Size Distribution and Production Structure of a Secondary Forest after Selective Cutting in the Mixed Dipterocarp Forest, Brunei Darussalam

By

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Summary : The structure and biomass of a secondary forest which was selectively cut about 25 years ago in a mixed Dipterocarp forest area of Brunei Darussalam was investigated, and its distinctive features were identified. Three plots (20m × 20m each) well closed with no gaps were set up. The density of secondary forests was 9 000-15 700 trees/ha with a basal area of 24.5-33.5 m^2/ha. Canopy height ranged from 24m to 32m. Tree density was high, and some trees remaining after selective cutting occupied a large amount of the basal area with excellent strata in height. Vertical distribution of the production structure in which the frequency of the stem weight increased linearly as the class decreased was different from that of temperate forests. Leaf distribution, which showed, normal shape, also differed from that of typical evergreen broad-leaved forests in the temperate zone. The aboveground biomass determined by a direct weighing method was 141t/ha, while biomass values estimated from the allometric relationship between the weight of each part (stem, branch and leaf) and $(\text{diameter})^2 \times$ height were extremely accurate. A 5-yr-old *Acacia mangium* plantation investigated for comparison showed a biomass value (147 t/ha) similar to that of the secondary forest. The ratio of trees of Dipterocarp species found in the study sites was only 1.8 %, and no individuals were distributed in the canopy layer. This suggests that these abandoned stands are unlikely to be Dipterocarp-rich, and that it is necessary to improve the environment of such stands in order to maintain Dipterocarp species.

1 Introduction

In Brunei Darussalam, forests are distributed widely in the lowlands and swamps near areas of human habitation. Recently mature forests have been extensively cut, and many areas have become secondary forests. Generally the natural forest in the forestry region is selectively cut under a management system adapted from the Malayan Uniform System (MUS) used in Malaysia.

In the MUS, felling operations are carried out on commercial overwoods, leaving trees of smaller diameters (≦45cm) to aid in the seedling and sapling regeneration of those commercial species already present on the floor. Post-felling removal of defective and non-commercial trees by poison girdling and climber cutting is repeated once or twice to enhance regeneration. Trees are expected to be harvested again in approximately 60 years (CHEAH, 1991).

In Brunei Darussalam, trees more than five feet in trunk circumference (diameter: 48.5 cm) for Dipterocarp species and greater than six feet (diameter: 58.2 cm) for other species are basically felled. Afterward the climber cutting is selectively conducted and remaining trees are left for

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approximately 30 years until the next logging (KOBAYASHI, 1988). However, most stands do not regenerate well after felling because of the damage from cutting and the proliferation of vines. Moreover, Dipterocarp trees are rare in such stands. Therefore, further technical development is necessary to improve the natural regeneration and maintain the forest resource.

Many studies on tropical rain forests have clalified structure (e.g. BONGERS *et al.*, 1988; HUBBELL and FOSTER, 1985; MANOKARAN and LAFRANKIE, 1990) and biomass (KIRA *et al.*, 1964; FABER-LANGENDONE and GENTRY, 1991 etc.). Some studies have examined the biomass and dynamics of the secondary forests following clear-cutting and burning (FOLSTER *et al.*, 1976; UHL and JORDAN, 1984), but few research had been conducted on the characteristics of a stand following selective cutting.

This study, we report on the structure and the biomass of a mixed Dipterocarp forest, in which selective cutting was conducted about 25 years ago, then discuss the characteristics of the size distribution and production structure and the dynamics of Dipterocarp species in stands abandoned after selective cutting.

2 Methods

2.1 Study site

Field surveys were carried in the secondary forest next to compartments 7 and 8 of the Andulau Forest Reserve, Sungai Liang, Brunei Darussalam. The forest was abandoned approximately 25 years after selective cutting. The study site is in the lowland forest area below 100m a.s.l. and widely spaced by gentle slopes of less than 20°. The soil type is typic paleudults in soil taxonomy (TAKAHASHI *et al.*, 1994). Before selective cutting, this forest was mature and likely dominated by Dipterocarp species, since the nearest well-preserved forest contained a canopy of several Dipterocarp species.

Three study plot (20m × 20m each) at different topographical sites were set up in 1988. Plots 1, 2 and 3 represented a ridge, a ravine and a midslope, respectively. The plots were located on a hillside facing northeast-northwest with a slope of 11-17° and elevation ranging from 55 to 70m (Table 1).

A 5-yr-old *Acacia mangium* plantation, approximately 15km north-east of the study site, Mt. Kukub (100m, a.s.l.) owned by the Settsu Co., was also investigated for purposes of comparison.

Table 1. Profile of research plots in a study site next to Compartments 7 and 8 of the Andulau Forest Reserve

Plot No.	Altitude (m)	Azimuth	Inclination (°)	Character	Soil Type*
1	60	NE	17	ridge	RD
2	55	NNW	14	ravine	YW
3	70	NNE	11	midslope	YD

*Based on soil map (TAKAHASHI *et al.*, 1994)

2.2 Field survey

Diameter (D) at breast height and height (H) of trees (height≧2m) were recorded in all plots. All trees in plot 3 were felled and cut into 2m sections, and the fresh weight (FW) of each part (stem, branch and leaf) was measured. Then 67 trees chosen randomly were weighed individually and the others in bundle. Six and five standard trees in plot 2 and the *A. mangium* plantation, respectively, were also felled. Some samples (of several hundred to 1 000g) were brought to the laboratory to measure their dry weight (DW).

ASHTON's (1964) manual was used to identify dipterocarp species from individual trees in plot 3.

2.3 Data analysis

The relationship between D and H was calculated using the following hyperbolic equation (OGAWA, 1969; OGAWA and KIRA, 1977):

$$1/\mathrm{H} = 1/A\mathrm{D}^{h} + 1/H^{*}, \tag{1}$$

with h, A, and H^* being coefficients specific to the forest. OGAWA (1969) showed that H^* gives an asymptotic maximum tree height and that A is related to the density of stand biomass per unit height (H^*). Since h is approximately equal to one in most natural forests, irrespective of their types, eq (1) can be simplified to

$$1/\mathrm{H} = 1/A\mathrm{D} + 1/H^{*}. \tag{2}$$

We then determined statistically whether the three-parameter (1) or the two-parameter model (2) would be better, using the F test between the residual sum of the squares of the two models.

Volume (V) was calculated with the following simple formula (WHITMORE, 1984):

$$\mathrm{V} = \mathrm{H} \times \mathrm{BA} / 2, \tag{3}$$

where BA is basal area (D^2).

The drying ratio (DW / FW) of three parts in each sample tree was calculated. Using this ratio, the biomass of plot 3 was calculated. The biomasses (dry weights) of plots 2 and 3 and the *A. mangium* plantation were estimated on the basis of the allometric relationship between $\mathrm{D}^2\mathrm{H}$ and dry weight of each part. KIRA *et al.* (1967) have estimated dry matter production in South East Asian tropical rain forests, using this allometry. The allometric equation is expressed as follows:

$$\log_{10}(\mathrm{W}) = A \log_{10}(\mathrm{D}^2\mathrm{H}) + B, \tag{4}$$

where W is the biomass, and A and B are coefficients.

3 Results and Discussion

3.1 General characteristics

Table 2 represents a general summary of the study plots. The maximum H was 32.0m at plot 1,while the mean D(2.98cm) was quite small. The density of trees more than 2m in height was much more than 9 000n/ha. BA was 24.5-33.5m^2/ha. Compare their values with those of other lowland rain forests, they were similar to Pasoh (MANOKARAN and LAFRANKIE, 1990), while the density of large trees was low and the canopy was rather open. However, the values were lower than those of well developed forests, e.g. Los Tuxtlas (BONGERS *et al.*, 1988). The form of trunks was characterized by a high form-quotient.

Table 2. General summary of each plot in the study site, approximately 25 years after selective cutting

Plot	D		H		BA	Density	Volume*
	max. (cm)	ave. (cm)	max. (m)	ave. (m)	(m^2/ha)	(n/ha)	(m^3/ha)
1	56.7	2.98	32.0	5.62	30.7	15 700	339
2	43.0	3.38	30.5	5.26	33.5	12 200	365
3	30.5	3.80	25.5	6.17	24.5	9 900	228

All values were calculated for trees more than 2m in height.
* Calculated with the following equation for single-tree volume (WHITMORE, 1984): Volume (m^3) = H (m) × BA (m^2) / 2

3.2 Size distribution

The D distribution in all plots was L-shaped (Fig. 1). The canopy trees remaining after selective cutting existed as the emergent in the larger D class of more than 30cm. The H distribution also formed a L shape, with the number decreasing exponentially as height class rose, as shown in Fig. 2. Some remaining trees projected above mean canopy height. The existence of remaining trees was more clear in BA distribution (Fig. 3). Generally the BA distribution pattern of mature natural forest shows the inverted H-distribution style. It usually changes gradually with height, although it did not show so in these plots. Past selective cuttings have influenced the pattern, and the difference among plots depend on the density of remaining trees.

Few of the Dipterocarp tree species (*Dipterocarpus confertus*, *Dryobalanops aromatica*, *Shorea ferruginea* and *Shorea maxwelliana*) were identified, and their density ratio was only 1.8%. Dipterocarp trees existed in the subcanopy and shrub layers but not in the canopy layer (Figs. 1 and 2). There were 3.5 Dipterocarp seedlings (*Shorea angustifolia* and *S. agami*) per m^2 on the floor (NIIYAMA *et al.*, 1994), but there were no individuals of these *Shorea* more than 2m in height.

When the results of the regression eqs (1) and (2) for each data set were compared, the difference between the residual sums of squares was small. The significant probability (*P*) of various ratios was consistently less than 0.01. Therefore, we used the simpler eq (2) to express the results of the D-H relationship.

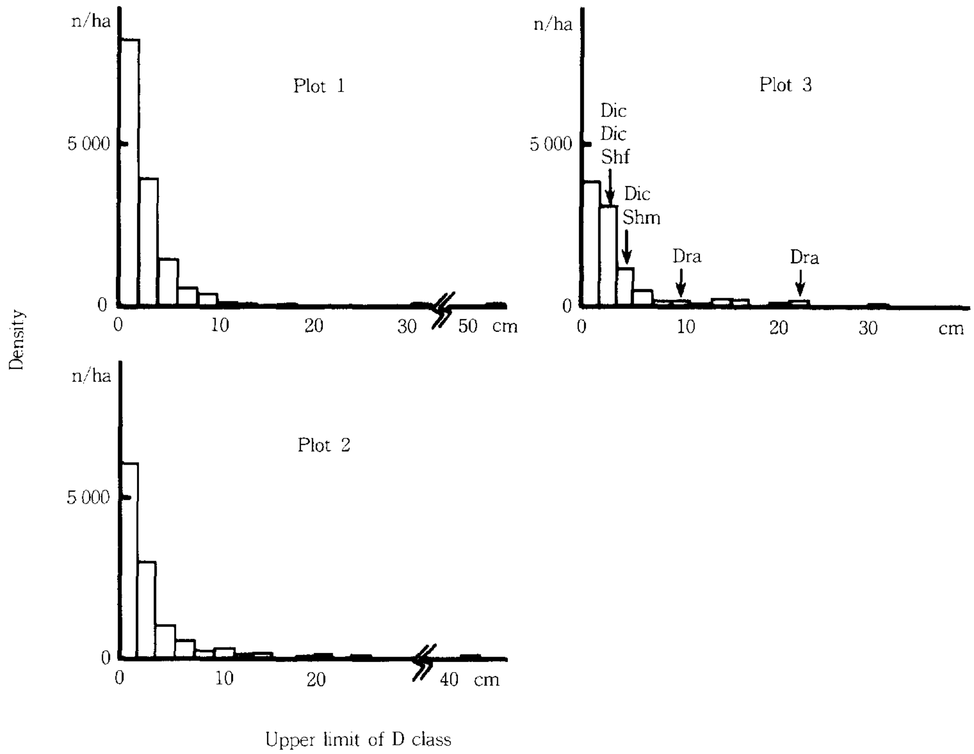

Fig. 1. D (dbh) distribution of all trees (≧ 2m in height) at each plot. In plot 3, the positions of seven individuals of Dipterocarp tree species are expressed with the following abbreviations: Dic, *Dipterocarpus confertus*; Dra, *Dryobalanops aromatica*; Shf, *Shorea ferruginea*; Shm, *Shorea maxwelliana*.

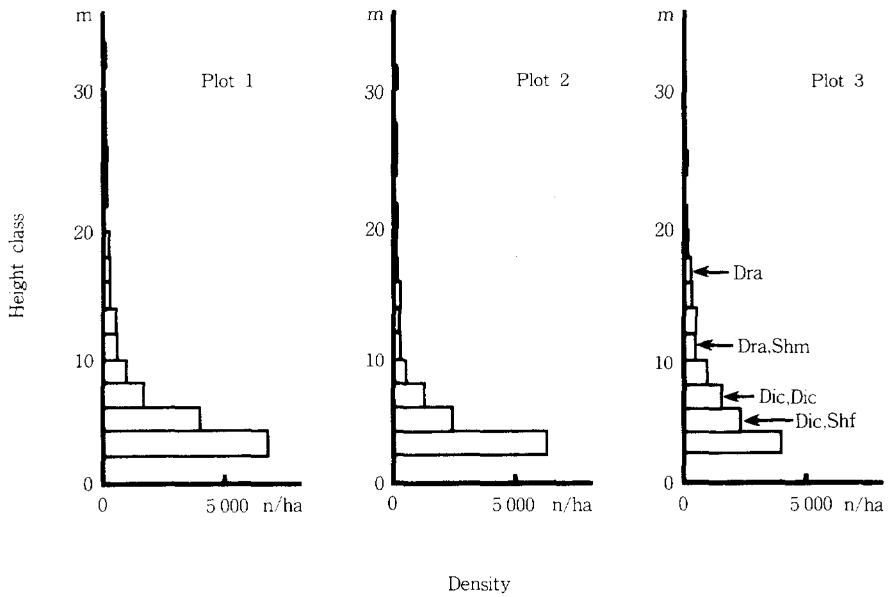

Fig. 2. H (height) distribution of all trees (≧2m in height) at each plot. Refer to Fig. 1 for abbreviations used in plot 3.

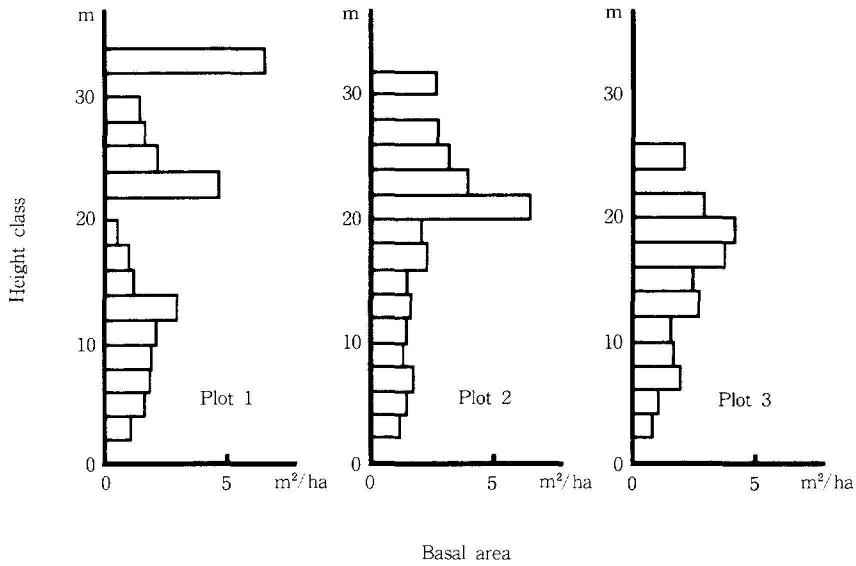

Fig. 3. BA (basal area, dbh^2) distribution of all trees (≧ 2m in height) at each plot.

The hyperbolic relation between D and H in all plots is shown in Fig. 4. The coefficients approximated by eq (2) are as follows:

	A	H^*
Plot 1	2.53	37.2
Plot 2	2.07	41.7
Plot 3	2.47	29.5

Parameter A was greater in this forest than either in other mature evergreen broad-leaved forests (OGAWA and KIRA, 1977; NAKA, 1982; KOHYAMA, 1987) or in closed-canopy tropical rain forests (OGAWA *et al.*, 1965; OGAWA, 1969). NAKA and YONEDA (1982) suggested that the value of A was greater in younger stands than in older stands. H^* showed approximately the same value as the mixed evergreen oak forest (OGAWA and KIRA, 1977). The study forest had a high value of A in spite of its being a secondary forest, which suggests that its space is densely filled.

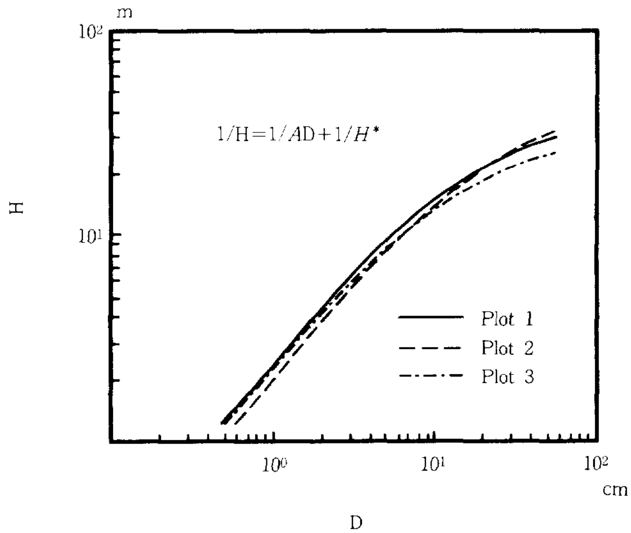

Fig. 4. Relationship between D (dbh) and H (height) for trees (≧ 2m in height) in the study plots (20m × 20m each). The expression was approximated by the generalized allometric equation (OGAWA, 1969).

3.3 Production structure

The production structure diagram of the stand (Fig. 5), especially the stem's vertical distribution, was different from that of temperate forests. The frequency of the stem weight in temperate forests increases exponentially as the vertical strata descends (KAN *et al.*, 1965), and a similar shape was also obtained in mature tropical rain forests. In this study, the frequency increased linearly as the class decreased. This shape means that the stand consists of tall and slender trees, which may be a distinctive feature of secondary forests after selective cutting.

Moreover the vertical frequency distribution of foliage was characterized that the mode was on 8-10m height, and the shape was similar to normal distribution. Two types of vertical foliage distribution, herb- and grass-types, have been recognized (MONSI and SAEKI, 1953). In the former, foliage is found mainly in relatively high strata whereas the latter concentrates in the lower. Homogeneous and even-aged forest stands tend to be of the herb-type, while uneven-aged stands tend to be the grass-type. Furthermore, deciduous broad-leaved stands are likely liable to be of the herb-type, whereas evergreen broad-leaved and needle-leaved stands are usually of the grass-type

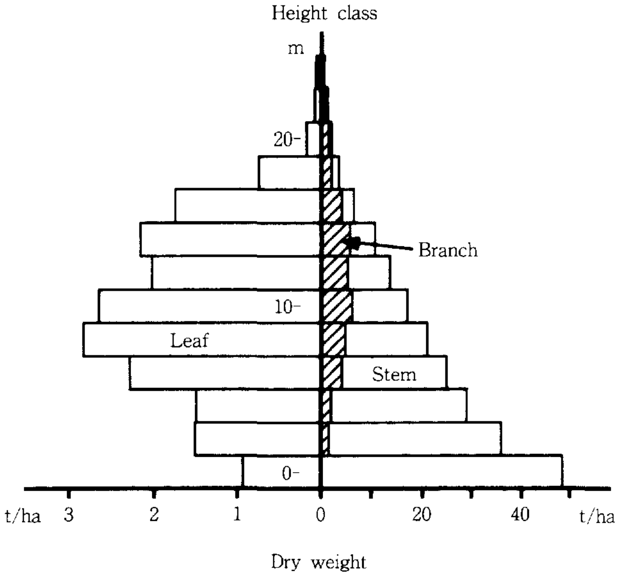

Fig. 5. Production structure diagram for plot 3, approximately 25 years after selective cutting of a mixed Dipterocarp forest.

(TADAKI, 1966, 1976). The foliage distribution of this stand was of the intermediate type. Although it should show the grass-type because the stand is an uneven-aged and broad-leaved evergreen forest. The selective cutting which caused the disproportionate canopy and foliage structure must have changed it to the intermediate type.

The foliage form of each tree was characterized by the vertical position and width of the foliage. It is expressed in the relationship between the deviation ratio (DR) and expanse ratio (ER) of foliage in H (Fig. 6).

$$DR = (H_{mode} - H_{midpoint}) / H, \qquad (5)$$

where H_{mode} and $H_{midpoint}$ are the mode of the vertical leaf distribution and the midpoint of the height, respectively.

$$ER = (H_{max} - H_{min}) / H, \qquad (6)$$

where H_{max} and H_{min} are the maximum and minimum of leaf distribution height, respectively. Eqs (5) and (6) were used to clarify the vertical position of foliage in trees. Generally the top leaf attaches the tip of trunk, this means that H_{max} equals to tree height, then the value locates in the right side of broken line in Fig. 6. Most trees had a DR of 0.2 or more, which means that foliage clustered in their upper strata. ER ranged widely from 0.02 to 0.77. Palm trees and a few other species had foliage only near their tops. Most canopy trees, as well as some Dipterocarps, had foliage above 1/2 of tree height ($DR \geqq 0$, $ER \leqq 0.5$). Shrub species had the mode of the foliage of which is below 2/3 of the tree height ($DR \leqq 0.17$), and the foliage tended to distribute widely in height (high value in ER).

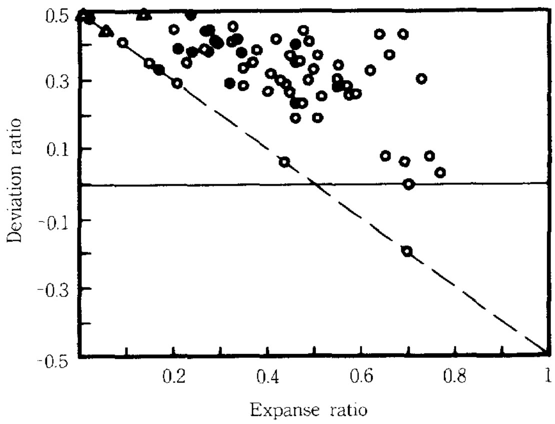

Fig. 6. Relationship between deviation ratio (DR) and expanse ratio (ER) for the vertical position of leaf biomass in trees.

DR = (mode of leaf biomass distribution (m) - midpoint of tree height (m)) / tree height (m).

ER = (maximum leaf distribution height (m) - minimum leaf distribution height (m)) / tree height (m).

Triangles, plam trees; solid circles, canopy trees; open circles, others.

3.4 Biomass

Similar allometry coefficients between the dry weights of stems (W_S), branches (W_B) and leaves (W_L) of a tree and D^2H were obtained from two study plots (Fig. 7, Table 3). Data from the 5-yr-old *Acacia mangium* plantation were used as reference. The values of coefficient A in the secondary forest differed greatly from the plantation's W_B and W_L. The standing biomass was calculated with eq (4) as shown in Table 4. The total biomass was different between plots 2 and 3, mainly because of the effect, noted above, of the number of remaining trees on values. The difference in relative error of estimation between the estimated method and the directly-determined method was less than 6%. KIRA and SHIDEI (1967) compared the two methods in their study of a tropical rain forest, and indicated a relative error of estimation of less than 12% at each part. The biomass of this stand, 141 t/ha, was lower than that of mature tropical rain forests in Thailand (KIRA and SHIDEI, 1967) and Colombia (FABER-LANGENDOEN and GENTRY, 1991) as estimated with the same allometry equation.

The *Acacia mangium* plantation therefore showed a similar value for each part (Table 4). The ratio of volume growth has been very high and the canopy height had already reached 6m one year after planting (YONEKAWA and MIYAWAKI, 1983).

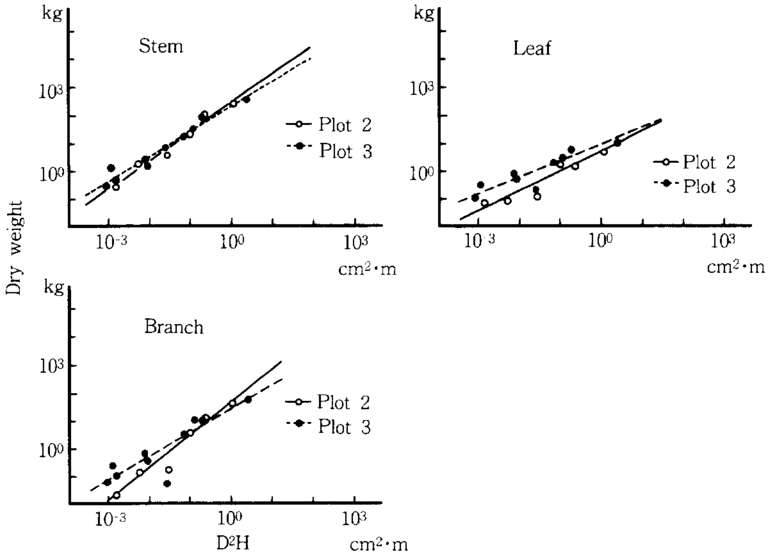

Fig. 7. Dry weights of stem, branch and leaf, and D^2H allometry in plot 2 and 3, approximately 25 years after selective cutting of a mixed Dipterocarp forest. Both axes are expressed in a logarithmic scale.

Table 3. Coefficient of allometric relationship between each part (stem, branch and leaf) and D^2H in the study site (plot 2 and 3) and a 5-yr-old *Acacia mangium* plantation (Mt. Kukub).

Stand	Part**	Coefficient***	
		A	B
Plot 2	W_S	1.025	2.478
	W_B	1.164	1.640
	W_L	.718	.674
plot 3	W_S	.870	2.293
	W_B	.848	1.414
	W_L	.594	.906
Mt.Kukub*	W_S	1.260	2.223
	W_B	3.686	1.266
	W_L	3.776	.765

* 5-yr-old *Acacia mangium* plantation, approximately 15km north-east of the study site.

** Abbreviations of each part are: W_S = dry weight of stem, W_B = dry weight of branch, W_L = dry weight of leaf.

*** Coefficient A and B were calculated with the following allometry.

$$\log_{10}(y) = A \log_{10}(x) + B$$

x : D^2 (cm^2) × H (m)

y : dry weight (kg) of each part

Table 4. Aboveground biomass, calculated directly and estimated for each plot

Stand	Method**	Biomass (t/ha)			
		Stem	Branch	Leaf	Total
Plot 2	estimation	242	7.3	4.1	283
Plot 3	estimation	122	16.6	7.6	146
Plot 3	direct	116	17.6	7.7	141
Mt.Kukub*	estimation	129	13.7	4.3	147

* 5-yr-old *Acacia mangium* plantation, approximately 15km north-east of the study site.

** Estimation is calculated by the allometric equations shown in Table 3, and direct determination is made by weighing each part measured by cross-cutting at 2m intervals.

3.5 Succession

We discuss the future of this stand by focus on the dynamics of Dipterocarp tree species. Some Dipterocarp individuals (275n/ha) existed in the subcanopy and shrub layers, but none were in the canopy layer (see Figs. 1 and 2). The density of seedlings and saplings was 3.75n/m^2 (NIIYAMA *et al.*, 1994). The D distribution of Dipterocarp trees (height $>$ 2m) before cutting was assumed, using the obsenation of the nearest Dipterocarp-dominated forest, the Andulau Forest Reserve, to have shown a bell-shaped distribution. In other words, there are few individuals in the smaller D classes. The distribution including the seedlings and saplings shows a bimodal shape, indicating good reproduction and discontinuous recruitment into large size classes (BONGERS *et al.*, 1988). Some studies have been proved that main canopy species has a few young trees in the understory, e.g. *Cymbopetalum baillonii*, BONGERS *et al.* (1988); *Quercus* spp., TANOUCHI *et al.* (1994).

All the Dipterocarp species, namely, *Dipterocarps confertus*, *Dryobalanops aromatica*, *Shorea ferruginea*, *Shorea maxwelliana* and *Shorea agami*, in plot 3, became emergent canopy trees with the exception of *Shorea angustifolia* and distributed in the mature forest of the Andulau district (ASHTON, 1964). It was unlikely that many mother trees of the Dipterocarp tree species are distributed through the size distribution in plot 3, which means that a large seed supply may not be expected. Indeed, no seedlings of *D. confertus*, *D. aromatica*, *S. ferruginea* or *S. maxwelliana* survived on the floor. *S. angustifolia* and *S. agami* existed as seedlings but were not distributed in the shrub or subcanopy tree layers. These seeds may have been dispersed from the adjacent mature forest.

The characteristics, the stand is composed of dense trees with the foliage which clusters upper position of trunk, must occur the scarcity of light on the floor. Actually the relative light intensity (RLI) in a floor adjacent to the study site was 1.1-1.2% (OCHIAI, personal communication). It has been shown that many Dipterocarp tree species do not have high shade-tolerance. SUZUKI and JACALNE (1986) proved that the seedlings of all Dipterocarps used in their study were unable to grow taller at a low light intensity (approximately 2% RLI) beneath a closed canopy. This light intensity was nearly identical to the light compensation point of Dipterocarp species (SASAKI and MORI, 1981). SUZUKI and JACALNE (1986) also pointed out that the improvement of RLI higher than 10% is required for seedlings to grow continuously. In other words, seedlings were able to survive for long periods, but not to grow, in this well-closed stand.

If this regime continues, the Dipterocarp cannot become a dominant species. However, the sapling bank can be patiently waiting for the change of light intensity as long as the seedlings are recruited, and they will be successful in growing to canopy trees. It is expected that artificial management on a large scale will be required to improve Dipterocarp reproduction.

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ブルネイにおける択伐後放置されたフタバガキ科二次林の構造

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摘　要

低地混交フタバガキ林で択伐後約25年放置した二次林に3か所の調査地を設定し，林分構造，生産構造及び現存量の解析を行い，その特質を明らかにした。また比較のため，5年生のアカシアマンギウム人工林の現存量測定も行った。

二次林の立木密度は高く，9 000～15 700本／haであった。胸高断面積は24.5～33.5m²／haで，樹高は24～32mに達し，林冠は良くうっ閉していた。林分構造（樹高や直径分布）は点在する残存高木によって特徴づけられた。生産構造では，幹と葉の垂直分布型が成熟した常緑広葉林のそれとは異なっていた。樹型を葉群の垂直頻度分布で評価すると，多くの木は葉群のモードが樹高の2／3以上の高さに位置し，その分布幅は小さかった。現存量は，直接測定では141t／haあり，相対成長式による推定法も精度が高かった。一方，5年生のアカシアマンギウム林の現存量は147t／haに達し，初期成長は著しく速かった。

高木性フタバガキ科木本の本数密度割合は1.8%と低く，林冠木を形成している個体はなかった。このことより，各種の攪乱が新たに生じていない現体制のままでは，再びフタバガキ林へと移行することは困難であると考えられた。

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