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The Effects of Environmental and Soil Fertility Factors on Plant Species Diversity in Kilim Geoforest Park, Langkawi, Malaysia

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ABSTRACT

Mangroves contain significant biodiversity and are highly valuable for coastal communities for their daily life and ecotourism attractions. It was observed that appropriate environmental and soil factors are important for conducive growth of mangroves, which in turn influence species distribution, composition and diversity. This study was carried out to compare soil fertility status among three main riverine systems and to analyze the effects of environmental and soil fertility factors on species richness, evenness and diversity in mangrove forest at Kilim Geoforest Park in Langkawi. A total of one hundred (20 m × 20 m) plots were established along both sides of the three rivers: River Kisap (40 plots), River Ayer Hangat (30 plots) and River Kilim (30 plots). All the species and trees of diameter 1 cm dbh and above found within the plots were enumerated and identified. Species richness was computed based on the Jackknife method and species diversity using Simpson's Index, Shannon-Wiener's Index and Brillouin's Index. The evenness index was measured by Simpson's measure of evenness, Camargo's index of evenness and Smith and Wilson's index of evenness. The composite soil samples of each riverine system were analysed for available P, dry Ph, total N & C and exchangeable (Ca, K, Mg & Na). The Canonical Component Analysis (CCA) method was used to show the relationship between the environmental and soil fertility factors and plant species diversity. Based on the analysis of the current study, soil fertility factors in the study areas were significantly different among the three rivers. Meanwhile, biodiversity indices like Brillouin's index, Shannon-Wiener index, Simpson's index, and Jackknife estimates of species richness were clustered together in River Kisap, as also indicated by the clustering of mangrove species such as *Avicennia marina*, *Acanthus volubilis*, *Bruguiera cylindrica*, *Ceriops decandra*, *Xylocarpus moluccensis*, *Rhizophora apiculata* and *Bruguiera parviflora*. Meanwhile, the ordination diagram of canonical redundancy analysis showed strong correlations between

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environmental and soil fertility factors and species diversity in Kilim Geoforest Park, Langkawi.

Keywords: Mangrove forest, Kilim Geoforest Park Langkawi, species richness, evenness and diversity, Jackknife method, Simpson, Shannon-Wiener, Brillouin, Camargo, Smith and Wilson indices

INTRODUCTION

Mangroves are defined as shrubs, trees, palms or ferns that grow within the inter-tidal region of coastal and estuarine environments throughout the tropical and subtropical areas around the world (Tomlinson, 1986). Mangroves can also include plants, associated forest communities and abiotic factors which form the mangrove ecosystem. The term 'mangrove' is also used to define both the plants that occur in tidal forests and to describe the community itself (Tomlinson, 1986; Wightman, 1989). Coastal ecosystems such as estuaries, wetlands and mangrove forests contain significant biodiversity and are highly valuable for coastal communities for their daily life. Mangrove ecosystem attracts intensive attention among the coastal ecosystems due to not only its peculiar habitat characteristics but also its rich biodiversity.

Mangrove forest in Langkawi is unique because they flourish on limestone formation, which is a rare occurrence and also supports unique flora and fauna species, some of which are endemic to the island, particularly the limestone vegetation. They are usually found on a shallow limestone substratum or Type VI of mangrove setting (Thom, 1984), and it is believed as one of its kinds in the world (Latiff, 2009). However, the anthropogenic pressure often leads to neglect the ecosystem and its surroundings culminate into a critical status of many coastal environments. Mangroves are the most threatened among the coastal ecosystems, more so throughout the tropical developing countries of the world as well as in Langkawi. Mangrove forest in Langkawi was reduced to 3270 ha or 10.6% reduction from 3657.67 ha in 1980 (Latiff, 2009). Knowing the fact that Langkawi is one of the biggest tourist attractions in Malaysia, Kilim Geoforest Park in Langkawi has been rapidly developed since the last 20 years mainly for tourism purposes. The mangrove areas in Kilim Geoforest Park cover approximately 3,142 ha, of which about 1,336 ha belong to Kisap Forest Reserve. There are several threats to Kilim Geoforest Park mangroves, specifically over-exploitation by the local people, such as natural resource development viz. coastal agriculture, salt production, intensive shrimp culture, as well as coastal industrialization and urbanization that completely destroy the mangrove ecosystem; and increasing facilities for yatch parking and activities for ecotourism.

As in other countries, the early attempts at mangrove restoration programmes in Malaysia met with mixed results, with some being successful, while others were doomed from the start. Reports by many experts (Field, 1996; Erftemeijer & Lewis 2000) showed that mangrove restoration programmes conducted before were not based on well-understood ecological principles and well-defined objectives. There are many factors affecting the diversity and composition of mangroves in the world.

In more recent years, attention has turned to the ecological processes that are present in the natural and restored mangrove systems (McKee & Faulkner, 2000; Alongi, 2002; Saenger, 2002; Lewis III, 2005). The relationship between the restored mangrove ecosystem and adjoining ecosystems such as salt marsh (Saintilan & Hashimoto, 1999) and sea grass beds (Hogarth, 2007) has also been a focus of attention. A consensus has also emerged that an understanding of mangrove hydrology is most important for successful restoration (Wolanski *et al.,* 1992). By establishing a new concept aiming at mangrove restoration programmes, degraded mangrove forest would probably be restored.

Of late, however, environmental factors have become the focus of discussion, for example, tidal waters bring nutrients along with other essential minerals to the on-shore region where they become available to mangroves. This tidal water was earlier considered to be the only factor playing a major role in the regeneration and growth of mangroves. Nonetheless, it has been observed that other factors such as rainfall (200cm–300cm), atmospheric humidity (60% - 90%), and moderate temperatures (19°C - 35°C) have also been considered ideal for mangroves' growth (Blasco, 1977; Naskar & Mandal, 1999).

On the contrary, a study in India showed different results; despite having the maximum tidal fluctuations, Bhabnagar estuary did not have high mangrove species diversity because of its low average rainfall (60 cm annum^{-1}) and inadequate upstream freshwater supply (Blasco & Aizpuru, 1997). Venkatesan (1966) argued that mangrove habitats would remain productive as long as they got inundated with tidal water, received high rainfall annually, and benefited from the continuous upstream freshwater which usually carries silt, sediments and organic matter. Mandal (1996) supported the above view while investigating seed germination and seedling development of mangroves. Mangroves initially require fresh water to continue their physiological process until they develop salt secretary organs such as salt glands, corkwart, gall and other related mechanisms (Naskar *et al*., 1997; Naskar & Mandal, 1999).

The objectives of this research were to compare the soil fertility status among the three main riverine systems, to establish interrelationship and relative roles of soil fertility in determining species diversity, as well as to relate environmental factors influencing species distribution, composition and diversity in the three main riverine systems - River Kisap, River Kilim and River Ayer Hangat in the Kilim Geoforest Park, Langkawi, in terms of species richness, evenness and diversity.

MATERIALS AND METHODS

Site Description

Kilim Geoforest Park, Langkawi, features limestone dominating the eastern part of the main Langkawi island and the adjacent small islands of Setul formation. Magnificently formed landscape of nearly vertical to subrounded karstic hills with pinnacles of various shapes and sizes can be viewed. It comprises three rivers, namely; River Kilim, River Ayer Hangat and River Kisap. These rivers have many tributaries, with mangrove forests line both sides of the rivers. Kilim karstic hills bear many beautiful caves, while karstic coastlines are provided with much more varied and colourful karstic features including sea notches, sea tunnels, sea caves, sea arches, sea stacks and remnant islands. The limestone of Kilim is also very rich in fossils, particularly those at Pulau Langgun. The region's highest (23m a.s.l.) Holocene (circa 7000m a.s.l) was also recorded within this Geoforest Park. The ecosystems of the old limestone rock formation, the caves, the mudflats and the seas that surround it have three main vegetations, namely; the mangroves, the vegetation of the limestone hills, and the flora of the mudflats and beaches.

The study area is located between the latitude 6^0 29' 33.20'' to 6^0 23' 6.24'' and between the longitude 99^0 48' 0.34'' to 99^0 55' 30.86'' at the northeast of Langkawi Island (Fig.1). The area is mainly covered by forest, mangroves, agricultural land and sand beaches. The topography varies from flat coastal plains to hilly areas to rugged mountains. All the data for this study were collected from November 2009 to February 2010.

Sampling for Plant Composition

Plots of 20 m × 20 m were established along River Kisap (40 plots), River Kilim (30 plots) and River Ayer Hangat (30 plots) within Kilim Geoforest Park. All the plots were 250 m apart from edge to edge of the plot along these rivers to the shoreline (Fig.2).

Within each plot, all trees ≥1 cm dbh (diameter breast height) were identified, measured and recorded. Other parameters recorded were species name and height. All other woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds were counted. However, a complete specimen was collected, tagged and recorded if the species were not known. They were brought to the Herbarium at the Faculty of Forestry, Universiti Putra Malaysia (UPM) for drying process and identification.

Soil Sampling

Soil samples were taken from 6 randomly chosen plots from each of the riverine systems. Within each 20 m × 20 m plot, 5 soil samples were taken – one point (3 soil samples/point) in the middle of the plot, the other four points were collected randomly within each quadrant of the plot. Hence, a total of 90 soil samples were collected using soil auger (10 to 20 cm soil layers) from the three riverine systems. The soil samples from each sampling point plot were mixed thoroughly as a composite sample, air dried and passed through a 2 mm mesh sieve to remove the stone pieces and large root particles. The composite soil sample was used for a detailed soil

Fig.1: Location of Kilim Geoforest Park, Langkawi, Malaysia and the sampling site

analysis, as follows: (i) Available P (ppm); (ii) Dry pH; (iii) Total N (%); (iv) Total organic C (%); (v) Exchangeable Ca (cmol/kg); (vi) Exchangeable K (cmol/kg); (vii) Exchangeable Mg (cmol/kg) and (viii) Exchangeable Na (cmol/kg).

Data Analysis

A data matrix X_{ij} was analyzed, where i= 1, 2, 3,.... 98, 99, 100 denote the 100 plots established along the three rivers, and j= 1, 2, 3...., 19, 20, 21 represent 21 indices of soil fertility, measure of plant diversity and

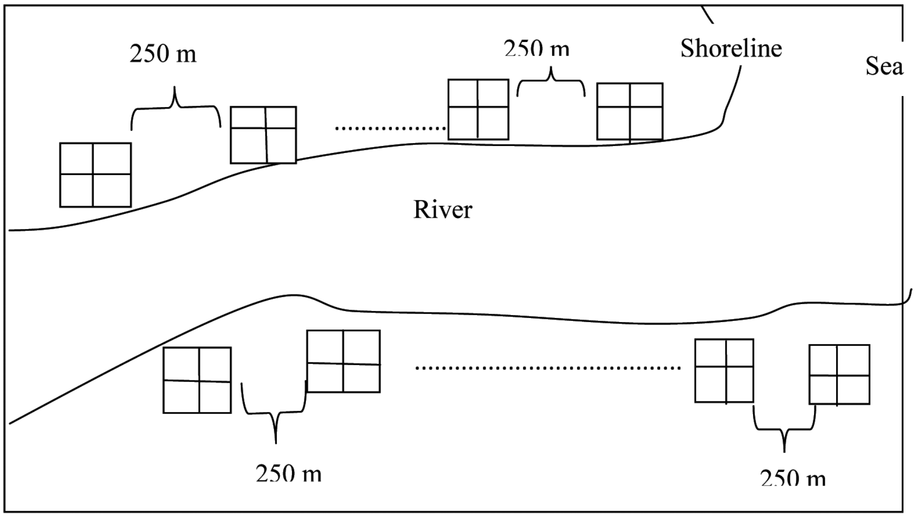

Fig.2: Plot layout at each of the three rivers

environmental factors. The j factors are as follows:

1. Environmental factors: (i) Total amount of rainfall (RF); (ii) Total number of raindays (RD); (iii) Mean temperature (T); (iv) Relative humidity (RH); and (v) Surface wind speed (WS)
2. Soil fertility factors: (i) Available P; (ii) Dry pH; (iii) Total N; (iv) Total organic C; (v) Ex. Ca; (vi) Ex. K; (vii) Ex. Mg; (viii) Ex. Na; (Ex. = Exchangeable).
3. Measures of plant diversity: (i) Total number of individual (NI), (ii) Brillouin's index H (BI), (iii) Shannon-Wiener index of diversity H' (SW); (iv) Simpson's index of diversity (SI); (v) Camargo's index of evenness (CE); (vi) Smith and Wilson's index of evenness (SW); (vii) Simpson's measures of evenness (SE); and (viii) Jackknife estimates of species richness (JR).

SAS (Statistical Analysis System) package was used to compare the soil fertility status among the three rivers. In order to investigate complex relationships, the multivariate statistical analysis techniques - Principal Component Analysis (PCA) and Canonical Correlation Analysis (CCA) were used. PCA was used to compute the Eigenvalues using Conoco 4.5 software. The CCA method was used to illustrate the interrelationships between the environmental factors, soil fertility and plant diversity groups.

Principle Component Analysis (PCA)

PCA is a useful statistical technique that is used to obtain a small number of linear combinations of the many factors (the 21 factors), which account for the most of the variability in the data. The components with Eigenvalues ≥ 1 and their cumulative percentages of variance are considered as the one accounted for the most of the variability.

Canonical Correlation Analysis (CCA)

CCA is a method to help identify the associations between two sets of variables. It does so by finding linear combinations of the variables in the two sets that exhibit strong correlations. The pair of the linear combinations with the strongest correlation forms the first set of canonical variables. The second set of the canonical variables is the pair of linear combinations that shows the next strongest correlation among all the combinations that are uncorrelated with the first set. Often, a small number of pairs can be used to quantify the relationship of the two sets.

Data for computing species richness, evenness and diversity indices were analyzed using Ecological Methodology Software (Krebbs 1998), as follows:

Species Richness

i. Jackknife Estimate

$$\hat{\mathbf{S}} = \mathbf{s} + \left(\frac{\mathbf{n}-\mathbf{1}}{\mathbf{n}}\mathbf{k}\right)$$

Where,

$\hat{\mathbf{S}}$ = jackknife estimate of species richness

s = total number of species present in quadrates

n = total number of quadrates samples

k = number of unique species (species which occur in only one quadrate)

Species Diversity

i. Simpson's Index

$$\hat{\mathbf{D}} = \mathbf{1} - \sum \mathbf{Pi}^{\mathbf{2}}$$

Where,

$\hat{\mathbf{D}}$ = Simpson's index

Pi = proportion of species i in the community

ii. Shannon-Weiner measure

$$H` = \sum (\mathbf{Pi})(\mathbf{logPi})$$

Where,

H ' = information content of the sample (bits/individual) and index of diversity

s = number of species

Pi = proportion of the total sample belonging to i species

iii. Brillouin's index

$$HB = \frac{\ln(N!) - \Sigma \ln(ni!)}{N}$$

Where,

HB = the Brillouin index,

N = total number of individuals in the sample

ni = number of individual of species i

ln(x) = natural logarithm of x (or logarithm base e)

N! means the factorial of N = 1 * 2 * 3 * 4... * N

Species Evenness

i. Simpson's measure of evenness

$$E_{\frac{1}{\hat{D}}} = \frac{\frac{1}{\hat{D}}}{s}$$

Where,

$E_{1/D}$ = Simpson measure of evenness
S = number of species in the sample
$\hat{D}$ = Simpson index

ii. Smith and Wilson's index of evenness
E_{var}=1-[2/(πarctan{}^{2}/s)}

E_{var}=1-[2/(πarctan{Σ↓(i = 1)↑ε [(log↓e (n↓i) − Σ↓(j = 1)↑ε (log↓e (n↓j))/s)^2/s)}

Where,

E_{var} = Smith and Wilson's index of evenness
n_i = Number of individuals in species i in the sample (i = 1, 2, ..., s)
n_j = Number of individuals in species j in the sample (j = 1, 2, ..., s)
s = Number of species in the entire sample

iii. Camargo's index of evenness

$$E' = 1 - \left(\sum_{i=1}^{s} \sum_{j=i+1}^{s} \left(\frac{|P_i - P_j|}{S} \right) \right)$$

Where,

p_i = proportion of individuals of a species at site i
p_j= proportion at site j;
s = total number of sites in the sample.

TABLE 1
Floristic composition and dominant tree species ≥1 cm dbh at Kilim Geoforest Park, Langkawi, Malaysia

Area	Family	Species	No. of Stem
	1. Avicenniaceae	1. *Avicennia officinalis*	20
	2. Rhizophoraceae	2. *Bruguiera gymnorhiza*	17
		3. *Bruguiera parviflora*	424
		4. *Bruguiera sexangula*	465
		5. *Ceriops tagal*	1264
		6. *Rhizophora apiculata*	1226
		7. *Rhizophora mucronata*	455
	3. Cycadaceae	8. *Cycas siamensis*	3
Sungai Kilim	4. Lythraceae	9. *Memecylon edule* Roxb. var. *ovatum*	1
		10. *Memecylon pauciflorum*	1
	5. Rutaceae	11. *Murraya paniculata*	2
	6. Anacardiaceae	12. *Pentaspadon curtisii*	3
	8. Moraceae	13. *Streblus ilicifolius*	19
		14. *Streblus laxiflorus*	1
	9. Polygalaceae	15. *Xanthophyllum discolor*	8
	10. Meliaceae	16. *Xylocarpus granatum*	124
		17. *Xylocarpus moluccensis*	18
		Total	**4051**

cont'd Table 1

Sungai Kisap	1. Avicenniaceae	1. *Avicennia marina*	55
	2. Rhizophoraceae	2. *Bruguiera cylindrica*	1110
		3. *Bruguiera parviflora*	311
		4. *Ceriops decandra*	1
		5. *Ceriops tagal*	367
		6. *Rhizophora apiculata*	1114
		7. Rhizophora mucronata	244
	3. Lauraceae	8. *Cinnamomun* sp.	4
	4. Ebenaceae	9. *Diospyros ismailii*	21
	5. Elaeocarpaceae	10. *Elaeocarpus griffithii*	1
	6. Erythroxylaceae	11. *Erythroxylum cuneatum*	9
	7. Euphorbiaceae	12. *Excoecaria agallocha*	4
	8. Loganiaceae	13. *Fagraea curtisii*	7
	9. Bignoniaceae	14. *Fernando adenophylla*	10
	10. Moraceae	15. *Ficus deltoidea*	5
		16. *Ficus rumpii*	2
		17. *Ficus superb*	4
	11. Flacourtiaceae	18. *Flacourtia rukam*	3
	12. Sterculiaceae	19. *Heritiera littoralis*	4
	13. Flacourtiaceae	20. *Hydnocarpus ilicifolia*	4
	14. Lythraceae	21. *Lagerstroemia floribunda*	9
	15. Euphorbiaceae	22. *Macaranga* sp.	1
		23. *Mallotus brevipetiolatus*	4
		24. *Mallotus dispar*	2
		25. *Phyllanthus pulcher*	15
	16. Lythraceae	26. *Memecylon edule* Roxb. var. *ovatum*	18
		27. *Memecylon pauciflorum*	35
	17. Tiliaceae	28. *Microcos* sp.	1
		29. *Pentace* sp.	3
	18. Anacardiaceae	30. *Pentaspandon curtisii*	9
		31. *Pentaspandon velutinis*	1
	19. Rubiaceae	32. *Psychotria angulata*	1

cont'd Table 1

Sungai Kisap	20. Sterculiaceae	33. *Pterospermum lanceaefolium*	5
	21. Bignoniaceae	34. *Radermachera pinnata*	11
		35. *Radermachera stricta*	3
	22. Araliaceae	36. *Schefflera heterophylla*	2
	23. Bignoniaceae	37. *Spatodea companulata*	9
	24. Anacardiaceae	38. *Spondias pinnata*	2
	25. Sterculiaceae	39. *Sterculia augustifolia*	17
		40. *Sterculia lancaviensis*	19
	26. Moraceae	41. *Streblus ilicifolius*	41
	27.Myrtaceae	42. *Syzgium* sp.	3
	28. Combretaceae	43. *Terminalia triptera*	5
	29. Verbenaceae	44. *Vitex pinnata*	1
	30. Polygalaceae	45. *Xanthophyllum affine*	3
		46. *Xantophyllum discolor*	3
	31. Meliaceae	47. *Xylocarpus granatum*	253
		48. *Xylocarpus moluccensis*	76
		Total	**3832**
Sungai Ayer Hangat	1. Avicenniaceae	1. *Avicennia marina*	37
	2. Rhizophoraceae	2. *Bruguiera cylindrical*	62
		3. *Bruguiera parviflora*	91
		4. Ceriops tagal	429
		5. Rhizophora apiculata	1109
		6. Rhizophora mucronata	265
	3. Ebenaceae	7. *Diospyros ferrea*	1
	4. Euphorbiaceae	8. *Excoecaria agallocha*	1
	5. Moraceae	9. *Ficus superb*	1
	6. Anacardiaceae	10. *Pentaspadon motley*	1
	8. Lythraceae	11. *Sonneratia alba*	1
	9. Moraceae	12. *Streblus ilicifolius*	5
	10. Polygalaceae	13. *Xanthophyllum affine*	4
	11. Meliaceae	14. *Xylocarpus granatum*	1517
		15. *Xylocarpus moluccensis*	27
		16. *Xylocarpus rumphii*	54
		Total	3605
		Grand Total	11488

RESULTS AND DISCUSSION

Overall Species Composition and Dominance

In this study, a total of 11,488 and 14,820 individual species of trees ≥1 cm dbh and other woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds were identified, measured and recorded, respectively. All the species were enumerated to determine species composition and dominance in the 4 hectares study plot at Kilim Geoforest Park, Langkawi. The identified species were further classified according to their family and number of stems. For each riverine system, at least 24 families, 37 genera and 58 species of all trees (Table 1) were identified, apart from 43 families, 88 genera and 114 species of non-trees (e.g., orchids, shrubs, climbers, epiphytes, grasses, bamboos, and weeds (Table 2).

TABLE 2
The floristic composition and dominant species of woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds at Kilim Geoforest Park, Langkawi, Malaysia

Area	Family	Species	No. of Stem
Sungai Kilim	1. Acanthaceae	1. *Acanthus volubilis*	40
	2. Euphorbiaceae	2. *Euphorbia antiquorum*	23
	3. Meliaceae	3. *Xylocarpus granatum*	66
		4. *Xylocarpus moluccensis*	27
	4. Moraceae	5. *Streblus ilicifolius*	45
	5. Polygalaceae	6. *Xanthophyllum discolor*	4
	6. Rhamnaceae	7. *Ziziphus affinis*	13
	7. Rhizophoraceae	8. *Bruguiera parviflora*	127
		9. *Bruguiera sexangula*	256
		10. *Ceriops tagal*	439
		11. *Rhizophora apiculata*	759
		12. *Rhizophora mucronata*	118
		Total	1917
Sungai Kisap	1. Acanthaceae	1. *Acanthus ebracteatus*	3
		2. *Acanthus ilicifolius*	68
		3. *Acanthus volubilis*	679
		4. *Justicia sp.*	6
		5. *Pseuderanthemum crenulatum*	6
	2. Aizoaceae	6. *Sesuvium portulacastrum*	5
	3. Anacardiaceae	7. *Pentaspadon curtisii*	1
		8. *Pentaspadon motleyi*	7
	4. Annonaceae	9. *Fissistigma fulgen*	63
	5. Apocynaceae	10. *Parameria* sp.	30

cont'd Table 2

	6. Araliaceae	11. *Schefflera heterophylla*	5
		12. *Scindapsus scortechinii*	3
	7. Araceae	13. *Alocasia denudate*	79
		14. *Amorphophallus haematospadix*	12
		15. *Amorphophallus variabilis*	60
		16. *Arisaema fimbriatum*	286
	8. Asclepiadaceae	17. *Hoya coronaria*	4
		18. *Hoya diversifolia*	73
		19. *Pentasacme caudatum*	15
	9. Asteracae	20. *Chromolaena odorata*	37
		21. *Pluchea indica*	1
	10. Avicenniaceae	22. *Avicennia marina*	85
	11. Begoniaceae	23. *Begonia curtisii*	169
		24. *Begonia phoeniogramma*	3
	12. Cycadaceae	25. *Cycas siamensis*	1
	13. Cyperaceae	26. *Fimbristylis calcicola*	6
	14. Davalliaceae	27. *Davallia denticulate*	44
	15. Dioscoreaceae	28. *Dioscorea calcicola*	53
		29. *Dioscorea tamarisciflora*	185
	16. Dryopteridaceae	30. *Dryopteris anneaphylla*	36
Sungai Kisap		31. *Dryopteris ludens*	51
		32. *Tectaria coadunata*	8
		33. *Tectaria keckii*	19
	17. Ebenaceae	34. *Diospyros ferrea*	33
		35. *Diospyros ismailii*	8
	18. Euphorbiaceae	36. *Croton cascarilloides*	58
		37. *Excoecaria agallocha*	6
		38. *Macaranga* sp.	3
		39. *Mallotus brevipetiolatus*	2
		40. *Mallotus dispar*	11
		41. *Phyllanthus columnaris*	5
		42. *Phyllanthus pulcher*	9
	19. Flacourtiaceae	43. *Flacourtia rukam*	1
	20. Gesneriaceae	44. *Boea acutifolia*	52
		45. *Didymocarpus lacunosus*	12
		46. *Henklia* sp.	146
		47. *Monophyllaea glabra*	33
		48. *Paraboea ferruginea*	128
	21. Gramineae	49. *Dendrocalamus elegans*	5
	22. Labiatae	50. *Orthosiphon aristatus*	14
	23. Leguminosae	51. *Bauhinia curtisii*	40

cont'd Table 2

		52. *Bauhinia flava*	22
		53. *Caesalpinia crista*	26
		54. *Derris trifoliata*	13
		55. *Mucuna gigantea*	15
	24. Loganiaceae	56. *Fagraea curtisii*	60
Sungai Kisap	25. Lythraceae	57. *Lagerstroemia floribunda*	3
		58. *Memecylon edule*	130
		59. *Memecylon pauciflorum*	2
	26. Meliaceae	60. *Xylocarpus granatum*	605
		61. *Xylocarpus moluccensis*	108
	27. Menispermaceae	62. *Stephania venosa*	3
		63. *Tinospora crispa*	9
	28. Moraceae	64. *Ficus deltoidea*	14
		65. *Streblus ilicifolius*	155
		66. *Streblus laxiflorus*	54
	29. Oleaceae	67. *Jasminum insularum*	75
	30. Orchidaceae	68. *Bulbophyllum vaginatum*	14
		69. *Bulbophyllum xanthum*	5
		70. *Dendrobium gemellum*	3
		71. *Dendrobium pachyglossum*	6
		72. *Eria bractescens*	25
		73. *Eulophia keithii*	12
		74. *Flickingeria fimbriata*	42
Sungai Kisap		75. *Geodorum citrinum*	3
		76. *Liparis elegans*	17
		77. *Nervilia calcicola*	428
		78. *Vandopsis gigantea*	16
	31. Polypodiaceae	79. *Drynaria quercifollia*	55
		80. *Drynaria sparsisora*	43
		81. *Microsorum punctatum*	80
		82. *Microsorum zippelii*	20
		83. *Phymatosorus nigrescens*	6
		84. *Pyrrosia lanceolata*	2
		85. *Pyrrosia piloselloides*	10
		86. *Selliguea* sp.	100
	32. Pteridaceae	87. *Acrostichum aureum*	11
	33. Rhamnaceae	88. *Ventilago oblongifolia*	8

cont'd Table 2

		89. *Ziziphus affinis*	16
		90. *Ziziphus oenoplia*	100
	34. Rhizophoraceae	91. B*ruguiera cylindrica*	809
		92. *Bruguiera parviflora*	273
		93. *Ceriops tagal*	455
		94. *Rhizophora apiculata*	1316
		95. *Rhizophora mucronata*	121
	35. Rubiaceae	96. *Antirhea atropurpurea*	61
		97. *Argostemma pictum*	137
		98. *Psychotria angulata*	18
		99. *Psydrax* sp.	47
Sungai Kisap	36. Rutaceae	100. *Micromelum minutum*	71
		101. *Murraya koenigii*	27
		102. *Murraya paniculata*	9
	37. Sapindaceae	103. *Allophylus ternatus*	26
	38. Selaginellaceae	104. *Selaginella* sp.	580
	39. Tiliaceae	105. *Microcos* sp.	32
	40. Verbenaceae	106. *Cissus repens*	71
		107. *Clerodendrum nutans*	8
	41. Vitaceae	108. *Tetrastigma leucostaphylum*	4
		109. *Vitex siamica*	4
	42. Zingiberaceae	110. *Kaempferia pulchra*	15
		Total	9069
	1. Acanthaceae	1. *Acanthus ebracteatus*	78
		2. *Acanthus ilicifolius*	162
		3. *Acanthus volubilis*	660
	2. Avicenniaceae	4. *Avicennia marina*	29
	3. Lythraceae	5. *Memecylon edule*	4
	4. Meliaceae	6. *Xylocarpus granatum*	702
		7. *Xylocarpus moluccensis*	77
		8. *Xylocarpus rumphii*	76
Sungai Ayer Hangat	5. Moraceae	9. *Ficus deltoidea*	3
	6. Rhamnaceae	10. *Ziziphus affinis*	2
	7. Rhizophoraceae	11. *Bruguiera cylindrica*	24
		12. *Bruguiera parviflora*	69
		13. *Ceriops tagal*	713
		14. *Rhizophora apiculata*	1174
		15. *Rhizophora mucronata*	56
	8. Rubiaceae	16. *Psydrax* sp.	5
		Total	3834
		Grand Total	14820

For trees ≥1 cm dbh as in Table 1, five most dominant species at each riverine system in terms of the number of stems are as follows:

Sg. Kilim: *Ceriops tagal* (1264 stems), *Rhizophora apiculata* (1226), *Bruguiera sexangula* (465), *Rhizophora mucronata* (455 stems), and *Bruguiera parviflora* (424 stems);

Sg. Kisap: *Rhizophora apiculata* (1114 stems), *Bruguiera cylindrical* (1110 stems); *Ceriops tagal* (367 stems), *Bruguiera parviflora* (311 stems); and *Rhizophora mucronata* (244 stems); and

Sg. Ayer Hangat: *Xylocarpus granatum* (1517 stems), *Rhizophora apiculata* (1109 stems), *Ceriops tagal* (429 stems), *Rhizophora mucronata* (265 stems); and *Bruguiera parviflora* (91 stems).

Meanwhile, the two most dominant families for trees ≥1 cm in the three riverine systems combined are Rhizophoraceae (8954 stems or 77.94% of the total stems) and Meliaceae (2069 stems or 18.01%). Rhizophoraceae has 8 species in 3 genera (8954 stems or 77.94%), the highest, and therefore, the most diverse among the trees ≥1 cm in the three riverine systems. This is followed by Moraceae (5 species in 1 genus: 78 stems or 0.68%) and Euphorbiaceae (5 species in 4 genera: 27 stems or 0.24%). On the other hand, the least diverse plant species were those with only one genus and one species in various families, while the most were with less that 10 individual stems.

For woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds, five most dominant species at each riverine system in terms of the number of stems are as follows (Table 2):

Sg. Kilim: *Rhizophora apiculata* (759), *Ceriops tagal* (439 stems), *Bruguiera sexangula* (256), *Bruguiera parviflora* (127 stems) and *Rhizophora mucronata* (118 stems);

Sg. Kisap: *Rhizophora apiculata* (1316 stems), *Bruguiera cylindrical* (809 stems); *Acanthus volubilis* (679 stems), *Ceriops tagal* (455 stems), and *Bruguiera parviflora* (311 stems); and

Sg. Ayer Hangat: *Rhizophora apiculata* (1174 stems), *Ceriops tagal* (713 stems), *Xylocarpus granatum* (702 stems), *Acanthus volubilis* (660 stems), and *Xylocarpus moluccensis* (77 stems).

The three most dominant families for plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds in the three riverine systems combined were Rhizophoraceae (6709 stems or 45.27% of the total stems), Acanthaceae (1702 stems or 11.48%) and Meliaceae (1661 stems or 11.21%). Orchidaceae has 11 species in 9 genera (571 stems or 3.85%), the highest and therefore, the most diverse for plants ≤ 1cm dbh in the three riverine systems. This is followed by Euphorbiaceae (9 species in 7 genera: 124 stems or 0.84%), Polypodiaceae (8 species in 5 genera: 316 stems or 2.13%), Rhizophoraceae (6 species in 3 genera: 6709 stems or 45.27%) and Gesneriaceae (5 species in 5 genera: 371 stems or 2.5%). On the other hand, the least diverse plant species are those with only one genus and one species in various families and the majority is with less 75 stems.

The Effect of Soil Fertility and Environmental Factors on Plant Species Diversity

Environmental factors for the year 2010, such as RF, RD, T, RH collected from a nearby meteorological station, are similar for all the study areas, namely; RF= 2398.2 mm, RD=180 days, T= 28.4 ^{0}C, RH= 78.8 % and WS=1.9 m/second, as the rivers are adjacent to each other.

The soil fertility factors in the three study areas (River Kisap, River Kilim and River Ayer Hangat) were also determined in this study. Many previous studies have shown that soil fertility is one of the key factors determining the species diversity in certain areas (Zack *et al*., 2003). Based on our analysis, some soil fertility factors in the study areas are significantly different among the three rivers (Table 3).

The soil fertility factors are closely related to soil organic matter (SOM) content and its mineralization. The extent of C mineralization determines soil nutrient release and therefore nutrient availability. In the study area, soil properties showed a slight heterogeneity among the study sites. The test results in Table 3 show that River Kisap has higher available P, total N and organic C contents as compared to River Kilim and River Ayer Hangat.

Analysis of the Plant Species Diversity

Interestingly, species richness, species heterogeneity and species evenness for both mangrove and woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds for the three locations showed that they are significantly diverse (Tables 4 and 5). Based on Jackknife's index, River Kisap, with an index equals to 53.32 and 126.85, is the richest area with mangrove and woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds, respectively as compared to River Ayer Hangat and River Kilim. In the River Kisap area, 15 mangrove species were identified, whereas only 8 species were identified at the other two rivers.

TABLE 3
Soil fertility factors at the three riverine systems at Kilim Geoforest Park, Langakwi, Malaysia (statistics sharing the same superscripts $^{(a\ or\ b)}$ are not significantly different at P > 5%)

Soil Fertility Factors	Locations		
	River Ayer Hangat	River Kilim	River Kisap
Available P (ppm)	153.94^a	148.59^a	166.07^b
Total N (%)	0.27^a	0.28^a	0.29^a
Total 0rganic C (%)	4.14^a	6.21^a	6.93^b
Ex. Ca (cmol/kg)	8.22^a	11.48^a	8.80^a
Ex. K (cmol/kg)	2.30^a	2.61^a	2.60^a
Ex. Mg (cmol/kg)	21.53^a	30.91^b	22.70^a
Ex. Na (cmol/kg)	54.34^a	79.23^b	57.62^a
Soil pH	5.83	5.28	6.04

TABLE 4
Species diversity of mangrove at three riverine systems in Kilim Geoforest Park, Langkawi

A. Measure of Species Richness			
Diversity Index	River Kilim	River Kisap	River Ayer Hangat
Jackknife estimates of species richness	19.48	53.32	18.32
B. Measure of Species Heterogeneity			
Diversity Index	River Kilim	River Kisap	River Ayer Hangat
Simpson's index of diversity (1-D)	0.77	0.81	0.70
Shannon-Wiener index of diversity H'	2.44	3.00	2.08
Brillouin index of diversity	2.43	2.97	2.07
C. Measure of Species Evenness			
Diversity Index	River Kilim	River Kisap	River Ayer Hangat
Simpson's measure of evenness	0.26	0.11	0.21
Camargo's index of evenness	0.25	0.14	0.22
Smith and Wilson's Index of Evenness	0.10	0.18	0.10

TABLE 5
Species diversity of woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds at three riverine systems in Geoforest Park, Langkawi, Malaysia

A. Measure of Species Richness			
Diversity Index	River Kilim	River Kisap	River Ayer Hangat
Jackknife estimates of species richness	13. 57	126.85	17.76
B. Measure of Species Heterogeneity			
Diversity Index	River Kilim	River Kisap	River Ayer Hangat
Simpson's index of diversity (1-D)	0.76	0.95	0.81
Shannon-Wiener index of diversity H'	2.55	5.11	2.72
Brillouin index of diversity	2.53	5.07	2.71
C. Measure of Species Evenness			
Diversity Index	River Kilim	River Kisap	River Ayer Hangat
Simpson's measure of evenness	0.35	0.17	0.32
Camargo's index of evenness	0.37	0.25	0.32
Smith and Wilson's Index of Evenness	0.29	0.23	0.16

TABLE 6
A summary of RDA ordination for mangrove tree species and their relationship with environmental factors in the Kilim Geoforest Park, Langkawi, Malaysia

Term	Axis				Total inertia
	1	2	3	4	
Eigenvalues:	0 .317	0.228	0.000	0.000	0.546
Species-environment correlations:	.000	1.000	0.000	0.000	
Cumulative percentage variance					
of species data :	58.2%	100%	0.0	0.0	
of species-environment relation:	58.2%	100%	0.0	0.0	
Sum of all eigenvalues:					0.546
Sum of all canonical eigenvalues :					0.546

TABLE 7
A summary of the RDA ordination for woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds and their relationship with environmental factors in the Kilim Geoforest Park, Langkawi, Malaysia

Term	Axes				Total inertia
	1	2	3	4	
Eigenvalues	: 0.418	0.152	0.000	0.000	0.570
Species-environment correlations:	1.000	1.000	0.000	0.000	
Cumulative percentage variance					
of species data	: 73.3%	100%	0.0	0.0	
of species-environment relation:	73.3%	100%	0.0	0.0	
Sum of all eigenvalues					0.570
Sum of all canonical eigenvalues					0.570

Based on the recorded data, all the indices showed that Sungai Kisap is the most diverse area in Kilim Geoforest Park, followed by Sungai Kilim and Sungai Ayer Hangat. As for woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds, the ranking is as follows: Sungai Kisap > Sungai Ayer Hangat > Sungai Kilim. Sungai Kilim showed the most evenness area for both mangroves and woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds, followed by Sungai Ayer Hangat and Sungai Kisap.

The Relationships between Environmental Factors and Measures of Plant Diversity

Tables 6 and 7 summarize the Eigenvalues, species-environment correlation and cumulative percentage variance of the species data and species-environment relation obtained through CCA. The results of the interaction of mangrove species with the environmental factors are explained at the first and second axis of canonical correlation. High Eigenvalues (0.317) and species-environment correlations (r =1.00) were obtained at the first axis. At the second axis, however, the Eigenvalues decreased (0.228), with species-environment correlation value was maintained. These values proved that the environmental factors strongly influenced species diversity in the study areas.

The ordination diagrams of canonical redundancy analysis (RDA) shown in Fig.3 and Fig.4 indicate a strong correlation between environmental factors and species diversity in Kilim Geoforest Park, Langkawi. Mangrove species such as AM, AV, BC, CD, XM, RA and BP were clustered together in the River Kisap area. This is due to the best soil fertility factors such as soil pH, available P (AP), total N (N), total organic C (OC), ex. K (eK), ex. Ca (eCa), ex. Mg (eMg), and ex. Na (eNa) induced by favourable environmental factors such as RF, RD, T, RH. Moreover, plant vigour variables such as dbh (DBH), height, basal area (BA) and the number of individual (N) also showed a strong correlation with soil fertility in the study areas (Fig.3).

By using the ordination diagram, it clearly shows that River Kisap is the most diverse area in the Kilim Geoforest Park, Langkawi. Many biodiversity indices such

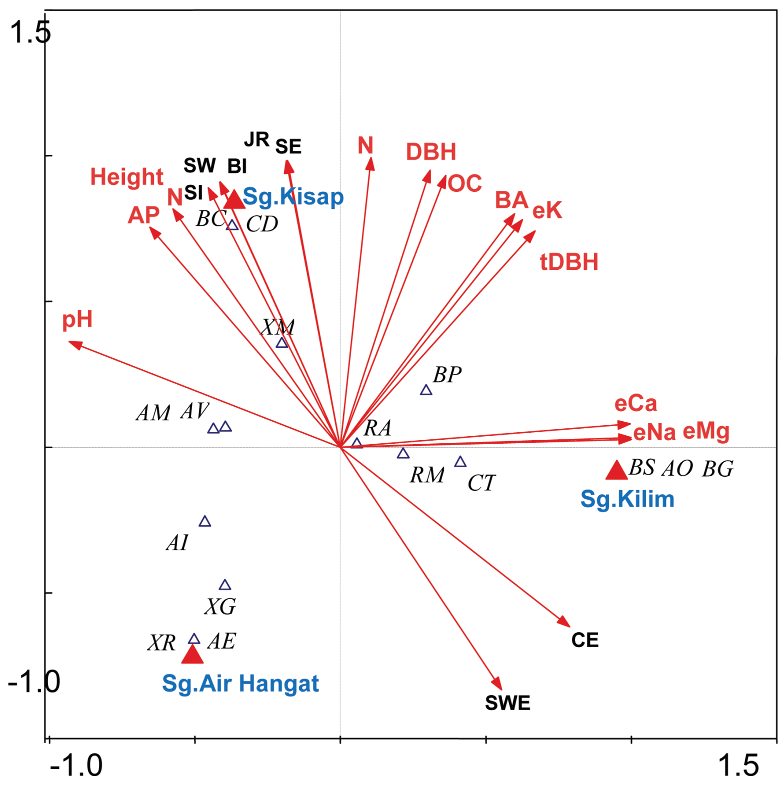

Fig.3: Ordination diagram of the first two axes of RDA for the mangrove species and their relationship with environmental factors in the Kilim Geoforest Park, Langkawi, Malaysia (see Appendix 1 for list of acronyms)

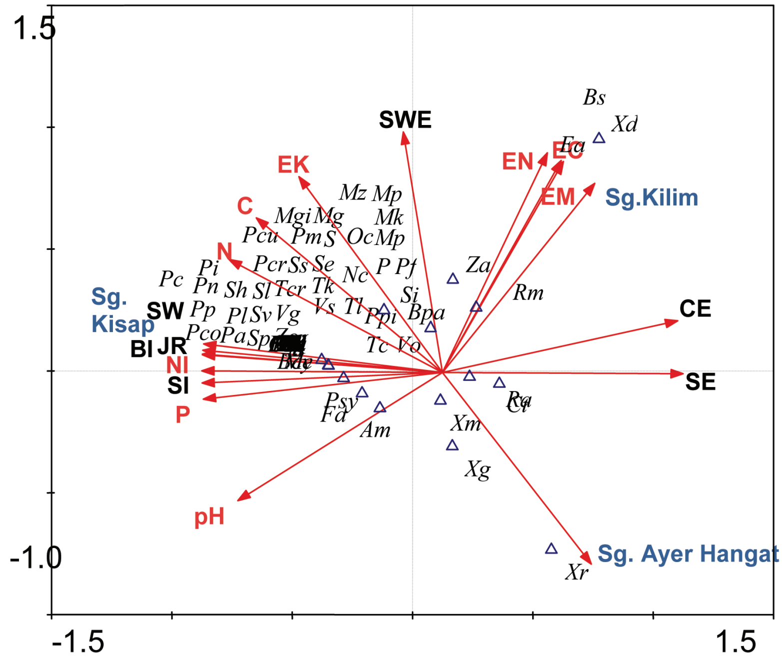

Fig.4: Ordination diagram of the first two axes of RDA for woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds and their relationship with environmental factors in the Kilim Geoforest Park, Langkawi, Malaysia (see Appendix 1 for list of acronyms)

as Brillouin's index H (BI), Shannon-Wiener index of diversity H' (SW), Simpson's index of diversity (SI), and Jackknife estimates of species richness (JR) were clustered together in River Kisap (Fig.3 and Fig.4).

CONCLUSION

Plant biodiversity provides a buffer against environmental fluctuations, because different species respond differently to these fluctuations, leading to more predictable aggregate community or ecosystem properties (Loreau *et al*., 2001). In the present study, the interrelationship and relative roles of soil fertility and environmental factors have been investigated to determine the effect to which they influence species distribution, composition and diversity in the three main rivers, namely; River Kisap, River Kilim and River Ayer Hangat in Kilim Geoforest Park, Langkawi. Multivariate statistical analysis techniques (PCA and its RDA ordination, CCA) were used to understand their relationships. The study area is also characterized by complex topography and heterogeneous vegetation.

Results from RDA and CCA indicate that soil fertility and environmental factors should be considered in explaining variability in plant diversity. It is a fact that organic matter is a critical factor in determining the status of soil fertility in a certain area. In the present study, River Kisap is found to be more fertile than River Kilim and River Ayer Hangat because it has higher content of organic C and available P, as well as suitable soil pH for the growth of vegetation. Hence, River Kisap is the most diverse area in terms of floristic composition as compared to River Kilim and River Ayer Hangat. Meanwhile, variation in diversity is often correlated with productivity, and also with many other factors that influence productivity such as soil fertility, climate, disturbance regime or herbivory (Loreau *et al*., 2001). Understanding how these atmospheric and climatic change factors may interact with one another is important because their interactions may affect individual, community and ecosystem level processes in previously unpredicted ways (Long, 1991; Morrison & Lawlor, 1999; Poorter & Pe´rez-Soba, 2001). The response of plant communities to the changes in resource availability is often mediated by species composition, particularly given the range of growth strategies, demography and productivity possessed by diverse plant communities (Niklaus *et al.,* 2001; Reich *et al.,* 2004).

Kilim Geoforest Park, Langkawi, is very sensitive, and it is also a protected area because it has been declared by UNESCO as one of the world heritage (UNESCO 2000). The diversity of the biological resources of this area provides direct economic benefits to the local people. This biological diversity provides timber and non-timber goods in the forestry sector, food and industrial crops in the agricultural sector, as well as food in the fisheries sector and for tourism attraction.

According to Malaysia's National Policy on Biological Diversity (2010) report, agriculture, forestry and fisheries have been major contributors to national wealth creation. The tourism industry relies on the country's diverse and unspoilt natural beauty including unique species of plants and animals in national parks, wildlife reserves, bird parks and in marine parks and the adjacent coral reefs. Kilim Geoforest Park, Langkawi, stands to gain due to the diversity of its biological resources.

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APPENDIX I
List of Acronyms

Acronym	Mangrove Species ≥1 cm dbh	Acronym	Environmental/ Metereological Data
AE	*Acanthus ebracteatus*	RF	Total Amount of rainfall
AI	*Acanthus ilicifolius*	RD	Total number of rainy days
AM	*Avicennia marina*	T	24 hour mean temperature
AO	*Avicennia officinalis*	RH	24 hour mean relative humidity (%)
AV	*Acanthus volubilis*	WS	Mean surface wind speed
BC	*Bruguiera cylindrica*		
BG	*Bruguiera gymnorrhiza*		**Soil FertilityFactors**
BP	*Bruguiera parviflora*	P	Available P
BS	*Brugueira sexangula*	pH	Dry pH
CD	*Ceriops decandra*	N (%)	Nitrogen
CT	*Ceriops tagal*	C (%)	Organic Carbon
RA	*Rhizophora apiculata*	EC	Exchangeable Calcium
RM	*Rhizophora mucronata*	EK	Exchangeable Potassium
XG	*Xylocarpus granatum*	EM	Exchangeable Magnesium
XM	*Xylocarpus moluccensis*	EN	Exchangeable Natrium
XR	*Xylocarpus rumphii*		
Woody plants ≤ 1cm dbh, shrubs, climbers, epiphytes and weeds		Measures of Plant Species Diversity	
AC	*Acrostichum aureum*	NI	Total number of individual
At	*Allophylus ternatus*	BI	Brillouin's index H
Ad	*Alocasia denudata*	SW	Shannon-Wiener index of diversity
Ah	*Amorphophallus haematospadix*	SI	Simpson's index of diversity (1-D)
Av	*Amorphophallus variabilis*	CE	Camargo's index of evenness E'
Aa	*Antirhea atropurpurea*	SWE	Smith and Wilson's index of evenness
Ap	*Argostemma pictum*	SE	Simpson's measures of evenness E1/D
Af	*Arisaema fimbriatum*	JR	Jackknife estimates of species richness
Am	*Avicennia marina*		
Bc	*Bauhinia curtisii*		Other parameters
Bf	*Bauhinia flava*	DBH	Total DBH (cm)
Bc	*Begonia curtisii*	tDBH	Mean total DBH (cm)
Bp	*Begonia phoeniogramma*	BA	Total Basal Area (m^2)
Bs	*Boea acutifolia*		
Cc	*Caesalpinia crista*		
Cr	*Cissus repens*		
Cn	*Clerodendrum nutans*		

Co	*Chromolaena odorata*	*Md*	*Mallotus dispar*
Cca	*Croton cascarilloides*	*Me*	*Memecylon edule*
Cs	*Cycas siamensis*	*Mp*	*Memecylon pauciflorum*
Dd	*Davallia denticulata*	*M*	*Microcos* sp.
Dg	*Dendrobium gemellum*	*Mm*	*Micromelum minutum*
Dp	*Dendrobium pachyglossum*	*Mp*	*Microsorum punctatum*
De	*Dendrocalamus elegans*	*Mz*	*Microsorum zippelii*
Dt	*Derris trifoliata*	*Mg*	*Monophyllaea glabra*
Dl	*Didymocarpus lacunosus*	*Mgi*	*Mucuna gigantea*
Dc	*Dioscorea calcicola*	*Mk*	*Murraya koenigii*
Dt	*Dioscorea tamarisciflora*	*Mp*	*Murraya paniculata*
Df	*Diopsyros ferrea*	*Nc*	*Nervillia calcicola*
Di	*Diopsyros ismailli*	*Oa*	*Orthosiphon aristatus*
Dq	*Drynaria quercifolia*	*Pf*	*Paraboea ferruginea*
Ds	*Drynaria sparsisora*	*P*	*Parameria* sp.
Da	*Dryopteris anneaphylla*	*Pc*	*Pentasacme caudatum*
Dl	*Dryopteris ludens*	*Pcu*	*Pentaspadon curtisii*
Eb	*Eria bractescens*	*Pm*	*Pentaspadon motleyi*
Ek	*Eulophia keithii*	*Pc*	*Phyllanthus columnaris*
Ea	*Euphorbia antiquorum*	*Pp*	*Pyllanthus pulcher*
Eag	*Excoecaria agallocha*	*Pi*	*Pluchea indica*
Fc	*Fagraea curtisii*	*Pc*	*Pseuderanthemum crenulatum*
Fd	*Ficus deltoidea*	*Pa*	*Psychotria angulata*
Fc	*Fimbristylis calcicola*	*Psy*	*Psyndrax* sp.
Ff	*Fissistigma fulgen*	*Pl*	*Pyrrosia lanceolata*
Fr	*Flacourtia rukam*	*Ppi*	*Pyrrosia piloselloides*
Ff	*Flickingeria fimbriata*	*Sh*	*Schefflera heterophylla*
Gc	*Geodorum citrinum*	*Ss*	*Scindapsus scortechinii*
H	*Henklia* sp.	*S*	*Selaginella* sp.
Hc	*Hoya coronaria*	*Se*	*Selligue* sp.
Hd	*Hoya diversifolia*	*Sp*	*Sesuvium portulacastrum*
Ji	*Jasminum insularum*	*Sv*	*Stephania venosa*
Js	*Justicia* sp.	*Si*	*Streblus ilicifolius*
Kp	*Kaempferia pulchra*	*Sl*	*Streblus laxiflorus*
Lf	*Lagerstroemia floribunda*	*Tc*	*Tectaria coadunata*
Le	*Liparis elegans*	*Tk*	*Tectaria keckii*
M	*Macaranga* sp.	*Tl*	*Tetrastigma leucostaphylum*
Mb	*Mallotus brevipetiolatus*	*Tc*	*Tinospora crispa*

Vg	*Vandopsis gigantea*
Vo	*Ventilago oblongifolia*
Vs	*Vitex siamica*
Xd	*Xanthophyllum discolor*
Xg	*Xylocarpus granatum*
Za	*Ziziphus affinis*
Zo	*Ziziphus oenoplia*