi	2°55’47”N, 101°46’44”E	KU836890	KU836922
	Kuala Selangor Nature Park, Kuala Selangor	3°20’16”N, 101°14’56”E	-	KU836920
	Ulu Gombak Field Studies Centre, Gombak	3°22’60”N, 101°47’20”E	KU836888	-
	Fraser Hill Forest Reserve, Raub	3°43’7”N, 101°44’25”E	-	KU836921
	Bako National Park, Kuching	1°41’8”N, 110°26’10”E	KU836887	-
[2]*Larinioides cornutus*	Point Pelee, Ontario, Canada	Unstated	JN308507	-
[1]*Gasteracantha cancriformis*	Heredia province, Costa Rica	10°25’53”N, 84°00’13”W	EU003287	-
[3]*Gasteracantha kuhlii*		Unstated	-	AB910478
[1]*Cyclosa conica*	Mon Hunoso Lake, Denmark	Unstated	-	EU003343

[1]Alvarez-Padilla *et al.* (2009); [2]Blagoev *et al*. (2016); Tanikawa *et al*. (2014)

5.3 RESULTS

The phylogenetic analyses produced almost similar topology for COI (BI and ML analyses) and 18S (BI and MP analyses) but with different bootstrap support values. Both genes revealed two main monophyletic clades, corresponding to the Leucauginae and Tetragnathinae subfamilies. The Leucauginae clade formed two separate monophyletic subclade, one subclade consisted of members from the genera *Leucauge*-*Opadometa* group (*L. argentina*, *L. celebesiana*, *L. decorata*, *L. sabahan*. *L. tessellata*, *Opadometa grata* and *O. kuchingensis*), and the second subclade consisted of members from the genera *Mesida*-*Tylorida* group (*M. gemmea*, *M. yini*, *T. striata*, *T. tianlin* and *T. ventralis*). On the contrary, the Tetragnathinae clade consists of *Tetragnatha hasselti*, *T. lauta*, *T. maxillosa*, *T. pinicola* and *Tetragnatha* sp. which form a monophyletic clade corresponding to the genus *Tetragnatha*. Overall, both genes support the monophyly for all 17 studied species.

Both COI and 18S phylogenetic trees were comprised of two main monophyletic clades. One clade consisted of members of the subfamily Leucauginae with high bootstrap support (ML: 60%, MP: 75%). The second clade consisted of the subfamily Tetragnathinae with low and high bootstrap support (ML: 45%, MP: 100%) (Figure 5.1). The subfamilies Leucauginae and Tetragnathinae were supported with 0.91-0.94 and 0.77-1.00 posterior probability values respectively. Members from the *Leucauge*-*Opadometa* group were supported by 0.87-1.00 posterior probability value, while *Mesida*-*Tylorida* group was supported by 0.98-1.00 posterior probability value. The *Tetragnatha* group was supported by 0.77-1.00 posterior probability value.

For COI gene, the aligned sequences consisted of 625 characters, including 362 constant, 25 uninformative and 238 parsimony informative sites. The genetic distance within the genus *Leucauge* ranged from 8.96-9.12% (*L. celebesiana* vs *L. tessellata*) to

15.52-16.32% (*L. argentina* vs *L. sabahan*), while the genus *Opadometa* is 0.00-0.32% (*O. grata* vs *O. kuchingensis*). Interspecific genetic distance within the *Leucauge-Opadometa* group ranged from 10.08-10.72% (*L. celebesiana* vs *O. kuchingensis*) to 14.08-15.84% (*L. argentina vs O. grata* and *L. argentina* vs *O. kuchingensis*). The distance within the genus *Mesida* is 15.04-15.84% (*M. gemmea* vs *M. yini*) while the genus *Tylorida* ranged between 15.52-16.16% (*T. striata* vs *T. ventralis*) to 17.12-17.76% (*T. tianlin* vs *T. ventralis*). Interspecific genetic distance within *Mesida-Tylorida* group ranged between 14.08-14.24% (*M. yini* vs *T. striata*) to 18.24-18.88% (*M. yini* vs *T. tianlin*). The genetic distance within the *Tetragnatha* group ranged from 14.24-15.04% (*T. maxillosa* vs *T. pinicola*) to 20.08% (*T. lauta* vs *T. hasselti*) (Table 5.2).

For 18S rRNA gene, the aligned sequences consisted of 945 characters, including 742 constant, 59 uninformative and 144 parsimony informative sites. The genetic distance within the genus *Leucauge* ranged from 0.21% (*L. decorata* vs *L. sabahan*) to 1.73% (*L. argentina* vs *L. celebesiana*), while the genus *Opadometa* is 0.11% (*O. grata* vs *O. kuchingensis*). Interspecific genetic distance within the *Leucauge-Opadometa* group ranged from 0.11% (*L. decorata* vs *O. kuchingensis*) to 1.51% (*L. argentina* vs *O. kuchingensis*). The distance within the genus *Mesida* is 0.76% (*M. gemmea* vs *M. yini*) while the genus *Tylorida* ranged between 2.81% (*T. tianlin* vs *T. ventralis*) to 4.54% (*T. tianlin* vs *T. striata*). Interspecific genetic distance within *Mesida-Tylorida* group ranged between 1.30% (*M. yini* vs *T. ventralis*) to 3.68% (*M. gemmea* vs *T. striata*). The genetic distance within the *Tetragnatha* group ranged from 1.73% (*T. maxillosa* vs *T. pinicola*) to 6.66% (*T. lauta* vs *Tetragnatha* sp) (Table 5.3).

The distance matrix calculated using the COI genes have shown a range of values for each species but not in the distance matrix of the 18S genes. More informative sites in the COI genes could have generated the wider range of genetic distance compared to the more conserved 18S genes. For the COI genes, the result signified a greater genetic distance between *T. tianlin* and other species within the *Mesida*-*Tylorida* group. Genetic distance of the18S gene showed consistency within the *Mesida*-*Tylorida* group in this species.

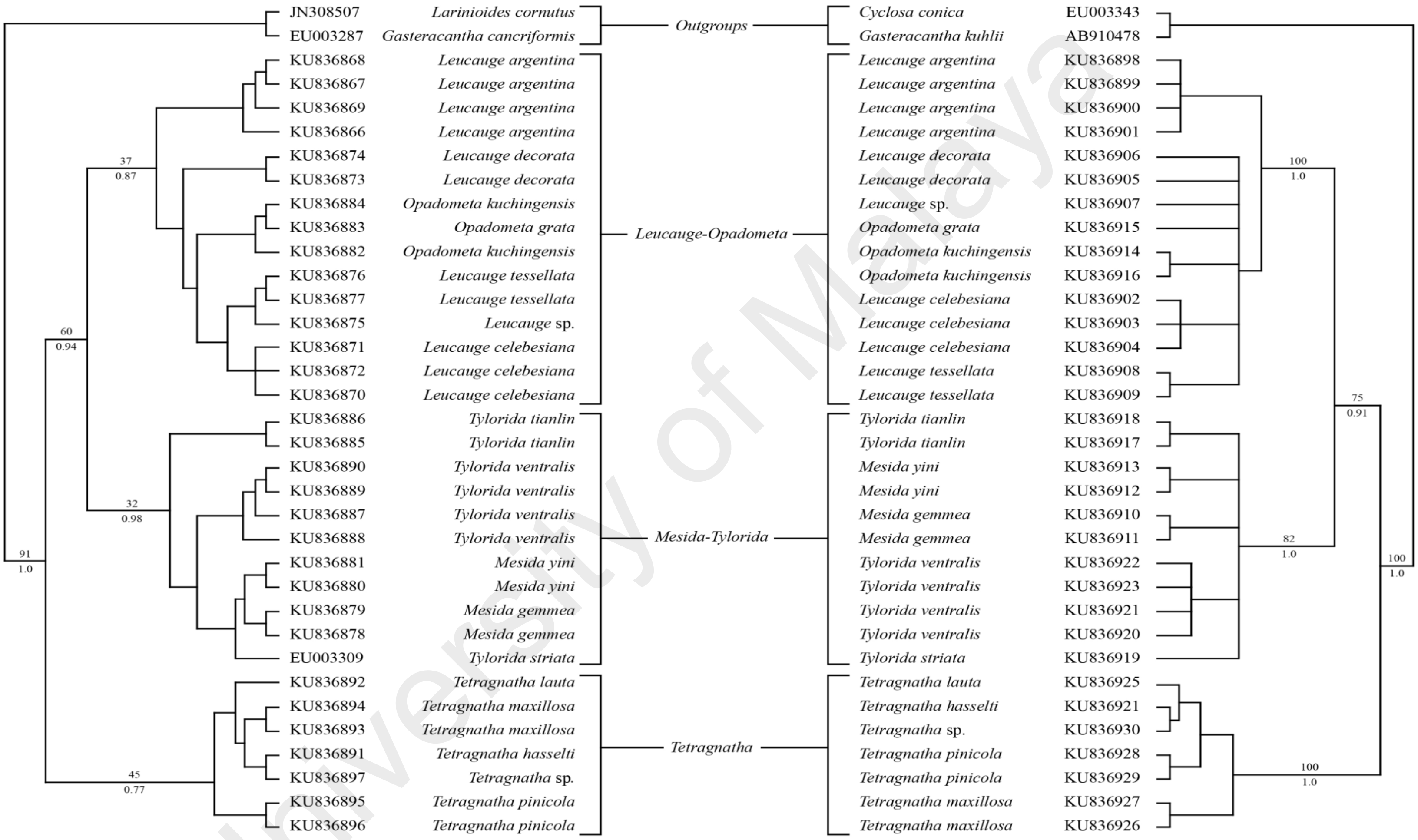

Figure 5.1: Phylogenetic trees of tetragnathid spider species from Malaysia, inferred from COI gene analyzed by Bayesian Inference and Maximum Likelihood (left), and 18S gene analyzed by and Bayesian inference and Maximum Parsimony (right). Bootstrap values with 50% majority rule applied (above) and posterior probability value (below) are as shown.

Table 5.2: Genetic pairwise distance (%) among 17 tetragnathid species and two outgroups (*Larinioides cornutus* and *Gasteracantha cancriformis*), *Leucauge* (5 species), *Mesida* (2 species), *Opadometa* (2 species), *Tetragnatha* (5 species), *Tylorida* (3 species) analysed based on COI gene sequences. Distances were calculated using the Kimura-two-model (Kimura 1980).

	Species	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]
[1]	*Tetragnatha pinicola*	0.00-0.32																		
[2]	*Tetragnatha maxillosa*	14.24-15.04	0.00-1.28																	
[3]	*Tetragnatha lauta*	15.2-15.36	14.88-15.04	—																
[4]	*Tetragnatha hasselti*	18.4-18.56	18.88-19.04	20.8	—															
[5]	*Tetragnatha* sp	14.88-15.04	15.68	16.48	17.28	—														
[6]	*Mesida gemmea*	17.28-17.76	18.08-19.36	19.84-20.00	22.24-23.84	19.68-19.84	5.92													
[7]	*Mesida yini*	17.44-17.92	18.72-19.68	20.48-20.96	22.40-22.72	19.36	15.04-15.84	1.12												
[8]	*Tylorida striata*	17.60	19.52-20.16	19.84	24.32	19.68	16.16-16.48	14.08-14.24	—											
[9]	*Tylorida ventralis*	16.80-18.40	16.32-16.80	18.40-19.20	21.92-22.72	18.88-19.20	15.84-16.48	16.80-17.44	15.52-16.16	0.00-4.64										
[10]	*Leucauge celebesiana*	14.24-14.56	15.84-16.32	16.64-16.80	18.88-19.20	16.16-16.48	16.32-16.80	16.00-16.64	16.00-16.32	15.52-16.16	0.16-0.32									
[11]	*Leucauge decorata*	16.00-16.16	14.88-15.52	17.28	19.84	16.96	16.32-16.64	17.44-17.76	17.60	16.00-16.80	9.44-9.60	—								
[12]	*Opadometa grata*	14.56-14.72	16.32-16.64	16.96	19.36	15.52	15.84-16.64	17.12	16.64	16.80-16.96	10.40-10.72	11.68	—							
[13]	*Opadometa kuchingensis*	14.56-14.72	16.16-16.64	16.80-16.96	19.20-19.36	15.52-15.68	15.52-16.64	16.80-17.12	16.48-16.64	16.48-16.96	10.08-10.72	11.36-11.68	0.00-0.32	0.00-0.32						
[14]	*Leucauge tessellata*	16.48	16.80-17.28	18.40	18.72	16.48	17.28-18.08	17.44-18.24	16.48	17.28-18.24	8.96-9.12	11.68	10.24	10.24	—					
[15]	*Leucauge* sp.	15.36-15.68	16.48	18.72	20.00	17.44	15.68-16.00	16.48-17.12	17.44	17.12-17.76	11.84-12.00	12.96	13.44	13.44	10.40	—				
[16]	*Tylorida tianlin*	17.76	16.16-16.96	17.44	22.72	19.04	17.28-17.92	18.24-18.88	16.96	17.12-17.76	13.76-13.92	15.84	15.36	15.36	13.44	14.40	—			
[17]	*Leucauge argentina*	16.64-17.28	15.84-16.96	17.12-18.88	19.20-20.16	17.44-19.20	16.32-16.80	17.44-19.20	16.96-17.92	16.00-16.48	12.80-13.92	12.96-14.08	14.40-15.84	14.08-15.80	13.60-14.72	15.52-16.32	18.08-18.24	0.16-12.48		
[18]	*Larinioides cornutus*	15.84-16.16	16.64-16.80	17.6	20.64	16.80	19.04-19.68	19.84-20.48	19.04	17.12-17.76	16.00-16.32	14.88	17.76	17.44-17.76	17.12	16.64	18.72	15.68-17.12	—	
[19]	*Gasteracantha cancriformis*	17.28	17.44-17.76	19.68	20.08	17.92	20.32-20.48	19.36-19.84	19.36	18.88-19.36	17.12-17.28	18.40	19.52	19.20-19.52	17.76	18.08	17.44	17.60-20.64	14.72	—

Table 5.3: Genetic pairwise distance (%) among 17 tetragnathid species and two outgroups (*Gasteracantha kuhlii* and *Cyclosa conica*), *Leucauge* (5 species), *Mesida* (2 species), *Opadometa* (2 species), *Tetragnatha* (5 species), *Tylorida* (3 species) analysed based on 18S gene sequences. Distances were calculated using the Kimura-two-model (Kimura 1980).

	Species	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]
[1]	*Leucauge decorata*	—																		
[2]	*Opadometa kuchingensis*	0.11	—																	
[3]	*Leucauge celebesiana*	0.43	0.54	—																
[4]	*Leucauge* sp.	0.21	0.32	0.43	—															
[5]	*Opadometa grata*	0.00	0.11	0.43	0.21	—														
[6]	*Leucauge tessellata*	0.54	0.65	0.97	0.54	0.54	—													
[7]	*Leucauge argentina*	1.40	1.51	1.73	1.30	1.40	1.30	—												
[8]	*Tylorida ventralis*	3.89	3.78	4.00	4.00	3.89	4.00	4.43	—											
[9]	*Mesida gemmea*	3.67	3.56	3.67	3.78	3.67	4.00	4.21	1.40	—										
[10]	*Mesida yini*	3.34	3.24	3.35	3.46	3.35	3.67	3.89	1.30	0.76	—									
[11]	*Tylorida tianlin*	4.32	4.21	4.43	4.43	4.32	4.21	4.64	2.81	2.37	2.27	—								
[12]	*Tylorida striata*	5.30	5.19	5.51	5.19	5.29	5.40	6.05	3.78	3.68	3.24	4.54	—							
[13]	*Tetragnatha hasselti*	8.29	8.18	8.50	8.40	8.29	8.07	8.62	7.51	7.74	7.42	7.41	9.00	—						
[14]	*Tetragnatha sp*	8.71	8.81	8.93	8.82	8.71	8.49	8.93	8.04	8.59	8.27	8.06	8.56	5.53	—					
[15]	*Tetragnatha lauta*	7.15	7.04	7.15	7.25	7.15	7.04	7.26	6.60	7.26	6.93	7.03	7.55	6.50	6.66	—				
[16]	*Tetragnatha maxillosa*	5.21	5.32	5.43	5.32	5.21	5.10	5.32	4.55	4.88	4.56	4.88	6.06	5.44	5.34	4.98	—			
[17]	*Tetragnatha pinicola*	5.52	5.63	5.84	5.63	5.52	5.41	5.63	4.98	5.42	5.09	4.98	6.58	4.89	5.53	5.07	1.73	—		
[18]	*Gasteracantha kuhlii*	8.64	8.75	8.53	8.75	8.64	8.97	9.40	9.08	8.86	8.64	9.94	10.38	11.79	12.74	11.71	8.90	9.53	—	
[19]	*Cyclosa conica*	9.08	9.19	9.08	9.19	9.08	8.97	9.41	9.31	8.86	8.65	9.62	10.50	11.92	12.65	11.72	8.59	9.44	3.23	—

5.4 DISCUSSION

Phylogenetic analyses inferred from the independent sequence alignments of COI and 18S produced almost identical tree structures with minor differences. The lineage history of the mitochondrial and nuclear DNA could have caused the differences in tree topology. In the family Tetragnathidae, two subfamilies and three sub-groups were clearly resolved within the phylogenetic trees for both COI and 18S genes (Figure 5.1). *Leucauge-Opadometa* and *Mesida-Tylorida* are clustered within the Leucauginae-group, while *Tetragnatha* is in the Tetragnathinae-group. Some of these groupings are strongly supported by bootstrap values greater than 70% (Hillis & Bull, 1993).

Phylogenetic trees reconstruction based on BI and MP (18S) and BI and ML (COI) corroborate with the internal relationships hypothesis of the family Tetragnathidae (Alvarez-Padilla *et al*., 2009; Alvarez-Padilla & Hormiga, 2011). Taken together, the trees strongly support that (1) subfamilies Leucauginae and Tetragnathinae are two distinct lineages that are related to Tetragnathidae; (2) separate grouping of *Leucauge-Opadometa* and *Mesida-Tylorida* within the subfamily Leucauginae are coherent with morphological characteristics. This suggests that the COI and 18S genes are reliable genetic markers to delineate the natural groupings of Tetragnathidae subfamilies (Alvarez-Padilla *et al*., 2009), as well as to other spider families, which were hypothetically related based on their morphology criteria (Astrin *et al*., 2006). Analysis using both COI and 18S genes clusters, *Leucauge* and *Opadometa* which are both within the same clade, resulted in a sister group. This is in coherence with Alvarez-Padilla & Hormiga (2011) where *Opadometa* has been suggested to be closely related to *Leucauge* based on their morphology, behaviour and DNA sequences.

The reclassification of the *Opadometa* species is still ongoing. The taxonomy of the *Opadometa* species has never been successfully revised, owing to the scarcity of male specimens, which are crucial for species identification. Overall, the general morphology of male *Opadometa* resembles the small *Leucauge* species (Alvarez-Padilla & Hormiga, 2011). Therefore, *Opadometa* is still grouped under the *Leucauge* species (Yoshida, 2009). However, the *L. argentina* actually forms a separate subclade (Figure 5.1), which is as a sister to the *Leucauge*-*Opadometa* group, because it is the only small size species (< 6 mm) found in the present study.

In the *Mesida*-*Tylorida* group, the members share many similar morphological characteristics (Tanikawa, 2001; Alvarez-Padilla & Hormiga, 2011) where these two genera can only be distinguished by minor differences on the outer appearance (Tanikawa, 2001; Tanikawa, 2004; Kulkarni, 2014), *Tylorida striata* was recognized as a sister-clade to *M. argentiopunctata* and *Mesida* species (Tanikawa, 2001) based on cladistic analysis using morphological characteristics. On the other hand, using a combination of morphology, behaviour and DNA sequence analysis, has revealed *Tylorida* as a sister group to *Orsinome* (Alvarez-Padilla & Hormiga, 2011). However, since this study lacked the *Orsinome* species from Malaysia, this observation cannot be fully verified as yet.

Meanwhile, *Tetragnatha* is the only genus from the family Tetragnathinae with available record in Malaysia. The *Tetragnatha* forms a sister clade to a grouping, inferred from the genetics, morphology and behaviour that comprises *Glenognatha* and *Pachygnatha* (Alvarez-Padilla & Hormiga, 2011), albeit both genera are yet to be documented in Malaysia (Norma-Rashid & Li, 2009; Dzulhelmi *et al*., 2014a; Dzulhelmi *et al*., 2014b). The Tetragnathinae-group differs significantly from the Leucauginae-group in term of their morphological characters (Alvarez-Padilla *et al*., 2009).

The tree-based taxon clustering in the present study indicates that molecular evidence does coincide with morphological hypothesis and is useful for spider taxonomic studies. Hence, COI and 18S genetic markers could assist in species identification. The current findings indicate that the COI gene has adequate variable regions, and is more informative in resolving intra and interspecific relationships among tetragnathid species. Similarly, a single marker of the COI gene is sufficient for studying the genetic relationships in other spider species (e.g. Garb *et al*., 2004; Tanikawa *et al*., 2006; Vink *et al*., 2009; Smith *et al*., 2012; Muslimin *et al*., 2015). Nonetheless, some groups of spiders achieve better results from using other genetic markers (e.g. Croom *et al*., 1991; Fang *et al*., 2000; Astrin *et al*., 2006), and a combination of several genetic markers (e.g. Benjamin *et al*., 2008; Alvarez-Padilla *et al*., 2009; Su *et al*., 2011; Franzini *et al*., 2013).

This study has utilized the COI and 18S markers as powerful markers to support the monophyly of 17 studied tetragnathid spider species, coherent with their morphological characteristics. However, using a single genetic marker independently is still inadequate to delineate the Malaysian tetragnathids at generic and species level. Therefore, it is highly recommended that a wider range of the Malaysian tetragnathid species be used in future studies to compare and contrast the compatibility of the two markers whence suitable specimens are made available in the future.

CHAPTER 6

WEB CHARACTERISTICS DETERMINE NICHE PARTITIONING FOR ORB-WEB SPIDERS (ARANEAE, TETRAGNATHIDAE) IN MALAYSIA

6.1 INTRODUCTION

Orb-web building spiders is a ‘sit-and-wait’ predator that employ a homogeneous foraging strategy across their life stages (Sensenig *et al.*, 2011), and highly depend on the web it constructs at strategic web-sites to obtain food. They invest a large amount of energy in their webs (Biere & Uetz, 1981) and also respond to specific abiotic (i.e. climatic conditions, vegetation structures) and biotic factors (i.e. prey availability, inter and intra species competition, predators, non-prey animal disturbance) (Vollrath *et al*., 1997; Richardson & Hanks, 2009; Sensenig *et al*., 2010) by altering their web characteristics to optimize their return. To reduce energetic costs, web builders will make decisions on web locations to obtain quality web sites that are able to provide adequate food supply sources (Olive, 1980) and optimize successful foraging (Alcock, 1993; Prokop, 2006; Wise, 1993), available space with physical structures to anchor the webs (Herberstein, 1997; Richardson & Hanks, 2009) and avoid direct and indirect competition with the coexisting species (Gillespie, 1987b; Salomon *et al.,* 2010; but see Rao 2009). Once the orb-web is constructed completely, any additional modifications are difficult, thus almost all choices have to be made before web-building (Prokop, 2006).

In order to avoid direct competition with other spider species, each orb-web spider species needs to construct their webs in different microhabitats and capture different prey. Hence, if the orb-web spider constructed its web in a certain locations, it will be able to capture prey type within that particular area. This is because different spider species with different sizes may respond according to the vegetation structure. Therefore, this indirectly influenced the web-site height (e.g. Enders, 1973; Moore, 1977; Herberstein, 1997). For instance, two *Micrathena* species showed little overlap between web area and web-site height which indicates niche partitioning (McCravy & Hessler, 2012) which is influenced by competition for suitable web-sites (Henaut *et al*., 2006). They may modify or relocate their webs to other more profitable web-sites when required (Scharf et al. 2011).

Larger orb-web spiders tend to capture larger prey (Enders, 1974; Ludy, 2007; Richardson & Hanks, 2009). For instance, larger *Leucauge venusta* construct larger webs and occupy higher web-sites than smaller sized individuals (Henaut *et al*., 2006), probably because difference in vertical web-sites differed in type of prey and abundance (Blackledge *et al*., 2003). These bigger bodied orb-web spiders are known to capture larger preys at higher web-sites (Tahir *et al*., 2010) and reduce competition with smaller size spiders. Yet, larger and faster preys usually have higher kinetic energy and larger spiders tend to invest quality silk concentration for better web performance (Sensenig *et al*., 2011). In other words, spiders will target prey that is relatively larger than their own size. However, web-site height does not always correlate to spider size (Richardson & Hanks, 2009). There could also be combination of many other factors such as disturbance, food supply, support structure, microclimatic condition that influence the web-site selection (Herberstein, 1997).

Currently, there are at least 37 tetragnathid species that have been recorded in Malaysia. Most of these tetragnathid species share many similar morphological features. They are also recognized for their horizontal orb-webs that have open-hubs constructed between 0^{o}-70^{o} with many variations in the web characteristics. Therefore, tetragnathid species are the perfect subject representing spider species that construct tilted angles or slightly horizontal orb-webs for niche partitioning investigation in response to habitat types. This study examines the niche partitioning of tetragnathid species in different habitat types based on their web characteristics. In order to define the importance of web architecture features, statistical analyses were performed using the combinations of several variables of web characteristics. We believe that the combination of these web characteristics variable serve important structural components of the web design. Therefore, they may affect the placement of webs in a particular location.

6.2 MATERIALS & METHODS

6.2.1 DATA COLLECTION

The vertical distance of webs from the ground (web-sites) were measured by measuring the height from soil surface to the center of the orb-webs as these are horizontal orb-webs. The webs were then dusted with powder to increase visibility and to enhance photography output. During the photography, a measuring tape was hold directly next to the webs to ensure proper scaling. Apart from the heights from ground and web angles, other web characteristics were measured directly from the photographs with the scale calibrated using the KLONK Image measurements software (Figure 6.1 & Figure 6.2). The characteristics measured were the number of spirals, number of radii, mesh-height, web area, free-zone area and hub-area. Spiders collected were stored in 75% ethanol for species identification. The absence of the male pedipalp was examined for each individual to ensure that only female spiders were used for the web characteristics analysis. Female genitalia were dissected, cleared in potassium hydroxide (KOH) and examined under the microscope.

6.2.2 STATISTICAL ANALYSIS

In this study, the selected location for analyses represent six different habitat types namely (A) long grasses (B) forest fringe (C) montane oak forest (D) dipterocarp forest (E) mangrove forest (F) heath forest (Table 6.1). Two tetragnathid species for each habitat types were selected based on the number of individuals collected. A total of 110 individuals from 12 tetragnathid species that constructed inclined orb-webs with open-hubs (except *Tetragnatha ceylonica* and *T. pinicola* which constructed orb-web with no free-zone area and close-hub) were used. The data was normalized by natural logarithm prior to principle component analysis (PCA) (Friedman *et al.*, 2001). PCA was then performed on the multivariate data of the web characteristics (Table 6.2). We examined the clustering of species based on different habitat types. All analyses were done using R 3.1. (R Core Team 2015).

Table 6.1: Sampling locations in search for tetragnathid spider species in Malaysia.

Localities	Habitat types
Kuala Selangor Nature Park, Kuala Selangor	Mangrove forest
UKM Permanent Forest Reserve, Bangi	Forest fringe
Gunung Gading National Park, Lundu	Dipterocarp forest
Kubah National Park, Matang	Heath forest
Crocker Range National Park Headquarters, Keningau	Long grasses (1000m a.s.l)
Mesilau National Park, Ranau	Montane oak forest (1950m a.s.l)

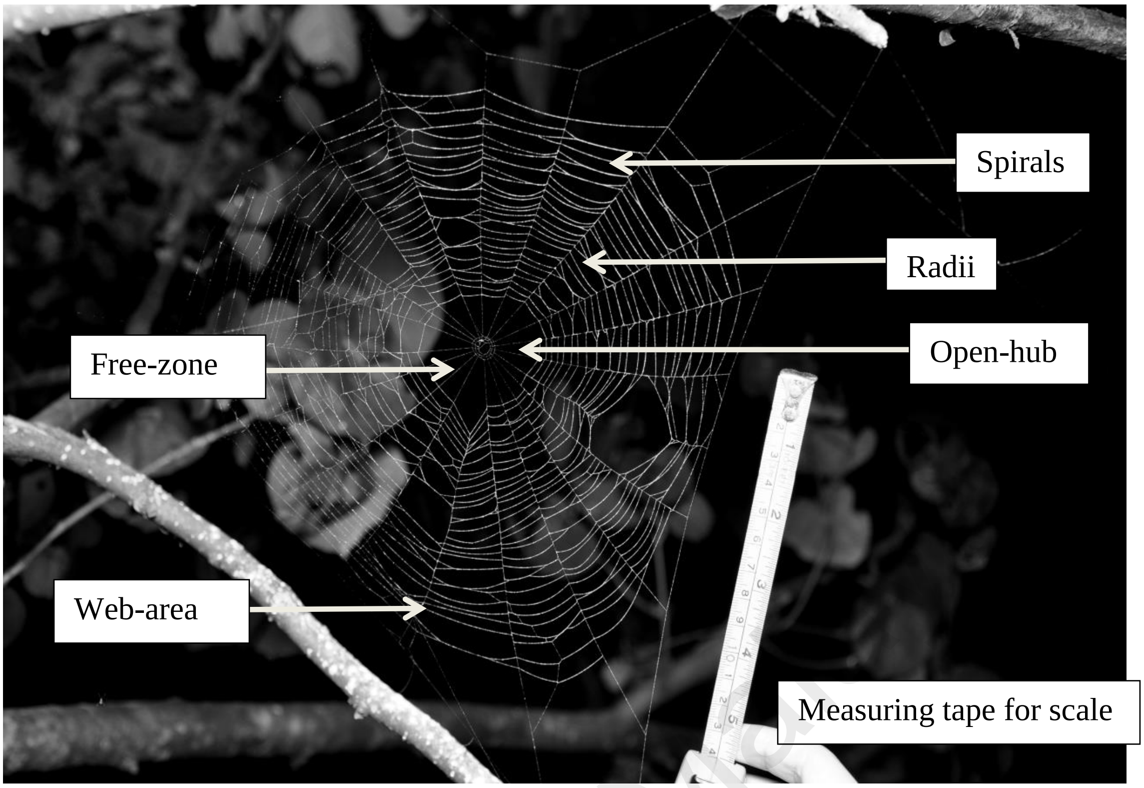

Figure 6.1: General web architecture with open-hub of tetragnathid spider species.

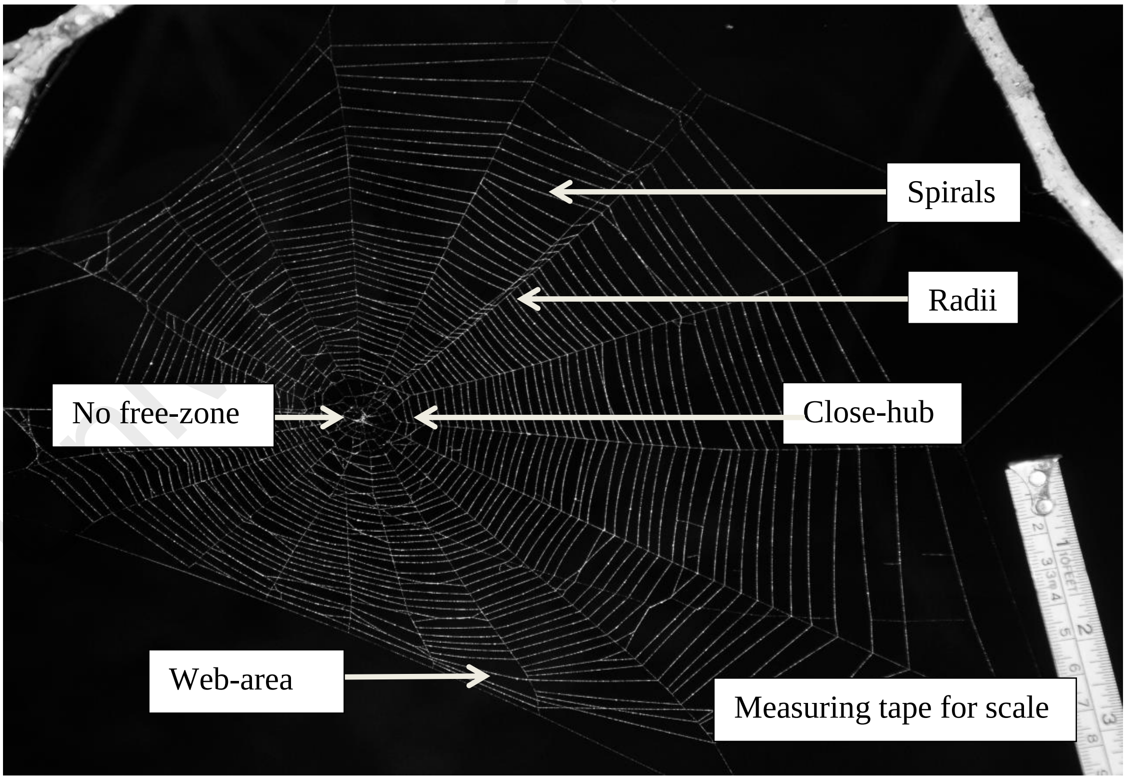

Figure 6.2: General web architecture with close-hub and no free-zone of tetragnathid spider species.

6.3 RESULTS

PCA results indicated that 59% (PC1) of the variance was described by variables that are related to the size of the web-area, while PC2 was strongly influenced by the web-sites in relation to the height from the ground that describes 23% of the variance (Figure 6.3). We projected all the specimens as points on the axis of PC1 and PC2, thus capturing 82% of the variance (Figure 6.3). The spider size (i.e. total length) and web characteristics of 12 selected female tetragnathid spider species used are summarized (Table 6.3).

When the web characteristics of all 12 tetragnathid species were combined in a single PCA analysis, the plot exhibited a large overlap among species from different genera (data not shown). This may indicate that most tetragnathid spiders exploit the similar resources when it is available. However, not all of these species coexist in the same habitat. The PCA plot clustering becomes more obvious when the web characteristics were investigated separately according to the occurring tetragnathid species in their respective habitat types. Some tetragnathid species that coexist within a particular habitat type form two close clustering in the PCA plots. Other tetragnathid species form two separate clustering in the PCA plot due to the wide variation in their web characteristics. This usually coincides with structural complexity of the habitat.

In habitats with low structural complexity such as grassland and low lying shrubs, any stratification was constrained by the physical structure of the habitat and hence any differences were much smaller than that of spiders in forested habitats. This is indicated by the vertically stratified clustering between *L. celebesiana* and *L. decorata* in long grasses (Figure 6.4A). *L. celebesiana* preferred to built webs lower than *L. decorata,* although both species had relatively similar web structures as indicated by their position on the PC1 axis. This exact pattern of resource partitioning by differences in web structure also occurred in forest fringes, with *T. striata* built smaller webs at lower web-sites while *M. yini* built larger webs at slightly higher web-sites (Figure 6.4B). A similar situation was shown in undergrowth shrubs in montane oak forest, where *L. liui* constructed webs with smaller web-area than *Ty. tianlin* but both species overlap in height from the ground on the PC2 axis (Figure 6.4C).

Larger differences, both intra-cluster and inter-cluster were displayed by species inhabiting habitats with more structural complexity. In dipterocarp forests, while there was an overlap in terms of web size *L. argentina* constructed webs at lower web-sites, while *M. gemmea* tends to make webs at higher web-sites (Figure 6.4D).

Some patterns were caused by the differences in web structures, as *T. ceylonica* and *T. pinicola* build webs without the free-zone areas. Only the habitat types that were occupied by these two species formed more distantly separated clusters compared to the other studied species. This clustering pattern was resulted from the PCA algorithm that interpreted the free-zone area as a zero value. Therefore, the presence of the free-zone area causes the large differences between clusters for *Tetragnatha pinicola* and *Tylorida ventralis* (Figure 6.4E) and *Leucauge sabahan* with *Tetragnatha ceylonica* (Figure 6.4F). However, if the free-zone areas were excluded from the analyses, the clusters referring to *T. pinicola* with *Ty. ventralis,* and *L. sabahan* with *T. ceylonica* desegregate in the PCA plots (data not shown). This indicates that the free-zone area is an important variable to be included in the analyses and reflects the actual conditions of the species in the field in that particular habitat type.

Table 6.2: The average values (mean ± standard deviation) of the web characteristics of selected female tetragnathid spider species.

Species	N	Total length (cm)	Web-area (cm^2)	Freezone-area (cm^2)	Hub-area (cm^2)	Spirals (n)	Radii (n)	Mesh-size (cm)	Web-sites (cm)
*Leucauge argentina**	14	3.09±0.78	132.85±74.40	7.08±4.56	0.42±0.18	29.62±10.28	26.29±5.58	0.24±0.07	47.14±39.70
*Leucauge celebesiana**	11	5.45±0.80	233.07±92.20	14.80±6.52	1.38±0.59	25.85±6.48	21.55±3.11	0.31±0.08	50.00±18.44
*Leucauge decorata**	13	6.52±1.61	248.39±73.29	12.01±3.14	1.46±0.45	34.49±5.52	23.31±3.92	0.24±0.03	70.77±9.54
*Leucauge liui***	5	4.45±0.30	83.84±36.57	5.57±2.12	0.57±0.18	19.93±7.50	20.80±5.89	0.24±0.08	100.00±38.89
*Leucauge sabahan**	7	4.28±2.29	144.31±97.23	9.23±8.60	1.23±1.02	29.00±6.78	30.71±11.24	0.25±0.05	90.00±20.62
*Leucauge tessellata****	2	6.21±0.93	188.21±25.53	16.42±5.32	2.02±0.79	20.17±5.42	23.00±4.24	0.36±0.12	25.00±7.07
*Mesida gemmea**	11	3.64±1.15	319.27±328.56	13.44±10.71	0.93±0.62	30.53±8.83	17.08±3.45	0.41±0.18	165.83±64.87
*Mesida yini***	5	3.55±0.39	322.27±217.77	14.19±7.41	0.71±0.27	31.89±4.09	17.20±1.64	0.31±0.04	77.00±6.71
*Opadometa kuchingensis****	2	6.78±2.05	167.54±20.36	11.33±11.50	0.70±0.66	39.67±20.27	31.50±10.61	0.24±0.17	180.00±28.28
*Opadometa sarawakensis****	1	9.05	779.87	29.84	4.77	67.00	39.00	0.23	200.00
*Tetragnatha ceylonica**	5	5.79±1.71	84.88±83.91	0.00±0.00	0.67±0.30	29.27±4.47	23.40±12.68	0.20±0.08	148.00±58.05
*Tetragnatha hasselti****	2	7.79±1.41	229.88±57.88	11.03±2.24	1.55±0.10	30.67±1.89	21.50±7.78	0.42±0.17	105.00±106.07
*Tetragnatha lauta****	1	4.46	368.17	18.26	0.92	23.00	21.00	0.35	50.00
*Tetragnatha maxillosa****	3	9.31±1.46	261.19±87.77	26.41±8.18	1.55±0.10	30.67±1.89	21.50±7.78	0.42±0.17	105.00±106.07
*Tetragnatha pinicola**	10	6.31±2.35	210.66±120.06	0.00±0.00	0.82±0.58	32.70±3.03	19.80±4.02	0.26±0.07	177.00±44.30
*Tylorida striata***	5	4.02±0.47	217.80±103.69	10.75±3.47	0.66±0.36	22.27±6.03	15.60±2.88	0.58±0.41	54.00±11.40
*Tylorida tianlin***	5	5.01±0.59	220.90±112.90	15.78±9.69	1.06±0.77	18.87±3.77	18.20±3.49	0.35±0.04	134.00±42.34
*Tylorida ventralis**	19	4.80±1.34	346.17±191.89	18.11±9.58	1.23±0.73	28.04±4.33	18.58±2.04	0.41±0.14	147.63±54.73

*Individuals represent mixture of adults and sub-adults of female tetragnathid species; **Individuals represent only adult female tetragnathid species; ***Individuals represent adult female tetragnathid species but was not used in the analyses; Web-sites: vertical distance of webs from the ground; n: number count.

Table 6.3: PCA loadings for each web characteristic variable.

Variables	PC1 (59%)	PC2 (23%)
Number of radii	-0.174	-0.686
Number of spiral	0.341	1.033
Mesh height	0.506	0.244
Web area	6.274	3.403
Free-zone area	10.113	-1.642
Hub area	2.085	1.039
Height from ground	-1.174	6.398

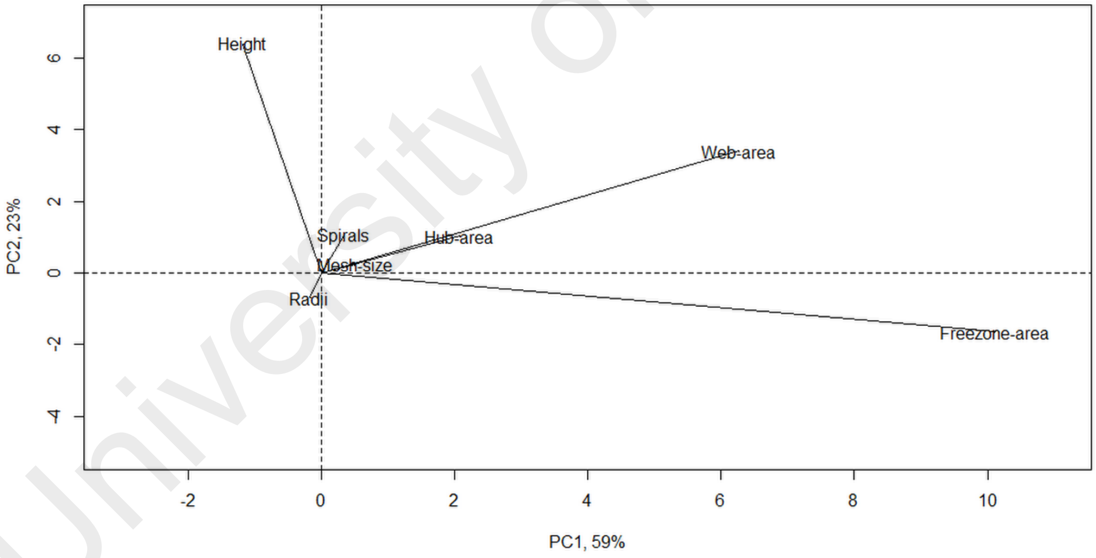

Figure 6.3: PCA plot of the web characteristic variable loadings.

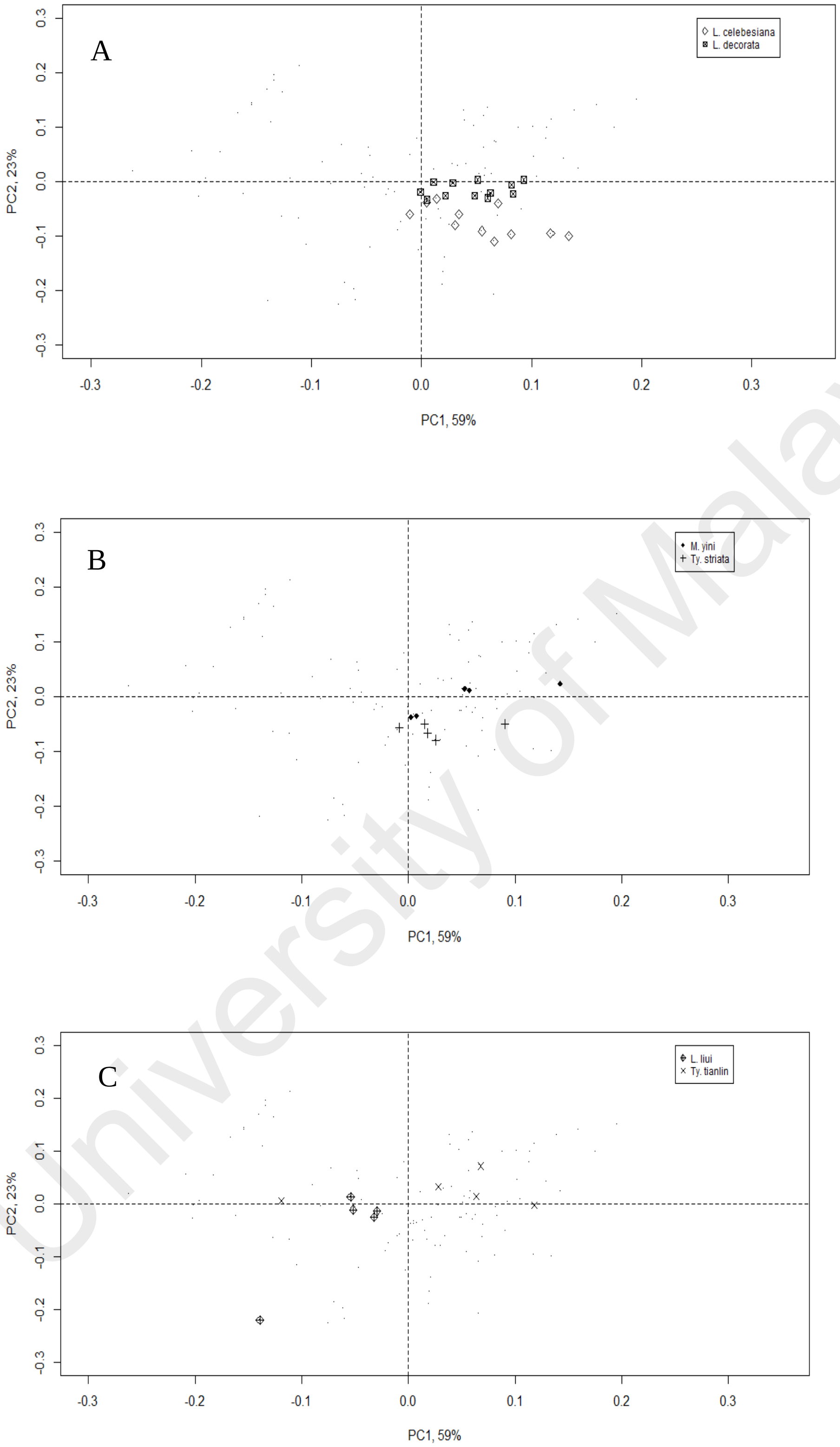

Figure 6.4: Results of PCA analyses on web characteristics of tetragnathid species in different habitat types (A) long grasses (B) forest fringe (C) montane oak forest.

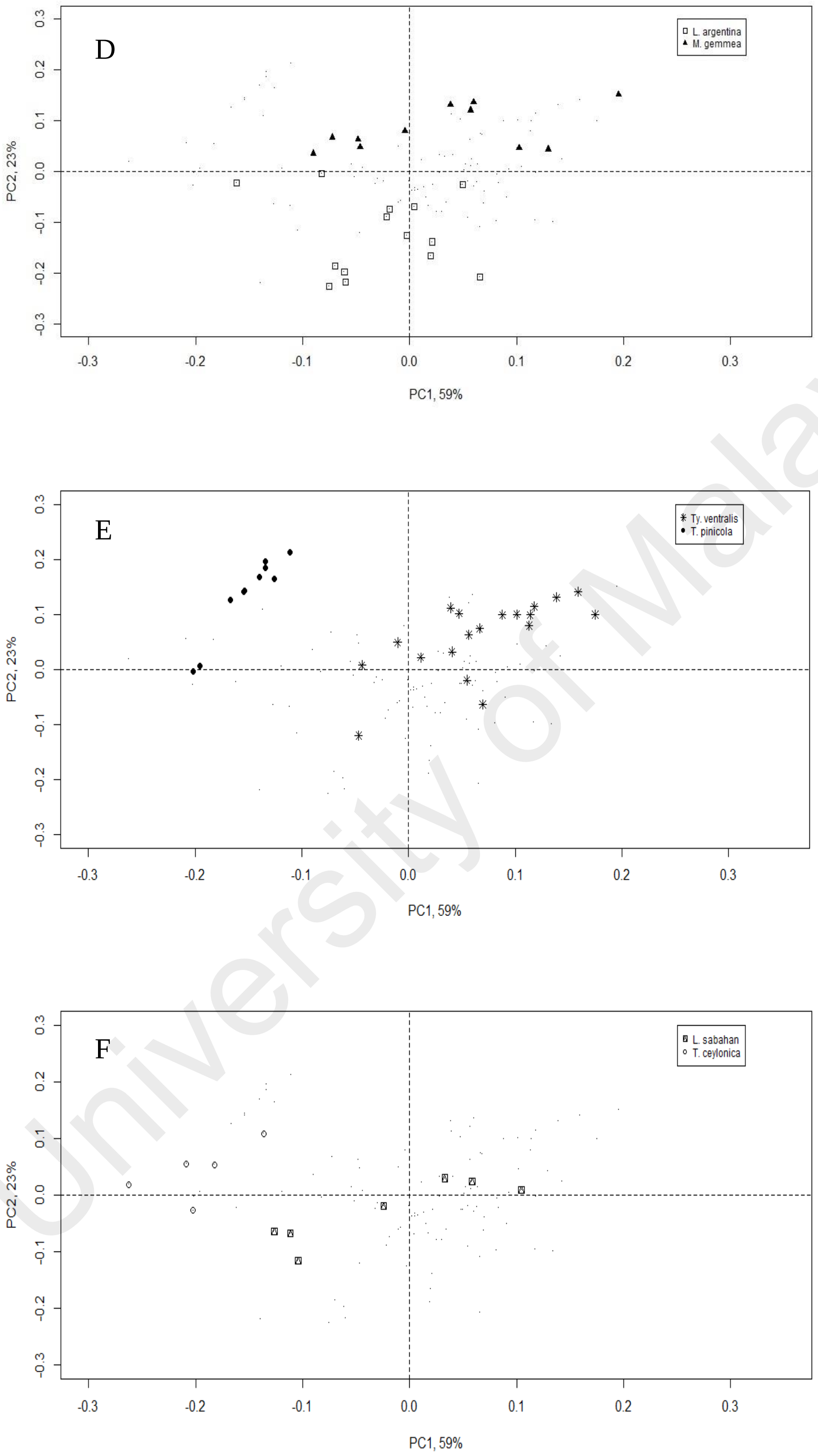

Figure 6.4 cont.: Results of PCA analyses on web characteristics on tetragnathid species in different habitat types (D) dipterocarp forest (E) mangrove forest and (F) heath forest.

6.4 DISCUSSION

The foraging success of orb-web spiders mainly depends on the characteristics of their webs and the choice of web-sites that provide sufficient prey and desirable microhabitat structures (Herberstein, 1997; McReynolds, 2000). The here investigated species constructed different web characteristics that vary with habitat, geographic location and presence of congeneric species. Individuals of the same species that share the same habitat with other species had clearly shown separate clustering in the PCA plots. This indicates that they have a tendency to construct distinctive web characteristics in relation to their preferred habitats. Some studies had demonstrated the correlation between web height and spider size (i.e. Henaut *et al*., 2006; Tahir *et al.*, 2010; McCravy & Hessler, 2012), while some studies have found no relationship between them (i.e. Kuntner *et al.*, 2008).

Wind damage becomes a factor in web construction in open areas because fragile and smaller webs are likely to be damaged by wind (Biere & Uetz, 1981; Eberhard, 1990a; Herberstein, 1997; but see Tew *et al*., 2015). There may be overlap and lower variation in web characteristics due to influence from wind disturbance. For instant, *Cyclosa mulmeinensis* have a larger mesh-height, less number of radii and smaller web-size compared to *C. ginnaga* as a result from difference in wind disturbance (Liao *et al*., 2009). *L. celebesiana* and *L. decorata* construct relatively similar web-areas and share the same web-sites, with relatively low web characteristic variation in open long grass areas bordering the montane forests. In long grasses area, the only available web-site attachment is the blades of grasses. However, both species faces almost similar wind disturbance depending on the web-sites. Therefore, space availability for larger web-area increases with the height of grasses but receive more wind disturbance.

Web-site stratification by spiders is affected by environmental factors (Mayfield & Levine, 2010). Herberstein (1997) stated that when the surrounding structure increased in height, the web-stratification of the sheet-web spiders (i.e. *Frontinellina frutetorum*, *Linyphia triangularis, Neriene radiata*) also increased as a consequence of undergrowth shrubs interfering with their webs. Also, vegetation structure growths had been reported to influence the web-site height of *Nephila clavipes* (Moore, 1977). This scenario was demonstrated by two tetragnathid species of same size found at forest fringes amongst undergrowth foliages. *T. striata* built webs with smaller web-area at lower web-sites while *M. yini* built webs with larger web-area slightly higher than *T. striata*. Prey selection may be a factor in this habitat partitioning, *Micrathena gracilis* targets a particular prey size (4-8 mm) and disregards smaller prey (2-4 mm) found at lower web-sites height (Biere & Uetz, 1981). Smaller prey can be caught with more abundance at lower web-sites compared to higher web-sites that capture larger but rarer prey (Henaut *et al*., 2006 but see Tahir *et al*., 2010).

In montane oak forests, both *L. liui* and *T. tianlin* construct their webs at similar height from ground. However, *L. liui* builds smaller webs with more than 50% of the web-sites were above dead leaves while *T. tianlin* constructs larger webs with more than 70% of the web-sites above shrubs. Enders (1974) discussed that web-site partitioning is a derived phenomenon from food partitioning, where different spider species target different food types. Therefore, both *L. liui* and *T. tianlin* may have different microhabitat preference, and target different prey types in those areas.

Larger webs that are constructed at higher heights are not spatially restricted by shrubs (McReynolds, 2000). However, the spider species that constructs its web in open spaces would need to overcome the direct disturbances due to climatic conditions (Biere & Uetz, 1981; Herberstein, 1997). In dipterocarp forests, the niche partitioning of *L. argentina* web-sites can be distinguished from *M. gemmea* web-sites throughout their life stages within a shared habitat. This is similar to the findings that *Argiope trifasciata* consistently placed their webs at higher web-sites than *A. aurantia* at all life stages from juveniles to adults (Enders, 1974). However, *L. argentina* constructed their webs in undergrowth shrubs of the forest floor at lower web-sites. This small sized spider might not have the capability to construct larger web and overcome strong winds at higher web-sites height, and only attach its web on available short plants that are available within the microhabitat. On the other hand, *M. gemmea* selects higher web-sites above undergrowth shrubs which are highly dependent on the type of vegetation available, shifting to vegetation that provides adequate space.

In mangrove forest, *T. ventralis* which is much smaller in size built larger web-area but at lower web-sites at the undergrowth shrubs. However, *T. pinicola* which are much larger in size preferred to construct smaller webs, but at higher web-sites in-between tree branches sticking out and exposed to air current. This is not surprising because web-site heights have significant relationships with the type of prey available (Moore, 1977; Blackledge *et al.*, 2003) and different spider species targeted different type of prey and large flying insects that would potentially destroy or damage the webs and be non-cost effective, thus web constructions should be able to withstand these impacts.

In addition, two tetragnathid species of similar size responded differently towards similar vegetation structure in heath forest. The *L. sabahan* constructed larger web-area but at lower web-sites, while *T. ceylonica* which constructed smaller web-area at higher web-sites. It is likely that the lower web-sites provide more open space rather than higher web-sites where space is restricted by dense foliage for horizontal web. However, the spider species which choose to construct webs at higher web-sites would need to choose stronger vegetation structure for support at strategic web-sites (McReynolds, 2000).

This study had shown that certain web characteristics of tetragnathid species determines niche partitioning in a particular habitat type. As a basic requirement, orb-web spiders are highly dependent on the availability of support structures to construct their orb-webs within a specific microhabitat. There are more options available for web attachment in a more complex habitat structure. Even though the web characters determine the web placement, the habitat types and vegetation structures may also influence the occurrence of spider species and the web characters in a particular habitat

CHAPTER 7

RELATIONSHIPS BETWEEN MORPHOLOGY AND WEB CHARACTERISTICS OF FOUR SPIDER SPECIES (ARANEAE, TETRAGNATHIDAE) IN MALAYSIA

7.1 INTRODUCTION

Most orb-web spiders select and build their first orb-web as early as the juvenile stage. The orb-webs must be built before the foraging success can be assessed (Higgins, 1995). The least energy usage for building webs is important in order to maximize the prey-capture efficiency (Blamires *et al.*, 2010). These orb-web spiders usually change the performances of their webs by altering one or a few web parameters (i.e. web area, mesh size, number of spirals and number of radii) that reflects the cost and benefits (Liao *et al.*, 2009; Wu *et al.*, 2013). They use similar type of silk and construct similar type of orb-webs from juvenile to the adult stage, but the silk amount and quality differ as large size spiders tend to target larger and profitable prey (Sensenig *et al.*, 2010). For instance, the stopping retention and performance of webs built by *Neoscona arabesca* are more effective for adult spiders than that of juvenile spiders although there were no changes in the mesh-size of the two stages (Sensenig *et al.*, 2011). This ‘stopping potential’ or ‘maximum energy absorption’ by the web built depends on the concentration and quality of the silk threads, and higher kinetic energy prey would result in a higher silk investment (Sensenig *et al.*, 2010). On the other hand, juvenile *Nephila clavipes* and *N. maculata* would alter their web parameters by either increasing or decreasing the web sizes in response to the level of reduction in prey capture (Higgins, 1995) which is learned through experience.

Some spiders would change their web-sites and microhabitats to achieve a higher rate of prey capture (Moore, 1977; Wise, 1993). For example, *Argiope aurantia* would take the chance to shift from a forest edge to an open field as they reach adulthood (Enders, 1973), because of the significant differences in prey type and abundance in the open field compared to the forest edge (McReynolds, 2000). This foraging investment reflects the spiders' response on the resource availability.

Though much of the natural history and ecology of other arthropod species remain unknown, previous studies that investigated spiders at species-level were based on other geographical regions (e.g. Enders, 1974; Higgins, 1995; Kuntner *et al.*, 2008) while studies on the Southeast Asia region are limited. During the field sampling to collect tetragnathid species that build orb-webs, four common species, *Leucauge argentina*, *L. celebesiana*, *Mesida gemmea* and *Tylorida ventralis* were identified at various locations in Malaysia (Norma-Rashid & Li, 2009; Koh *et al*., 2013; Dzulhelmi *et al.*, 2014a; Dzulhelmi *et al.*, 2014b), and their distributions are the evidence of their successful ecological adaptation. Unfortunately, very little is known about the relationship between the life stages and web characteristics of these four species. As orb-web spiders build their first similar complete type of orb-web at their first attempt, some behaviours show that orb-web spiders alter their web characteristics as an adaptation in response to biotic and abiotic factors at an early stage of life. This study aims to determine whether there are relationships between morphology and web characterization of these tetragnathid species. This study hypothesized that if the morphology and web characteristics are not correlated, the variability of web characteristics could probably be influenced by environmental factors instead of morphological characteristics.

7.2 MATERIALS AND METHODS

7.2.1 DATA COLLECTION

Field surveys were conducted during the day and night time to search for spider webs. The web orientation or web angle was measured using the protractor by placing the straight edge of the protractor parallel to the underside of the slanted web (Ramirez *et al*., 2003), while distance of web from the ground (web-sites) was measured using a measuring tape. The webs were then dusted with powder to increase visual contrast for photography. Collected specimens were stored in 75% ethanol for species identification. The presence of the male pedipalp was examined for each individual to ensure that only female spiders were used for the web characteristics analysis. Female genitalia were dissected, cleared in potassium hydroxide (KOH) and examined under a dissecting microscope.

Measurements were obtained from morphological characteristic variables: total length (TL), carapace length (CL), carapace width (CW), abdomen length (AL), length of leg I-II-III-IV and web characteristics (i.e. web area, free-zone area, hub area, mesh-size, number of spirals, number of radii, angle and web-sites). Both morphological and web characteristic variables were measured using the KLONK Image measurements software.

7.2.2 STATISTICAL ANALYSIS

One hundred individuals from four tetragnathid species collected were used in the analysis. This included *L. argentina* (14 individuals from Gunung Gading National Park and 11 individuals from Kubah National Park), *L. celebesiana* (29 individuals from Mesilau National Park), *M. gemmea* (12 individuals from Gunung Gading National Park and nine individuals from Ulu Gombak Field Studies Centre) and *T. ventralis* (19 individuals from

Kuala Selangor Nature Park and six individuals from Bako National Park). As *L. argentina*, *M. gemmea* and *T. ventralis* were found in more than one site, Welch t-test with a modification for degrees of freedom was conducted in order to determine whether all the individuals from the same species could be pooled. The Welch t-test was used to compare the same web characteristic variables in both sites. Variables with no significant difference in means were pooled together for further analyses. The test was also used to analyze web characteristic variables that are not influenced by the habitat of the spider.

Instead of using a single proxy variable for the spider size, the morphological variables were log normalized [log (x+1)] (Table 7.1). The eight morphological variables were then combined and converted into first principal components and treated as an independent variable. Since there was a very high covariance between the morphological variables, the first principle component was able to summarize more than 80% of the variance in the tetragnathid species (Table 7.2). Then, the correlation of this variable with each of the web characteristics were investigated consequently. The analysis was carried out using R 3.1.0 (R Core Team, 2015).

7.3 RESULTS

The Welch t-test identified that the web characteristic variables for *L. argentina*, *M. gemmea* and *T. ventralis* showed no significant difference between different populations in different habitats except for the hub-area of *L. argentina* (Table 7.3).

The correlation between the first principle component (PC1) of the morphological characteristic variables and each web characteristic variable indicates that variables related to the size of webs such as web-area, freezone-area, hub-area and mesh-size (except mesh-size for *M. gemmea*) were significantly correlated with the spider size (Table 7.4).

Web characteristic variables that have no correlation with the spider size include the number of radii, number of spirals, web-angle and web-sites (Table 7.4). This implies that these variables do not change as the spider develops to maturity. This lack of change in the variables is an indication of environmental factors within a particular habitat types that do not change with the development of the spiders. The scatter plots between the morphological characters (PC1) and each web characters variables for the *L. argentina* (Figure 7.1), *L. celebesiana* (Figure 7.2), *M. gemmea* (Figure 7.3) and *T. ventralis* (Figure 7.4) are as presented.

Table 7.1: Loadings of the first principle component (PCA) for each morphological variable.

Variables	*L. argentina*	*L. celebesiana*	*M. gemmea*	*T. ventralis*
TL	1.116	0.916	1.050	0.891
CL	0.586	0.663	0.609	0.720
CW	0.743	0.572	0.488	0.632
AL	1.271	0.859	0.864	0.840
Leg I	1.252	1.272	1.528	1.398
Leg II	1.026	1.2151	1.229	1.271
Leg III	0.819	1.010	0.852	0.896
Leg IV	0.969	1.237	0.981	1.092

Table 7.2: The proportion of variance morphological principle component for each species.

	Principal component (PC1)			
Species	*L. argentina*	*L. celebesiana*	*M. gemmea*	*T. ventralis*
Standard Deviation	0.44	0.76	0.61	0.61
Proportion of variance	0.84	0.86	0.87	0.91

Table 7.3: Results of the t-test of web characteristic variables from two different populations of spiders of the same species. *Significant to 0.05; ^{NS} Not significant.

Species		t	df	p	
L. argentina	Radii	-0.594	22.499	0.5587	^{NS}
	Spirals	-1.089	21.474	0.288	^{NS}
	Mesh-size	-0.215	18.963	0.832	^{NS}
	Web-area	-1.553	21.278	0.135	^{NS}
	Freezone-area	-1.498	22.478	0.148	^{NS}
	Hub-area	-3.058	22.867	0.005	*
	Web-angle	-1.186	22.957	0.248	^{NS}
	Web-sites	0.186	22.899	0.854	^{NS}
M. gemmea	Radii	-0.102	18.121	0.920	^{NS}
	Spirals	1.269	18.801	0.220	^{NS}
	Mesh-size	1.027	18.273	0.318	^{NS}
	Web-area	1.318	18.833	0.203	^{NS}
	Freezone-area	1.381	18.849	0.183	^{NS}
	Hub-area	1.557	17.698	0.137	^{NS}
	Web-angle	-0.064	15.656	0.949	^{NS}
	Web-sites	0.515	15.771	0.613	^{NS}
T. ventralis	Radii	1.110	8.385	0.298	^{NS}
	Spirals	0.408	5.350	0.699	^{NS}
	Mesh-size	0.383	6.881	0.713	^{NS}
	Web-area	0.369	7.119	0.723	^{NS}
	Freezone-area	-0.110	6.435	0.916	^{NS}
	Hub-area	0.331	7.771	0.749	^{NS}
	Web-angle	1.203	6.455	0.271	^{NS}
	Web-sites	-0.946	10.457	0.365	^{NS}

Table 7.4: Correlation between morphological principle components and web characteristic variables. *Significant to 0.05; ^{NS} Not significant.

Species	Variables	rho	t	df	p	Sig.
L. argentina	Radii	-0.314	-1.585	23	0.127	NS
	Spirals	0.060	0.289	23	0.774	NS
	Mesh-size	0.469	2.544	23	0.018	*
	Web-area	0.628	3.870	23	0.001	*
	Freezone	0.647	4.073	23	0.001	*
	Hub-area	0.499	2.761	23	0.011	*
	Web-angle	-0.012	-0.056	23	0.956	NS
	Web-sites	-0.074	-0.354	23	0.726	NS
L. celebesiana	Radii	0.125	0.656	27	0.517	NS
	Spirals	0.015	0.079	27	0.937	NS
	Mesh-size	0.394	2.225	27	0.034	*
	Web-area	0.468	2.754	27	0.010	*
	Freezone	0.669	4.681	27	0.0001	*
	Hub-area	0.483	2.873	27	0.008	*
	Web-angle	-0.124	-0.649	27	0.521	NS
	Web-sites	0.115	0.600	27	0.553	NS
M. gemmea	Radii	-0.268	-1.214	19	0.240	NS
	Spirals	0.400	1.902	19	0.072	NS
	Mesh-size	0.215	0.960	19	0.349	NS
	Web-area	0.777	5.385	19	0.0001	*
	Freezone	0.709	4.383	19	0.0001	*
	Hub-area	0.781	5.460	19	0.0001	*
	Web-angle	-0.191	-0.847	19	0.408	NS
	Web-sites	-0.153	-0.677	19	0.506	NS
T. ventralis	Radii	-0.260	-1.294	23	0.208	NS
	Spirals	0.068	0.330	23	0.745	NS
	Mesh-size	0.554	3.189	23	0.004	*
	Web-area	0.655	4.163	23	0.001	*
	Freezone	0.719	4.963	23	0.0001	*
	Hub-area	0.641	4.009	23	0.001	*
	Web-angle	0.059	0.281	23	0.781	NS
	Web-sites	0.272	1.356	23	0.188	NS

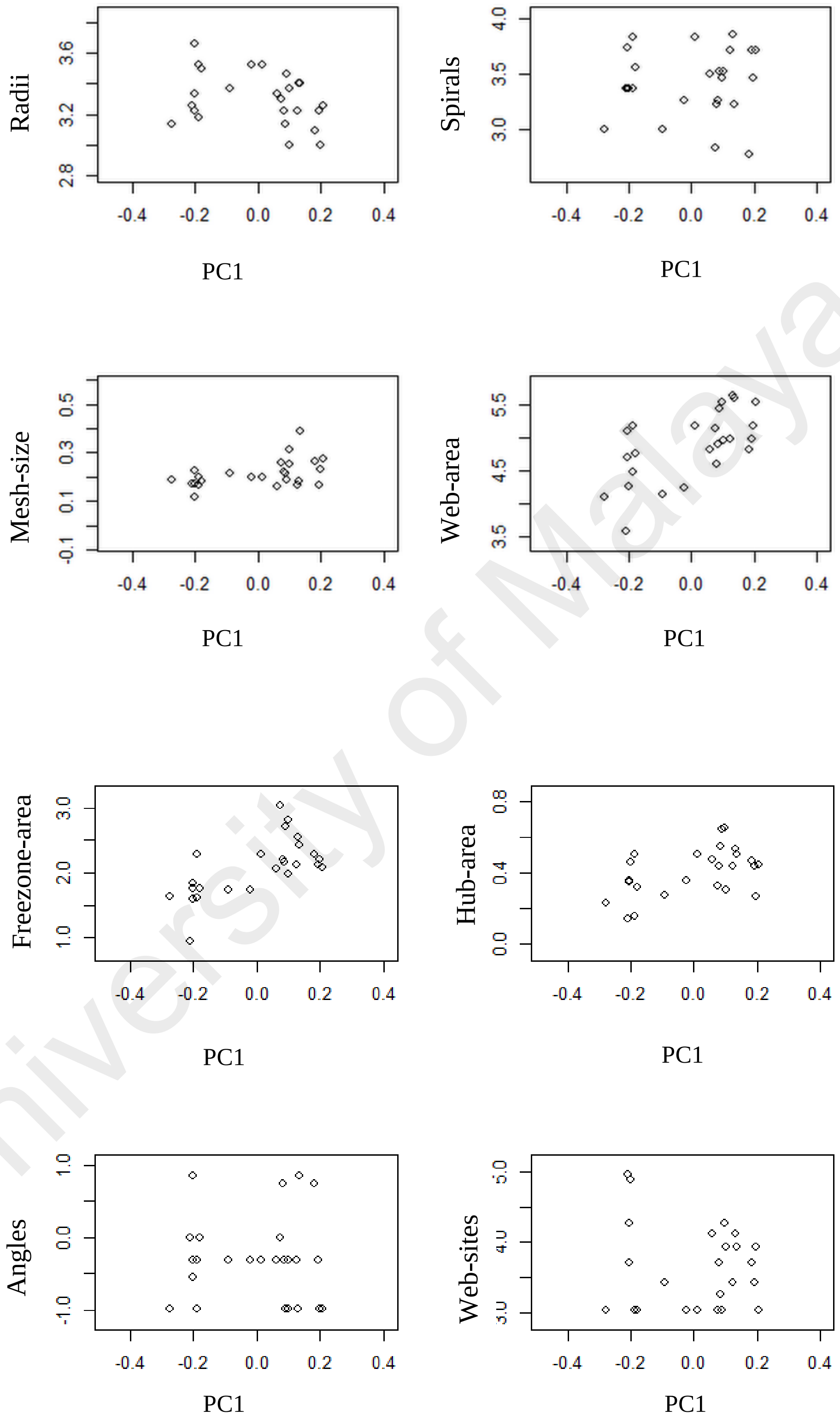

Figure 7.1: Scatter plots between morphological characters (PC1) and each web characteristic variable of *L. argentina*.

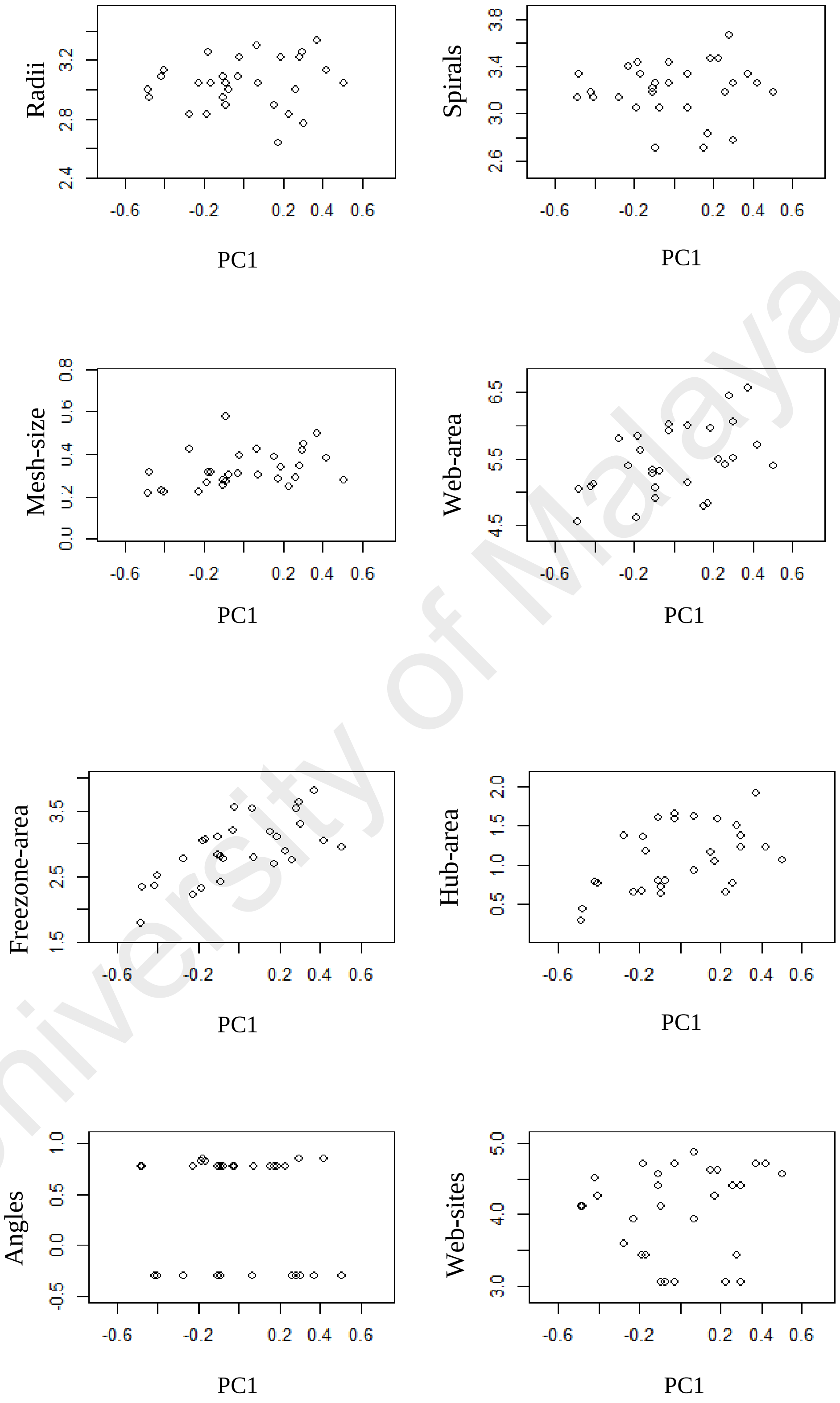

Figure 7.2: Scatter plots between morphological characters (PC1) and each web characteristic variable of *L. celebesiana*.

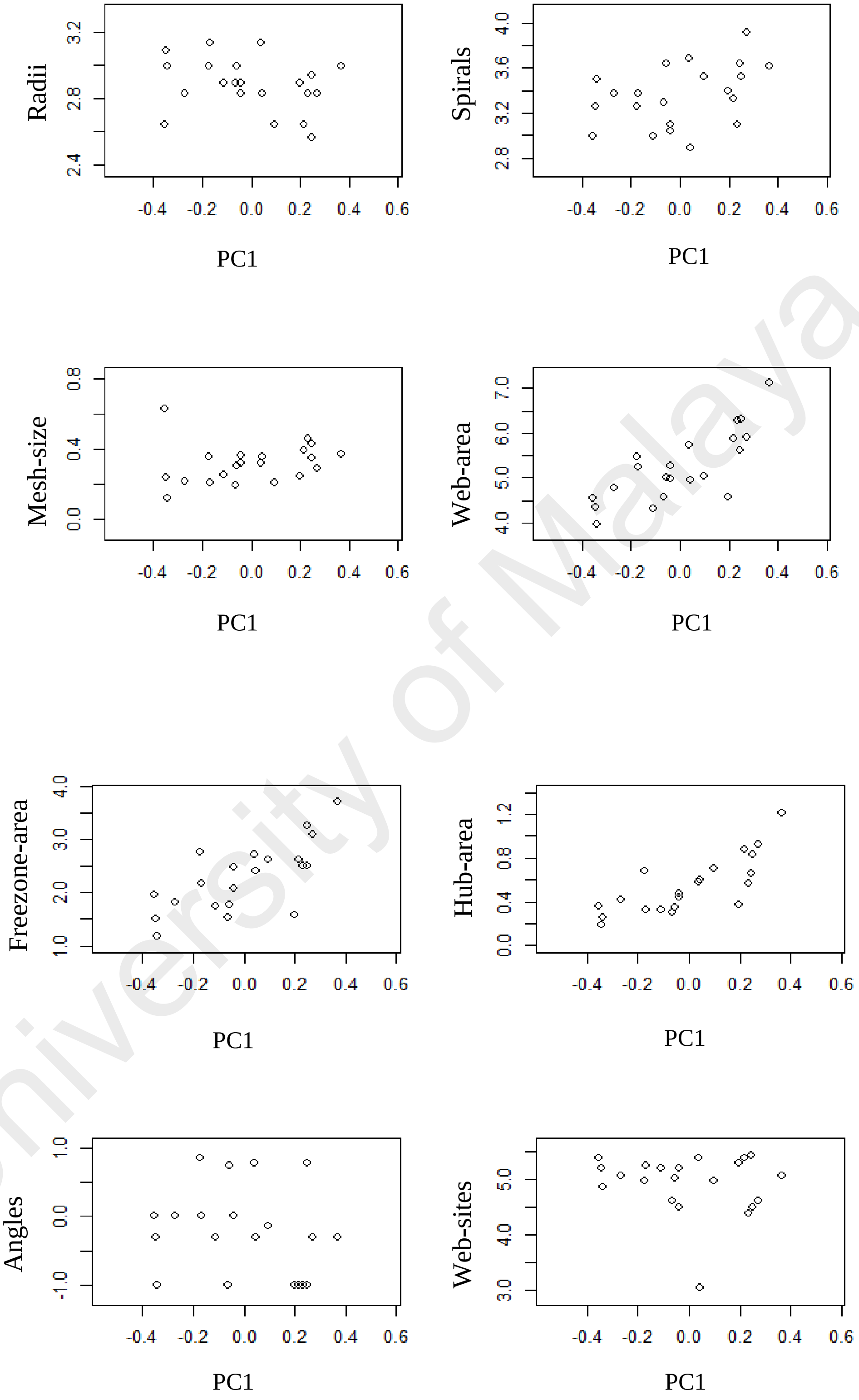

Figure 7.3: Scatter plots between morphological characters (PC1) and each web characteristic variable of *M. gemmea*.

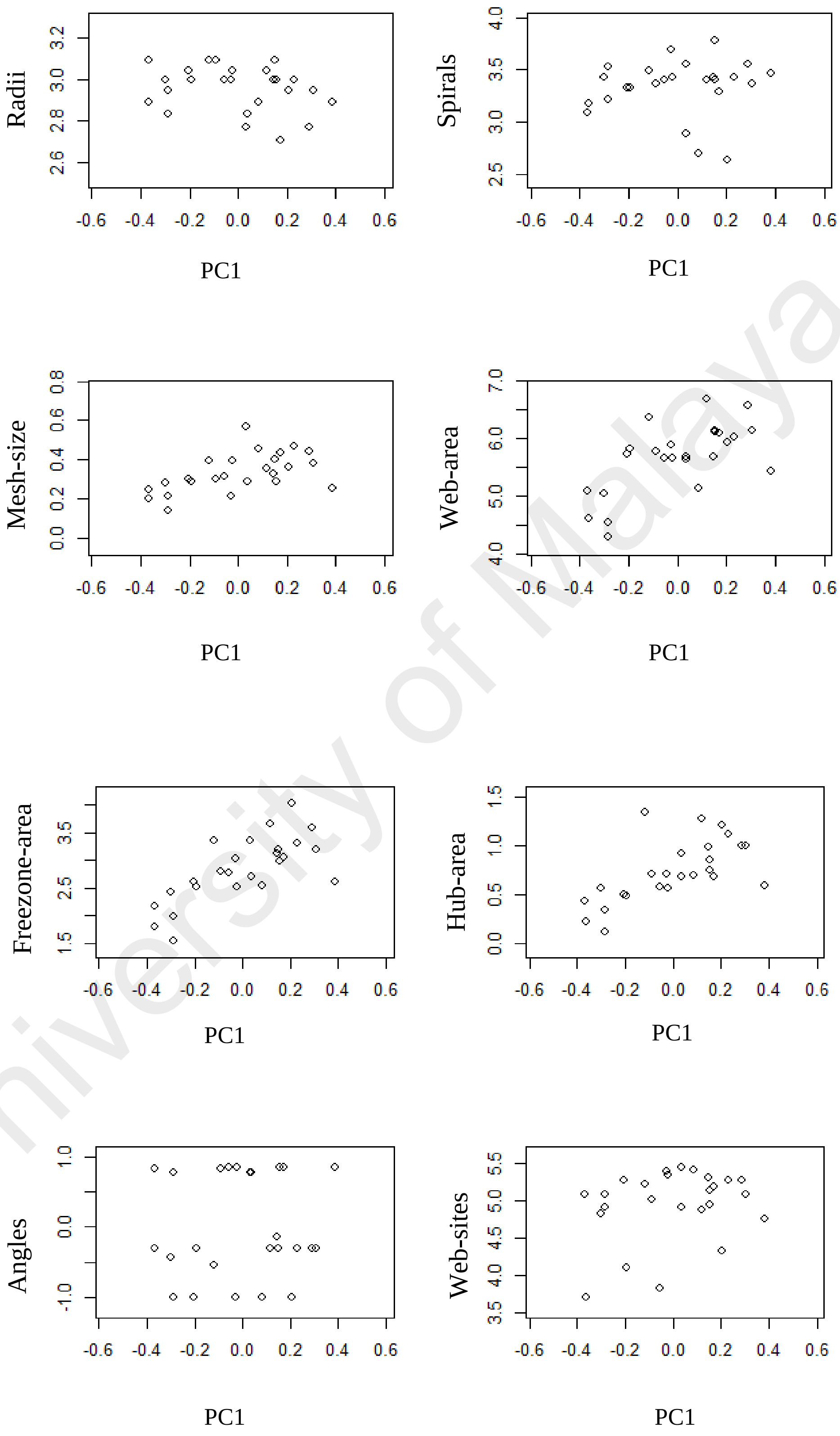

Figure 7.4: Scatter plots between morphological characters (PC1) and each web characteristic variable of *T. ventralis*.

7.4 DISCUSSION

Generally, when the web-area increases, the freezone-area and hub-area increase proportionally and these web characteristics are related to each other. Adult spiders with larger body sizes would construct larger web sizes than the juvenile spiders with smaller body sizes to sustain their own body weights (Sensenig *et al.,* 2011). This is consistent with the present result where body sizes are positively correlated with web-area, freezone-area and hub-area of these spider species. The web material properties improved significantly as the spider grows to adulthood (Sensenig *et al.,* 2011) which suggests the different types of prey captured (Richardson & Hanks, 2009) at different life stages.

Then again, this study has identified the correlation between spider body size and mesh-size, which is in concordance with other previous studies (i.e. Eberhard, 1988; Herberstein *et al.,* 2000a, but see Tahir *et al.*, 2010). Although numerous field studies had failed to find a consistent relationship between the mesh-size and prey size (Herberstein & Heiling, 1998), several studies suggested otherwise. For instance, when diverse preys of different sizes were available, the spider species (e.g. *Argiope keyserlingi*) did not alter its mesh size (Herberstein e*t al.,* 2000). Some spider species such as *Leucauge mariana* increased their web-area but reduced the mesh-size (Eberhard, 1988) as they develop to maturity. This study did not identify the relationship between mesh-size of different body sizes of spiders and prey size due to lack of prey collected on the spiders' web.

Analyses on all four tetragnathid found no correlation between body size and the number of radii. Witt *et al.* (1972) found that the juvenile had more number of radii than the adult spider in *Araneus diadematus*. Spiders are able to save more energy and maintain the same web effectiveness, stiffness and function even if they reduce the number of radii (Sensenig *et al.,* 2010). In contrast, other species such as *Nephila, Nephilengys* and

Herennia species increase the number of radii as the spider size increases. More number of radii proportionate to the spider size results in stronger webs. This allows effective capturing of faster and heavier prey because of the increment in kinetic energy absorption from the impact (Eberhard, 1990; Wise, 1993). Too much tension on the web might permit the prey to fly through or bounce off depending on the size and velocity of the prey, a phenomenon known as 'trampoline effect' (Sensenig *et al*., 2012).

Furthermore, none of the four tetragnathid species showed correlation between body size and the number of spirals. This is consistent with the finding by Tahir *et al.* (2010) which stated that the spider body size is not correlated to the number of spirals. In contrast, Henaut *et al*. (2006) identified that the number of spirals differed between individuals at different web-sites. The abdomen width is also correlated to the number of spirals which is related to maturity growth (Henaut *et al*., 2006). However, Eberhard (1988) suggested that a broader abdomen and a heavier weight showed the sign of greater feeding success, and are also associated with the developmental stage of the eggs it carries.

Web-sites selection appears to be related to the sexual development of the spiders, and larger size spiders choose higher web-sites than smaller size spiders of conspecifics (Enders, 1974; Henaut *et al*., 2006). This is probably because different web-sites have significant relationships with the type of prey availability (Moore, 1977; Blackledge *et al.*, 2003), and spiders may relocate their web-sites in response to these prey types (Moore, 1977; McReynolds, 2000; Henaut *et al*., 2006). Some studies had found correlation between body sizes and web-sites (e.g. Henaut *et al*., 2006). The current results demonstrated that spider body size does not correlate with web-sites in any of the four spider species. There is, however an alternative interpretation for this result. Different tetragnathid species of different sizes may have responded to the vegetation structure. For instance, larger spiders would construct larger webs at higher web-sites where there is more open space rather than at lower web-sites where space is restricted by shrubs and grass (McReynolds, 2000). On the other hand, if there is enough space to construct the webs, it would be preferable to maintain the web at the available web-sites, especially when there is excess of food supplies within reach and with less competition. Repairing, abandoning or reconstructing webs in other web-sites would be a waste of energy (Biere & Uetz, 1981; Sensenig *et al.*, 2010). Therefore, the four tetragnathid species maintain their web-sites at certain height from the ground as they grow from juvenile into adult.

Meanwhile, orb-weavers have the capability to orient their planar webs in response to factors such as climate and prey flight paths (Biere & Uetz, 1981). They choose web-sites that provide desirable prey types and microhabitat structures, depending on their web characteristics (Herberstein, 1997; McReynolds, 2000). This study identified that the four tetragnathid species constructed horizontal orb-webs, and tilt the web angle more vertically within the provided space as they grow to maturity. This study found no correlation between the body size and web angle. Nonetheless, horizontal orb-webs have the disadvantages of reduced web capture by about 70%, lower retain of prey capture by 20%, and increased damage from rain drops and falling debris (Eberhard, 1990). Hence, the web angle is tilted to the condition of available space when the requirements of the tetragnathid species are fulfilled.

Many biotic and abiotic factors have to be taken into consideration to determine the reasons for the variations in web characteristics of each tetragnathid species. The four tetragnathid species in this study produce a comparable number of spirals and radii at different body sizes. This could indicate that the corresponding amount of spirals and radii are genetically encoded. Other factors that reflect web characteristics of different body sizes are likely to be influenced by maturity. Similarly, changes of other web characteristics could be a response to the requirements of a particular situation within the habitats types.

CHAPTER 8

GENERAL DISCUSSION

The occurrence and distribution of spider species in this country are not well documented. There is lacking of information concerning the different types of habitats and locations where these spider species can be found. This study has documented information on the occurrence of the spider species at eleven selected locations focusing on the west coast of Peninsular Malaysia. A systematic and detailed work survey should be broadened to other habitat including caves, reservoir, tree canopies and ground which would greatly increase the total spider species richness in Peninsular Malaysia. The checklist of spider presented in this study can improve species inventories to assist future conservation efforts in this region.

In this study, most of the tetragnathid species recorded were found in selected preserved environment consisting of national parks, nature reserves, tourism spots, gardens and forest fringes within preserved sites, while other habitat types (e.g. agriculture, caves and human settlement) were not covered. From this study, it was found that certain tetragnathid species dominated selected forest types. Sample collections at different forest types and localities in this study provided broader views on the ecology and distribution of this species. Future work should focus on collecting tetragnathid species by extending surveys to other potential localities (e.g. wetlands, caves) and wider locality coverage at different habitat types would lead to higher chances of discovery of cryptic, rare and probably new records and new species in Malaysia. However, it should be noted that this study had focused only on tetragnathid species that build orb-webs while non-web-building species were disregarded, which therefore attributed to the number of species captured. For example, *Pachygnatha* species was not included as a research subject because they do not build orb-web at adult stages (Alvarez-Padilla, 2008).

The genus *Tetragnatha* has the most diverse species in Malaysia (World Spider Catalog, 2016). This study has identified that other genera were easier to find compared to *Tetragnatha* in which very few species could be found within their habitats. Moreover, it is known that some *Tetragnatha* species live as cryptic species, hiding in-between dense tree foliages (e.g. *T. hasselti*), while some species do not build webs at all (Okuma, 1987; Okuma 1988). Different preferences of habitat in some *Tetragnatha* species (Okuma, 1987; Okuma, 1988; Koh, 1989), posed even more difficulties in locating these species. Locations where *Tetragnatha* species have been recorded previously (Norma-Rashid *et. al*., 2009; Koh *et al*., 2013) were not covered in this study.

Most research interests have been focusing on the taxonomic study of *Leucauge* (e.g. Kim *et al*., 1999; Zhu *et al*., 2003), *Tetragnatha* (e.g. Okuma, 1987; Okuma, 1988) and *Tylorida* (e.g. Zhu *et al*., 2002; Tanikawa, 2004) species, as opposed to *Mesida*, *Opadometa* and *Orsinome* species. Consequently, the taxonomic statuses of *Leucauge*, *Tetragnatha* and *Tylorida* have been tentatively revised. While there was no intensive taxonomic study on the genus *Mesida* and *Orsinome*, new species are being discovered. In this study, three new species; *Opadometa kuchingensis*, *O. sarawakensis* (Dzulhelmi *et al*., 2015) and *Leucauge sabahan* were proposed. *Opadometa* species were found in Sarawak while *L. sabahan* were found in Sabah, where many photographs of the species taken by tourists had been available online. Yet, there were no formal descriptions documented. Even though the *L. sabahan* and two *Opadometa* species were described, the identification made was based on female specimens. The collected male specimens were insufficient for morphology description attributed to their unfully developed adult features.

Previous records of Malaysian tetragnathid species did not provide informative data particularly on their morphological features to assist in identification (i.e. Norma-Rashid & Li, 2009; Koh *et al*., 2013; Dzulhelmi *et al*., 2014a; Dzulhelmi *et al*., 2014b). On the contrary, many literatures on taxonomic descriptions, keys to species and illustrations are available for spider species found in other countries such as the Philippines (e.g. Barrion & Litsinger, 1995) and India (e.g. Sen *et al*., 2015). Moreover, establishing and updating taxonomic references for spider species in Malaysia are a challenging process due to lack of sample collections and comprehensive taxonomic documentation. Thus, this study has described and constructed sets of dichotomous keys based on selected morphology features of female tetragnathid species collected in this country. The collected specimens used for the dichotomous key constructions represented 56% of total tetragnathid species found in Malaysia. The keys were made by referring to the outer appearances to distinguish between species. For diagnostic description purposes, only tetragnathid species recorded within South East Asian countries were used for comparison. However, detailed diagnoses for a few tetragnathid species (i.e. *Leucauge subgemmea*) were not possible due to inaccessible source of references (i.e. Kim *et al*., 2008; see World Spider Catalog, 2015). Therefore, some species were excluded for comparison among the tetragnathid species collected.

Apart from representing tetragnathid species using morphology description, dichotomous keys, photography and illustrations, this study has also constructed data matrix as an alternative approach. Unlike the dichotomous keys, the data matrix remarks on the presence of certain characters to support species identification. In addition, the data matrix can also determine their sexual dimorphism. Species that might exhibit sexual dimorphism such as *Leucauge sabahan*, *Opadometa kuchingensis* and *O. sarawakensis* can be difficult to recognize, unless they were found in pairs. Many male spiders have very cryptic lifestyles, and individuals can be found on webs of female spiders especially during their mating season. Identities of some tetragnathid species such as *O. grata* and *O. fastigata* have remained ambiguous as incongruent genders were used for species description (Koh & Ming, 2013). It is to emphasize that the dichotomous keys and data matrix in this study were constructed based on female specimens. Male specimens were limited in collection, and therefore were insufficient for constructing dichotomous keys and data matrix. However, more than 60% of the collected male specimens are monomorphic.

Species identification using morphology and genitalia characteristics in spiders can be misleading due to complex variation (Barrett & Hebert, 2005) and polymorphism in some species (Huber & Gonazalez, 2001; Jocque, 2002). Therefore, molecular approach is required to support and verify species identification and in discovery of new species (Franzini *et al*., 2013). However, there is lacking of study on the phylogenetic relationships of Malaysian tetragnathid species. Furthermore, there are not many DNA sequences of Malaysian tetragnathid strains available in the GenBank (see blast.ncbi.nlm.nih.gov). This is one of very few studies using COI and 18S markers to determine the genes' compatibility in species delineation. Both COI and 18S genes were used independently in this study to relate the morphology of tetragnathid species in Malaysia.

The phylogenetic relationships were analysed using NJ, ML, MP and BI. The tree topologies for the COI gene reconstructed using ML and BI were identical. Meanwhile, MP and BI tree reconstruction have generated similar topologies using the 18S gene. Both markers were resolved into two clades, each representing subfamily Leucauginae and Tetragnathinae, which are consistent with their taxonomic statuses. Within the Leucauginae clade, both genes were able to group the closely related genera; *Leucauge* and *Opadometa* form as one sub-group while *Mesida* and *Tylorida* form another sub-group. On the other hand, *Tetragnatha* formed a separate sub-group in the Tetragnathinae clade. These molecular evidences are coherent with morphological characteristics, which suggest COI and 18S genes reliability as genetic markers in discriminating the grouping at generic level. However, the more complex relationship at generic and species level were not resolved using the same genes.

There are several factors to be considered in performing phylogenetic analyses in Malaysian tetragnathid species: (1) number of individuals used for each species (2) number of species used for each genus and (3) selection of outgroups. Combination of several markers in current study was not possible as the extraction of DNA of some tetragnathid species were unsuccessful (i.e. *Leucauge liui*), apart from the limited number of samples. The results obtained in this study suggest that the COI gene is more informative in resolving intra- and interspecific relationship among Malaysian tetragnathid species. Nonetheless, as a single gene marker is inadequate, using other genetic markers (e.g. 12S, 16S, 18S, 28S and H3) or using combination of several genetic markers should be implemented when more number of tetragnathid species found in Malaysia has been collected in the future.

Tetragnathid species depend solely on the quality of the web-sites for foraging success (Prokop, 2006). In this study, web-site selection of tetragnathid species for building webs at different habitats was investigated to determine its influence on the web characters. From the seven web variables used in the PCA, two most significant variables are web-size and web-sites in relation to distance from the ground. Despite their sizes and life stages, the statistical analysis showed that some tetragnathid species that coexist within the same habitat had very little clustering in terms of web characteristics, while other species showed many similarities in web characters. This study on the web characteristics provides an insight on the tetragnathid species' ability to respond to different habitats and developing niches. Based on the PCA using web characters as variables, individual clustering of conspecifics were achieved rather than mixtures between individuals of different species.

The variations in orb-webs among species may be due to spatial constraints, differences in body size and prey availability (Herberstein *et al*., 2000; Richardson & Hanks, 2009). Tetragnathid species found in homogenous habitat types (i.e. long grasses, forest fringe and montane forest) showed similarity in web characters, while species found in heterogenous habitat types (i.e. dipterocarp forest, mangrove forest and heath forest) have distinct web characters. Therefore, the results obtained in this study support that (1) orb-web species exhibit niches partitioning and are selective in positioning their webs within a vegetation structure (Weeks & Holtzer, 2000) (2) if different orb-web spiders exist within the same habitat, they minimize their competition by constructing webs that have different characters and web-sites (Sherman, 1994; Richardson & Hanks, 2009).

In this study, sub-adult and adult individuals were pooled for the analysis due to limited number of collected individuals. Most tetragnathid species are very difficult to encounter and collect. Active searching of these small and solitary creatures is a very challenging task. Limited information on the population of the studied species had influenced the number of individuals collected.

Meanwhile, the present study investigates the relationships between the morphology and web characteristics. The morphology was represented by eight morphological variables converted to the first principal component. Correlation between morphology and each web characteristic was tested. The test showed that when web sizes change significantly, there were no significant correlation in the number of spirals, number of radii, web-sites and web-angles. Previous analysis highlighted that web size and web-sites were one of the significant web character variables that influence niche partitioning (McCravy & Hessler, 2012). Hence, allometric relationships that correlate the true index of body size (relative leg length to carapace length) with web characters are recommended for future study.

This study showed that web sizes showed correlation to morphology. There was no correlation observed between the morphology and the number of spirals and radii. There are several explanations to this condition. As most orb-web spiders select and build their first orb-webs as early as during the juvenile stages, these spiders would construct orb-webs with particular web characters within certain web-building sites that were able to fulfill their criteria and needs. As the spider grow, the web size increases, but the web-sites will remain at certain level of distance from the ground (Henaut *et al*., 2006).

The results obtained in this study support that (1) orb-web spiders construct web of different sizes but always maintain the basic web architecture (Tahir *et al*., 2010) (2) As there is lack of correlation in the number of spirals and radii when there are differences in body sizes, both web variables possibly influenced by environmental factors. The present study was not able to collect adequate amount of specimens for further analysis. Two different populations of same species of *L. argentina*, *M. gemmea* and *T. ventralis* were pooled. Although the t-test supported that the two populations pooled were similar, the number of individuals used is still limited. More samples for each species should be collected for larger overview of the studied species.

CHAPTER 9

CONCLUSION

This study documented an additional 219 spider species to the previous checklist for Peninsular Malaysia. The species recorded comprised of field specimens and lists obtained from available literatures. A total of 70 spider species from field collection were considered as new records while the other 149 spider species were compiled from available literatures. This documentation added up to a total of 644 spider species currently recorded in Peninsular Malaysia.

Meanwhile, this study successfully documented 44.12% of web-building tetragnathid spider species in Malaysia. Out of 34 tetragnathid species recorded in this country, a total of 18 species from five genera including three newly described species were managed to be collected. The sampling took place at four locations in peninsular Malaysia, three in Sabah and three in Sarawak representing ten different habitat types. Moreover, this study also manages to describe and proposed one new *Leucauge* species from Sabah and two new *Opadometa* species from Sarawak. In comparison with the number of species that had been documented in other South East Asian countries, more species of tetragnathid could be discovered in Malaysia due to greater habitat varieties, topographies and greater land masses.

The COI and 18S genes have proved to be useful in delineating Malaysian tetragnathid species. Thirty-three DNA sequences were successfully extracted from 17 species collected in this study. The phylogenetic relationships of tetragnathid species in Malaysia inferred using COI and 18S genes had shown that both genes revealed two main monophyletic clades, corresponding to the Leucauginae and Tetragnathinae subfamilies.

The tree-based taxon in the present study indicates that molecular evidence does coincide with morphological hypothesis and is very useful for taxonomic purposes. This study had identified that COI gene was more informative in contrast to 18S gene.

Meanwhile, this study managed to discuss on how niche partitioning succeeded in tetragnathid species that coexist within the same habitat based on web characteristics. This study recognized that web characteristics variables differed for different tetragnathid species. Tetragnathid species in homogeneous habitats constructed almost similar in web characteristics compared to the ones living in heterogeneous habitats. Two out of seven web characteristic variables that were identified played significant roles in exhibiting niche partitioning. Tetragnathid species altered their web sizes and maintained a certain level of distance from the ground to enable them to niche partition and coexist with other spider species.

In addition, relationships between web character alterations at different body sizes from the four selected tetragnathid species were discussed. The four spider species in this study altered their web characteristics but maintained certain number of spirals and radii. No correlation was shown between the body size with the number of spirals and radii. This could indicate that the two web characteristic variables were genetically encoded for each tetragnathid species. The information on tetragnathid species obtained from this study could benefit researchers, particularly in Malaysia.

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LIST OF PUBLICATIONS

Journals

1. **Dzulhelmi, M.N**., Suriyanti, S., Zulqarnain, M., & Norma, C. Y. (2014). New distributional records of spiders (Arachnida: Araneae) from the west coast of peninsular Malaysia. *Pakistan Journal of Zoology, 46*: 1573-1584.

2. **Dzulhelmi, M.N**., Suriyanti, S.N.P., Zulqarnain, M. & Norma, C.Y. (2015). Two new *Opadometa* species (Araneae, Tetragnathidae) from Sarawak, Malaysia. *Annales Zoologici, 65*, 101-107.

3. **Dzulhelmi, M.N**., Suriyanti, S.N.P., Low, V.L., Zulqarnain, M. & Norma-Rashid, Y. Phylogenetic relationships of tetragnathid spiders (Araneae, Tetragnathidae) in Malaysia inferred from partial sequences of the COI and 18S rRNA genes, in review.

4. **Dzulhelmi, M.N**., Goh, T.G., Asraf, B., Faszly, R., Zulqarnain, M. & Norma-Rashid, Y. Web characteristics determine niche partitioning for orb-web spiders (Araneae, Tetragnathidae) in Malaysia. *Oriental Insects*, accepted.

5. **Dzulhelmi, M.N.**, Goh, T.G., Zulqarnain, M. & Norma-Rashid, Y. Relationships between morphology and web characteristics of four spider species (Araneae, Tetragnathidae) in Malaysia, in review.

Conference

6. **Dzulhelmi, M. N**., Suriyanti, S. N.P., Zulqarnain M & Norma-Rashid Y. Ecology and web characteristics of the spider genus *Leucauge* (Araneae: Tetragnathidae). 18th Biological Sciences Graduate Congress. University of Malaya, 6-8th Jan 2014, International.

Seminar

7. **Dzulhelmi M. N**., Suriyanti SNP, Zulqarnain M, Norma-Rashid Y. Spiders of Peninsular Malaysia: New records and the needs for documentation. Seminar on zoological & ecological research in progress 2013, 27th Dec 2013, National.