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Article

Tree Size in a Mature Dipterocarp Forest Stand in Sebulu, East Kalimantan, Indonesia

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Abstract

The forest plant size, especially tree size, was examined in a mature dipterocarp forest stand in Sebulu, East Kalimantan, Indonesia. One hundred and ninety-one living trees 1.3 m high and higher, three lianas living on dead trees, one small standing liana, and one palm were felled, and their sizes were measured using the stratified clip technique and recorded. Of these sample plants, the largest was a *Shorea laevis* tree: total height was 70.7 m; stem diameter at the terminal of its buttresses, 4.6 m high, was 130.5 cm; stem volume was 41.1 m^3; stem dry weight was 33129.768 kg; branch dry weight was 9586.120 kg; leaf dry weight was 107.614 kg; leaf area was 767.372 m^2. The plant mass of dependent plants living on independent plants was also measured using the stratified clip technique. The aboveground biomass in a narrow 0.125 ha sampling spot was calculated by summing the plant mass values of individual sample plants. It totaled 872.949 t/ha in dry weight for all living plants and 7.962 ha/ha in leaf area, although these values were too large to represent the mean biomass of the dipterocarp forest in the study area because that forest patch included the huge emergent tree.

Introduction

There is evidence that the tropical rain forests of Southeast Asia are the tallest type of all similar plant formations in the world. Foxworthy [1926; 1927] reported that a *Koompasia excelsa* tree in Sarawak had a total height of 275 ft (84 m) which is the highest recorded height in tropical regions. The next tallest tree he recorded was a *Dryobalanops aromatica* tree whose height was 220 ft (67 m). Ashton [1964] reported possible maximum heights for various dipterocarp species in Brunei. They ranged from 15 m for *Hopea vaccinifolia* to 75 m for *Shorea laevis*, and their average was 47.8 m. Meijer and Wood [1964] also recorded maximum tree heights

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for various dipterocarp species in Sabah. Their measurements ranged from 50 ft (15 m) for *Shorea amplexicaulis* to 250 ft (76 m) for *Shorea acuminatissima*, *Shorea laevis*, and *Dryobalanops lanceolata*. The mean of their height values was 45.6 m, similar to the mean value (47.8 m) calculated from Ashton's measurements.

Whitmore [1975] pointed out the high frequency of tall trees reaching 60 m in Malaysia. Of 150 species of Dipterocarpaceae recorded in Brunei [Ashton 1964], 42 species exceeded 60 m. Moreover, 20 species of a total of 75 species in Sabah were over 60 m [Meijer and Wood 1964]. In addition to these records, Richards [1974], quoted by Kira [1978], stated his experience that in African and Latin American tropics only one tree was observed to exceed the height of 60 m. This statement by Richards coincides with the records of maximum tree height for various species in West Tropical Africa [Hutchinson and Dalziel 1954–1972; Swaine and Hall 1983]. Thus, tropical rain forests in Southeast Asia, especially on the Malay Peninsula and Borneo, include tall trees which frequently exceed 60 m or 70 m in height and are rare in other tropical regions.

In addition to tall trees, a rich species diversity is a conspicuous feature of tall tropical forests on the Malay Peninsula and Borneo, as reviewed in the works of Richards [1952] and Whitmore [1975]. Corresponding to the tall forest structure and abundant floral composition, the individual trees in the forests are different in their dimensions and geometrical shapes. However, very little has been described in quantitative terms, such as stem weight, leaf area, *etc.*, concerning the size and form of the trees in tall forests. Only one study [Kato *et al.* 1978] of plant mass in a tall forest at Pasoh Forest Reserve in West Malaysia has recorded information with regard to the size and form of the tall-forest trees. The lack of available records of tree dimensions is especially severe for Indonesian Borneo. To fill this gap in our knowledge, the present study describes the tree size of the component trees of a tall tropical forest in East Kalimantan, Borneo, in terms of plant mass dimensions.

Study Area

Our investigation was made in a concession area of P. T. Kutai Timber Indonesia in Sebulu (latitude 1.5°S, longitude 116°58′E) about 40 km to the northwest of Samarinda, the capital of East Kalimantan Province, Indonesia (Fig. 1). Access to Sebulu from Samarinda was provided by the Mahakam, the third largest river (about 775 km long) in Borneo. The concession area was on a low undulating plateau and included some small rivers and shallow basins. The height differences between hill tops and basins did not exceed 30 meters. This topography is common over a wide range of the lowlands of East Kalimantan.

No exposed rocks were observed, since the soil in this area consists of clay and sand with coal deposited in the Neozoic. Mohler quoted by van Bemmelen [1970], drew parallels between the lower parts of the Tertiary of Borneo and the classical European stratigraphy by aid of the *Aleveolinellidae*, and drafted a preliminary stratigraphical correlation among eight categorized areas in

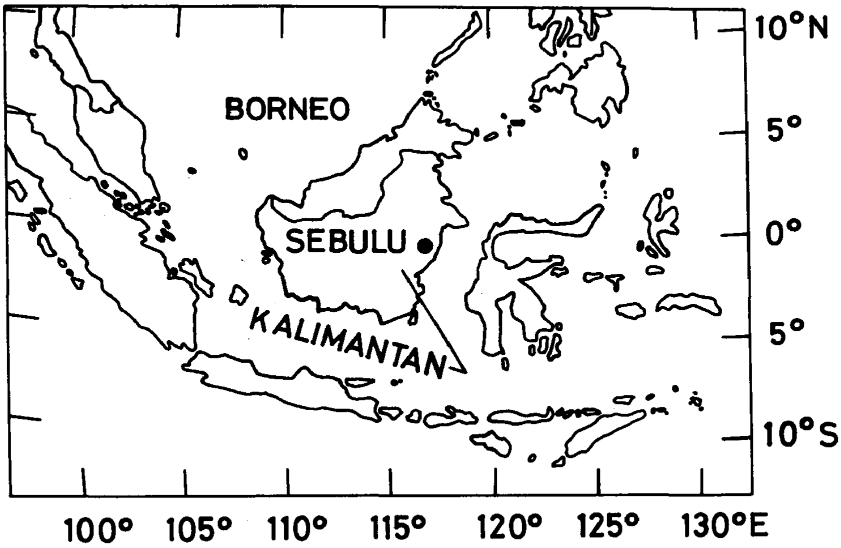

Fig. 1 Map showing the location of Sebulu in East Kalimantan, Borneo

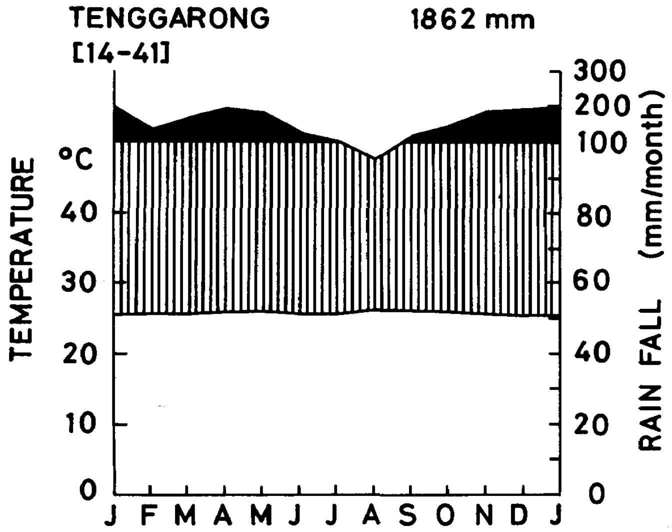

Fig. 2 Walter's climatic diagram at Tenggarong about 13 km south of Sebulu. The rainfall data came from Berlarge [1949] and temperature data were calculated by extrapolating temperature records at Balikpapan [Sukanto 1969]. Details of the diagram followed Walter [1971].

the central, southern, and western parts of Borneo. Of the eight areas differentiated by Mohler, the upper Mahakam and Kutai-Lake areas includes Sebulu. His accounts identified the surface lithology of the study area to be composed of post-ologenic sediments, such as clay, sand, and coal, deposited in the Pliocene, when Sebulu was submerged in the ancient Kutai Basin. Furthermore, Suprianta and Rustendi [1979] differentiated the Purau Beds (or formation) in their geological map of Samarinda Province. This formation covered the Sebulu District and was composed of clay and sand stone intercalated with limestone and coal. Corresponding to the variability of the surface lithologies and topographies, different soil types were observed. The soils of the site rich in clay belong to the red yellow podozolic soil group and typical lowland podozols could be observed in the sites rich in coarse sandy deposits. Details of the soil chemical analyses will be described in a separate paper.

No meteorological records are available in Sebulu. However, the records at Tenggarong [Berlarge 1949] near Sebulu provide a fairly good approximation of the climatic conditions of this area. Fig. 2 represents Walter's [1971] climatic diagram. Mean annual rainfall is 1862 mm, which is distributed evenly throughout the year. Mean monthly rainfall exceeds 100 mm 11 months of the year. August is the driest month, although it receives 95 mm of rainfall. According to the *Q* system proposed by

Schmidt and Ferguson [1951], the climate of the area belongs to the wettest climatic type or rainfall type A [Kartawinata 1975; 1980]. The *Q* value calculated by Kartawinata [1975] was 13.4, which is close to the upper limit of the *Q* value (14.3) of type A. On Whitmore's [1975] map of rainfall types for the tropical Far East, the area is situated between A type and B type. Thus, water stress is absent or only very brief, and severe draughts do not occur ordinarily.

The main forest formation of this area is a tropical lowland evergreen rain-forest dominated by various dipterocarp species or dipterocarp forest (*e.g.* Richards [1952], Whitmore [1975]). This forest type occurs on sites rich in clay, and covers most of the area. Although there are differences in physiognomy, structure, and flora from place to place within the forest, emergent trees easily exceed 65 m in total height. Tall emergents over 70 m in height are common, which suggests a favourable climate and fertile soil.

In the dipterocarp forests, islands of heath forest or kerangas forest (*e.g.* Whitmore [*ibid.*]) occurred on the coarse sandy soil. Kartawinata [1980] reported the flora, structure, and chemical properties of the surface soil of the heath forests in this area.

Alluvial forests probably covered the narrow area along the Mahakam River in the past, but they have been cleared for cultivation. Thus, the forest formations observed in this area are dipterocarp and heath forests. After the reconaissance of the concession area, our sample plot was chosen to represent a typical dipterocarp forest of this area.

Sample Plot and Methods

Sample Plot

A sample plot, 1.0 ha in size, was established on flat ground within terrain dominated by various dipterocarp species, in December, 1980. The plot was situated 32 km north of the village of Sebulu, and was about 70 m in altitude.

There were different levels in the tree layers of the forest profile. The first story consisted of emergent trees, 60–70 m tall. Their crowns were 20–25 m in diameter and about 20–40 m in depth, but did not form a continuous canopy. They were mostly Dipterocarpaceae, especially *Shorea cf. laevis*. Only three emergents were found in the 1.0 ha plot. Of the three emergents, one was over 70 m, while the others were between 60 m and 70 m. The second story was composed of large trees, 30–55 m tall, and included various tree families in addition to Dipterocarpaceae. Important non-dipterocarp families, were Leguminosae, Myrtaceae, Euphorbiaceae, and Guttiferae. This story was more continuous, and could be further divided into two layers: 30–45 m and 45–55 m. The third layer consisted of various trees less than 30 m. The mean height was about 12 m. Below these three stories, there were other stories consisting of small trees, palms, pandans, and herbs.

The plot was established so as to include the different stages of forest maturity, *i.e.*, gap, building, and mature phases [Whitmore 1975]. Although the details will be described in a separate paper, the fractions of gap, building, and mature areas to the entire plot of 1.0 ha were 22%, 35%, and 43%, respectively. Tree samples to determine tree dimensions were made within a patch of the mature stage. Details of the tree sampling are given below.

Methods

The plot was subdivided into 16 subplots (25 m×25 m), which were used as the main sample grids in subsequent investigations. Of the 16 subplots, eight subplots were further divided into 5 m×5 m lattices, and were used as the plots for detailed studies. The other eight subplots were used as the plots for studies on flora and stand structure. This paper is concerned with the results of the investigation in the eight subplots for detailed studies.

In the eight subplots for detailed studies, all trees, woody climbers, and palms 4.5 cm and over in diameter at breast height (DBH, 1.3 m aboveground) were simultaneously labelled with plastic number tape (Suzuki Shokai, Tokyo), and mapped. The DBHs of labelled trees were measured with a diameter tape, and recorded with the species name. For trees having buttresses over 1.3 m high, the diameter at the terminal end of the buttress was adopted as a substitute for DBH. After preparing the inventory of the trees in the subplots, trees were sampled in four subplots, which represented a mature forest stage. Different sampling areas were used for different size classes of plants:

Plants less than 1.3 m high	$4\ m^2 \times 16$
Plants 1.3 m and higher	
DBH<4.5 cm	$25\ m^2 \times 4$
4.5 cm≦DBH<10 cm	$25\ m^2 \times 20$
10 cm≦DBH<20 cm	$25\ m^2 \times 28$
20 cm≦DBH<40 cm	$25\ m^2 \times 29$
DBH≧40 cm	$25\ m^2 \times 50$

One hundred and ninety-one trees, three lianas growing on dead trees, one small standing liana, and one palm were individually felled in four months from December, 1980 to March, 1981, and their total height (H), clear bole length (H_B), crown diameter (R), stem diameter at one tenth of H ($D_{0.1}$), stem diameter just below the lowest living branch (D_B), stem diameters at 0.0 and 1.3 m above the ground (D_0 and D), and stem diameters at 5.0 m intervals were measured. The stratified clip technique [Monsi and Saeki 1953; Research Group on Forest Productivity 1960] was utilized to measure the dimensions of sample trees: the strata were 0.0–1.3 m, 1.3–5 m, 5–10 m, and then at intervals of 5 m. The tree body in each stratum was separated into stem, branches, leaves, and fruits or flowers (if present), and each organ was weighed with balances appropriate to the size of the organ. The weight of a big stem bole over 40 cm in diameter was estimated from its volume and specific gravity. Epiphytes, climbers, and stranglers growing on the sample trees were similarly weighed using the stratified clip technique, although stem and branches were not separated. Root weight was not measured.

Small samples of stems, branches, and leaves were taken from each stratum of sample trees for estimating the ratios of fresh/dry mass, specific gravity of stem, and leaf area. Leaf samples were either traced by hand or photocopied.

All of the samples were brought to Osaka City University, Japan. They were dried in a ventilated oven at 80°C for at least one week and weighed. Ratios of dry/fresh mass were calculated, and used for converting fresh weight into dry weight. From tracings or photocopies, leaf area was measured either by using a planimeter or counting squares (5 mm × 5 mm). Then, leaf area and sample dry weight were used for calculating specific leaf area, *i.e.*, leaf area in unit leaf weight. Specific leaf area increased as stratum height decreased. Hence, the leaf area of each stratum was calculated by multiplying leaf weight by the corresponding specific leaf area, and then the leaf area values of all the strata were added to obtain leaf area value per tree.

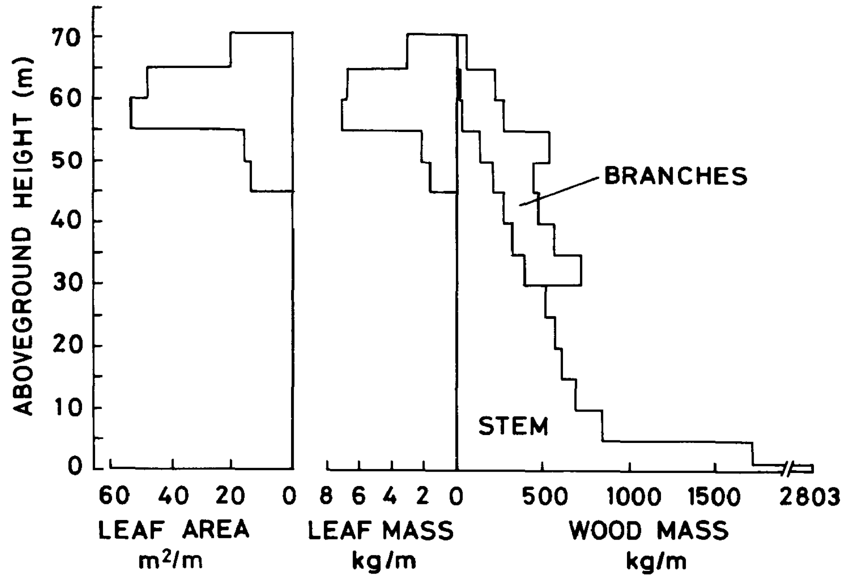

Fig. 3 Vertical changes of leaf area, leaf mass, and wood mass at different horizontal strata of an emergent tree, *Shorea laevis*

Results

Dimensions of an Emergent Tree

Of the 191 sample trees, *Shorea laevis* was the only emergent attaining a total height of 70.7 m. Buttresses, which spread over the ground as large branching roots, were 4.6 m tall, about 50 cm thick, round in shape at the ground, and about 4.2 m in diameter at the ground. The stem bole was columnar and tapering, and branched into two big shoots 30.5 m above the ground. For further studies, one of the branched shoots was designated as the stem and the other a branch. Thus, the clear bole length of this tree was 30.5 m. Stem diameters at buttress height and 30.5 m above the ground were 130.5 cm and 84.3 cm, respectively. Stem volume with bark and stem dry weight were 41.13 m^3 and 33129.768 kg, respectively.

The crown was very large, hemispherical, and sympodial with a few ascending sinuate branches, as Ashton [1964] already described. Crown diameter and the height of the lowest leaf were 24.2 m and 45.0 m, respectively. Corresponding to these values, branch weight, leaf weight, and leaf area were very large, and totalled 9586.120 kg, 107.614 kg, and 767.372 m^2, respectively.

The vertical distribution of leaf area, leaf mass, and wood mass is graphically represented in Fig. 3. The pattern of vertical distribution of these quantities will be discussed in a separate paper.

Climbers and stranglers were tentatively grouped together. *Agelaea borneensis*, *Connarus* sp., *Tetracera scandens*, *Mastixia* sp., a species of Araceae, *Ficus pisocarpa*, and *Ficus* sp. made up this group. Of these species, *Agelaea borneensis*, a woody climber, was the heaviest. The weight of nonproductive organs, such as volubile stems, tendrils, aerial roots, *etc.*, was 22.408 kg. Leaf weight and leaf area were 4.013 kg and 22.962 m^2, respectively.

Freycinetia javanica, *Scindapsus* sp., and *Drynaria* sp. were considered epiphytes, lumped together, and then, weighed. Their nonproductive organs (*e.g.* aerial roots, rhizome, *etc.*) weighed 1.766 kg. Leaf weight and leaf area were 0.565 kg and 4.774 m^2, respectively.

The vertical distribution of plant mass and leaf area of climbers, stranglers, and epiphytes is presented in Fig. 4. As is clear

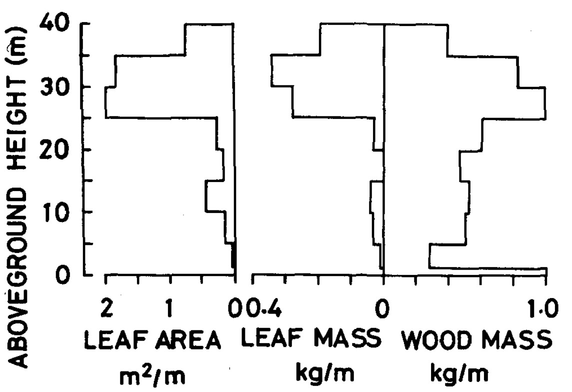

Fig. 4 Vertical distribution of leaf area, leaf mass, and wood mass of dependent plants supported by the emergent *Shorea laevis*

from Fig. 4, these mechanically dependent plants [Richards 1952; Whitmore 1975] were not observed over 40 m, and thus, did not disturb the leaf growth and production of the supporting emergent tree. This relation between dependent plants and the supporting emergent was repeatedly observed in the study area. Of the dependent plants, *Ficus pisocarpa* and *Ficus* sp. were the only species that could possibly harm their supporting emergent. *Agelaea borneensis*'s volume was large; however, this liana species stopped climbing after reaching the top of the continuous second story of the forest profile. The presence of lianas suggests that enough light reaches the second story, because lianas are generally light-demanding plants.

Dimensions of a Large Canopy Tree

The study plot consisted of a mosaic of patches at different stage of maturity, and included gap and mature phases [Whitmore 1975], as already described. Although the crown projection diagram is not presented, the mature phase parts were completely covered by the crowns of trees with DBHs of 20 cm or larger. Therefore, the canopy trees were tentatively defined as trees whose DBH≧20 cm, in this study. In addition to the emergent tree, 20 other sample trees belonged to this size class. Of the 20 trees, *Dipterocarpus crinitus* was the largest tree; its dimensions are given below.

The dipterocarp tree was 46.5 m high, and belonged to the second story or stratum B [Richards 1952], which developed continuously beneath the discontinuous emergent layer. There were many buttresses which were bifurcated as pleates, lower than 0.9 m, round in shape at the ground, and very concave. The cylindrical stem bole was tapered, fluted, and rugged. The height of the lowest living branch was 18.0 m. Stem diameters at buttress height, breast height, and 18.0 m aboveground were 137.0 cm, 127.0 cm, and 85 cm, respectively. Stem volume with bark and corresponding stem dry weight were 20.31 m^3 and 16291.214 kg, respectively. The crown was semi-elipsoidal and sympodial with a few sinuate branches. Crown diameters projected on the ground were 22.8 m for the longest axis and 15.2 m for the shortest axis. Branch weight, leaf weight, and leaf area were 7815.260 kg, 127.210 kg, and 968.015 m^2, respectively. The crown surface appeared red because of the red wings of the seeds which weighed 54.370 kg.

The vertical distribution of leaf area, leaf mass, and wood mass is shown in Fig. 5. The pattern of this plant mass distribution will be analysed in a separate paper.

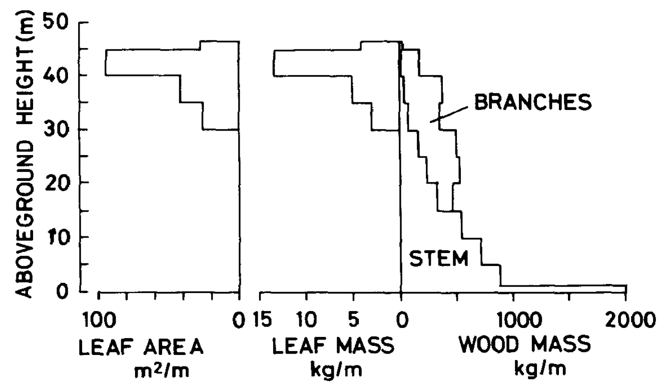

Fig. 5 Plant mass profile of a large canopy tree, *Dipterocarpus crinitus*

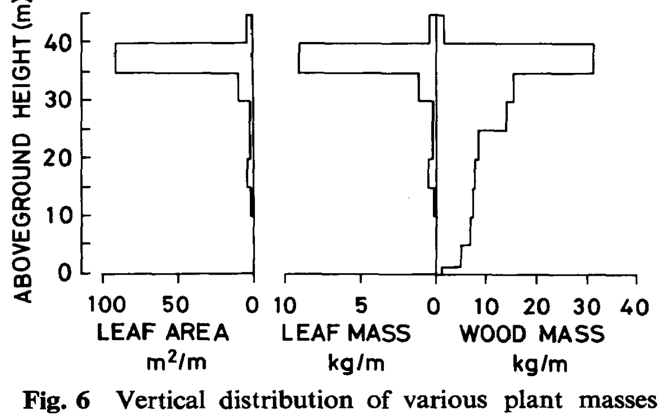

Fig. 6 Vertical distribution of various plant masses of dependent plants living on the large *Dipterocarpus crinitus*

There were many mechanically dependent plants, and they covered the crown of the supporting tree heavily. As already described, dependent plants were tentatively divided into two groups. One consisted of climbers and stranglers; while, the other included various epiphytes. *Ampelocissus spicigera*, *Connarus* sp., *Salacia* sp., *Spatholobus* sp., *Ficus pisocarpa*, and *Ficus* sp. were lumped into the former group, and weighed. The weight of nonproductive organs of these plants was 648.195 kg. Leaf weight and leaf area were 53.161 kg and 526.553 m^2, respectively.

Asplenium nidus, *Bulbophyllum* sp., *Coelogyne* sp., *Dendrobium* sp., *Drynaria* sp., *Erica* sp., *Humata* sp., *Medinilla speciosa*, *Pandanus* sp., and two unknown species made up the epiphyte group. These epiphytes totalled 13.517 kg in weight of nonproductive organs, 4.018 kg in leaf weight, and 30.910 m^2 in leaf area.

The vertical distribution of the plant mass and leaf area of climbers, stranglers, and epiphytes is graphed in Fig. 6. *Ficus* spp. were observed in the top stratum (45–46.5 m) of the supporting tree, and their nonproductive organ weight was 7.70 kg, leaf weight was 1.982 kg, and leaf area was 19.860 m^2. Climbers and epiphytes were not found in the top stratum. The second stratum, between 40 m and 45 m above the ground, contained the greatest amount of plant mass (*cf.* Fig. 4), and included many epiphytes and climbers. Below it, plant mass decreased as height decreased. The nonproductive organs of dependent plants weighed 661.712 kg, their leaves weighed 57.129 kg, and their leaf area was 557.463 m^2. These values are far greater than the same values obtained from dependent plants on the aforementioned emergent tree. For example, nonproductive organ weight is 27 times larger than the weight of the dependent plants on the emergent tree. To evaluate the load of dependent plants on independent plants, the ratio of leaf weight of dependent plants to leaf weight of independent plants was calculated for 21 canopy trees. The ratios were 0.45 for this *Dipterocarpus crinitus* and 0.04 for the emergent tree. The ratios for the other 19 canopy trees (Appendices 1 and 2) ranged from 0.13 for *Horsfieldia grandis* to 0.00 for five trees (*i.e.*, *Hopea mangerawan*, *Shorea ovalis*, *Dialium indum*, and *Dialium* sp.). Thus, the heavy burden of dependent plants could have hindered the shoot growth of this *Dipterocarpus crinitus*, and limited it to the second story of the forest profile. Therefore, differences between emergent trees and huge trees of the second story may result from the amount of dependent plants.

Dimensions of Other Sample Plants

The dimensions of 76 sample trees with DBHs greater than 4.5 cm are summarized in Appendices 1 and 2. Of these trees, two have already been described in terms of their dimensions. The other 74 trees have DBHs smaller than 100 cm, as shown in the Appendices. Of the 74 trees, only one tree, *Baccaurea deflexa* (*cf.* Tree No. 147), bore fruit, which weighed 2.485 kg dry and 21.700 kg fresh. Further descriptions are abbreviated here because the Appendices give all of the dimensions.

Borassodendron borneensis was the only Palmae of the sample plants with a DBH greater than 4.5 cm. The total height to the top of the highest leaf, height of the stem reaching the meristem and, height of the lowest living petiole were 7.6 m, 4.1 m, and 2.7 m, respectively. Values of stem diameter at 0.0 m, 0.3 m, 0.76 m, 1.3 m, and 2.7 m were 23.6 cm, 19.6 cm, 19.0 cm, 17.8 cm, and 16.6 cm, respectively. The stem, petiole, and leaf excluding petiole weighed 26.859 kg, 2.653 kg, 2.272 kg, respectively. Leaf area was 17.651 m^2.

A liana, *Dalbergia* sp., covered a standing dead tree whose height and DBH were 16.5 m and 12.8 cm, respectively. The nonproductive organs of this liana weighed 1.828 kg. Leaf weight and leaf area were 0.183 kg and 1.812 m^2, respectively. These values were larger than the corresponding values obtained from dependent plants on *Xanthophyllum heteropleurum*, whose DBH and height were 12.8 cm and 12.5 m, respectively (*cf.* Tree No. 161 in Appendices). However, these values were smaller than the values of *Ochanostachys* sp., whose DBH was 12.2 cm (*cf.* Tree No. 664 in Appendices). Therefore, it is doubtful that dependent plants caused the death of the supporting tree.

Small plants with DBHs less than 4.5 cm and taller than 1.3 m were harvested from four sample 5 m × 5 m grids. The harvested plants included 115 trees, two lianas growing on small dead trees, and one standing liana growing independently. Therefore, sample plants of this size class did not include herbs, palms, *etc.*, frequently observed in other parts of the study area. The dimensions of these sample plants are graphed

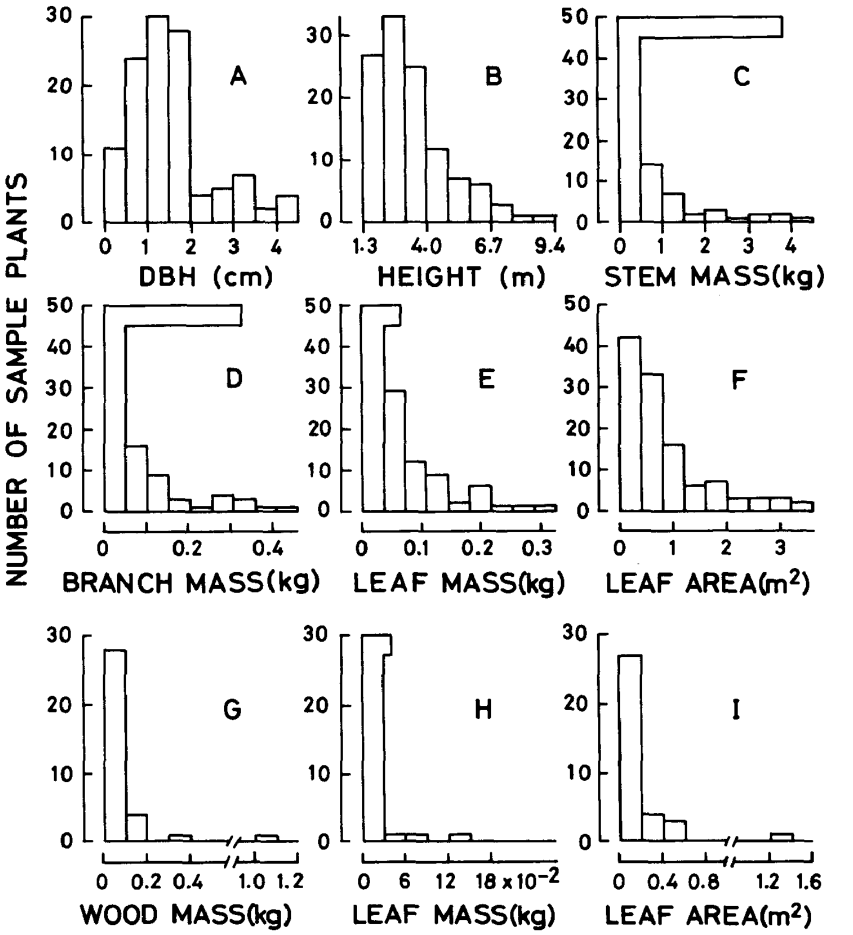

Fig. 7 Frequency distribution of various measurements of small plants (DBH<4.5 cm and tree height≧1.3 m) sampled from four 5m × 5 m quadrats. Six figures, Figs. 7A–7F, represent independent plants and the other figures, Figs. 7G–7I, represent the samples of dependent plants supported by independent plants.

in Fig. 7. One hundred and fourteen of the 115 sample trees were identified to tree species, and they represented 42 species plus one unidentified species. The 42 identified species were from 34 genera and 18 families. *Hydnocarpus polypetala*, a species of Flacourtiaceae, was the most numerous; there were 62 trees of this species (54%). *Shorea excemia* was second with five trees. Thirty-five species were represented by only one tree including the unidentified species. Therefore, *Hydnocarpus polypetala* was clearly dominant among small trees (DBH<4.5 cm and tree height ≧1.3 m). Of the 18 families, Flacourtiaceae was also the most numerous, even though *Hydnocarpus polypetala* was the only species from this family. Euphorbiaceae was second and included five genera and ten trees. Leguminosae and Dipterocarpaceae were third with four genera and seven trees. Small dipterocarp trees were unexpectedly rare. *Shorea excemia* with five individuals, *Shorea ovalis* with one individual, and *Shorea smitiana* with one individual composed the representatives of this family. Other dipterocarp species and genera were not found in the sample grids. The DBHs of the 115 trees ranged from 0.2 cm to 4.3 cm, and their mean, variance, and coefficient of variation were 1.51 cm, 0.880 cm^2, and 62.1%, respectively (Fig. 7A). The heights of the trees were between 1.3 m and 8.6 m (Fig. 7B). The mean, variance, and coefficient of variation of tree heights were 3.30 m, 2.43 m^2, and 47.2%, respectively. Stem weights of the trees were distributed from 0.011 kg to 4.444 kg, and exhibited a typical L-shaped in their frequency distribution as shown in Fig. 7C. The mean, variance, and coefficient of variation of stem weights were 0.567 kg, 0.6984 kg^2, and 147.4%, respectively. The branch weights of trees ranged between 0.452 kg and 0.000 kg, which indicates that the trees had no branches (Fig. 7D). Three trees did not have branches. The mean, variance, and coefficient of variation of branch weights were 0.063 kg, 8.06×10^{-3} kg^2, and 142.5%, respectively. Leaf weight values of trees ranged from 0.005 kg to 0.321 kg with a mean of 0.059 kg, a variance of 3.69×10^{-3} kg^2, and a coefficient of variation of 103% (Fig. 7E). Corresponding to these values of leaf weight, the maximum, minimum, mean, variance, and coefficient of variation of leaf area were 3.534 m^2, 0.067 m^2, 0.815 m^2, 0.616 m^4, and 96.3%, respectively (Fig. 7F).

There were 31 lumps of lianas and epiphytes collected in the harvest of 115 small trees. These dependent plants were weighed by the same method described in the preceding sections. In addition to these dependent plants, two lianas growing on two dead trees and one liana standing independently were individually harvested and weighed. Thus, 34 samples of dependent plants were obtained, including at least 14 climber species and seven epiphyte species. Of the climber species, *Agelaea borneensis* had the largest volume. Epiphytes included ferns (*e.g. Asplenium* sp.) and orchids (*Dendrobium* sp.). The frequency distribution of the nonproductive organ weight of the 34 samples is given in Fig. 7G. Weights ranged from 1.002 kg to a negligible 0.0005 kg. Mean weight per sample was 0.075 kg. Leaf weights ranged from 0.144 kg per sample to 0.0001 kg, and their mean was 0.013 kg per sample (Fig. 7H). Leaf area was between 1.221 m^2 and 0.001 m^2 per sample, and its average was 0.141 m^2 per sample (Fig. 7I).

Plants less than 1.3 m high were tentatively designated as ground vegetation, and included tree seedlings, small shrubs, lianas, palms, and pandans, and herbs. Of 142 plants collected from four sample 2 m $\times$ 2 m quadrats, 92, 9, 1, 1, and 39 individuals were trees including small shrubs, lianas, palms, pandans, and herbs, respectively. Many lianas in the ground vegetation were quite similar to trees because they stood independently without leaning and coiling round supporting plants. All 142 plants could not be identified; however, at least 36 species were present. *Hydnocarpus polypetala* was the dominant species of 26 identified tree species in this group, too. As for dipterocarp species, one *Dipterocarpus* sp., four *Dryobalanops* sp., and one *Shorea laevis* were found. *Phrynium jagorianum* was the most abundant herb species.

Sixteen quadrats, 2 m $\times$ 2 m, were established to investigate the plant mass of the ground vegetation. All of the plants in each quadrats were clipped, divided into six groups (trees, lianas, herbs, palms, or pandans) and weighed. Stems and branches were not separated, but weighed together as nonproductive organs. The mean plant mass of ground vegetation per quadrat was 41.8 $g \cdot m^{-2}$ in stems and branches, 23.0 $g \cdot m^{-2}$ in leaf weight, and 0.467 m^2m^{-2} in leaf area.

Plant Dimensions of a Mature Phase Community

Although different sized sampling areas were used for different size classes of plants, plant sampling was based on land area.

Therefore, the values of plant mass were transformed into corresponding values of unit land area.

The basal area calculated from the DBH data of all sample trees 1.3 m high and higher was 50.91 m^2ha^{-1}, of which 48.08 m^2ha^{-1} resulted from trees with DBHs greater than or equal to 4.5 cm. Besides these values, the basal area of palms, 0.36 m^2ha^{-1} had to be included for calculating the total basal area of all independent plants. These basal area values suggest that the tree sampling was carried out in a narrow plot (0.125 ha) of a well developed part of the forest. Thus, the estimate of forest biomass described below is of a specific patch which includes a tall emergent in an extended forest area, although these kind of patches were rare and covered only about 13% of the entire study plot of 1.0 ha.

Aboveground biomass calculated from all sample plants was 872.949 ton/ha (Tables 1

Table 1 Plant Mass Estimates of Various Forest Components on the Study Plot*

Size Class of Plants	Life Form of Plants	Plant Mass in Dry Weight (t/ha)					Leaf Area
		Stem	Branch	Stem & Branch	Leaf	Fruit	(ha/ha)
Plants less than	Trees			0.289	0.124		0.239
1.3 m in height	Lianas			0.049	0.022		0.045
or plants having	Dicotyledonous herbs			0.072	0.077		0.172
no DBH	Monocotyledonous herbs			0.003	0.002		0.005
	Palms			0.005	0.003		0.004
	Pandans			**	0.002		0.002
Plants of different DBH classes in cm							
0≦DBH<4.5	Trees	6.568	0.726	7.294	0.679		0.937
	Climbers			0.255	0.044		0.047
	Epiphytes			0.002	0.001		0.001
4.5≦DBH<10	Trees	7.907	1.415	9.322	0.569		0.727
	Climbers			0.310	0.053		0.076
	Epiphytes			0.006	0.002		0.003
10≦DBH<20	Trees	20.448	3.425	23.873	0.722		0.758
	Climbers			0.731	0.091		0.118
	Epiphytes			0.004	0.001		0.001
	Palms	0.384	0.038	0.422	0.032		0.025
20≦DBH<40	Trees	79.062	16.577	95.639	1.727	0.034	1.600
	Climbers			0.377	0.028		0.030
	Epiphytes			0.003	0.001		0.002
DBH≧40	Trees	556.601	159.849	716.450	3.154	0.435	2.585
	Climbers			9.195	0.540		0.524
	Epiphytes			0.221	0.084		0.061
Total		670.970	182.030	864.522	7.958	0.469	7.962

* Different sampling areas were applied for different size classes of plants.

** Very small quantity less than 0.001 t/ha in dry weight.

and 2). This large value was closely related to the aforementioned tall emergent tree and high tree density suggested by the large basal area in the study plot. Climbers, epiphytes, palms, pandans, and herbs were conspicuous components of the forest; however, they accounted for only 1.2% of the total biomass, 12.5% of the leaf mass, and 14.0% of the leaf area.

Table 2 Biomass of Different Life Forms of Plants in the Study Plot

Life Form of Plants	Stems & Branches (t/ha)	Leaves (t/ha)	Fruits (t/ha)	Leaf Area (ha/ha)
Trees	852.867	6.975	0.469	6.846
Climbers & Stranglers	10.917	0.778		0.840
Epiphytes	0.236	0.089		0.068
Palms	0.427	0.035		0.029
Pandans	*	0.002		0.002
Dicotyledonous herbs	0.072	0.077		0.172
Monocotyledonous herbs	0.003	0.002		0.005
Total	864.522	7.958	0.469	7.962

* Very small quantity less than 0.001 t/ha in dry weight.

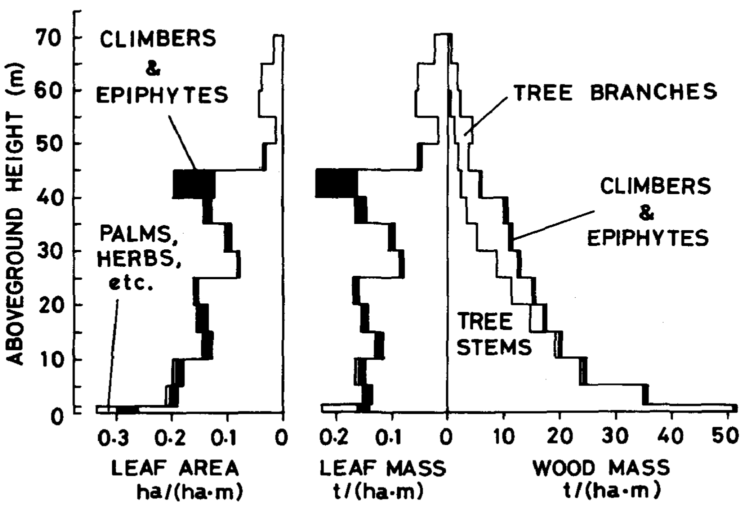

Fig. 8 Profile structure of the study plot showing the vertical distribution of leaf area, leaf biomass, and wood mass

The vertical distribution of leaf area, leaf mass, and wood mass is shown in terms of biomass density in Fig. 8. Wood mass increased as stratum height decreased. The pattern of vertical leaf mass distribution was characterized by five peaks (at 65–55 m, 40–45 m, 20–25 m, 5–10 m, and 0.0–1.3 m) and four depressions (at 50–55 m, 25–30 m, 10–15 m, and 1.3–5 m). These peaks and depressions suggest differentiation in the strata of the forest architecture. The first layer, 50–70.7 m, consisted of the emergent tree *Shorea laevis* only. The leaf mass of this layer was 0.792 ton/ha which is 10% of the total leaf mass. The second layer (25–50 m) formed a dense canopy and consisted of 15 trees belonging to six families. The leaf mass in the layer was 3.226 ton/ha or 40% of the total. The third story (10–25 m) consisted of 36 trees from 14 families and its leaf mass was 2.275 ton/ha or 29% of the total. The fourth layer (1.3–10m) included the other 139 trees and one palm and its leaf mass was 1.371 ton/ha or 17% of the total. The fifth layer (0–1.3 m) was the ground vegetation and its leaf mass was 0.294 ton/ha or 4% of the total. The pattern of vertical leaf area distribution was similar to the leaf mass distribution, although a depression at 1.3–5 m for leaf area density was not clear. This small difference between leaf mass distribution and leaf area distribution resulted from the specific leaf area, whose changes at different strata are graphed in Fig. 9. The specific leaf area of trees decreased as stratum height increased. Hence, a smaller value of leaf weight at a lower stratum tended to result in a larger value of leaf area. Thus, a depression at 1.3–5 m in leaf mass distribution was not found in leaf area distribution.

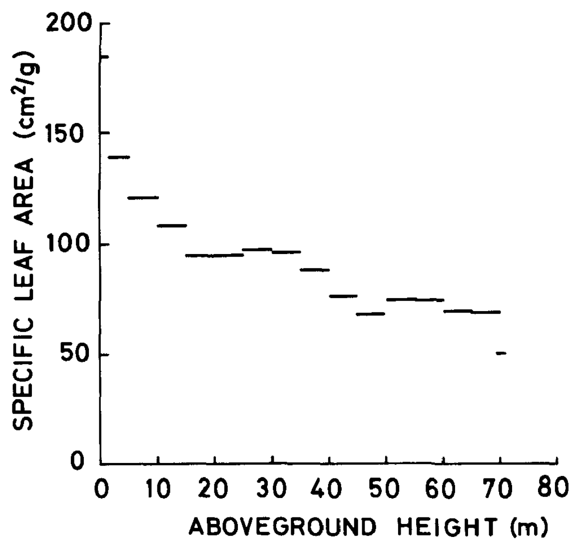

Fig. 9 Decrease of specific leaf area with an increase of aboveground height

Although specific leaf area decreased as stratum height increased, two low peaks were observed at 25–30 m and 50–55 m in stratum height (Fig. 9). These two peaks coincided with depressions in the vertical distributions of leaf mass and leaf area, respectively (*cf.* Figs 8 and 9). In general, if sample leaves are collected from a single tree or single species, specific leaf area decreases constantly as stratum height or relative light illuminance increases [Kira 1975; Tadaki 1970]. Therefore, the two peaks suggest the sudden change in tree species at the boundaries of different layers of forest architecture, which in turn suggests that species are replaced gradually between 1.3 m and 5 m in stratum height.

Liana's and epiphyte's leaves peaked at 40–45 m. Below this stratum, they were distributed fairly evenly at all height levels (Fig. 8). Although the peak is not clear in the diagram (Fig. 8), the wood mass of dependent plants peaked at 30–35 m.

Discussion

Comparison of the Size of the Sampled Emergent Tree with Trees in Other Tropical Forests

The height, 70.7 m, of the emergent *Shorea laevis* was much lower than the height of a big *Koompasia excelsa*, 84 m, recorded by Foxworthy [1926; 1927]. However, its height resembled the maximum tree height records of *Shorea laevis* reported by Ashton (75 m [1964]) and Meijer and Wood (76 m [1964]). The stem diameter of 130.5 cm was also smaller than the diameters reported for *Balanocarpus heimii* King (391.2 cm: Foxworthy [1926]) and *Shorea laevis* (222.8 cm: Ashton [1964]). Thus, the tree height and stem diameter of the largest tree of the plot were within the range of tree sizes previously reported by various authors.

Few data for other dimensions, such as stem weight, leaf weight, *etc.*, are available for comparison. Furthermore, emergent trees have not always been sampled in the studies so far made. The stem weight of 33129.768 kg was larger than values previously measured in Malaysia (11590.240 kg: Kato *et al.* [1978]), Cambodia (26502 kg in fresh weight for *Anisoptera* sp.: Hozumi *et al.* [1969]), and New Guinea (4637 kg for *Podocarpus archboldii* in montane forests: Edwards and Grubb [1977]). The branch weight including non-photosynthetic organs of dependent plants was 9610.294 kg. This value was greater than the values, 4281 kg (Kato *et al.* [1978]) and 1225 kg for *Podocarpus archboldii* (Edwards and Grubb [1977]), and seemed to be greater than the branch weight of *Anisoptera* sp. examined by Hozumi *et al.* [1969]. According to Hozumi *et al.*, the fresh weight of *Anisoptera* sp. was 12933 kg, which they considered to be equivalent to about 5820 kg in dry weight. The leaf weight of 112.192 kg including the leaves of dependent plants was less than the weight of the second largest sample tree, *Dipterocarpus crinitus* (184.389 kg). Furthermore, this leaf weight value was also smaller than the weight of *Anisoptera* sp. (182.530 kg) investigated by Hozumi *et al.*, although it was larger than leaf weight values recorded by Kato *et al.* (75.61 kg) and Edwards and Grubb (61.6 kg).

Production of Seeds and Fruit

Dipterocarpus crinitus, the second largest tree, bore fruit, which was 54.370 kg in dry weight and produced about 187,000 seeds. The number of seeds per tree was close to the numbers of seeds per tree for *Shorea curtisii* studied by Burges [1970]. The approximate fruit size was 0.29 g in dry weight; seed diameter was 0.7 cm; length 1.3 cm; wing length 6 cm. These fruit size values were less than the corresponding values measured by Tang and Tamari [1973] and suggest that the fruit was immature. According to Symington [1943] and Tang and Tamari [1973], fruit of this species tends to be vulnerable to insects. Furthermore, Tang and Tamari could not obtain viable seeds from two trees that produced a lot of fruit. Unfortunately, we were not aware of these properties and did not test seed viability when they were collected. The few seeds brought to the laboratory were too dry to test. If all the seeds were not viable, a fruit weight of 54.370 kg is extremely large.

The fruit of *Baccaurea deflexa* (*cf.* Tree No. 147 in Appendices 1 and 2: 2.485 kg in dry weight) was not comparable to other data recorded in natural forests. The weight of a single fruit was not clear because fruit samples were crushed by careless handling during drying and transportation. There is no record of whether the fruit is edible. If animals eat this fruit, *Baccaurea* sp. is probably a food source.

Comparison of Forest Biomass with Other Tropical Forests

It is widely accepted that forests, especially tropical rain forests, consist of a mosaic of patches at different stages of maturity (Richards [1952]; Whitmore [1975; 1978]; Oldeman [1978]; Ashton [1978]; Hartshorn [1978]), and that biomass estimates vary from place to place within any wide forest area. Our biomass estimate, 872.5 ton/ha, represents the plant mass accumulation in a narrow plot with a huge mature tree, and is not directly applicable to an extended area that includes various stages of forest development. Although details of the biomass variation between different small areas at different growth stages in the forest will be

Table 3 Aboveground Biomass and Some Related Characteristics in Various Tropical Forests

Forest Type & Locality	Basal Area (m^2/ha)	Maximum Tree Height (m)	Wood Mass (t/ha)	Leaf Mass (t/ha)	Above-ground Biomass (t/ha)	Leaf Area Index (ha/ha)	Sampl-ing Area (ha)	Authors
Evergreen seasonal forest (Colombia)	22.0*	29.0	168.2	10.3	178.5	5.5	0.25	Fölster *et al.* [1976]
Savanna forest (Thailand)	11.2	16.5	43.2	1.8	45.0	0.6	0.05	Ogino *et al.* [1967]
Savanna forest (Thailand)	19.3	15.5	87.9	1.8	89.7	0.8	0.05	*ibid.*
Evergreen seasonal forest (Thailand)	26.3	20.9	131.9	8.2	140.1	8.9	0.05	*ibid.*
Evergreen seasonal forest (Thailand)	42.6	22.9	179.1	7.1	186.2	8.6	0.05	*ibid.*
Savanna forest (Thailand)	15.3	22.0	70.4	1.9	72.3	1.6	0.25	Ogawa [1969]
Savanna forest (Thailand)	19.1	25.0	89.6	2.2	91.8	1.8	0.10	*ibid.*
Savanna forest (Thailand)	17.4	19.0	66.2	2.7	68.9	3.0	0.16	Ogawa *et al.* [1965]
Savanna-monsoon forest ecotone (Thailand)	23.9	29.0	139.3	4.9	144.2	6.3	0.16	*ibid.*
Monsoon forest (Thailand)	35.4	36.0	263.1	4.7	267.8	6.6	0.16	*ibid.*
Lowland rain forest (Thailand)	37.5	36.0	324.8	8.4	333.2	12.3	0.32	*ibid.*
Evergreen seasonal forest (Cambodia)	33.4	44.2	337.6	7.3	344.9	7.4	0.25	Hozumi *et al.* [1969]
Evergreen seasonal forest (Cambodia)	30.4	42.9	290.0	7.2	297.2	7.3	0.25	*ibid.*
Melaleuca swamp forest (Cambodia)	3.3	19.5	22.1	6.3	28.4	0.4	0.10	*ibid.*
Heath forest (Cambodia)	23.9	30.7	145.1	7.7	152.8	7.1	0.10	*ibid.*
Lowland rain forest (Malaysia)		48.9[a]	655.0	9.0	664.0	7.2	0.06	Kato *et al.* [1978]
Lowland rain forest (Malaysia)		57.5[a]	467.0	8.2	475.2	8.0	0.20	*ibid.*
Lowland rain forest (Indonesian Borneo)	48.4	70.7	865.0	8.0	873.2	8.0	0.125	This study
Montane rain forest (New Guinea)	70.0*	35.0[b]	496.1	8.9	505.0	5.5	0.04	Edwards & Grubb [1977]
Montane rain forest (New Guinea)	47.0*	35.0[b]	301.1	8.9	310.0	5.5	0.24	*ibid.*

* Basal area of larger trees DBH≧10 cm.

a: Personal communication with authors.

b: Maximum tree height of sample trees.

Basal area values without asterisk stand for all independent plants, such as trees and palms, DBH≧4.5 cm.

described in a separate paper, the biomass estimate in the study plot is compared with other tropical forests (Table 3) previously studied.

As is clear from Table 3, biomass was estimated using a small sampling area. However, it is obvious that forest biomass increases with the increase of maximum tree height and basal area of the plot. The dependence of forest biomass upon the development of tree height and basal area is graphed in Fig. 10. In Fig. 10, closed circles represent the basal area calculated for trees with DBHs greater than or equal to 10 cm (or 30 cm in stem girth), while open circles stand for the basal area of independent plants (*e.g.* trees and palms)

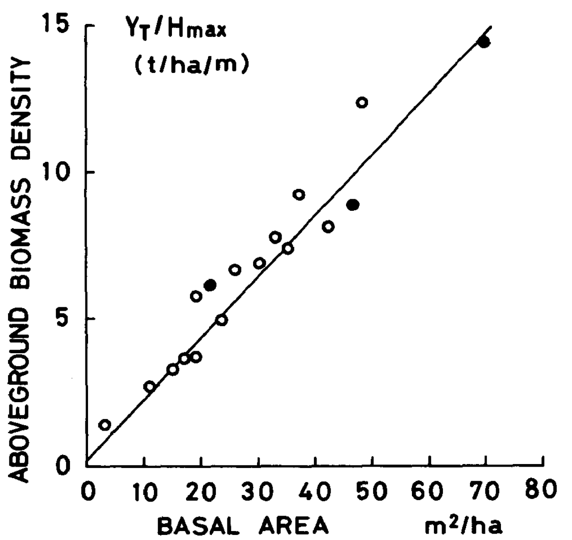

Fig. 10 Linear relation between basal area and aboveground biomass density defined by the ratio of aboveground biomass (Y_T) to the maximum tree hight (H_{max}) in the stand. Open circles and closed circles represent observed values. The mark's differences result from the lower limit of DBH in the computation of basal area (○, DBH ≧ 4.5 cm; ●, DBH ≧ 10 cm). The straight line represents calculated values of Eqn (2).

with DBHs greater than or equal to 4.5 cm. Biomass density calculated from the ratio of aboveground biomass (Y_T, ton/ha) to the observed maximum tree height (H_{max}, m) was linearly correlated with respect to basal area (BA, m^2/ha), *i.e.*,

$$Y_T/H_{max}=aBA+b, \quad (1)$$

where a and b are coefficients (*cf.* Fig. 10). This relation represents a rewritten expression of the biomass density properties, which were first postulated by Hozumi [1964] and later generalized by Shidei [1965] and Kira and Shidei [1967]. These three ecologists stated that basal area is approximately constant in well developed forest stands, and that Y_T divided by the mean tree height of dominant trees tends to range from 10 ton/(ha·m) to 15 ton/(ha·m) and is similar to the atmospheric density at sea level, 1.3 kg/m^3. Furthermore, they concluded that this trend is not true for shrub type communities, such as dense stands of *Abies sachalinensis* seedlings, Japanese highland scrub of *Pinus pumila*, and salt sprayed stands of *Quercus phillyraeoides* less than 10 m high. In these dwarf communities, biomass density increased as community height decreased. Therefore, the linear relation between Y_T/H_{max} and BA of Eqn (1) seemed to hold for tall forests with large trees over 15 m high (*cf.* Table 3). Using the values of BA calculated from DBHs greater than or equal to 4.5 cm and corresponding Y_T/H_{max}, we determined the coefficients of Eqn (1) by the least squares method, *i.e.*,

$$Y_T/H_{max}=0.2237BA+0.1628 \quad (2)$$

and

$$r^2=0.9202,$$

where r^2 is the square of the correlation coefficient. In the above equation, the coefficient of 0.1628 reflects the biomass density of ground vegetation less than 1.3 m high. As is clear from the method of processing the data, if BA is calculated for larger plants with DBH≧10 cm, the coefficients of Eqn (2) will change into other values. However, the observed values of BA and Y_T/H_{max} scattered around the expected values of Eqn (2) in the $BA-Y_T/H_{max}$ diagram, even if the lower limit of DBH differed in the computation of BA (Fig. 10) because the basal area of small trees with DBHs less than 10 cm is much smaller than the basal area of plants with DBH≧10 cm. For example, in our plot of 0.125 ha, the BA of independent plants (trees and palms), whose DBH ranged between 4.5 cm and 10 cm, was 2.2 m²/ha; while, the BA of independent plants DBH≧10 cm was 46.2 m²/ha. Therefore, if the BA of trees with DBH<10 cm is small enough, Eqn (2) may be widely applicable to the $BA-Y_T/H_{max}$ relation, in spite of the aforementioned difference in the lower limit of DBH in BA computation.

In our whole plot of 1.0 ha, the basal area values were 32.8 m²/ha for trees of DBH≧10 cm; 3.2 m²/ha for trees of DBH<10 cm, but DBH≧4.5 cm; 0.8 m²/ha for palms of DBH≧4.5 cm. Thus the total basal area of independent plants was 36.8 m²/ha. Substituting the total basal area value and the maximum tree height of 70.7 m into Eqn (2), we got an estimate of aboveground biomass,

$$Y_T=593.5 \text{ ton/ha}.$$

Although this estimate will be checked in detail in a separate paper, the estimate seems to be reasonable because of the forest's tall architecture.

Of the forest types in Table 3, the tropical rain forest studied by Kato *et al.* [1978] in Malaysia is most similar to the forest examined in this paper. Thus, our results should be compared with the results of Kato *et al.* The aboveground biomass of 664 ton/ha in a Malaysian rain forest resulted from the high tree density in the plot. Although they did not determine basal area, the values, $Y_T=664$ ton/ha and $H_{max}=48.9$ m, suggest a large basal area of 60 m²/ha. Hence, the biomass of 664 ton/ha in Malaysia represents a plant mass in the mature stage and comparable to our biomass estimate of 873 ton/ha in a 0.125 ha plot. In addition, the other biomass estimate of 475.2 ton/ha by Kato *et al.* is comparable to our estimate of 593.5 ton/ha in 1.0 ha plot, since the values, $Y_T=475.2$ ton/ha and $H_{max}=57.5$ m, of Kato *et al.* implied a basal area of 36.2 m²/ha. Differences of these values between the Malaysian forest and Indonesian forest suggested favourable environmental conditions for tree growth in East Kalimantan, Indonesia. In spite of large differences in aboveground biomass between the two tropical rain forests, leaf area values were similar to one another, about 8.0 ha/ha.

Small roots, less than 5 cm in diameter, in a pit (1 m×2 m in ground surface area and 1 m in soil depth) for soil sampling were 5.2 kg in dry weight. This weight value was equivalent to 26 ton/ha in root biomass. The roots of other size classes were not sampled. Thus, the information on root mass was insufficient in this study.

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Appendix 1 Linear Dimensions of Sample Trees Greater Than and Equal to 4.5 cm in Stem Diameter at Breast Height

D : Stem diameter at breast height of 1.3 m aboveground.
D_{But} : Stem diameter at buttress height.
D_0 : Stem diameter at the ground level.
D_{30} : Stem diameter at 30 cm aboveground.
$D_{0.1}$: Stem diameter at 1/10 of the tree height.
* : No available record due to high buttresses.
D_B : Stem diameter just below the lowest living branch.
H : Total height of trees.
H_{But} : Buttress height.
H_B : Height of the lowest living branch.
R : Crown diameter.
** : No available record due to no buttress.

Species Name	Tree No.	D (cm)	D_{But} (cm)	D_0 (cm)	D_{30} (cm)	$D_{0.1}$ (cm)	D_B (cm)	H (m)	H_{But} (m)	H_B (m)	R (m)
Shorea laevis	166	*	130.5	*	*	140.7	84.3	70.7	4.6	30.5	24.2
Dipterocarpus crinitus	639	127.0	137.0	*	*	112.0	85.0	46.5	0.9	18.0	19.0
Dialium platycephalum	507	*	64.1	*	*	63.6	52.4	43.5	4.2	27.5	13.8
Hopea mangerawan	333	64.3	66.0	*	*	58.9	44.8	42.5	1.2	26.5	12.5
Shorea ovalis	165	58.6	61.0	*	*	57.0	35.9	42.1	0.6	26.0	7.1
Hopea mangerawan	168	46.5	47.5	*	*	44.1	40.0	37.2	1.0	21.6	5.7
Hopea mangerawan	311	53.4	58.0	*	*	51.2	33.2	40.7	0.9	27.5	9.7
Hopea mangerawan	654	48.1	48.2	*	*	43.5	30.7	38.3	1.0	27.5	15.0
Santiria tomentosa	33	29.5	33.8	*	*	27.8	26.3	30.0	0.7	12.3	14.1
Baccaurea deflexa	147	25.3	29.6	*	28.3	24.9	20.5	26.1	0.3	13.3	6.0
Polyalthia glauca	149	22.1	**	33.6	29.7	21.2	17.2	19.3	**	11.6	10.9
Horsfieldia grandis	162	20.8	**	27.2	24.0	19.6	7.0	23.4	**	21.5	6.2
Litsea sp.	164	22.9	**	28.3	24.1	21.9	13.6	26.8	**	20.2	3.1
Dialium sp.	167	22.6	25.3	*	*	21.5	18.1	24.7	0.4	14.1	4.2
Dialium indum	181	26.3	**	32.3	29.5	23.2	13.4	33.5	**	27.1	4.2
Baccaurea sp.	182	25.0	**	31.0	27.4	24.0	17.3	27.7	**	16.0	6.4
Elaeocarpus sp.	291	20.2	21.2	*	*	19.5	18.8	24.6	0.8	10.3	5.4
Strombosia rotundifolia	502	25.6	**	40.0	36.1	23.8	19.3	28.9	**	16.8	6.8
Drypetes sp.	515	36.0	37.0	*	*	32.1	25.5	27.0	1.2	15.3	5.7
Aporosa sphaedophora	657	25.4	**	38.4	29.6	24.2	18.1	24.4	**	16.3	7.1

Species Name	Tree No.	D (cm)	D_{But} (cm)	D_0 (cm)	D_{30} (cm)	$D_{0.1}$ (cm)	D_B (cm)	H (m)	H_{But} (m)	H_B (m)	R (m)
Dryobalanops sp.	661	30.1	31.6	*	*	29.3	25.7	31.9	0.8	20.8	7.9
Xanthophyllum heteropleurum	161	12.8	**	14.4	11.8	13.5	10.0	12.5	**	7.5	5.8
Dialium indum	187	13.5	14.6	*	*	11.2	8.1	20.0	0.8	13.6	5.3
Girroniera nervosa	188	15.3	**	18.0	15.3	15.0	7.7	17.2	**	12.7	7.9
Strombosia sp.	189	10.5	**	16.4	11.5	10.5	7.4	11.6	**	6.4	4.1
Eugenia sp.	198	11.9	12.5	*	*	12.3	9.8	16.3	0.5	8.4	5.3
Xanthophyllum heteropleurum	201	13.7	**	15.6	13.8	13.6	10.7	15.9	**	9.3	5.4
Baccaurea sp.	204	19.0	22.0	*	*	17.5	15.2	18.0	0.6	7.8	7.1
Artocarpus anisophyllus	299	11.4	**	16.2	12.5	11.4	3.2	13.7	**	11.0	1.7
Oxymitra grandiflora	308	19.0	**	23.8	20.5	18.2	13.7	16.2	**	5.9	7.0
Polyalthia rumphii	309	9.8	**	12.6	11.0	9.4	8.0	15.0	**	6.4	6.9
Ostodes macrophylla	312	12.2	**	19.0	14.4	11.6	8.6	14.8	**	9.1	4.2
Myristica sp.	313	10.4	**	15.3	12.1	10.8	10.2	13.0	**	8.0	1.8
Baccaurea pendula	317	16.3	**	27.9	19.8	16.1	12.7	20.0	**	13.6	6.4
Santiria tomentosa	338	12.2	14.7	*	13.3	12.0	7.5	18.6	0.2	12.9	5.3
Dialium indum	644	14.8	15.6	*	*	14.0	11.5	25.0	0.8	14.4	3.3
Dillenia excemia	646	15.0	15.8	*	*	14.3	11.1	16.7	0.7	10.8	4.1
Polyalthia glauca	656	11.6	**	15.3	13.5	11.7	9.9	12.3	**	5.5	6.9
Ochanostachys sp.	664	12.2	**	16.0	12.6	12.2	6.7	17.6	**	12.6	3.4
Milletia sericea	148	6.2	**	7.1	6.3	6.2	5.0	10.3	**	5.3	2.9
Aporosa elmeri	179	6.4	**	11.5	9.7	6.6	6.0	12.4	**	6.8	2.2
Ochanostachys amentacea	180	5.9	**	7.5	6.3	7.2	4.0	9.1	**	6.6	3.5
Neoscortechinia kingii	183	7.5	**	9.6	7.9	7.6	5.6	12.7	**	6.6	3.2
Sindora sp.	184	5.8	**	8.8	6.6	6.1	5.3	7.7	**	3.4	1.7
Beilschmiedia sp.	185	7.7	**	9.4	8.4	7.7	1.7	7.2	**	6.3	1.3
Santiria operculata	186	5.6	**	7.2	6.1	5.5	3.3	8.8	**	7.6	1.8
Aporosa elmeri	190	6.0	8.4	*	*	6.3	5.2	8.9	0.4	4.9	3.3
Polaquem dasyphyllum	191	5.6	**	7.0	6.2	5.8	3.6	8.1	**	5.8	1.8
Sterculia rubiginosa	197	5.3	**	6.7	6.6	5.4	2.6	7.4	**	5.4	2.4
Aporosa elmeri	199	4.6	**	5.8	5.3	4.8	3.7	8.8	**	5.1	3.1
Neoscortechinia kingii	200	5.7	**	7.0	6.3	5.9	3.7	10.5	**	5.5	2.5
Barringtonia macrostachy	202	7.1	**	11.7	9.9	11.8	2.0	5.0	**	3.6	1.2
Eugenia cuprea	203	6.9	**	10.7	7.8	7.0	5.8	12.7	**	7.0	4.4
Milletia sericea	292	5.1	**	6.3	5.4	5.2	5.7	8.9	**	3.5	2.1
Pometia tomentosa	294	5.3	**	6.7	5.6	5.3	3.2	10.0	**	7.4	2.0
Strombosia sp.	295	5.4	**	6.6	5.6	5.3	4.5	10.3	**	5.4	3.2
Eugenia cuprea	310	6.8	**	8.2	7.4	6.9	5.3	11.2	**	7.0	3.7
Polyalthia glauca	314	9.0	**	10.5	9.9	8.9	7.2	10.0	**	6.0	5.3
Shorea laevis	504	5.5	**	5.6	5.5	5.6	4.0	10.3	**	6.6	3.9
Aporosa elmeri	505	4.5	**	5.3	4.9	4.9	4.0	8.6	**	4.0	2.7
Aporosa elmeri	506	5.4	**	6.0	5.7	5.6	4.3	8.6	**	4.1	2.7
Litsea noronhae	522	8.4	**	10.4	7.9	7.8	5.8	9.5	**	5.1	3.5

Species Name	Tree No.	D (cm)	D_{But} (cm)	D_0 (cm)	D_{30} (cm)	$D_{0.1}$ (cm)	D_B (cm)	H (m)	H_{But} (m)	H_B (m)	R (m)
Ochanostachys amentacea	627	4.9	**	4.8	6.0	5.4	3.2	7.9	**	5.3	2.9
Dillenia excelsa	629	4.6	**	5.4	4.7	4.7	2.4	7.9	**	6.1	1.0
Baccaurea kunstleri	631	8.3	**	9.7	10.0	8.3	6.0	12.7	**	10.0	3.8
Aporosa elmeri	633	4.7	**	6.0	5.4	5.1	4.2	8.1	**	3.0	3.0
Shorea leprosula	636	5.1	**	6.6	6.1	5.3	3.5	9.7	**	6.4	2.8
Aporosa sphaedophora	637	5.0	**	6.3	5.5	5.1	4.0	10.0	**	4.2	2.3
Milletia sericea	640	5.0	**	6.0	5.7	5.8	3.7	9.5	**	4.2	1.9
Mallotus echinatus	641	5.2	**	6.4	5.5	5.3	4.4	9.6	**	4.5	2.1
Unidentified sp.	643	7.1	**	8.1	14.6	7.1	5.2	13.4	**	7.4	3.1
Mallotus echinatus	645	4.5	**	5.7	5.2	5.0	1.5	6.5	**	5.1	0.9
Drypetes sp.	647	5.0	**	6.1	5.4	5.1	3.4	9.7	**	5.5	2.2
Dacryodes rugosa	648	5.1	**	6.8	5.6	5.1	3.4	9.6	**	5.5	2.2
Baccaurea pendula	682	5.6	**	7.1	6.0	5.8	3.6	9.1	**	7.1	4.2
Baccaurea sp.	1139	4.6	**	6.8	5.4	4.9	3.5	8.0	**	3.8	1.0

Appendix 2 Plant Mass of Sample Trees Greater Than and Equal to 4.5 cm in Stem Diameter at Breast Height

V: Stem volume with bark.
w_S: Dry weight of stem.
w_B: Dry weight of branches.
w_L: Dry weight of leaves.
U: Total leaf area.
T: Trees.
C: Climbers on the numbered tree.
E: Epiphytes on the numbered tree.

Tree No.	Life Form	V (m^3)	w_S (kg)	w_B (kg)	w_L (kg)	U (m^2)
166	T	4.113×10^1	33129.768	9586.120	107.614	767.372
	C			22.408	4.013	22.962
	E			1.766	0.565	4.774
	T+C+E	4.113×10^1	33129.768	9610.294	112.192	795.108
639	T	2.031×10^1	16291.214	7815.260	127.210	968.015
	C			648.195	53.161	526.553
	E			13.517	4.018	30.901
	T+C+E	2.010×10^1	16291.214	8476.972	184.389	1525.469
507	T	9.593	6327.740	1022.780	52.844	465.666
	C			158.316	2.241	17.450
	E			11.404	5.046	30.886
	T+C+E	9.593	6327.740	1192.500	60.131	514.002
333	T	7.257	4250.199	490.652	8.265	71.236
165	T	5.755	1972.916	238.826	25.192	237.031
168	T	3.527	1994.260	217.540	22.825	239.923
	C			72.815	0.549	5.567
	E			0.644	0.252	2.534
	T+C+E	3.527	1994.260	290.999	23.626	248.024

Tree No.	Life Form	V (m^3)	w_S (kg)	w_B (kg)	w_L (kg)	U (m^2)
311	T	5.386	3343.066	391.293	26.331	263.635
	C			234.711	6.217	70.488
	E			0.295	0.580	6.570
	T+C+E	5.386	3343.066	626.299	33.128	340.693
654	T	3.686	2110.430	218.710	23.868	217.217
	C			12.974	1.345	12.269
	T+C	3.686	2110.430	231.684	25.213	229.486
33	T	1.204	563.740	398.300	18.501	130.976
	C			12.361	0.484	5.680
	E			0.101	0.043	0.987
	T+C+E	1.204	563.740	410.762	19.028	137.643
147	T	7.879×10^{-1}	431.452	107.634	11.307	109.929
	C			8.670	0.491	5.625
	E			0.004	0.001	0.007
	T+C+E	7.879×10^{-1}	431.452	116.308	11.799	115.561
149	T	4.579×10^{-1}	252.610	55.720	8.695	89.367
	C			0.444	0.017	0.235
	T+C	4.579×10^{-1}	252.610	56.164	8.712	89.602
162	T	3.679×10^{-1}	185.838	4.671	1.630	10.677
	C			2.117	0.208	1.817
	E			0.021	0.011	0.107
	T+C+E	3.679×10^{-1}	185.838	6.809	1.849	12.601
164	T	6.228×10^{-1}	226.494	12.396	0.782	5.706
	E			0.008	0.002	0.024
	T+E	6.228×10^{-1}	226.494	12.404	0.784	5.730
167	T	5.410×10^{-1}	353.580	83.132	6.733	103.705
181	T	8.669×10^{-1}	498.997	16.249	3.625	18.488
182	T	7.085×10^{-1}	387.085	84.154	14.250	90.156
	C			0.001	0.001	0.006
	T+C	7.085×10^{-1}	387.085	84.155	14.251	90.162
291	T	4.104×10^{-1}	200.734	65.140	11.413	129.220
	C			0.243	0.006	0.062
	T+C	4.104×10^{-1}	200.734	65.383	11.419	129.282
502	T	8.101×10^{-1}	575.266	42.778	8.780	82.453
	C			0.334	0.252	3.642
	T+C	8.101×10^{-1}	575.266	43.112	9.032	86.095
515	T	1.348	876.291	213.234	18.695	145.315
	E			0.013	0.008	0.075
	T+E	1.348	876.291	213.247	18.703	145.390
657	T	7.781×10^{-1}	389.710	74.680	13.329	134.053
	C			3.189	0.572	4.435
	E			0.032	0.006	0.057
	T+C+E	7.781×10^{-1}	389.710	77.907	13.907	138.545

Tree No.	Life Form	V (m^3)	w_S (kg)	w_B (kg)	w_L (kg)	U (m^2)
661	T	1.573	790.210	43.630	7.441	110.519
144	T	1.582×10^{-1}	26.859	2.653	2.272	17.651
146	C			1.828	0.812	1.812
161	T	9.144×10^{-2}	55.732	22.424	4.195	45.219
	C			0.175	0.014	0.224
	T+C	9.144×10^{-2}	55.732	22.599	4.209	45.443
187	T	2.986×10^{-1}	117.407	17.969	3.010	34.766
	C			9.418	0.383	4.267
	E			0.006	0.002	0.017
	T+C+E	2.986×10^{-1}	117.407	27.393	3.395	39.050
188	T	1.655×10^{-1}	65.232	6.712	2.686	23.952
	C			2.589	0.052	0.643
	T+C	1.655×10^{-1}	65.232	9.301	2.738	24.595
189	T	5.750×10^{-2}	32.300	4.858	1.685	14.475
	E			0.001	*	0.003
	T+E	5.750×10^{-2}	32.300	4.859	1.685	14.478
198	T	9.771×10^{-2}	76.933	25.151	4.954	69.964
	C			2.106	0.444	6.027
	T+C	9.771×10^{-2}	76.933	27.257	5.398	75.991
201	T	1.354×10^{-1}	85.228	28.185	3.836	37.092
	C			3.063	0.074	0.758
	T+C	1.354×10^{-1}	85.228	31.248	3.910	37.850
204	T	2.942×10^{-1}	159.356	16.736	1.565	23.425
	C			10.600	1.524	21.405
	T+C	2.942×10^{-1}	159.356	27.336	3.089	44.830
299	T	6.319×10^{-2}	21.706	0.154	0.321	3.512
	C			0.236	0.033	0.536
	T+C	6.319×10^{-2}	21.706	0.390	0.354	4.048
308	T	1.910×10^{-1}	103.597	46.757	11.523	86.823
	C			6.098	1.470	16.478
	T+C	1.910×10^{-1}	103.597	52.855	12.933	103.301
309	T	6.337×10^{-2}	39.648	8.911	2.242	27.834
	C			0.001	*	*
	E			0.004	0.008	0.009
	T+C+E	6.337×10^{-2}	39.648	8.916	2.250	27.843
312	T	8.518×10^{-2}	38.880	5.643	1.084	14.953
	C			0.006	0.012	0.194
	T+C	8.518×10^{-2}	38.880	5.709	1.096	15.147
313	T	7.270×10^{-2}	32.859	1.104	1.229	9.997
317	T	4.648×10^{-1}	156.440	8.292	1.035	11.551
	C			3.564	0.655	7.618
	E			0.300	0.083	0.885
	T+C+E	4.648×10^{-1}	156.440	12.156	1.773	20.054

Tree No.	Life Form	V (m^3)	w_S (kg)	w_B (kg)	w_L (kg)	U (m^2)
338	T	1.231×10^{-1}	64.431	9.460	1.427	16.177
644	T	2.867×10^{-1}	206.000	11.359	2.519	23.576
	C			6.554	0.734	12.815
	T+C	2.867×10^{-1}	206.000	223.913	3.253	36.391
646	T	1.807×10^{-1}	104.591	9.346	0.925	12.061
	C			0.438	0.131	1.613
	T+C	1.807×10^{-1}	104.591	9.784	1.056	13.674
656	T	7.469×10^{-2}	39.724	20.351	7.348	85.325
664	T	1.246×10^{-1}	70.939	5.268	1.165	18.186
	C			4.461	0.632	8.399
	T+C	1.246×10^{-1}	70.939	9.729	1.797	26.585
148	T	1.812×10^{-2}	12.867	2.282	0.973	16.393
	C			0.128	0.037	0.545
	T+C	1.812×10^{-2}	12.867	2.410	1.010	16.938
179	T	2.844×10^{-2}	16.959	2.629	1.279	13.056
	C			1.491	0.058	0.892
	T+C	2.844×10^{-2}	16.959	4.120	1.337	13.948
180	T	1.553×10^{-2}	9.197	1.689	0.309	5.454
183	T	3.405×10^{-2}	21.098	3.618	1.147	11.257
	C			0.539	0.002	0.024
	T+C	3.405×10^{-2}	21.098	4.157	1.149	11.281
184	T	1.351×10^{-2}	8.396	0.569	0.119	1.563
185	T	2.446×10^{-2}	12.089	0.045	0.050	0.579
186	T	1.312×10^{-2}	5.602	0.238	0.605	5.149
190	T	1.786×10^{-2}	10.718	2.265	0.862	10.775
	C			0.405	0.052	0.753
	T+C	1.786×10^{-2}	10.718	2.670	0.914	11.528
191	T	1.247×10^{-2}	5.669	0.291	0.112	1.191
	C			0.195	0.021	0.397
	E			0.205	0.067	0.964
	T+C+E	1.247×10^{-2}	5.669	0.691	0.200	2.552
197	T	9.439×10^{-3}	3.138	0.377	0.119	2.532
199	T	9.044×10^{-3}	5.645	1.457	0.785	12.693
200	T	1.530×10^{-2}	9.425	1.710	0.831	10.387
202	T	1.957×10^{-2}	7.107	0.120	0.329	4.876
203	T	3.026×10^{-2}	20.996	5.294	1.360	21.691
	C			0.010	0.016	0.244
	T+C	3.026×10^{-2}	20.996	5.304	1.376	21.935
292	T	9.073×10^{-3}	6.195	2.998	0.349	4.383
	C			0.302	0.064	0.996
	E			0.003	0.003	0.027
	T+C+E	9.073×10^{-3}	6.195	3.303	0.416	5.406
294	T	1.572×10^{-2}	4.848	0.450	0.499	6.497

Tree No.	Life Form	V (m^3)	w_S (kg)	w_B (kg)	w_L (kg)	U (m^2)
295	T	1.430×10^{-2}	9.841	2.289	1.179	12.549
	C			0.289	0.067	0.997
	T+C	1.430×10^{-2}	9.841	2.578	1.246	13.546
310	T	2.596×10^{-2}	18.112	4.100	1.521	23.899
314	T	4.349×10^{-2}	22.486	8.713	2.872	34.071
	C			0.491	*	0.491
	T+C	4.349×10^{-2}	22.486	9.204	2.872	34.562
504	T	1.490×10^{-2}	7.297	1.099	1.002	12.287
	C			0.835	0.195	2.095
	T+C	1.490×10^{-2}	7.297	1.934	1.197	14.382
505	T	8.345×10^{-3}	5.260	1.056	0.600	7.429
	C			0.491	0.054	0.632
	T+C	8.345×10^{-3}	5.260	1.547	0.654	8.061
506	T	1.199×10^{-2}	6.937	1.840	0.982	12.887
	C			0.353	0.047	0.776
	T+C	1.199×10^{-2}	6.937	2.193	1.029	13.663
522	T	2.823×10^{-2}	10.420	1.220	1.144	8.569
	C			3.531	0.814	11.892
	E			0.087	0.037	0.361
	T+C+E	2.823×10^{-2}	10.420	4.838	1.995	20.822
627	T	8.300×10^{-3}	5.960	0.768	0.252	4.639
629	T	7.769×10^{-3}	3.770	0.081	0.261	1.837
	C			0.085	0.012	0.276
	T+C	7.769×10^{-3}	3.770	0.166	0.273	2.113
631	T	4.757×10^{-2}	31.041	2.972	0.422	6.706
	C			5.043	0.898	12.458
	T+C	4.757×10^{-2}	31.041	8.015	1.320	19.164
633	T	8.494×10^{-3}	5.095	1.056	0.692	9.587
	C			0.788	0.083	1.739
	T+C	8.494×10^{-3}	5.095	1.844	0.775	11.326
636	T	1.206×10^{-2}	4.742	0.808	0.468	7.853
	C			0.367	0.157	2.097
	T+C	1.206×10^{-2}	4.742	1.175	0.625	9.950
637	T	1.797×10^{-2}	5.738	1.244	0.705	11.318
	C			0.032	0.008	0.117
	T+C	1.797×10^{-2}	5.738	1.276	0.713	11.435
640	T	9.788×10^{-3}	3.680	0.565	0.841	11.119
641	T	1.209×10^{-2}	6.663	1.309	0.712	10.180
643	T	2.470×10^{-2}	17.123	2.610	0.591	6.701
645	T	6.050×10^{-3}	3.667	0.083	0.050	0.411
647	T	1.048×10^{-2}	7.717	1.042	0.561	5.868
648	T	1.054×10^{-2}	6.572	0.669	0.352	3.404
682	T	1.408×10^{-2}	8.982	1.180	0.532	10.018

Tree No.	Life Form	V (m^3)	w_S (kg)	w_B (kg)	w_L (kg)	U (m^2)
682	C			0.109	0.019	0.298
	T+C	1.408×10^{-2}	8.982	1.289	0.551	10.316
1139	T	8.530×10^{-3}	4.589	1.049	0.617	5.794
	C			0.034	0.041	0.585
	T+C	8.530×10^{-3}	4.589	1.083	0.658	6.379

*: Very small values less than 0.001 kg in weight.
The tree number is the same as in Appendix 1.

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