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GROWTH PATTERN, BIOMASS ALLOCATION AND RESPONSE OF *CRYPTOCORYNE FERRUGINEA* ENGLER (ARACEAE) TO SHADING AND WATER DEPTH

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Abstrak: Kajian ekologi *Cryptocoryne ferruginea* Engler telah dijalankan di tiga kawasan berasingan, iaitu Sabal Kruin, Balai Ringin dan Sungai Kerait. Corak pertumbuhan dan peruntukan biojisim *C. ferruginea* adalah berbeza dengan signifikan antara kawasan, keamatan cahaya dan kedalaman air seperti yang telah ditunjukkan oleh nilai jumlah berat kering pokok dan daun, luas daun dan jumlah tumbuhan di dalam kuadrat berukuran 1 m × 1 m. Nisbah berat daun (LWR), nisbah berat akar (RWR), nisbah luas daun (LAR), nisbah berat rizom (UWR), luas daun spesifik (SLA), pengeluaran berat bahan (DMP), nisbah asimilasi (NAR) dan jangka luas daun (LAD) adalah berbeza dengan signifikan antara keamatan cahaya dengan kedalaman air. Keadaan cahaya dan kedalaman air juga mempengaruhi dengan signifikan kadar fotosintesis dan corak lengkung cahaya. Dua puluh tujuh spesies pokok berkayu (118 individu) telah direkodkan di Sabal Kruin dan 18 spesies pokok berkayu daripada 88 individu direkodkan di Balai Ringin daripada lima plot berukuran 20 m × 10 m. Anggaran jumlah biojisim permukaan tanah ialah 94.26 tan/ha di Sabal Kruin dan 128.64 tan/ha di Balai Ringin dengan luas pangkal 1936.42 m^2/ha dan 2336.75 m^2/ha masing-masing. Anggaran jumlah biojisim permukaan tanah bagi ladang getah yang terbiar di Sungai Kerait ialah 172.51 tan/ha. Spesies paling dominan di Sabal Kruin ialah *Neonauclea synkorynes* Merr. (Iv = 32.64), diikuti oleh *Ptychopyxis arborea* (Merr.) Airy Shaw (Iv = 22.42), *Ilex cymosa* Blume (Iv = 11.16), *Glochidion littorale* Bl. (Iv = 11.09) dan *Shorea seminis* (de Vriese) Stooten (Iv = 10.32). Manakala hutan di Balai Ringin telah didominasi oleh *P. arborea* (Iv = 45.09), diikuti oleh *Baccaurea bracteata* M.A. (Iv = 41.33), *N. synkorynes* (Iv = 35.65), *Litsea nidularis* Gamble (Iv = 29.48) dan *Aglaia rubiginosa* (Hiern) Pannell (Iv = 23.23). pH air di Balai Ringin dan Sungai Kerait adalah berasid dengan pH 5.24 dan 5.11 masing-masing. Suhu air ialah 25.5°C and 25.4°C, manakala keupayaan oksigen terlarut ialah 1.36 mg/l di Balai Ringin dan 2.06 mg/l di Sungai Kerait. CEC tertinggi (62.23 + cmol/kg) direkodkan di Sabal Kruin, diikuti oleh Balai Ringin (39.79 + cmol/kg) dan Sungai Kerait (19.80 + cmol/kg). Tanah di Sungai Kerait mengandungi peratusan tanah liat paling tinggi (14.51%) berbanding di Sabal Kruin (9.36%) dan Balai Ringin (7.59%).

Abstract: The ecological study of *Cryptocoryne ferruginea* Engler was carried out at three different localities, *vis.* Sabal Kruin, Balai Ringin and Sungai Kerait. The growth pattern and biomass allocation of *C. ferruginea* were significantly varied between localities, light intensity and water depth as demonstrated by their total dry weight of both plants and leaves, leaf area and total plants in 1 m × 1 m quadrate. The leaf weight ratio (LWR), root weight ratio (RWR), leaf area ratio (LAR), rhizome weight ratio (UWR), specific leaf area (SLA), dry matter production (DMP), nett assimilation ratio (NAR) and leaf area duration (LAD) were significantly differed between light intensity and water depth. Light condition and water depth were also significantly influenced the rate of photosynthesis and light curve pattern. Twenty-seven trees species (118 individuals) were recorded at Sabal Kruin

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and 18 trees species from 88 individuals at Balai Ringin from five plots of 20 m × 10 m. The estimation of total above ground biomass was 94.26 ton/ha at Sabal Kruin and 128.64 ton/ha at Balai Ringin with the basal area of 1936.42 m^2/ha and 2336.75 m^2/ha, respectively. The estimated above ground biomass of the abandoned rubber farm at Sungai Kerait was 172.51 ton/ha. The dominant species at Sabal Kruin forest was *Neonauclea synkorynes* Merr. (Iv = 32.64), followed by *Ptychopyxis arborea* (Merr.) Airy Shaw (Iv = 22.42), *Ilex cymosa* Blume (Iv = 11.15), *Glochidion littorale* Bl. (Iv = 11.09) and *Shorea seminis* (de Vriese) Stooten (Iv = 10.31). However, forest at Balai Ringin was dominated by *P. arborea* (Iv = 45.09), followed by *Baccaurea bracteata* M.A. (Iv = 41.33), *N. synkorynes* (Iv = 35.65), *Litsea nidularis* Gamble (Iv = 29.48) and *Aglaia rubiginosa* (Hiern) Pannell (Iv = 23.23). Water pH at Balai Ringin and Sungai Kerait were both in acidic condition with pH of 5.24 and 5.11, respectively. The water temperatures were 25.5°C and 25.4°C, while the dissolved oxygen capacity were 1.36 mg/l in Balai Ringin and 2.06 mg/l at Sungai Kerait. The highest CEC (62.23 + cmol/kg) was recorded at Sabal Kruin, followed by Balai Ringin (39.79 + cmol/kg) and Sungai Kerait (19.80 + cmol/kg). Sungai Kerait have the highest percentage of clay (14.51%) compared to Sabal Kruin (9.36%) and Balai Ringin (7.59%).

Keywords: *Cryptocoryne ferruginea*, Biomass Allocation, Dominant Species, Shading, Water Depth, Photosynthesis

INTRODUCTION

Cryptocoryne, which locally known as kiambang batu (Melayu Sarawak), kelatai (Iban), hati-hati paya (Semenanjung Malaysia) and tropong ajer (Banjarmasin, Kalimantan) are native in shaded Malaysian's forests. It is a soft-tissue throughout the plant. They are herbaceous; and thrived in rivers, streams, open pools and slow-running water channels of freshwater swamps (Wong 1997). *Cryptocoryne* are well known to people who keep aquarium (Holttum 1977). They are popular aquatic plant in aquascaping (Jacobsen 1976; Rataj & Horeman 1977; Wit de 1983). They have unique leaves and the flowers of various species come in different attractive colours. These factors explain their popularity as horticultural plants (Kiew 1990).

Most of the *Cryptocoryne* species that occurred in Sarawak are endemic and may increasingly faced the possibility of extinction (Jacobsen 1985; Mansor 1994). *Cryptopcoryne* are very sensitive to changes occurred in their surroundings. Factors that were identified as the main threats are pollution, deforestation (Douglas *et al*. 1995) and habitat disturbances (Jacobsen 1985; Mansor 1994).

According to Jacobsen (1985), *Cryptocoryne ferruginea* has a unique spathe shape and can usually be found in deep mud of the inner part of the freshwater tidal zone. Due to the lack of plant materials in the greenhouse cultivation and limited natural populations, there was little information on further understanding of the species (Jacobsen 1985). Plasticity of the *Cryptocoryne* species are considerable (Ipor *et al*. 2005); and the morphological characteristics, biomass allocation pattern and photosynthesis rate depend on the environmental conditions of the surroundings.

MATERIALS AND METHODS

The ecological study and plant material collections were carried out at Balai Ringin, Sabal Kruin and Sungai Kerait, Serian in the Samarahan Division of Sarawak (Fig. 1).

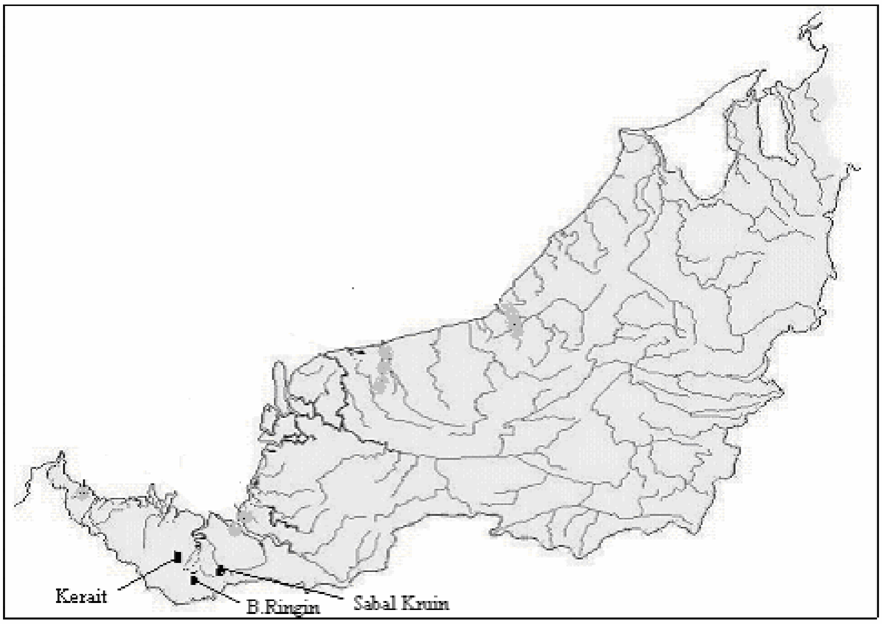


Figure 1(a): The study sites of *C. ferruginea* at Balai Ringin, Sungai Kerait and Sabal Kruin in Kota Samarahan, Sarawak.

Structure and Floristic Composition of Riverine Forest with the Occurrence of *C. ferruginea*

Five plots of 20 m × 20 m were established randomly in the areas with the occurrence of *C. ferruginea* by following the methods by Ashton (1964) and Kochummen (1982). Each plot was then divided into four subplots of 10 m × 10 m. In each plot, all trees with ≥ 5 cm diameter at breast height (DBH) were enumerated and identified to family, genus or species level. Voucher specimens were collected to confirm the species at the Sarawak Herbarium, Forest Research Centre, and Forest Department Sarawak. All trees with the DBH of 5 cm or above were enumerated and identified. The total leaf area, basal area (BA), relative frequency (Rf), relative density (Rd), relative dominance (RD) and

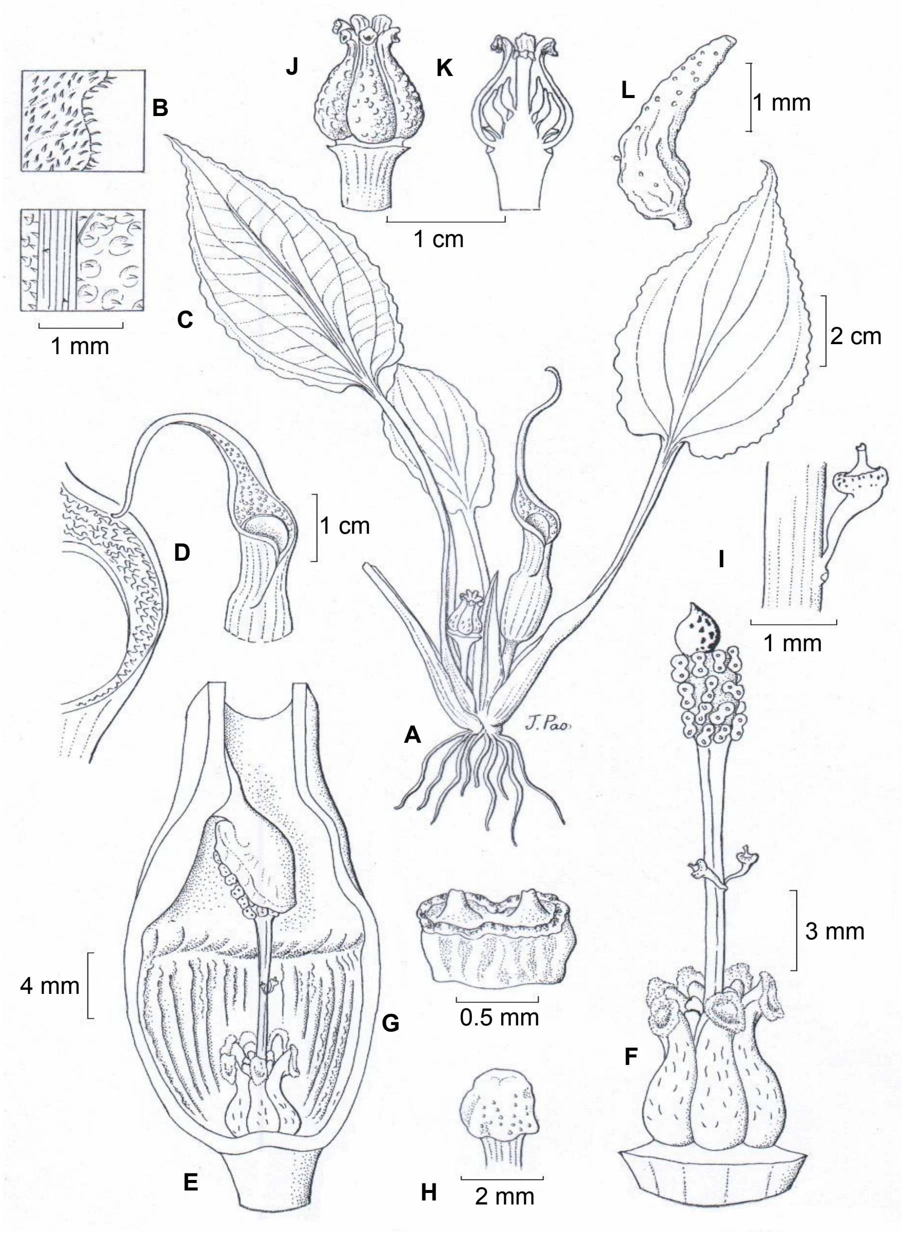


Figure 1(b): *C. ferruginea* showing the vegetative parts. A = whole plant with fruit and inflorescence; B = leaf blade, lower surface with hairs; C = stomata; D = spathe; E = kettle; F = spadix with female and male flowers; G = male flowers with two thecae; H = olfactory body; I = abnormal structure of male flower with one thecae; J and K = syncarpous fruit; and L = seed.

importance values (Iv) of the trees were determined according to the method described by Brower *et al.* (1990). Total above ground biomass of trees was estimated from the DBH and height measurements by an allometric correlation method (Kato *et al.* 1978; Yamakura *et al*. 1986). The quantities of height, stem dry weight (W_S), branch dry weight (W_B) and leaf dry weight (W_L) were estimated using the formula of Yamakura *et al*. (1986).

Growth Pattern and Biomass Allocation of *C. ferruginea*

Quadrates of 1 m × 1 m were established randomly to determine the total number of plants, dry weight of the vegetative parts such as leaf blades, petioles, roots and rhizomes. The leaf blades petioles, roots and rhizome were severed and dried in an oven at 60°C for 7 days to determine the total dry weight, leaf weight ratio (LWR), root weight ratio (RWR), petiole weight ratio (PWR) and specific leaf area (SLA) of the individual plant. Prior to drying, the leaf areas of the individual leaves were determined. The biomass distribution pattern then analysed mathematically based on the methods described by Peterson and Flint (1983).

Water and Soil Analysis

The water parameters were measured using *Horiba water checker U-10* such as pH, conductivity, dissolved oxygen (DO), temperature and salinity. The formula of m1v1 = m2v2 was used to prepare the buffer solution (Benefield *et al.* 1982). The water samples were taken randomly to detect the availability of chlorine, nitrate and sulphate.

Soil samples were taken from each sites for chemical analysis such as pH (Hesse 1971; McLean 1986); soil organic carbon (C) (Dewis & Freites 1970); nitrogen (N) amount (Anon 1980; Beitz 1974); cation exchange rate (CEC); calcium (Ca^{3+}), magnesium (Mg^{2+}), potassium (K^{+}) and sodium (Na^{+}) ion amount; and basic saturate (BS).

Response to Shading

The lateral shoots of *C. ferruginea* at the second leaf stage collected from Balai Ringin were transplanted into plastic pots (14 cm diameter and 9 cm height) and placed inside trays (47 cm × 24 cm). One week of transplanting, 20 pots were transferred to each of three shade levels: under tree canopy (UTC) condition, 50% shading area (50% sunlight) and 75% shading area (25% available sunlight). The different shading regimes were built by using different intensity of lathe houses of 2 m × 2 m × 2 m. Full sunlight was not included as the plants died under such conditions.

Five plantlets from each light regime were selected randomly for vegetative growth measurement such as plant height, leaf and plantlet number. The vegetative measurement was commenced on the first day of placement and every two weeks of different light regimes.

Thirty days after transplanting, ten uniform plants from each light regime were selected. Five plants were then severed to determine the biomass allocation. Leaf areas were measured prior to oven drying at 60ºC for 72 hrs to determine the dry weight. Similar harvest and assessment were carried out after 30 days of the first harvest. The growth analysis and biomass allocation pattern of the plantlets were assessed using the method described by Patterson and Flint (1983).

Response to Water Depth

The uniform second leaf of lateral shoots were placed into three different water depth, *vis.* 0 cm (same level with the soil surface), 5 cm and 15 cm water level from the soil surface. The designated water levels were monitored and maintained daily by adding appropriate amount of water. The plant growth assessment and biomass allocation were similar to those previously mentioned. Prior to drying, the leaf area of individual leaves was determined.

Photosynthesis Measurement

Fifteen plants from each light regimes and different water depth were randomly selected for photosynthesis rate measurement using underwater fluorometer diving-PAM. Photosynthesis rate measurement was carried 2–4 hrs after sunrises. For each plant, three leaves were chosen randomly for the photosynthesis rate measurement.

RESULTS

Habitat

At Sabal Kruin, the *C. ferruginea* population was found growing in the riverine habitat that were proned to flash flood after a short tropical rainstorm. The water condition was muddy with considerably strong current after short heavy rainfall. *C. ferruginea* population could sustain the persistent dry season, as stagnant clear water trapped in the ditches and thus formed in patches ranged at 0.5–12.0 m^2 in size. The sustainability and survivorship of the *Cryptocoryne* population were probably contributed by the frequent washed away of the litter falls and debris deposited on the *Cryptocoyrne* patches. Meanwhile, the occurrence of *C. ferruginea* at Balai Ringin was approximately 300–400 m inward within the inundated region of the riverine forest. During flooding, this area was usually inundated with black peat water mainly from the inward part of the upper stream. The frequent short inundation of the habitat after heavy rain was identified as one of the important factor in sustaining the population of *C. ferruginea.* Water here was normally clear and flown steadily with litter fall washed out to the river system.

The total of 118 trees from 27 species was recorded through the survey at Sabal Kruin. The five most common and dominant species recorded at Sabal Kruin were *Neonauclea synkorynes* Merr. (Iv = 34.62*)*, *Ptychopyxis arborea* (Merr.) Airy Shaw (Iv = 22.42*)*, *Ilex cymosa* Blume (Iv = 11.16), *Glochidion littorale* Bl. (Iv = 11.09) and *Shorea seminis* (de Vriese) Stooten (Iv = 10.32)*.* The total individuals for these species were 30, 16, 9, 6 and 5, respectively. The dominance of *N. synkorynes* and *P. arborea* were contributed by the high values of relative density and relative frequency (Table 1). The densities were 25.42 and 13.56 for *N. synkorynes* and *P. arborea*, respectively.

The total above ground biomass of forest at Sabal Kruin was 94.26 ton/ha. *P. arborea* contributed the highest total above ground biomass value, which was 2501 kg (Table 1). The ranking was followed by *N. synkorynes* (2109 kg), *S. seminis* (1417 kg), *I. cymosa* (998 kg) and *Aglaia rubiginosa* (Hiern) Pannell (512 kg). *Quassia indica* (Gaertn.) Nooteboom contributed the lowest total above ground biomass, 1.80 kg. *P. arborea* contributed 77.7% of the whole biomass; while *N. synkorynes* had the highest amount of BA with 3319 cm^2 and *Q. indica* contributed the lowest BA (28.26 cm^2).

Table 1: Rd, Rf, RD and Iv of tree species with a DBH of ≥ 5 cm in areas with the occurrence of *C. ferruginea* at Sabal Kruin.

No.	Taxon	Rd	Rf	RD	Iv	BA (cm^2)	LAI (cm^2)	Biomass (kg)
1	*Neonauclea synkorynes* Merr.	25.42	8.62	4.53	34.62	3318.98	487.32	2109.05
2	*Ptychopyxis arborea* (Merr.) Airy Shaw	13.56	8.62	0.66	22.42	1832.98	432.14	2500.50
3	*Ilex cymosa* Blume	4.24	6.90	0.41	11.16	946.71	174.47	997.87
4	*Glochidion littorale* Bl.	7.63	3.45	0.68	11.09	416.84	54.97	124.55
5	*Shorea seminis* (de Vriese) Slooten	5.08	5.17	0.43	10.32	673.53	238.18	1416.54
6	*Aglaia rubiginosa* (Hiern) Pannell	3.39	6.90	1.11	10.30	526.74	99.38	511.92
7	*Nauclea parva* Merr.	4.24	5.17	0.33	9.43	468.65	88.69	323.57
8	*Grewia borneensis* Warb. Ex P. S. Ashton	5.93	3.45	2.70	9.40	391.72	59.65	163.13
9	*Intsia bijuga* (Colebr.) Kuntze	4.24	3.45	2.70	7.69	287.31	47.75	128.40
10	*Ficus annulata* Blume	3.39	3.45	0.24	6.84	204.89	34.86	90.77
11	*Mesua beccariana* (Baill.) Kosterm	1.69	3.45	1.76	5.15	292.81	48.23	197.22
15	*Antidesma coriaceum* Tul.	1.69	3.45	2.47	5.14	76.93	9.90	17.82
13	*Ardisia polyactis* Mez	1.69	3.45	3.37	5.14	47.89	9.84	17.00
14	*Brownlowia havilandii Stapf*	1.69	3.45	8.14	5.14	78.50	6.01	9.81
12	*Dialium laurinum Baker*	1.69	3.45	3.58	5.14	128.74	15.81	35.65
16	*Shorea platycarpa F. Heim*	1.69	3.45	0.43	5.14	78.50	9.48	16.63
17	*Litsea nidularis Gamble*	1.69	1.72	1.01	3.42	116.97	17.92	40.52

(continued on next page)

Table 1: *(continued)*

No.	Taxon	Rd	Rf	RD	Iv	BA (cm^2)	LAI (cm^2)	Biomass (kg)
25	*Calophyllum hosei* Ridl.	0.85	1.72	0.24	2.57	50.24	6.61	12.25
28	*Elaeocarpus beccari* Aug. DC	0.85	1.72	5.79	2.57	38.47	5.02	8.25
19	*Endiandra coriacea* Merr.	0.85	1.72	2.52	2.57	314.00	30.72	113.52
20	*Eugenia christmannii*	0.85	1.72	4.03	2.57	314.00	38.88	159.86
29	*Eugenia havilandii* Merr.	0.85	1.72	0.68	2.57	28.26	3.66	5.23
26	*Linociera evenia* Stapf	0.85	1.72	1.52	2.57	50.24	7.15	13.74
24	*Mangifera havilandi* Ridl.	0.85	1.72	15.76	2.57	63.59	7.77	15.48
18	*Pentaspadon motleyi* Hook. F.	0.85	1.72	0.55	2.57	452.16	51.96	243.71
22	*Pometia pinnata* J R Forster & J G Forster	0.85	1.72	3.89	2.57	94.99	13.47	34.35
30	*Quassia indica* (Gaertn.) Nooteboom	0.85	1.72	0.43	2.57	28.26	1.74	1.80
21	*Shorea longiflora* (Brandis) Symington	0.85	1.72	28.54	2.57	176.63	22.93	74.26
23	*Stemonurus scorpiurus* Merr.	0.85	1.72	0.82	2.57	78.50	11.14	26.08
27	*Vatica mangachapoi* Blanco	0.85	1.72	0.68	2.57	50.24	8.19	16.72
							2043.8	**94.26 ton/ha**

As for Balai Ringin, the five most dominant species were *P. arborea* (Iv = 45.09), *Baccaurea bracteata* M.A. (Iv = 41.33), *N. synkorynes* (Iv = 35.65), *Litsea nidularis* Gamble (Iv = 29.48) and *A. rubiginosa* (Iv = 23.23) (Table 2). The amounts of individuals for each species were 17, 12, 12, 10 and 6, respectively from 88 trees of 18 species with the total above ground biomass of 128.64 ton/ha. *P. arborea* contributed the highest total above ground biomass (3346 kg), followed by *Teijmaniadendro hollrungii* (2042 kg), *B. bracteata* (1339 kg), *A. rubiginosa* (1297 kg) and *L. nidularis* (1110 kg). *Sterculia bicolor* Mast. contributed the lowest above ground biomass of 7.10 kg. *P. arborea* contributed 26% of the whole above ground biomass with the highest BA of 5701 cm^2 while *S. bicolor* contributed the lowest BA of 38.47 cm^2.

Table 2: Rd, Rf, RD and Iv of tree species with DBH of ≥ 5 cm in forest with the occurrence of *C. ferruginea* at Balai Ringin.

Taxon	Rd	Rf	RD	Iv	BA (cm^2)	LAI (cm^2)	Biomass (kg)
Aglaia rubiginosa (Hiern) Pannell	5.68	7.50	10.05	23.23	2670.57	230.62	1296.54
Eugenia christmannii	6.82	10.00	4.44	21.25	1179.07	115.91	431.19
Teijmanniadendro hollrungii	2.27	2.50	13.36	18.14	3552.13	266.30	2041.59
Mezzettia leptopoda (Hk.f. et Thoms.) Oliv.	6.82	5.00	4.42	16.24	1175.93	113.58	459.43
Myristica lowiana King	2.27	5.00	2.80	10.08	744.97	69.46	297.93
Mammea acuminate	2.27	2.50	2.50	7.28	665.68	68.65	341.28
Dillenia pulchella (Jack) Gilg	1.14	2.50	0.96	4.59	254.34	28.04	99.45
Ilex cymosa Blume	1.14	2.50	0.24	3.88	63.59	9.03	19.26
Dialium laurinum Baker	2.27	5.00	1.60	8.87	424.69	41.28	146.60
Quassia indica (Gaertn.) Nooteboom	1.14	2.50	0.19	3.83	50.24	6.61	12.25
Laphopetalum multinervium	1.14	2.50	1.18	4.82	314.00	37.32	150.61
Sterculia bicolor Mast.	1.14	2.50	0.14	3.78	38.47	4.53	7.10
Macaranga triloba (Bl.) M.A.	2.27	2.50	3.84	8.61	1020.5	91.41	441.48
Ptychopyxis arborea (Merr.) Airy Shaw	13.64	10.00	21.45	45.09	5701.46	536.73	3345.69
Baccaurea bracteata M.A.	19.32	10.00	12.01	41.33	3191.81	323.35	1339.15
Litsea nidularis Gamble	11.36	10.00	8.12	29.48	2157.97	220.16	1109.87
Neonauclea synkorynes Merr.	13.64	12.50	9.51	35.65	2528.49	244.97	993.33
Phoebe opaca.	5.68	5.00	3.19	13.87	847.02	93.24	332.15
						2501.19	**128.64 ton/ha**

C. ferruginea occurred along the small stream of Sungai Kerait under moderate deep shading canopy of mature abandoned rubber farm with the estimated above ground biomass of 172.51 ton/ha. The populations formed small patches due to frequent strong current during heavy rain. The population was constantly treated by fishing activities in traditional ways by the local people.

Water and Soil Analysis

The water from Balai Ringin had the pH of 5.24, with the temperature of 25.5°C and DO of 1.36 mg/mol. Water from Sungai Kerait was also in acidic condition with pH = 5.11. The water temperature was 25.4°C with DO of 2.06 mg/l (Table 3). Sabal Kruin had pH of 4.60. The CEC at Sabal Kruin was 63.23 + cmol/kg with the exchange Ca^{3+}, Mg^{2+}, K^{+} and Na^{+} of 2.30, 0.69, 0.11 and 0.04 + cmol/kg, respectively. The soil constituted of 9.36% clay and 5.50% silt with the percentage of fine and coarse were 69.01% and 16.13%, respectively. The percentage of N, C and BS in the soil at Sabal Kruin were 0.39%, 6.07% and 24.44%, respectively.

The CEC recorded at Balai Ringin were 39.79 + cmol/kg, with the exchange of Ca^{3+}, Mg^{2+}, K^{+} and Na^{+} were 4.77, 1.98, 0.45 and 0.11 + cmol/kg, respectively. The soil contained 7.59% clay and 6.32% silt, while the percentage of fine component was 84.39%. The soil had 1.03% N and 17.35% C in the soil, with the BS of 18.37%.

From Sungai Kerait, the CEC was 19.80 + cmol/kg with CEC of Ca^{3+}, Mg^{2+}, K^{+} and Na^{+} were 3.79, 0.71, 0.27 and 0.07 + cmol/kg, respectively. The soil at Sungai Kerait contained 8.87% clay and 3.03% silt, while the fine component was 88.06%. The total percentage of N was 0.53% and 0.55% for C. The BS was 4.97%.

Table 3: Soil composition, which are the pH; CEC; percentage of clay, silt and fine course, N, C, and BS; at Sabal Kruin, Balai Ringin and Sungai Kerait.

Location	pH	CEC + cmol/kg	+ cmol/kg				%					
			Ca^{3+}	Mg^{2+}	K^{+}	Na^{+}	Clay	Silt	Fine	N	C	BS
Sabal Kruin	4.60	63.23	2.30	0.69	0.11	0.04	9.36	5.50	69.01	0.39	6.07	24.44
Balai Ringin	5.24	39.79	4.77	1.98	0.45	0.11	7.59	6.32	84.39	1.03	17.35	18.37
Sungai Kerait	5.11	19.80	3.79	0.71	0.27	0.07	8.87	3.03	88.06	0.53	6.55	4.97

Growth Pattern and Biomass Allocation of *C. ferruginea*

The total dry weight of *C. ferruginea* in 1 m × 1 m quadrate at Sabal Kruin was 47.50 g while in Balai Ringin 38.12 g and 24.83 g in Sungai Kerait from the total plants of 449, 283 and 223, respectively [Fig. 2(a) & 2(b)]. Both total dry weight of leaves and total plant dry weight were significantly differed between the three localities. Different site had different nature of habitat. It was observed that only the population of *C. ferruginea* at Sungai Kerait was the only population recorded in the river system that directly affected by the water flow. The population of *C. ferruginea* both at Sabal Kruin and Balai Ringin was located at the upper parts or inland of affected rivers. Although Sabal Kruin has the highest total dry weight, the number of leaves per quadrate was lower than those from Balai Ringin and Sungai Kerait. The total number of leaves in Sabal Kruin was 458, while in Balai Ringin 1207 and 914 in Sungai Kerait [Fig. 2(c)]. It was stated before that Balai Ringin had the most in term of total number of plants with comparatively smaller plants than those for Sabal Kruin. The total leaf area of those from Sabal Kruin was 68,664.8 cm^2, while 24,252.6 cm^2 from Sungai Kerait and 23,779.2 cm^2 from Balai Ringin [Fig. 2(d)]. The dry weight of leaves was the highest at Balai Ringin

(12.31 g), followed by Sabal Kruin (9.33 g) and Sungai Kerait (6.40 g) [Fig. 2(e)]. The dry weights of petioles were 9.76 g, 8.18 g and 4.98 g for Sabal Kruin, Balai Ringin and Sungai Kerait, respectively. The dry weight of root was the highest at Sabal Kruin (27.96 g), 17.63 g at Balai Ringin and 13.45 g at Sungai Kerait.

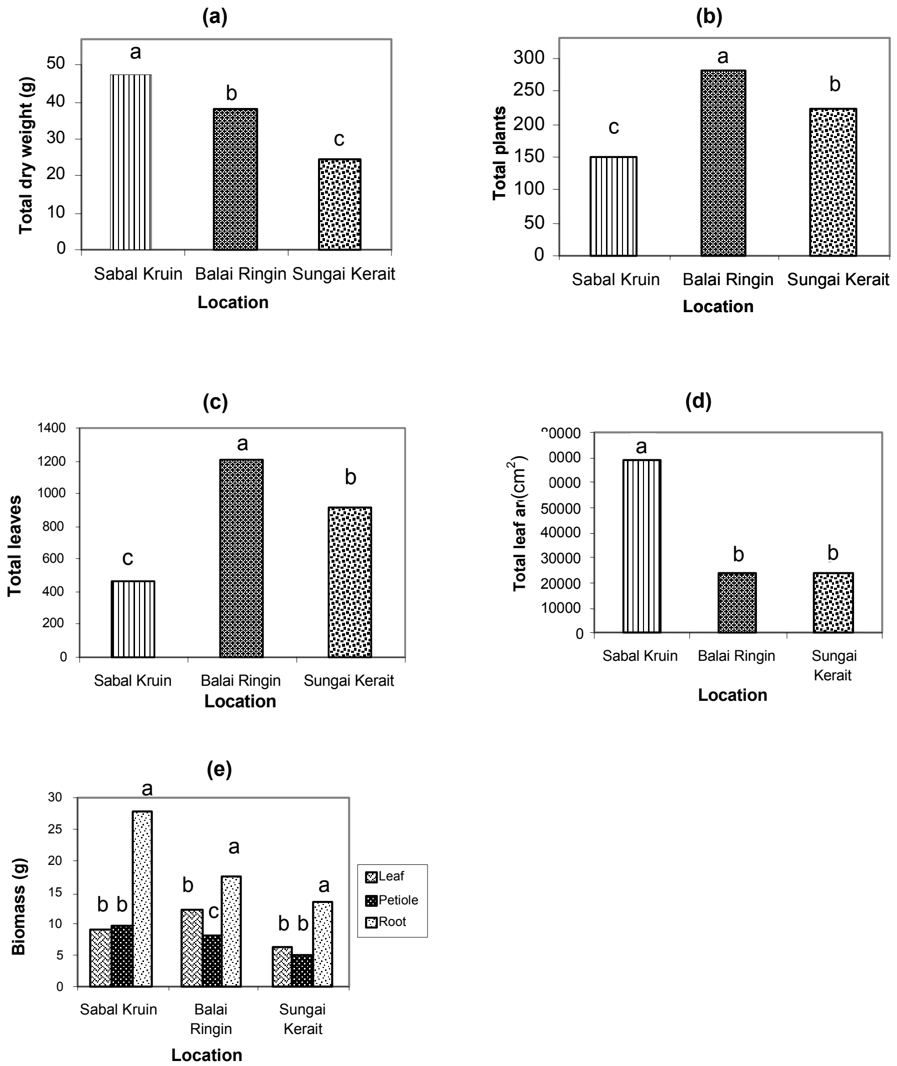


Figure 2: The vegetative characteristics of *C. ferruginea* sampled in 1 m × 1 m quadrate from Sabal Kruin, Balai Ringin and Sungai Kerait (a = total dry weight; b = total plants; c = total leaves; d = total leaf area; and e = dry weight of leaves, petioles and roots). Values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

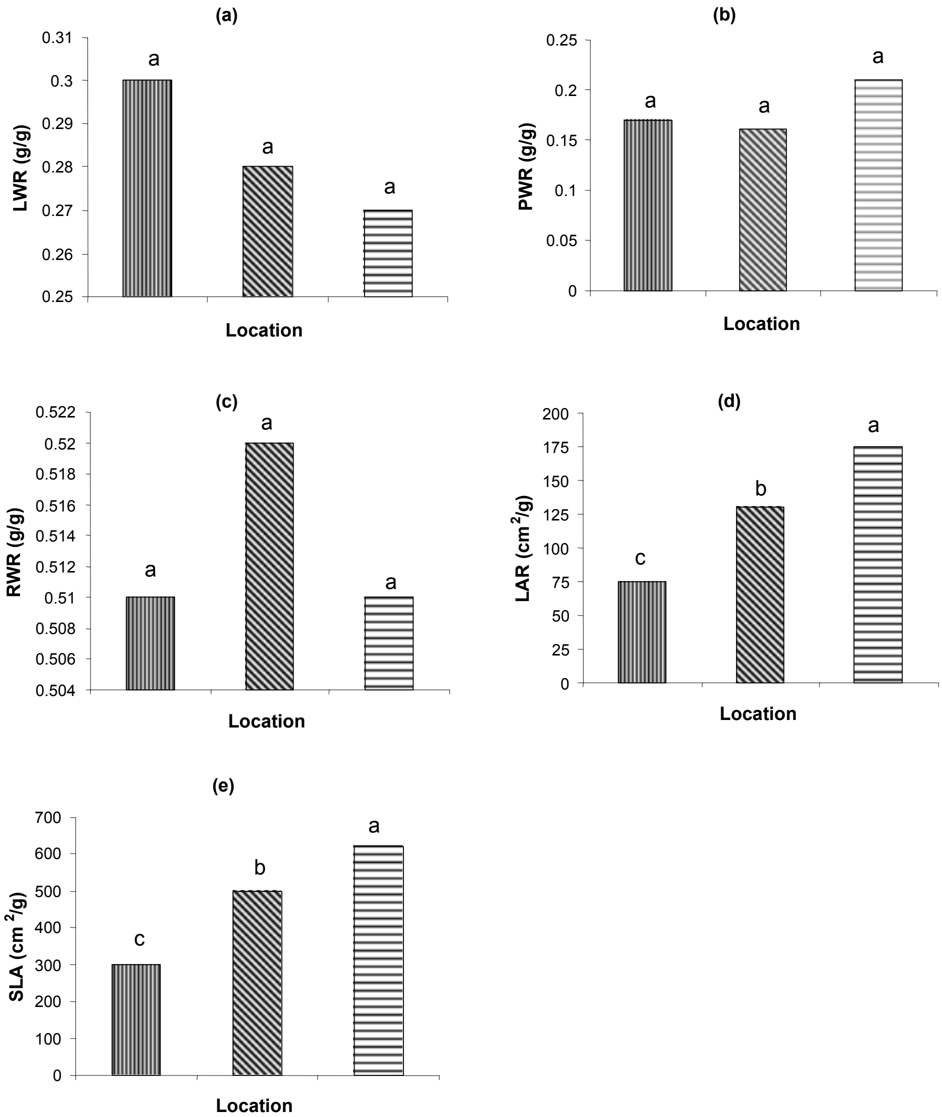


Figure 3: Biomass partitioning of *C. ferruginea* from Sabal Kruin, Balai Ringin and Sungai Kerait. Bars sharing the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

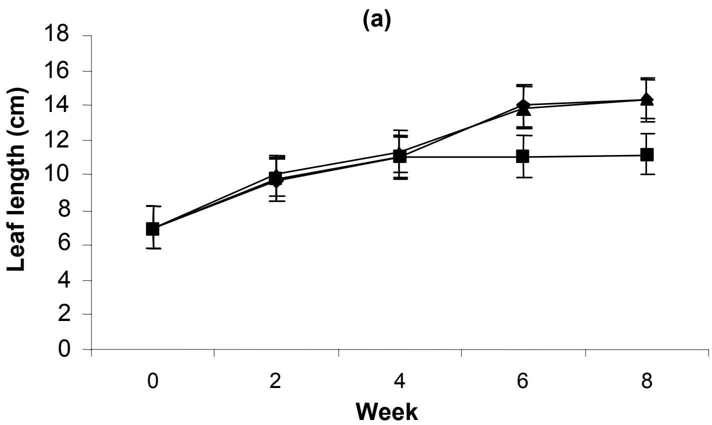
The LWR, PWR and RWR between Sabal Kruin, Balai Ringin and Sungai Kerait had no significant difference (Fig. 3). The LWR at Sabal Kruin was 0.30 g/g, followed by Balai Ringin (0.28 g/g) and Sungai Kerait (0.27 g/g). The PWR was 0.20 g/g, 0.18 g/g and 0.16 g/g for Sungai Kerait, Sabal Kruin and Balai Ringin, respectively.

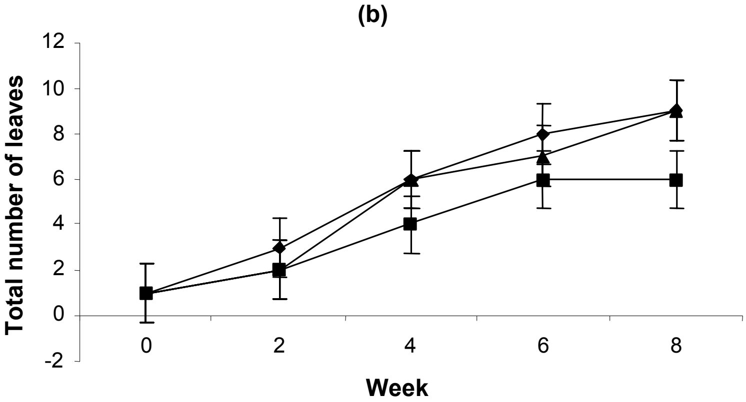
The plants at Balai Ringin tended to assimilate more biomass to the roots as demonstrated by its RWR. The RWR exceeded half of the total amount of the entire plant biomass. RWR were 0.56 g/g, 0.53 g/g and 0.52 g/g for Balai Ringin, Sabal Kruin and Sungai Kerait, respectively. The leaf area ratio (LAR) at Sungai Kerait (175 cm^2/g) was significantly higher than those from Balai Ringin and Sabal Kruin which were 130 cm^2/g and 75 cm^2/g, respectively. There was no significant difference between LAR of Balai Ringin and Sabal Kruin. Similar trend of SLA was recorded throughout the study. However, the mean of SLA were significantly different between Sungai Kerait (608 cm^2/g), Balai Ringin (500 cm^2/g) and Sabal Kruin (300 cm^2/g).

Effects of Shading on Growth and Biomass Allocation of *C. ferruginea*
The plant height (or in term of petiole length) from all light regimes was almost the same for the first 4 weeks transplanting [Fig. 4(a)]. After this period, the increment of plant height was significantly differed between different shadings.

After the first 2 weeks transplanting the plants at UTC condition and 50% shading level had more leaves than those grown under 75% shading [Fig. 4(b)]. However after the 6th week transplanting, the plants grown at under 75% shade level had more new leaves. After the 8th week, higher leaf production was revealed by plants grown at UTC condition and 75% shading. Meanwhile, plants grown at 50% shading level had shown a slow increase in the number of leaves as illustrated from 6–8 weeks of transplanting with no emergence of new leaves.

Increasing shade level to 75% had significantly differed the number of lateral shoots of *C. ferruginea*. This was the only shade regime that produced lateral shoots compared to those UTC condition and 50% of shade levels [Fig. 4(c)].





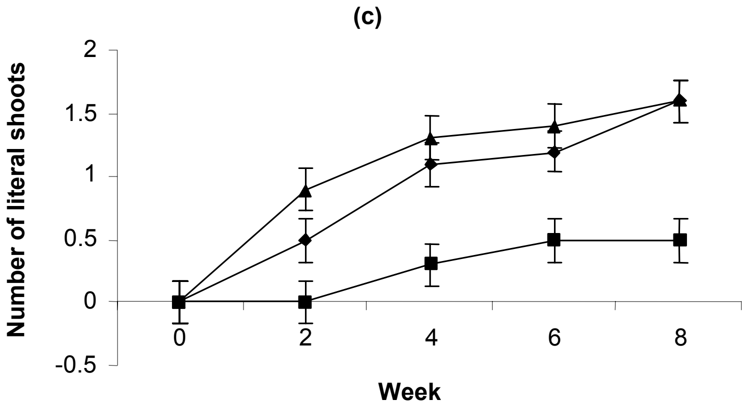


Figure 4: Effect of shading on (a) leaf length (cm), (b) total number of leaves, and (c) number of lateral shoots (—◆— = UTC, —■— = 50% shading, —▲— = 75% shading). Vertical bars are value of least significant difference (LSD) = 0.05.

The total dry weight of *C. ferruginea* was 0.376 g, 0.336 g and 0.386 g for those UTC condition, 50% and 75% shading, respectively (Table 4). It was observed that the leaves from those UTC condition were generally larger and broader. The total leaf area (A) of those UTC condition was 17.0 cm^2, while at 50% shading 12.4 cm^2 and at 75% shading 10.2 cm^2. The W_L was highest for UTC condition (0.112 g), followed by 75% shading (0.090 g) and 50% shading (0.084 g). The petiole dry weight was 0.064 g, 0.068 g and 0.072 g for UTC condition, 50% and 75% shading, respectively. The dry weight of roots was highest at 75% shading (0.212 g), 0.182 g at 50% shading and 0.190 g for UTC condition. The dry weight of rhizome was the highest at 75% shading (0.012 g) followed by UTC condition with 0.01 g and 50% shading with 0.02 g.

The LWR, PWR and RWR between UTC condition, 50% and 75% shading had no significant difference (Table 4). The LWR of those UTC condition was 0.302 g/g, 0.150 g/g at 50% shading and 0.220 g/g at 75% shading. The mean shoot weight ratio (SWR) was 0.196 g/g, 0.200 g/g and 0.194 g/g for UTC condition, 50% shading and 75% shading, respectively. The RWR was 0.502 g/g, 0.540 g/g and 0.218 g/g for UTC condition, 50% and 75% shading, respectively. The LAR of UTC condition (46.706 cm^2/g) was significantly higher than those from 75% shading followed by 50% shading (36.494 cm^2/g) and 75% shading (30.482 cm^2/g). There was no significant different between LAR of 50% shading and 75% shading. The mean of SLA was not significantly different between UTC condition (159.2 cm^2/g) 50% shading (164.5 cm^2/g) and 75% shading (137.6 cm^2/g).

Table 4: The effect of shading on vegetative growth, leaf area production and biomass allocation in *C. ferruginea* plantlets (30th day harvest).

Shade level	Plant dry weight (W)	Total leaf area (A)	LWR	SWR	RWR	UWR	SLA	LAR
		cm^2	g/g				cm^2/g	
UTC	0.376a	17.0a	0.302a	0.196a	0.502a	0.022a	159.2a	46.706a
50%	0.336a	12.4b	0.150a	0.200a	0.540a	0.008b	164.5a	36.494b
75%	0.386a	10.2b	0.226a	0.194a	0.218b	0.016a	137.6b	30.482b

UWR = rhizome weight ratio.
Note: Within column, values sharing the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

There was no significant difference between dry matter production (DMP) and net assimilation rates (NAR) between UTC condition, 50% shading and 75% of shading (Table 5). While in leaf area duration (LAD), there was a significant different between UTC condition, 50% shading and 75% shading.

Table 5: The effect of shading on DMP, NAR and LAD in *C. ferruginea* plantlets during the 30th to 60th day interval (2nd harvest).

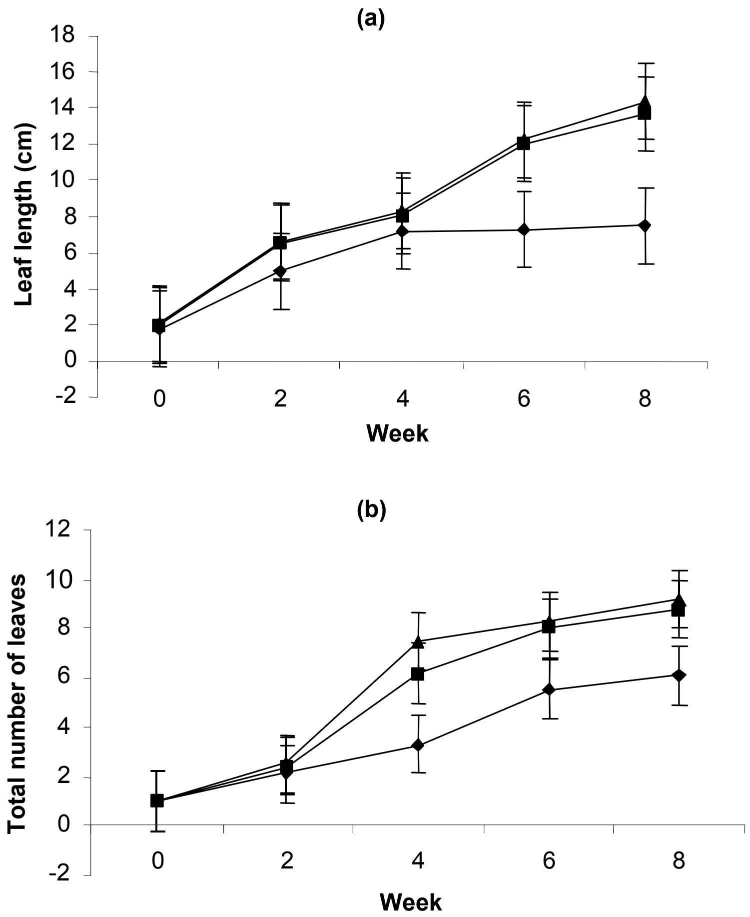
Shade level	DMP (g)	NAR (mg/dm^2/day)	LAD (dm^2/day)
UTC	0.368a	0.018a	21.992a
50%	0.382a	0.026a	11.546b
75%	0.348a	0.024a	4.542c

Note: Within column, values sharing the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

Effects of Water Depth

It is clearly shown in Figure 5(a) that the water depth was significantly influenced the growth development and performance of *C. ferruginea*. Plants at 5 cm and 15 cm water depth were higher compared to those placed under 0 cm of water level from the 1st week of transplanting [Fig. 5(a)]. The plant length from 5 cm and 15 cm were differed from 0 cm of water depth.

The level of water depth was not significantly influenced the number of leaves. Since the 1st week of transplanting, result were almost similar for plants at any water depth level [Fig. 5(b)]. At 8th week period, the plants at 15 cm depth tended to produce more than those at 0 cm and 5 cm water depth.



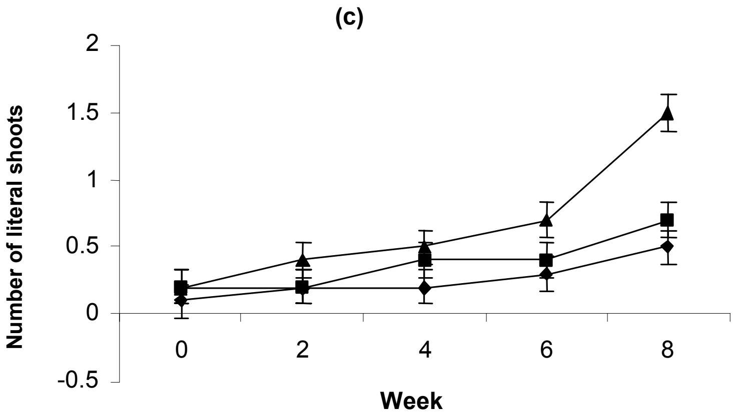


Figure 5: Effect of water depth on (a) leaf length (cm), (b) total number of leaves, and (c) number of lateral shoots (—◆— = 0 cm, —■— = 5 cm, —▲— = 15 cm). Vertical bars are value of LSD = 0.05.

Plants grown in different water depth levels to 15 cm had a significant effect on the number of lateral shoot of *C. ferruginea* [Fig. 5(c)], as they had the most lateral shoot as compare to plants grown at 0 cm and 5 cm of water level after 8 weeks period.

The total dry weight of *C. ferruginea* in 0 cm water depth was 0.386 g; while 0.376 g and 0.336 g from 5 cm and 15 cm water depth, respectively (Table 6). Throughout our observation, the leaves of *C. ferruginea* that were submerged at 5 cm depth had larger and broader leaves. The total leaf area in 0 cm water depth was 4.0 cm^2, while it was 10.2 cm^2 at 5 cm water depth and 9.8 cm^2 at 15 cm water depth. The LWR was highest in 5 cm water depth (0.302 g/g), followed by 0 cm water depth (0.226 g/g) and 15 cm water depth (0.015 g/g). The PWR was 0.194 g/g, 0.196 g/g and 0.20 g/g for 0 cm, 5 cm and 15 cm water depths, respectively. The RWR was highest in 15 cm water depth (0.540 g/g), followed by 0.502 g/g in 5 cm water depth and 0.218 g/g in 15 cm water depth. The UWR at 0 cm water depth was 0.016 g/g, at 5 cm water depth had 0.022 g/g, while in 15 cm water depth was 0.008 g/g.

The mean of SLA was significantly different between 0 cm water depth (52.65 cm^2/g), 5 cm water depth (97.11 cm^2/g) and 15 cm water depth (119.40 cm^2/g) (Table 6). The LAR in 15 cm water depth (30.31 cm^2/g) was significantly higher than those at 0 cm water depth (11.594 cm^2/g). There was no significant difference of LAR between 5 cm and 15 cm water depths.

Table 6: The effect of water depth on vegetative growth, leaf area production and biomass allocation in *C. ferruginea* plantlets (30th day harvest).

Water depth	Plant dry weight (W)	Total leaf area (A)	LWR	SWR	RWR	UWR	SLA	LAR
	g/g	cm²	g/g				cm²/g	
0 cm	0.386a	4.0b	0.226ab	0.194a	0.218b	0.016b	52.65b	11.594b
5 cm	0.376a	10.2a	0.302a	0.196a	0.502a	0.022a	97.11a	29.160a
15 cm	0.336a	9.8a	0.150b	0.20a	0.540a	0.008a	119.40a	30.310a

Note: Within column, values sharing the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

Effect of Shading and Water Depth to Photosynthesis

The measurement of rate of photosynthesis by using PAM showed that different light regimes and water depths significantly affected the rate of photosynthesis. Plants grown at UTC conditions (shading equivalent to 75% shading) and 75% shading had significantly higher total yield than those from 50% shading (Fig. 6). At 50% shading the total yield was closed to 0.5. The performance of photosynthesis was significantly higher at the 0 cm and 5 cm water depths as compared to the15 cm water depth (Fig. 7).

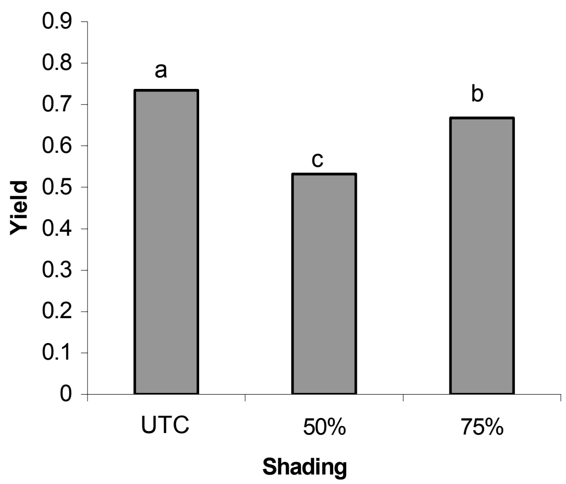


Figure 6: Effect of shading on maximal quantum yield in *C. ferruginea.* Values sharing the same letter are not significantly different at P ≤ 0.05 according to Duncan's multiple range test.

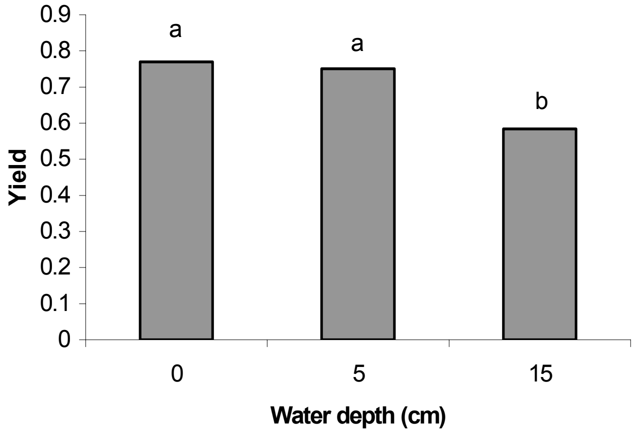


Figure 7: Effect of water depth on maximal quantum yield in *C. ferruginea.* Values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

The electron transport rate (ETR) increased significantly with increase in photosynthetic active radiation (PAR) values from different light intensities (Fig. 8). The ETR of plants raised at 50% shading was significantly higher than those at 75% shading and UTC conditions. Highest ETR was recorded at PAR 300 of plants from 50% shading. Lowest rate of ETR was demonstrated from plants at 75% shading (Fig. 9).

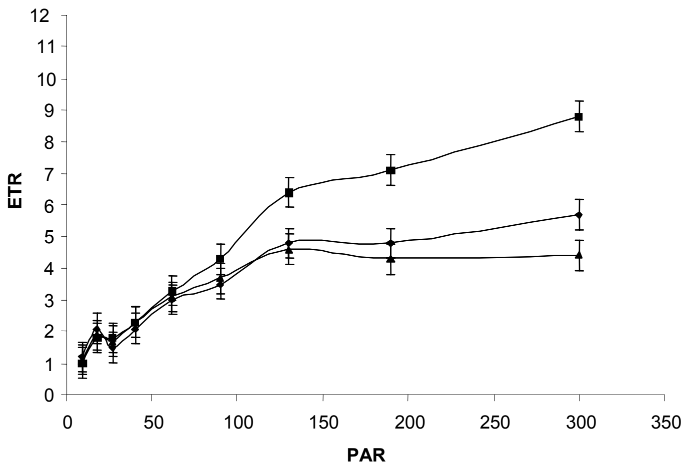


Figure 8: Effect of shading on light curve ETR versus PAR in *C. ferruginea*. UTC condition (—◆—), 50% shading (—■—), 75% shading (—▲—). Vertical bars are values of LSD = 0.05.

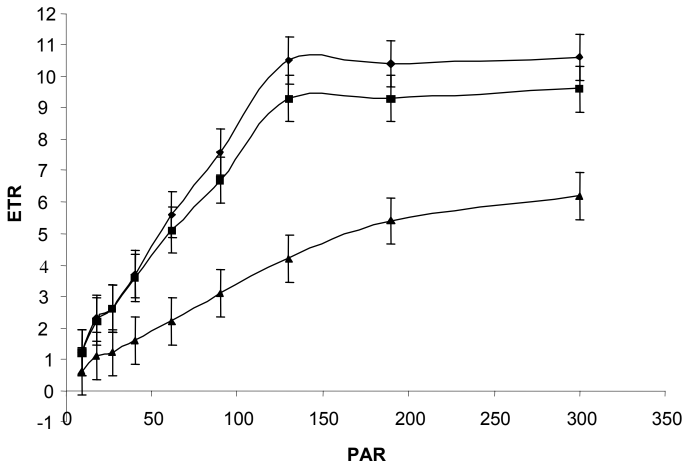


Figure 9: Effect of water depth on light curve ETR versus PAR in *C. ferruginea*. 0 cm (—◆—), 5 cm (—■—) and 15 cm (—▲—). Vertical bars are values of LSD = 0.05

Table 7: The effect of water depth on DMP, NAR and LAD in *C. ferruginea* plantlets during the 30th to 60th day interval (2nd harvest).

Water depth	DMP (g)	NAR (mg/dm²/day)	LAD (dm²/day)
0 cm	0.402b	0.044a	6.482b
5 cm	0.816a	0.042a	21.776a
15 cm	0.822a	0.044a	19.724a

Note: Within column, values sharing the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

DISCUSSION

To date, *C. ferruginea* has been recorded in Sarawak only at Sabal Kruin, Balai Ringin and Sungai Kerait from Kota Samarahan. Two localities at Serikin, Bau and Sungai Bayor at Sungai Sarawak Kanan were not included in this study as both localities were discovered later after the commencement of the study. The population of *C. ferruginea* at Sungai Kerait occurred only in the river system that was directly affected by the water flow and in mature rubber farm with estimated total above ground biomass of 172.51 ton/ha, while the population of *C. ferruginea* at Sabal Kruin and Sungai Kerait grew on the riverine habitat that prone to flood after a short period of heavy rain. Sungai Bayor often inundated with brackish water while the *Cryptocoryne* plants at Serikin were the only population sustained in a limestone habitat. The vegetative characteristics and biomass allocation varied between the two locations. The trend was obviously showed by its dry weight, plant density, leaf area, total biomass, LWR, PWR, RWR, LAR and SLA (Figs. 2 & 3). Ipor *et al*. (2005) stated that the protective biomass established from secondary forest at Sungai Stuum Muda, Bau, Sarawak played important role in sustaining the abundant population of *C. striolata*. This forest consisted of 78.39 ton/ha of above ground biomass. Holmes and Klein (1987) elaborated the effect of shading created from overlying vegetation on the changes of both quality and quantity of radiation. Radiation impinging on green leaf is selectively absorbed, reflected and transmitted accordingly.

Occasionally inundation or seasonal flooding of the entire habitats of *C. ferruginea* was observed to be significant contributed to the sustainability of the *C. ferruginea* population. The draining out process of each inundation is normally facilitated the cleaning up of most of the *C. ferruginea* patches from being covered by forest litter falls. As frequently observed during our extensive survey of *Cryptocoryne* population throughout Sarawak, the localities with thick cover of litter falls were always with the absence of of *Cryptocoryne* plants. The wash away of the litter falls was essentially needed particularly for amphibious *C. ferruginea.*

The aquatic plants normally absorbed nutrients both through the root system as well as through the entire surface area (Kasselmann 2003). The nutrient uptake through root system depends closely on the soil structure. The soil analysis showed that the soil sampled from the selected localities was generally considered poor in nutrient and comprised of high percentage in fine particles ranging from 69–88% (Table 3). Soil with pure clay is rich in nutrients and has high percentage of very fine gravels that would allow hardly any air or water exchange and soil fertility. The availability of organic matter from plant biomass debris deposited and eventually decomposed within the patches of *Cryptocoryne* and the substrate are of great importance as the sources of nutrients. Fertile soil would lead to better formation of good root system as to efficiently extract sufficient amount of most nutrients required by plants. It could be easily determined by the high value of RWR demonstrated in the biomass allocation pattern analysis.

Besides soil characteristics, water also plays very important ecological role to the life of aquatic plants. Water movement, currents, hardiness, pH and nutrient composition were also identified to determine the growth performance and patterns of aquatic plants (Kasselmann 2003). Unfortunately, there was no nutrient analysis for the water samples due to some constraint in financial support.

Determining the response of an aquatic plant such as *C. ferruginea* to different shade levels and water depths are extremely important for the better understanding of the optimum requirement of light in different aquatic conditions and to enable effective maintenance of a suitable environment. As light is the provider of energy for photosynthesis, it is important for major growth and development processes of plants. Increase in water depth meant decrease in the availability of light. The study revealed that the significantly better growth performance of *C. ferruginea* at UTC conditions and 75% shading compared to that of 50% shading. The shade levels and water depths were significantly influenced the growth of *C. ferruginea* as demonstrated by their height, number of leaves and lateral shoots (Figs. 4 & 5) The biomass allocation of *C. ferruginea* as shown by values of LWR, SWR, RWR, SLA, LAR, DMP, NAR and LAD (Tables 4 & 5) was also significantly differed between shade levels. The forest formation with substantial leaf area index that provided appropriate shade level above *C. ferruginea* population was obviously influenced the growth performance and growth pattern strategy of this species. It could be assumed that *C. ferruginea* could respond dramatically to small scale temporal and spatial variation in habitat quality. The light at UTC conditions was similar to those at 75% shade except for a sharp pulse that was equivalent to a condition without shading or direct to sunlight from 2–5 p.m. Pulses of light could trigger physiological and morphological responses that enable the plants to adjust effectively to temporal changes of their environment. Plants were assumed to respond by adhering growth and for adjusting biomass partitioning in various organs (Dale & Causton 1992; Meekins *et al.* 2000). RWR of *C. ferruginea* tended to decrease and increase in LWR as the availability of light decreased (Table 4). The better growth performance of *C. ferruginea* observed under reduction in light availability and in deeper water agreed with the common response of the shade plants (Kasselmann 2003). Shade plants are able to fully utilize and adapt to low light intensity compared to sun plants. They reached their highest assimilation during conditions of weak-light intensity. The plant chloroplasts which are the organelles contained chlorophyll are often located in layer of leaves to ensure that as much light as possible is absorbed. The plant also has a low light compensation point (LCP). With these typical characteristics, the plants are able to sustain and thrive well under weak-light conditions and relatively dark localities. Low LCP would allow the plants to grow to depths that received only 1–4% of full light. The better growth performance of *C. ferruginea* could also be explained in term of higher rate of photosynthesis as recorded in this study.

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