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Soekotjo

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of the requirements for

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Jonathan W. Wright
Major professor

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DIAMETER GROWTH OF RESIDUAL STANDS IN LOGGED OVER AREAS IN EAST KALIMANTAN TROPICAL RAIN FOREST INDONESIA

By

Soekotjo

A DISSERTATION

Submitted to
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ABSTRACT

DIAMETER GROWTH OF RESIDUAL STANDS IN LOGGED OVER AREAS IN EAST KALIMANTAN TROPICAL RAIN FOREST INDONESIA

By

Soekotjo

Modern exploitation in tropical rain forest of East Kalimantan, Indonesia started in 1967. To regulate the cut on a sustained yield basis, growth data are needed.

The goals of this study were: (1) to obtain information on growth rates of different species; (2) to evaluate how much competition of neighboring trees determines diameter growth; and (3) to determine how much release due to logging stimulate diameter growth.

A total of 29 one-hectare permanent growth plots were located in recently logged over forests. Three years after establishment, diameter growth, basal area of tree's competitors, and distances from the opening were measured.

For each species strong correlation between diameter growth and initial diameter; the greater the diameter, the greater the growth rate. Comparisons of growth rate among species were performed using a homogeneity test. There were differences in Y-intercept but not in the slope among red meranti, white meranti, yellow meranti and bangkirai. These four species belong to the genus *Shorea*. There were differences among the slopes and Y-intercepts of genera *Shorea*, *Dipterocarpus* and *Cotylelobium*.

The basal area of each tree's competitors was measured. The greater the basal area of the competitors and the greater the competition, the less the diameter growth. Logging reduced basal area and competition, thus increasing diameter growth.

Tables were constructed showing predicted diameters 15, 25 and 35 years hence for trees of varying present diameter. From these tables, estimates were made of the numbers of trees reaching merchantable diameter (50 cm) in 35 years. According to these estimates, 9-11 trees per hectare will reach merchantable size in 35 years. Those numbers are almost the same as the number of trees cut during the original logging.

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INTRODUCTION

Borneo is a large tropical island, located on the equator between Australia and Asia. Borneo belongs to two countries, Malaysia and Indonesia. The Indonesian territory is called Kalimantan. Kalimantan consists of four provinces: West, Central, South and East Kalimantan. East Kalimantan has an area of 202,000 km^2 (89,700 mi^2), about the same size as the state of Nebraska. The forest of East Kalimantan is called "Tropical rain forest."

The tropical rain forest of East Kalimantan covers about 172,000 km^2 or about 85% of the total land area. Roughly 50% of Indonesian log exports are from this forest. Timber in Indonesia is the second most important resource after oil. Therefore, East Kalimantan tropical rain forest is the most important forest of Indonesia. Before 1967, forest exploitation in this province was restricted to areas very close to rivers. In 1967 tractor and truck logging started. Roads were constructed to facilitate year-round logging operations. Since then, log exports have increased very sharply from 2.8 million m^3 in 1967 to 19.4 million m^3 in 1973 and 19.8 million m^3 in 1977 (Forest Products Marketing Development Project, 1978).

Logging is being done using a method called "Indonesian Selective Logging" (Tebang Pilih Indonesia). According to law "Indonesian Selective Logging" consists of removal of veteran and mature trees with diameter above 50 cm before they begin to stagnate and deteriorate. Approximately 25 young and healthy overstory trees are left per hectare. These trees should be well distributed spatially and of adequate economic value. After logging, stands are inventoried 100% for exportable trees 20 cm diameter and up to determine the amount of damage. Regeneration inventory is done by linear sampling, one 4 m^2 plot per ha. If less than 40% of the plots contain seedlings belonging to exportable species, enrichment planting should be done. Enrichment planting is also suggested on skid roads and log yards of logged over areas. Tending to free regeneration from competition should be done as needed (Direktur Jendral Kehutanan, 1972). Actually concession holders do not obey all rules of Indonesian Selective Logging. They only follow the diameter limit. The amount cut ranges from 3 to 22 trees per hectare.

To date there are few data concerning the effects of logging on East Kalimantan tropical rain forests. Felling and skidding cause logging damage to 45% of the trees in residual stands. Logging damage is related to number and basal area of trees extracted (Syachrani _et al_., 1974 and Soekotjo _et al_., 1976). However, logging may stimulate the growth of undamaged trees as demonstrated by Miller (1980).

Sustained yield management of the forest requires a large amount of information from various fields. Such information is necessary if a company is to evaluate its operations and forecast future developments. Information on growth by species is especially needed.

Growth data are basically needed to regulate the cut on a sustained yield basis. With sufficient and reliable growth data, the companies will be able to predict the quantity of wood that can be removed from a forest land within a given period of time.

Tropical rain forest trees do not produce annual rings. Whenever growth rings are present, they are not clearly distinguishable and are not necessarily annual. It has been impossible to determine the rate of growth in this forest by stem analysis. The only method to determine growth rates is by establishing permanent plots in which the same trees are measured at intervals of time.

As part of East Kalimantan Forest Service's long term forest management plan, Gadjah Mada University has established 79 one-hectare permanent plots. These plots were established directly after logging in 1977 in logged over forests throughout East Kalimantan. In 1980, I reexamined 29 of these one-hectare plots.

The objectives in my study were: (1) to obtain information on growth rates of different species, (2) to evaluate how much competition of neighboring trees determines diameter growth, and (3) to determine how much release by logging stimulates diameter growth.

LITERATURE REVIEW

Introduction

In previous growth studies of dipterocarp forests both very slow and fast growth rates were reported. This variation in growth rates arises from two reasons. First, the forests are extremely rich in number of tree species. This richness was reported by Poore (1968) in his study of Jangka forest of Malaysia. Within 23 hectares, he found 52 tree families. The most common families, each with 22 or more species, were Dipterocarpaceae, Euphorbiaceae, Myrtaceae, Burseraceae, and Lauraceae. With so many species, growth rates vary.

The second reason lies in variation in initial diameters. Comparisons of growth rates are complicated by the fact that initial diameter affects growth rate but is ignored in most publications.

Mean annual diameter growth in logged over and uncut forests

In Basilan working circle in Republic of the Philippines, five permanent growth plots were established in 1956 (Sulit *et al*., 1962). Plot size ranged from 0.25 to 1 hectare. Three plots were located in old forests, logged over by the highlead system, and two plots were in recently cut areas logged with tractors. Plots were remeasured 4 years after establishment. Growth data ranged from very low to high. Diameter growth rates in excess of 10 mm per year were recorded for meranti almon and urat mata. The lowest growth rates were for meranti gisok and lempung abang (Table 1).

In 1966, 20 one-hectare plots were established in northern Borneo by Fox (1970). Plots were located in forests logged over in 1957 and 1959 in Segaluid, Lokan, Sabah, Malaysia. The forest is typically lowland dipterocarp in which urat mata beludu, meranti merkuyung, meranti tembaga, kapur tanduk, and keruing tempurung are the dominant species, all belonging to the family Dipterocarpaceae. Measurements were made annually for 5 years. Growth data were reported by Wong (1973). Growth rates also ranged from very low to high. Diameter growth rates in excess of 10 mm per year were recorded for meranti merkuyung and seraya melantai. The lowest growth rates were for balau putih and keruing tempurung (Table 1).

In 1936, three growth plots were established in Negeri Sembilan, Malaysia. Plots were located 75 to 300 m above sea level. About 57 trees of seraya melantai were selected for growth studies. The last measurement was in 1956. Data were reported by Vincent (1961). The mean annual diameter growth for seraya melantai was 13 mm (Table 1).

One large plot was established in 1939 in Perak, Malaysia. The plot was located at altitudes from 16 to

Table 1. Mean annual diameter growth of dipterocarp species in logged over stands in Malaysia (MAL) and the Philippines (PH).

Genus and species	Mean annual diameter growth	Province and country	Author
	mm		
Anisoptera			
Mersawa	6	Basilan, PH	Sulit *et al.*, 1962
Dipterocarpus			
Keruing tempurung	4	Sabah, MAL	Wong, 1973
Keruing hijau	6	Basilan, PH	Sulit *et al.*, 1962
Dryobanalops			
Kapur tanduk	6	Sabah, MAL	Wong, 1973
Parashorea			
Urat mata	12	Basilan, PH	Sulit *et al.*, 1962
Urata mata beludu	8	Sabah, MAL	Wong, 1973
Shorea			
Meranti almon	12	Basilan, PH	Sulit *et al.*, 1962
Meranti gisok	3	Basilan, PH	Sulit *et al.*, 1962
Meranti tembaga	10	Sabah, MAL	Wong, 1973
Meranti merkuyung	12	Sabah, MAL	Wong, 1973
Balau Putih	3	Perak, MAL	Vincent, 1962
Seraya Melantai	13	Negeri Sembilan, MAL	Vincent, 1961
Meranti merah	7	Basilan, PH	Sulit *et al.*, 1962
Lempung abang	4	Basilan, PH	Sulit *et al.*, 1962
Merkabang	7	Basilan, PH	Sulit *et al.*, 1962

100 m above sea level with varying aspects and slopes. A total of 23 balau putih trees were selected for annual measurement. Mean annual diameter growth over a period of 18 years was reported by Vincent (1962). The mean annual diameter growth for balau putih was 3 mm. It is a disappointingly low diameter growth for a species of meranti (*Shorea*).

From Table 1 it can be seen that both Malaysia and the Philippines had similar ranges of growth rates. In both countries members of the genus *Shorea* show the highest variability in growth rate of all genera of dipterocarp.

Mean annual diameter growth in logged over forests of East Kalimantan was reported by Setijono *et al*. (1979). Their report was based on 2 years of observation in eight study areas (79 one-hectare plots). In that report, species were grouped into exportable, locally commercial and other species. The results are summarized in Table 2. Mean annual diameter growth of exportable species ranged from 6 mm in Inne Dong Wha to 18 mm in Avedeco. The average for all concessions for exportable species was 10 mm. This figure is within the range of mean annual diameter growth of Malaysia and the Philippines' dipterocarp as shown in Table 1. Mean annual diameter growth in excess of 10 mm were in Avedeco, KRTP and Ratah Timber. This high growth rate may be due to more available space per tree, greater initial diameter, the presence of faster growing species, or

Table 2. Mean annual diameter growth by group of species in eight concessions in East Kalimantan (from Setijono *et al*., 1979).

Concession	Annual diameter growth of			
	All species	Exportable species	Locally commercial species	Other species
	mm	mm	mm	mm
Avedeco	15	18	11	15
BFI	6	8	6	5
GPI	7	8	7	7
Inne Dong Wha	6	6	5	6
ITCI	7	8	8	8
KRTP	11	12	11	11
KTI	6	7	6	6
Ratah Timber	16	16	18	16
Average	9.2	10.4	8.7	9.1

better soils in those three concessions.

When the first year's growth was compared with that for the second year, Setijono et al. (1979) reported that in four out of five concessions first year diameter growth was greater than that for the second year. This may be due to greater competition from ground vegetation in the second year than in the first year. These same authors calculated the relationship between diameter and diameter growth rate in all eight concessions. The relation was significant statistically in four of the eight concessions. In doing this, they lumped data for all species, a practice which reduced the validity of the results.

Diameter growth in unlogged dipterocarp forests at Pasoh, Malaysia was measured by Kato, Tadaki and Ogawa (1978). The growth data were based on trees over 10 cm diameter in a plot of 40 m x 200 m. Diameter was measured with tape at three different heights above ground, 1.23 m, 1.30 m, and 1.37 m. The three readings were averaged. Measurements were done over a period of 1.9 years. Maximum diameter growth recorded was 0.9 mm during the first year and 1.3 mm during 1.9 years. The growth was disappointingly slow.

In East Kalimantan, ITCI established four permanent plots in unlogged forests, and eight permanent plots in logged over forests. Plots were established in 1972. Plot size ranged from 0.25 to 1.75 hectares. Trees over 15 cm diameter were individually numbered and diameter measured yearly. Over a 6-year period, growth rates of trees in unlogged forests were compared with those of undamaged trees in logged over forests (Miller, 1980). The results were summarized in Table 3. Logging stimulated growth for the small diameter class. For medium diameter class, growth was stimulated when percent of trees cut was 20 percent. Growth rates in the most heavily cut areas was comparable with growth rates of exportable species in Avedeco, KRTP and Ratah Timber as reported by Setijono *et al*. (1979). The fact that logging stimulates growth may be due to more available growing space for trees remaining in the logged over forests. The results are open to question because Miller did not analyze separately for different species, grouping such diverse genera as *Shorea* and *Anthocephalus*.

The evidence that growth rate in logged over forests is greater than in unlogged forests is not surprising. The logging permits the remaining trees to have more growing space and develop larger crowns, and thus to grow faster.

Growth related to crown position

The effect of crown position on growth was studied by Murphy (1970). At El Verde, Luquillo forest in Puerto Rico, growth of trees in the lower canopy was compared with growth of trees in the upper canopy. It can be seen in Table 4 that basal area growth of upper canopy trees was at least

Table 3. Mean diameter growth of undamaged trees 6 years after logging and of similar trees in unlogged forests (from Miller, 1980).

Diameter class, mm	Mean diameter growth (mm/year)			
	Unlogged forest	Logged over forest with following percent of trees cut or damaged		
		4%	15%	20%
150 - 249	2	4	4	16
250 - 349	6	4	6	12
350 - 449	7	4	10	16

Table 4. Basal area increase by species as related to crown position (from Murphy, 1970)

Species	Basal area increase (cm^2) per tree	
	Lower canopy	Upper canopy
Dacryodes excelsa	6.8	23.2
Manilkara bidentata	4.6	17.5
Sloanea berteriana	1.7	20.9
Croton poecilanthus	3.7	9.6

three times greater than that for lower canopy trees.

Further evidence on this point was reported by Crow and Weaver (1977). They studied 100 plots, each 0.08 hectare in size, located in Luquillo mountain of Puerto Rico. These plots were established 19 years ago. For a given species, trees were grouped into dominant, codominant, intermediate, and suppressed crown classes. Dominant trees grew fastest and suppressed trees the slowest.

Problems in measurement

Both very slow and fast growth of tropical rain forest trees were reported everywhere (Dawkins, 1959; Crow and Weaver, 1977; Sulit *et al*., 1962). The great diversity of species and sites, and the lack of annual rings poses more problems than in temperate forests for developing suitable measurement techniques. It has been impossible to determine the rate of growth in tropical rain forest by stem analysis. The only method for determining the rate of growth of trees species is by laying out permanent plots in which the same trees are measured at intervals.

The problem of how to select a suitable method which is simple, accurate and fast has challenged tropical researchers. Dawkins (1956) suggested painting ten parallel rings on each tree and averaging the three closest readings. The method was found quite accurate in Sarawak and Sabah, but it was expensive (Nicholson, 1958). Furthermore Nicholson was doubtful whether Dawkins' method had any real advantage over the usual methods used in Sarawak and Sabah.

For 52 weeks of 1955 and 1956, diameters of 10 trees each of Levoa brownii and Entandrophragma angolensis were measured weekly in Mpanga, Uganda (Dawkins, 1956). He correlated diameter growth with rainfall. Growth was greater in the wet than in the dry season.

THE STUDY AREAS

Location

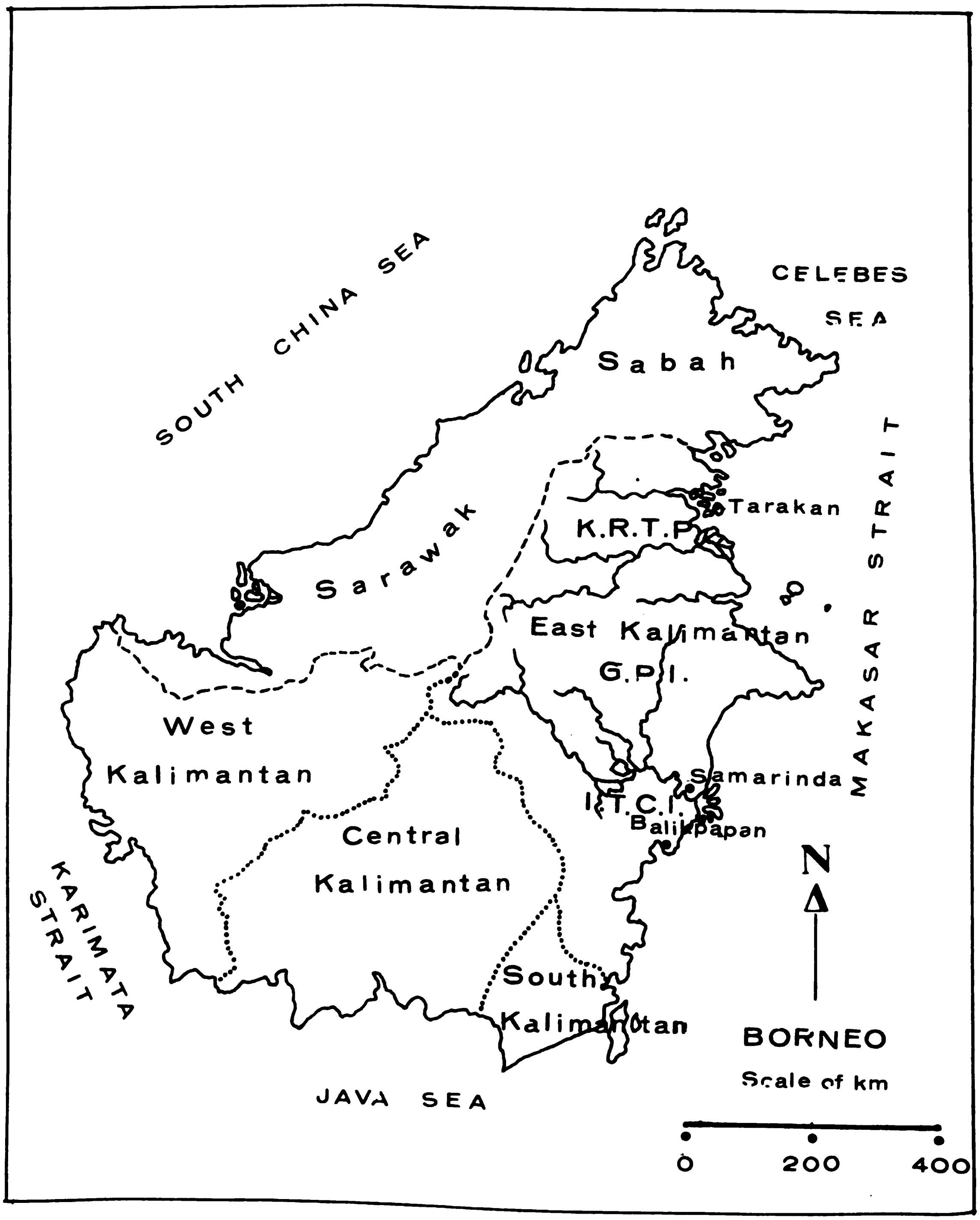
The study areas are located on three concessions in East Kalimantan forests. A concession is a tract of land leased by a company under a long term agreement. In this agreement the concessioner has cutting rights on a sustained yield basis. These concessions are: International Timber Corporation Indonesia (ITCI), Georgia Pacific Indonesia (GPI), and Kayan River Timber Products (KRTP).

The ITCI concession is located in the southern part of East Kalimantan between the cities of Balikpapan and Samarinda (Figure 1). It takes about one hour to reach by boat from Balikpapan. ITCI holds a forestry license on 601,750 hectares. The study site lies 60 km from ITCI's base camp and about 0.2 to 0.5 km from road 2321-A.

The GPI concession is located in the center of East Kalimantan northwest of Samarinda (Figure 1). It takes about 45 minutes by GPI's plane from Samarinda. GPI holds a forestry license on 350,000 hectares. The study site lies 50 km from GPI's base camp about 0.2 to 0.8 km from the main road.

The KRTP concession is located in the northern part of East Kalimantan, west of Tarakan, a northern city of East

Figure 1. The location of I.T.C.I., G.P.I. and K.R.T.P. concessions in East Kalimantan.


SOUTH CHINA SEA
CELEBES SEA
Sabah
Sarawak
Tarakan
K.R.T.P.
MAKASAR STRAIT
East Kalimantan
G.P.I.
West Kalimantan
Samarinda
I.T.C.I.
Balikpapan
Central Kalimantan
KARIMATA STRAIT
South Kalimantan
N
BORNEO
Scale of km
0
200
400
JAVA SEA

Kalimantan (Figure 1). It takes about six hours by boat from Tarakan. KRTP holds a forestry license on 325,000 hectares. The study site lies 9 km from KRTP's base camp, about 0.2 to 0.5 km from road M.

Climate

East Kalimantan climate is uniform throughout the year. The temperature varies only minimally, from 25.9^{o}C in the coldest month of February to 27.4^{o}C in the warmest month of September (Central Bureau of Statistics, 1976).

Rainfall data are summarized in Table 5. The annual rainfall varies from 2,000 to 2,800 mm and is distributed throughout the year. Therefore, the soils just under the surface practically always remain continuously moist. This rainfall is important as a source nutrient input into the ecosystem (Jordan *et al*., 1980).

Even though July is the month with the least rainfall, it is still wet, with 118 to 191 mm rainfall for the month. However, in ITCI and GPI three weeks without rain were recorded in 1980. Those three weeks may be the only period of water stress during the year.

Both temperature and rainfall in the three study areas provide favorable conditions for plant growth.

Topography

East Kalimantan is level and near sea level in the east. In the middle it is generally undulating or hilly, about 40%

Table 5. Amount and distribution of rainfall in the three study areas (Directorate of Forest Inventory and Planning, 1968, and ITCI unpublished data)

Study areas	Annual		Month with least rain		Month with most rain	
	Rainfall	Days of Rain	Month	Amount of rain	Month	Amount of rain
	mm			mm		mm
ITCI	2123	177	July	118	Dec.	236
GPI	2580	121	July	144	Dec.	321
KRTP	2768	162	July	191	Dec.	261

of the land having elevations 500 to 1000 m above sea level. The mountainous mass is located on the border of Sarawak, Sabah and Central Kalimantan. This mountain range is less than 2,000 m in elevation. Mt. Kinabalu, 4,500 m above sea level, is located in Sabah.

The ITCI concession is located at elevations of 0-100 m above sea level. The topography is generally undulating with some parts hilly with slopes over 60%. The study site is undulating. In some parts of plots 5, 6 and 8, the slope is more than 75%.

GPI concession has altitudes varying from 100 to 645 m above sea level. The topography generally is undulating in the west part. The swampy area is found in the southern part between Long Nah and Muara Mawai villages.

KRTP concession is located at altitudes varying from 100 to 1,500 m above sea level. Its topography varies from undulating to mountainous (Directorate of Forest Inventory and Planning, 1968).

Soils

The references used to estimate the most common soil orders in the three study areas were from Directorate of Forest Inventory and Planning, 1968 and ITCI's soil map. These references use old terminology. Their equivalents in new terminology and interpretation were obtained by using Buol, Hole and McCraken, 1973; Soil Survey Staff, 1975 and Foth and Schafer, 1980.

The most extensive soils in the three study areas are Red and Yellow Podsolic Soils. These soils are presently recognized as Ultisols. Ultisols are soils that are the most weathered and show the ultimate effects of leaching. Ultisols are characterized by mineral soils that have B-2 horizon, 20 percent more clay than the upper on B-1. Ultisols have low base saturation, the base saturation decreases with increasing soil depth. Normally most of the bases are held in the vegetation and the upper few centimeters of soil. The higher base saturation in the upper soil layers reflects the direct cycling of bases by vegetation. When the climax forest is cut and burned, nutrients stored for thousands of years in the vegetation are suddenly made soluble. Large amounts are lost to leaching and washing, causing a sudden decline of the nutrient level of the entire system. This is shown in slash and burn agriculture as practiced by native East Kalimantan cultivators.

The next most common soils in the three study areas are Reddish Brown Lateritic, Yellowish Brown Lateritic and Latosols. These soils are presently recognized as Oxisols. They have very stable soil structure consisting of fine and stable aggregates. The water availability to plants is very low. Unless there is frequent rain the soils are droughty. Oxisols are characterized by the presence of an oxid upper horizon, at least 30 centimeters thick. They have subsurface horizons which are intensively weathered.

The subsurface horizons consist of very insoluble minerals such as quartz and hydrated oxides or iron and aluminum.

Vegetation

In the three study areas the vegetation is called tropical rain forest. The vegetation is dominated by the family Dipterocarpaceae. The tallest and most abundant species of Dipterocarpaceae in the three study areas are meranti merembung, meranti merkuyung and meranti tembaga, all called red meranti. They reach far above other trees, attaining heights of 60, 75 and 70 m respectively. All have large buttresses, 4, 2 and 1 m tall respectively. They may occur singly or in a group.

Among the tallest and most abundant species of Dipterocarpaceae in one study area, but least abundant in other study areas are kapur tanduk, damar siput, urat mata and meranti kalunti. Kapur tanduk is abundant in ITCI, where it grows 80 m tall. Damar siput, a yellow meranti, is abundant in GPI, reaching heights of 60 m. The buttresses are usually short. The name is derived from the damar exudate of yellow to dark brown crust, and siput the word for snail. So damar siput means snail-shaped exudation. Urat mata and meranti kalunti are found only in KRTP. Urat mata is a large tree up to 65 m high. The buttresses are large, up to 5 m high. Meranti kalunti is a large tree reaching a height of 60 m.

The second tall canopy is called second layer. Members of the second layer which are most abundant are Dipterocarpaceae, Sepotaceae and Lauraceae. Among Sapotaceae is nato, a group of species of the genus Palaquium. The trees have white latex in the bark and often also in the leaves, flowers and fruits. Nato may grow 50 m tall and most have columnar boles and buttresses. Among the Lauraceae are Medang and Ulin. Medang is abundant only in ITCI, while Ulin is abundant only in ITCI and GP. Medang includes many tree species, all characterized by aromatic substances smelling of resin, cinnamon and citronella. Medang may reach 40 m height. Ulin (Eusideroxylon zwageri) is known as ironwood because the wood is very strong and heavy. It is resistant to sea water. Ulin grown 50 m tall.

Trees with crowns below the second layer are called the third layer. The most abundant species was kayu darah. Darah means blood, from a blood-like exudate. It is a small to medium tree up to 30 m, often with stilt roots.

The average numbers of trees per hectare in unlogged forests of the three concessions is summarized in Table 6. That table is based on the areas logged in a 1-year period (1975-1976) in each concession. In Table 6 are given the numbers of trees per hectare in various diameter classes in the three concessions. The upper most three lines are based on a sampling of 0.75% of the area cut in one year, 1975-1976. The bottom six lines are based on the 29 plots

Table 6. Average number of trees per hectare by diameter class in the three concessions (from Soekotjo *et al*., 1976 and Setijono *et al*., 1978).

Location	Diameter in cm			
	10 to 20	20 to 35	35 to 50	50+
Area logged in 1975-1976, before logging				
ITCI	145	21	33	32
GPI	110	89	46	38
KRTP	109	63	26	26
My study area, before logging				
ITCI	--	42	18	17
GPI	--	14	9	17
KRTP	--	29	11	18
My study area, after logging				
ITCI	146	18	8	7
GPI	183	9	4	7
KRTP	152	16	4	7

which I studied. In all cases the number of trees 10-20 cm in diameter was greater than the number of trees in the 20-35 or 35-50 cm diameter class. The logging itself removed trees 50 cm and over in diameter, the only 50 cm trees left standing belonging to unmerchantable species. As the bottom six lines show, the logging caused considerable mortality in the trees less than 50 cm in diameter.

Logging operations

Logging operations have been conducted since 1967. The amounts cut are summarized in Table 7. To meet the annual harvest target, hundreds of km of rocked main line roads have been established in all three concessions. This road facilitates year-round logging operations.

The annual area cut is divided into blocks as logging units. Each logging unit covers an area of approximately one hundred square kilometers. Felling and bucking are done by chain saw. Skidding is done by caterpillar tractors. Logs are loaded onto logging trucks and transported to a log pond.

Table 7. Average cut per hectare by group of species and total cut in last 10 years operation in the three concessions (from ITCI, GPI, and KRTP's working plan 1980-1981).

Study areas	Average cut by group of species						Total cut in 10 years 1970 1979	
	Meranti	Kapur	Keruing	Agathis	Other	Total	Area	Volume
	m^3 per ha.						1,000 ha	Million m^3
ITCI	54.0	6.7	1.9	-	3.4	65.6	167.2	9.2
GPI	48.7	4.8	1.3	-	0.4	55.2	41.7	2.3
KRTP	49.6	3.6	20.3	8.1	6.2	87.8	49.5	2.7

METHODS

Plot establishment and measurement

In February 1977, 29 one-hectare permanent growth study plots were established in three concessions. The number and distance of plots from base camp and main road by concessions are given in Table 8. The location of each plot is shown in Figure 2, 3 and 4.

Plot boundaries and trees along paths to the plots were carefully painted red to ensure that the plots could be found for subsequent measurement. All trees 10 cm diameter and up were numbered with aluminum tags nailed to the tree above the point of measurement (1.30 m). At the point of measurement a ring was painted at 1.3 m height. For a buttressed tree, the point of measurement was located 2 m above the buttress. Trees were identified and their diameters measured with diameter tape to the nearest mm.

Before logging in 1977, the following data were recorded for each tree: number, species (full common name written out) and diameter in mm. These data were recorded on tally sheets. Immediately after logging, the plots were revisited, and the percentage of crown (to the nearest 25%) damaged on each tree was recorded on the same tally sheets. When the plots were remeasured in 1978 and 1979, new tally sheets

Table 8. Number and location of plots on the three concessions

Concessions	No. of plots	Distance from base camp	Road name	Distance from road
		km		km
ITCI	9	60	2321-A	0.2 to 0.5
GPI	10	50	1000	0.1 to 0.8
KRTP	10	9	Road-M	0.2 to 0.5

Figure 2. The distribution of permanent growth plots in
I.T.C.I. concession.

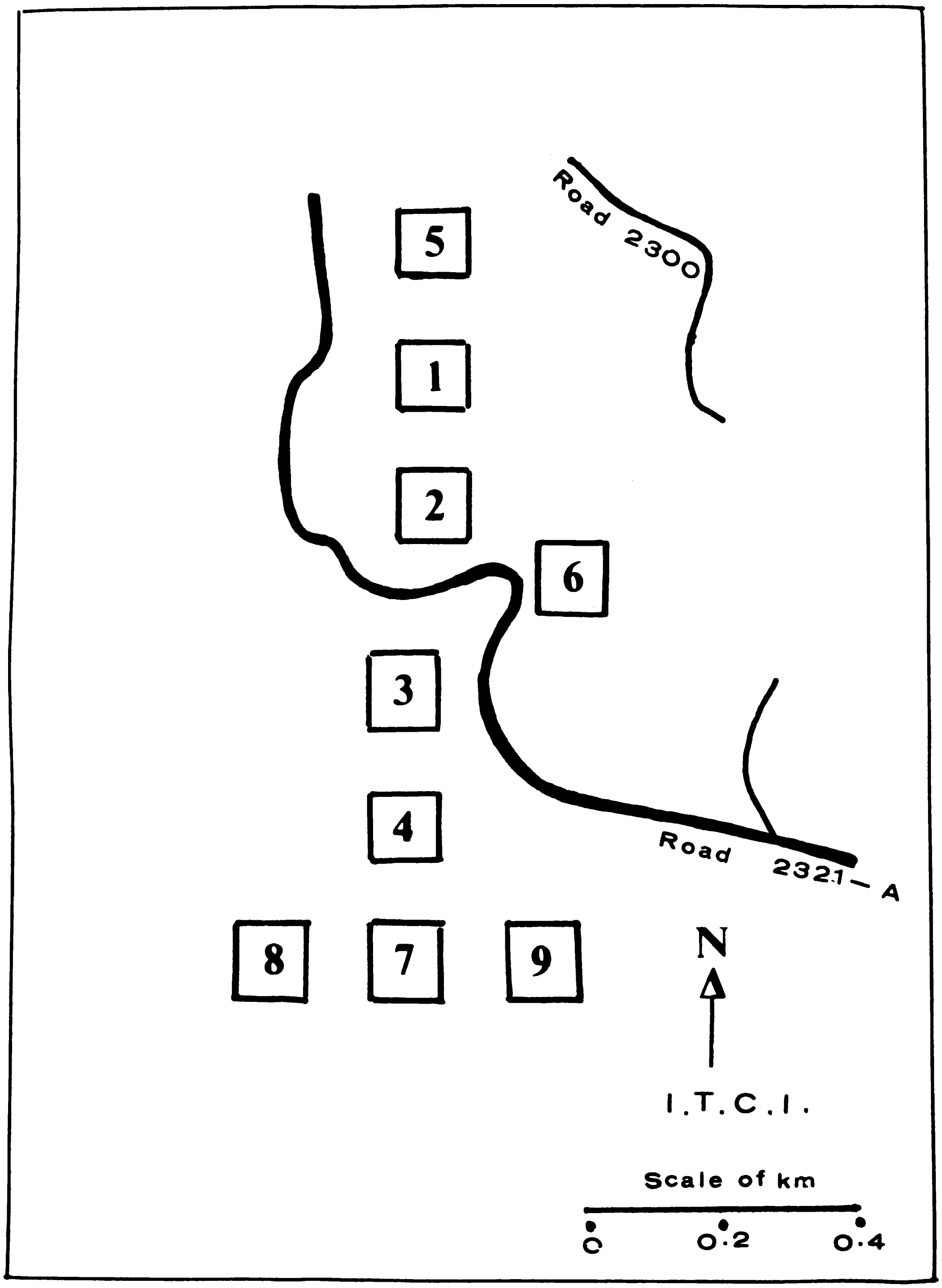

Road 2300
5
1
2
6
3
4
Road 2321 – A
8
7
9
N
I.T.C.I.
Scale of km
0
0·2
0·4

Figure 3. The distribution of permanent growth plots in G.P.I. concession.

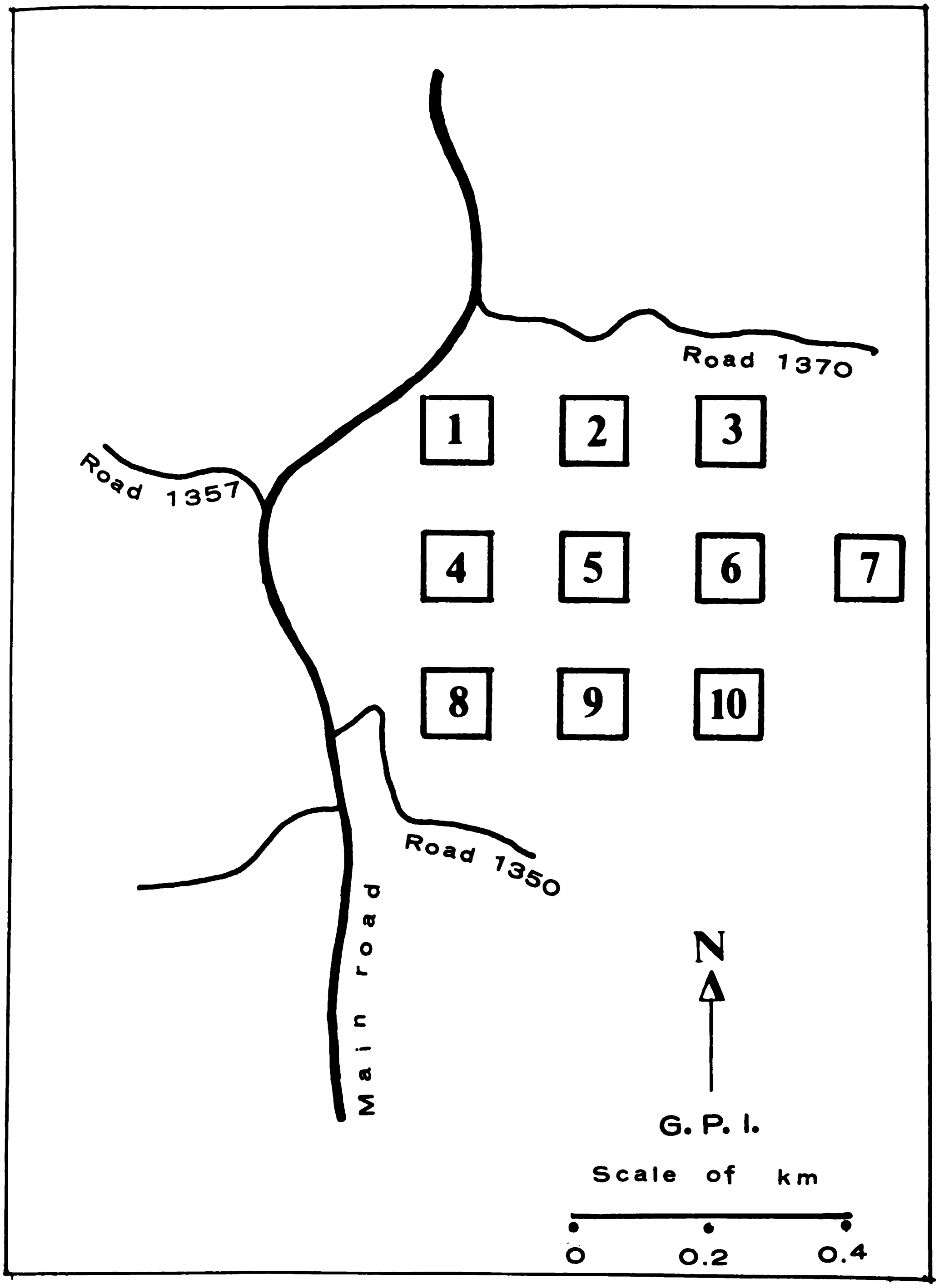
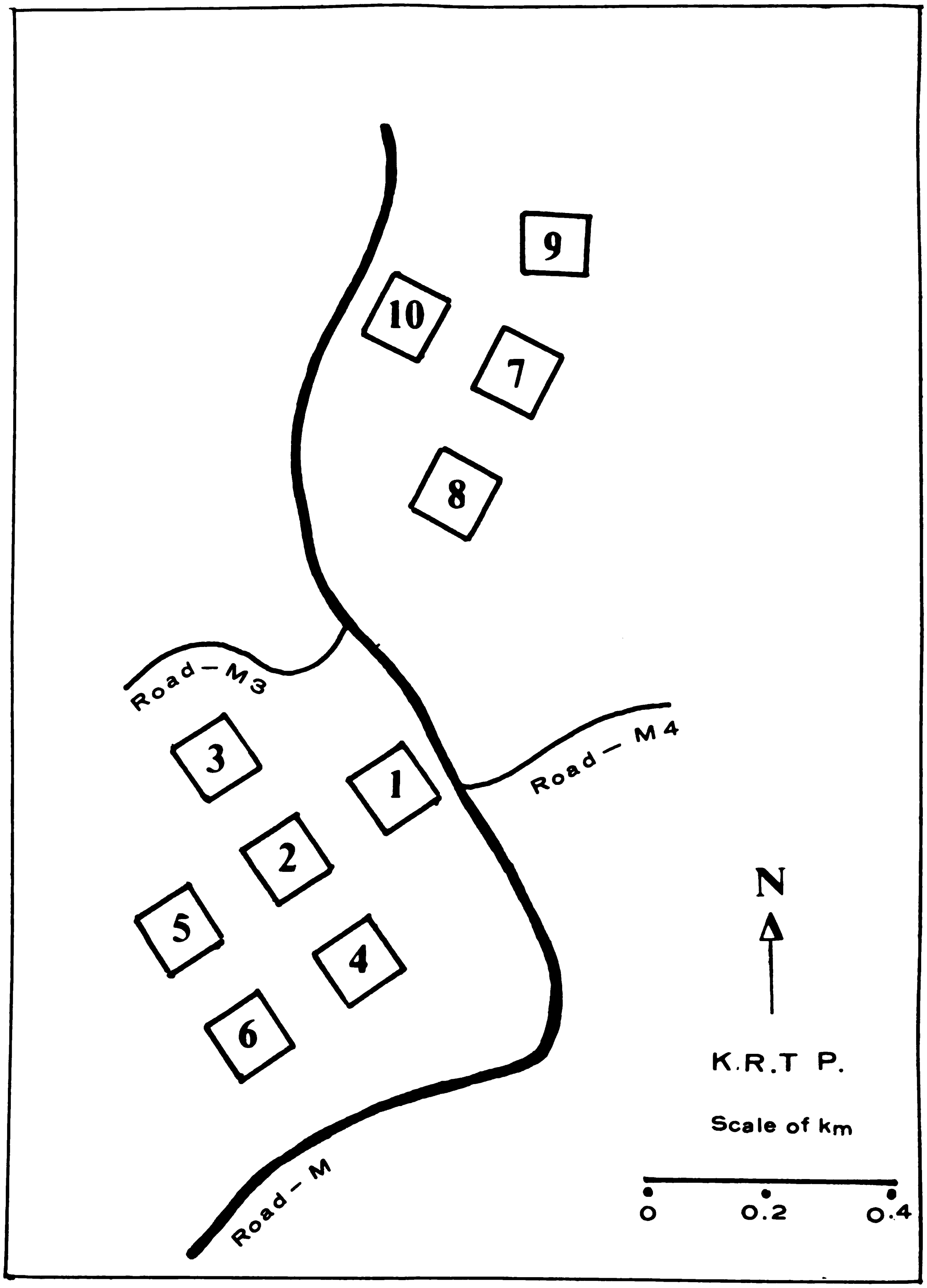

Road 1370
Road 1357
Road 1350
Main road
1
2
3
4
5
6
7
8
9
10
N
G. P. I.
Scale of km
0
0.2
0.4

Figure 4. The distribution of permanent growth plots in K.R.T.P. concession.


9
10
7
8
Road – M3
Road – M4
3
1
2
5
4
6
N
K.R.T P.
Scale of km
0
0.2
0.4
Road – M

were used (containing no data from the 1977 measurements) and diameters were recorded for each tree. When the plots were remeasured in 1980 tally sheets were prepared beforehand. Those tally sheets included number, species and 1977 diameter, but not the logging damage nor the 1978 or 1979 diameters. The 1980 diameters were recorded on these already prepared data sheets.

Measurements were done by a crew consisting of one leader and six members for ten plots in each company. This crew spent 45 days for plot establishment.

In June 1980, I and four crew members returned. We mapped all trees, using a grid system in which each plot was divided into 25 subplots, each 20 m x 20 m. Using a scale 1 m in the field equal to 1 mm on paper, the tree's locations were charted on cross section paper. We also measured distance of each tree to the nearest opening caused by logging diameter, and basal area of the trees nearest neighbors. To obtain this measure of competition around each tree, I used the "Panama Basal Area Angle Gauge", an instrument designed for plotless timber cruising. I used the subject tree as a center of measurement. By looking in every direction through the instrument, and counting the number of trees whose d.b.h. appear larger than the crosspiece or aperture the basal area of its competitors was determined.

In 1978 and 1979, when the tally sheets did not contain data from the previous measurement, there was no opportunity to check on possible mistakes in measurement or recording. In 1980 there was such an opportunity, but there was actually no such check as the recorder did not ask for re-measurement of trees which had a smaller diameter in 1980 than in 1977.

Actually about 2% of the trees had smaller recorded diameters in 1980 than in 1977, presumably due to a mistake in recording at one time or the other. These trees were eliminated from all further analyses. Presumably mistakes in the opposite direction were made on an equal number of trees, but such mistakes were not detectable.

Data handling

Data from the tally sheets were punched using an IBM 026 keypunch. I used a card coded to the specifications as shown in Table 9. This instruction card can be set up to allow the IBM 026 keypunch to duplicate automatically or skip unused columns of the data cards.

After all cards were punched, proofreading was needed to correct punching errors in the cards. This proofreading was accomplished by using lister/printer. Lister/printer output printed data for each plot by companies in the same format as in the original tally sheets. The possibility to correct errors and enter new data is easier in this way.

To rearrange the contents of a file into the order that meets the specification may be done through the use of a sorting machine. After we determine which columns in the

Table 9. Instruction card using keypunch drum

Columns	Character in the first and following columns field	Data entry
1 - 6	-+++++	skip.
7 - 8	/A	company - letter code.
9 - 10	-+	skip.
11 - 12	space +	plot number - numeric code
13 - 14	-+	skip.
15 - 16	space +	sub-plot number-numeric code.
17 - 18	-+	skip.
19 - 21	space ++	tree number - numeric code.
22 - 23	-+	skip.
24 - 26	/AA	species - letter code.
27 - 29	-++	skip
30 - 31	space +	distance - numeric code.
32 - 34	-++	skip.
35 - 37	space ++	diameter 1977 - numeric code.
38 - 52	-++++++++++++++	skip.
53 - 55	space ++	diameter 1980 - numeric code.
56 - 57	-+	skip.
58 - 59	space +	basal area - numeric code.
60 - 62	-++	skip.
63 - 64	space +	diameter growth - numeric code.

field have to be sorted, sorting is performed in descending order from high to low field.

Finally the data were stored in a magnetic tape called a "stranger" tape. I did this so that I could return to Indonesia with all the data in a convenient form.

Computations

The previously punched IBM cards were sorted by species, so that regression equations could be calculated for each species. All computations were performed using Texas Instruments TI Programmable 58 C calculator, using a library module. The procedures are summarized in Table 10.

Once the library module was inserted in the calculator, the next step was to initialize the calculator for statistics by pressing 2nd Pgm 1 SBR CLR. Data entry has to be in pair of values (X_i, Y_i). A faulty entry can be removed by reentering the unwanted pair of value and pressing INV 2nd Σ +.

To determine whether two regression lines have a common slope I used Student's "t" test as described by Steel and Torrie (1980). The procedure is relatively easy, and is shown below.

To calculate "t", I used the following equation derived from that given by Steel and Torrie (p. 258).

$$t = \frac{b_1 - b_2}{\sqrt{S_p^2(1/SSX1 + 1/SSX2)}}$$

where b_1 = slope of regression 1

Table 10. Procedures used to calculate growth as related to initial diameter using TI Programmable 58 C

Step	Data entry	Press
1. Initialize		2nd Pgm 1 SBR CLR
2. Enter data point (X_i, Y_i)		
X-array	X_i	X_i x:t
Y-array	Y_i	Yi 2nd Σ +
3. To remove unwanted data point		
(X_j, Y_j)	X_j	X_j x:t
	Y_j	Y_j INV 2nd Σ +
4. Computation:		
Y-intercept		2nd Op 12
Slope		x:t
Mean Y-array		2nd x
Mean X-array		x:t
Variance Y N weighting		2nd Op 11
Variance X N weighting		xit
Correlation Coefficient		2nd Op 13
Compute estimate		
Y' on X_k	X_k	X_k 2nd Op 14

b_2 = slope of regression 2

SSX1 = sum of squares X of regression 1

$= \Sigma (X_{1j} - \overline{X}_{1\cdot})^2$

SSX2 = sum of squares X of regression 2

$= \Sigma (X_{2j} - \overline{X}_{2\cdot})^2$

s^2_p = pooled residual sums of squares for two separate regressions divided by degree of freedom

$$= \frac{(SSY1 - (CSP1)^2/SSX1 + SSY2 - (SCP2)^2/SSX2)}{n_1 + n_2 - 4}$$

where

SSY1 = sum of squares Y of regression 1

$= \Sigma (Y_{1j} = \overline{Y}_{1\cdot})^2$

SSY2 = sum of squares Y of regression 2

$= \Sigma (Y_{2j} - \overline{Y}_{2\cdot})^2$

SCP1 = sum of cross-products of regression 1

$= \Sigma (X_{1j} - \overline{X}_{1\cdot})(Y_{1j} - \overline{Y}_{1\cdot})$

SCP2 = sum of cross-products of regression 2

$= \Sigma (X_{2j} - \overline{X}_{2\cdot})(Y_{2j} - Y_{2\cdot})$

n_1 = number of observations of regression 1

n_2 = number of observations of regression 2

Computation procedures to calculate "t" are summarized in Table 11. From Table 11 it can be seen that s_p^2 is equal to (line 1 + line 2 in column 10) divided by (line 1 + line 2 in column 2 minus 4), while (1/SSX1 + 1/SSX2) is equal to line 1 + line 2 in column 7. Therefore, using this table t is easy to solve.

Table 11. Procedures used to calculate student's "t" for testing difference between two b's, using Tl - 58 C calculator

1/

Column									
1	2	3	4	5	6	7	8	9	10
Press (Key Sequence)									
		2nd op 12	x:t	2nd op 11 times col. 2	x:t times col. 2	1 divided col. 6	2nd op 13	col. 4 squares times col. 6	col.5 minus col.6
Elements of computation									
spp	n	a	b	SSY	SSX	1/SSX	R^2	SCP^2/ SSX	(SSY- SCP^2)/ SSX
...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...
	x					x			x
			v						

1/ x Sum line 1 + line 2.

v Subtract line 1 - line 2.

Procedures for calculating the effect of basal area of tree competitor on growth are as follows:

Step 1. Set up table for the analysis (Table 12)

where SS between-class = $\frac{(D_{20})^2}{n_{20}} + \frac{(D_{30})^2}{n_{30}} + \ldots\ldots\ldots\ldots$

$$\frac{(D_{90})^2}{n_{90}} - \frac{(D)^2}{n}$$

SS within-class = SS total - SS between-class

SS total = SS residual of regression.

Procedures for calculating the effect of distance to the opening to subject tree on growth are the same as those for calculating the effect of basal area of tree competitor on growth.

Table 12. Procedures used to calculate the effect of basal area of tree's competitors on diameter growth of subject tree, using TI.58 C calculator

basal area	n	initial dia. (X) ΣX	initial dia. (X) $\Sigma X/n$	actual dia. growth Y	calculated ΣY	calculated Y'	Y - Y' = D
20							
30							
..							
..							
90	$\overline{\Sigma n}$						$\overline{\Sigma D}$

Step 2, Calculate ΣY by addition and Y' from

$$Y' = a + b\ (\Sigma X/n). \quad \Sigma Y' = nY'$$

Step 3, Set up table for the analysis of variance

RESULTS AND DISCUSSION

Mean annual diameter growth

I present mean annual diameter growth data of the most common species in Table 13. My analysis was based on locally recognized species, some of which may contain several species as recognized by taxonomists. Mean annual diameter growth ranged from 4 to 11 mm. It was greatest for dipterocarps belonging to the overstory or first layer, and least for non-dipterocarps belonging to the second layer. The ranges of mean annual diameter growth were similar to those reported in other countries (Tables 1 and 14).

Growth related to initial diameter

Of greater value than mean annual diameter growth is the relationship between initial diameter and diameter growth. For a given species I considered diameter growth as the dependent variable and initial diameter as the independent variable. Then I calculated the correlation between these two variables. The results are shown in column 4, 5 and 6 of Table 14, and are based on data from 40 to 388 trees per species. In all species there was a strong and statistically significant correlation between diameter and diameter growth, the greater the diameter, the

Table 13. Mean annual diameter growth by species as related to initial diameter

Species	Mean ann. diam. growth	Mean init. diam.	Growth (Y) as a function of initial diameter (X)		
			r^2	Slope growth/diam.	Y intercept
	mm	mm		mm/mm	mm
Dipterocarps					
Shorea					
Red meranti	10.0	298	.56	.018	4.5
White meranti	8.6	253	.45	.019	3.7
Yellow meranti	9.6	331	.61	.018	3.4
Bangkirai	8.8	298	.62	.017	3.6
Dryobalanops					
Kapur	10.0	303	.74	.020	3.9
Parashorea					
Bagtikan	9.0	274	.76	.026	2.2
Dipterocarpus					
Keruing	9.0	254	.76	.024	2.7
Cotylelobium					
Resak	7.5	199	.64	.029	1.6
Hopea					
Nyerakat	9.0	288	.85	.021	3.0
Non Dipterocarps					
Commercial					
Ulin	11.0	348	.80	.021	3.6
Nato	7.5	214	.71	.024	2.2
Medang	7.0	207	.83	.024	1.7
Non commercial					
Langsat	6.3	245	.63	.030	1.3
Lalan	6.0	219	.89	.030	-1.0
Temberas	5.7	196	.78	.029	0.2
Kayu arang	6.0	208	.86	.028	0.0
Jambu	6.1	204	.85	.026	0.8
Marjelawat	4.5	148	.77	.025	2.7
Banitan	5.3	168	.72	.024	1.3

Table 13. (continued)

Species	Mean ann. diam. growth	Mean init. diam.	Growth (Y) as a function of initial diameter (X)		
			r^2	Slope growth/diam.	Y inter-cept
Mendarahan	4.9	183	.74	.024	0.6
Margelang	4.5	148	.77	.023	1.0
Api	4.6	175	.79	.021	0.9
Kempas	7.7	292	.59	.020	1.9
Margaram	4.5	178	.63	.017	1.0
Marakeladi	4.4	182	.53	.017	1.1

Table 14. Mean annual diameter growth data by species, in tropical rain forests of Zimbabwe, Guyana and Puerto Rico

Species	Mean annual diameter growth	Location	Author
	mm		
Baikiaeae plurijuga	5	Zimbabwe	Osmaston (1956).
Ocotea rodiaei	5	Guyana	Prince (1973).
Fast growing species:		Puerto Rico	Crow and Weaver (1977).
Buchenavia capitata	7	"	"
Guarea trichilioides	8	"	"
Slow growing species:		"	"
Tabebuia heterophylla	2.8	"	"
Dacryodes excelsa	2.5	"	"
Didymopanax morototoni	3.1	"	"

more rapid the growth.

Column 4 is r^2. It is called the coefficient of determination and is a measure of the variation due to differences in initial diameter. In my results ranged from 0.45 to 0.89, showing that 45-89% of the variation in diameter growth was associated with variation in initial diameter.

Column 5 is the slope. Slope tells us the relationship of growth to change in initial diameter. An example, for yellow meranti the slope is 0.018. Thus, for 1 mm increase in initial diameter, diameter growth will increase 0.018 mm.

Column 6 is the Y-intercept, a measure of inherent growth rate. The Y-intercepts ranged from -1.0 to 4.5. Red meranti and kapur had highest Y-intercept. This is interesting because some members of red meranti and kapur are capable to be the tallest canopy in tropical rain forest. Most merantis have high Y-intercepts. On the contrary, third layer species have low Y-intercepts.

Comparisons of diameter growth among species

The previous discussion on growth related to initial diameter pointed out that slope may serve as a measure of rate of change of diameter growth. This rate of change supplies for a tool of comparing growth rate among species. For that reason, comparisons of growth rates among species have to use slope. It is possible to test the homogeneity of slopes by using Student's "t" test.

Table 15 summerizes results of student's "t" for dipterocarp species. Yellow meranti, White meranti, Red meranti and Bangkirai belong to the genus Shorea. The values of "t" among these species are small, showing that they do not differ statistically. That is, they have a common slope, as shown in Figure 5. They do not differ in rate of change in diameter growth but do differ in inherent growth rate. Red meranti shows the highest inherent growth rate among genus Shorea, while yellow meranti the lowest.

The slopes of the merantis (Shorea) and of keruing (Dipterocarpus) differ statistically. Figure 6 shows that the regression line of keruing crosses the regression lines of yellow meranti and bangkirai at initial diameter of 131 and 150 mm respectively.

Growth related to competition

Each individual tree in a forest has a definite amount of growing space. As a tree grows, it must compete with its neighbors. The degree of competition is determined by the ability of a tree to utilize limited resources. Numerous calculation methods for competition have been proposed and tested under a variety of conditions. In this dissertation I regarded the distance to competitors and size of competitors as most important. The greater the distance or the smaller the competitors, the more the available growing space. As a matter of convenience, I used basal area of each

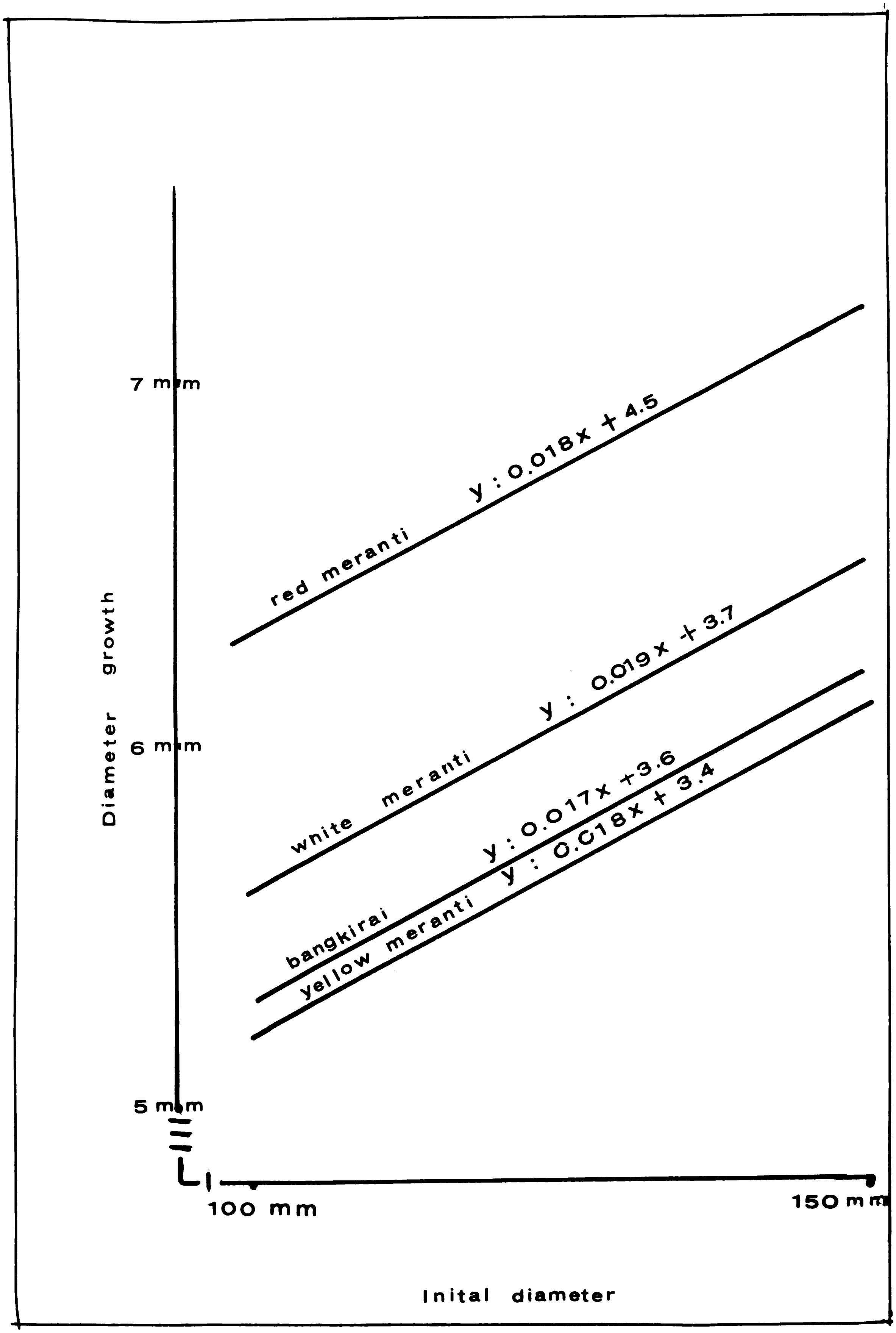
Table 15. Matrix of Student's "t" for b's for species of Dipterocarpaceae

	Yellow meranti	White meranti	Red meranti	Bangkirai	Bagtikan	Keruing	Kapur	Resak	Nyerakat
Yellow meranti	---	.22	.30	.56	1.95	2.61**	.39	2.07*	.94
White meranti		---	.54	.74	1.77	2.18	.15	2.02*	.68
Red meranti			---	.48	3.31**	3.53**	.75	2.27**	1.27
Bangkirai				---	2.53*	3.36**	1.04	2.46*	1.57
Bagtikan					---	.48	2.21*	.89	1.71
Keruing						---	2.45*	1.32	1.54
Kapur							---	2.56*	.79
Resak								---	2.38*
Nyerakat									---

1/ *Significance at the level 5%.

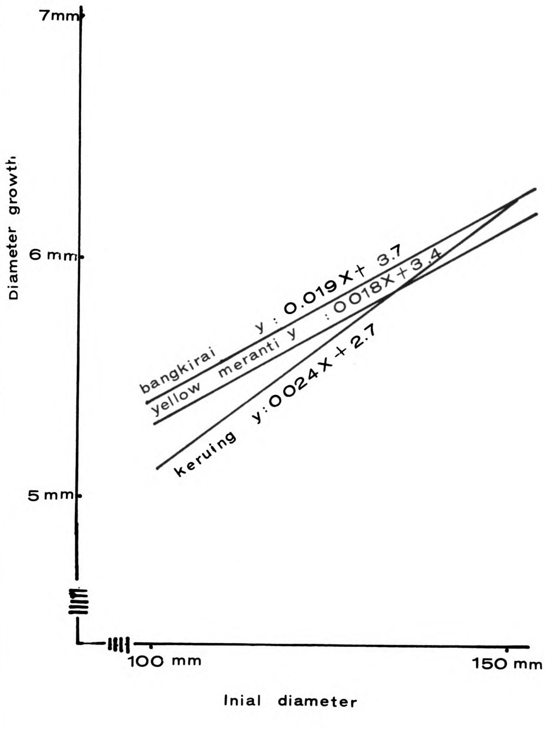
**Significance at the level 1%.

Figure 5. The four parallel regression lines of red meranti, white meranti, bangkirai and yellow meranti.



7 mm
6 mm
5 mm
Diameter growth
red meranti
y : 0.018x + 4.5
white meranti
y : 0.019x + 3.7
bangkirai
y : 0.017x + 3.6
yellow meranti
y : 0.018x + 3.4
100 mm
150 mm
Inital diameter

Figure 6. The regression line of keruing crosses regression line of yellow meranti and bangkirai.


7mm
6 mm
5 mm
Diameter growth
bangkirai y : 0.019X+ 3.7
yellow meranti y : 0.018X+3.4
keruing y:0024X+2.7
100 mm
150 mm
Inial diameter

tree's neighbors as a measure of competition, measuring basal area with a Panama Basal Area Angle Gauge.

The effect of competition on diameter growth is summarized in Table 16. In computing this table, I grouped all species. The greater the basal area of competitors and the more intense the competition, the less the diameter growth. An analysis of variance showed that the differences were statistically significant (0.1% level).

Growth related to distance from the opening

Soekotjo and Dickmann (1978) reported that opening of the canopy by logging increased survival and growth of seedlings of exportable species. Partial shade was beneficial for small seedlings, but seedlings taller than 1 m grew most rapidly in full sunlight.

The present study was designed to test diameter growth response of larger trees of dipterocarp species under different degrees of crown release. I measured the distance from sample trees to the openings caused by logging. I analyzed the data in terms of deviations from the average growth rate expected for a given species and diameter (as shown in Table 13). The results are summarized in Table 17. The closer the subject trees to the openings the more that actual diameter growth exceeded predicted diameter growth.

Table 16. The effect of competition on diameter growth

Basal area of competitors	Number of trees	Amount actual growth exceeded (or was less than) average growth for trees of the same diameter
m^2 per ha.		mm
4.6	6	11.0
6.9	5	8.0
9.2	44	4.4
11.5	103	2.1
13.8	192	.7
16.1	332	.6
18.4	865	- .4
20.7	286	-1.8

Table 17. Diameter growth of dipterocarps at varying distances from openings caused by loggings

Distance to openings	Number of trees	Amount actual growth exceeded (or was less than) average growth for trees of the same diameter
m		mm
2	7	3.8
3	34	1.3
4	65	.4
5	158	.1
6	176	- .1
7	401	- .1
8	77	- .8

The application of growth data

In the previous discussions, I tried to show growth behavior of residual stands in logged over forests of East Kalimantan. Every year concession holders have to allocate the annual cut in such a way so that no abrupt reduction in the next series of cut.

Logging is done in virgin forests. Mature and overmature trees of exportable species, diameter above 50 cm are cut. Residual stands have to function as the source of later cuts. Consequently, it is of interest to calculate period of change from one diameter to the next diameter class.

I summarized diameter changes for trees of three different initial diameters in Table 18. The calculations used in preparing Table 18 were as follows, using data from Table 13.

a. A red meranti tree growing from 200 to 300 mm grows at an average rate equal to that of a 250-mm tree, which

$$= \text{Y intercept} + (\text{rate of increase})\ \text{diameter}$$

$$= 4.5 + (.018)(250) = 9.02\ \text{mm/year}$$

b. For red meranti, the number of years needed to grow 100 mm from 200 to 300 mm

$$= \frac{100\ \text{mm}}{9.02\ \text{mm/year}} = 11\ \text{years}$$

Using the above method, I calculated the times necessary for trees to grow from 200 to 300 mm, from 300 to 400 mm,

Table 18. Years needed for trees of given present diameters to attain future diameters of 350, 450 and 550 mm.

Group of species	Initial diameter	Mean annual diameter growth	Years needed to attain diameter of		
			300 mm	400 mm	500 mm
	mm	mm	---------years----------		
Red meranti	200	9.0	11	20	28
	300	10.8		9	17
	400	12.6			8
White meranti	200	8.5	12	22	31
	300	10.3		10	19
	400	11.2			9
Yellow meranti	200	7.9	13	23	32
	300	9.7		10	19
	400	11.5			9
Bangkirai	200	7.8	13	24	34
	300	9.5		11	20
	400	11.7			9
Kapur	200	8.9	11	20	28
	300	10.9		9	17
	400	12.9			8
Bagtikan	200	8.7	12	21	28
	300	11.3		9	16
	400	13.9			7
Keruing	200	8.7	12	21	28
	300	11.1		9	16
	400	13.5			7
Resak	200	8.8	11	20	27
	300	11.7		9	16
	400	14.5			7
Nyerakat	200	8.2	12	22	30
	300	10.3		10	18
	400	12.4			8
Ulin	200	8.8	11	20	28
	300	10.9		9	17
	400	13.0			8
Nato	200	8.2	12	21	31
	300	10.6		9	18
	400	13.0			8

Table 18 (continued)

Group of species	Initial diameter	Mean annual diameter growth	Years needed to attain diameter of 300 mm	400 mm	500 mm
	mm	mm	--------years---------		
Medang	200	7.7	13	23	31
	300	10.1		10	18
	400	12.5			8
Langsat	200	8.8	11	29	--1/
	300	11.7		-	--
Lalan	200	6.5	15	25	--
	300	9.5		10	--
Temberas	200	7.2	14	24	--
	300	10.1		10	--
Kayu arang	200	6.9	15	25	--
	300	9.7		10	--
Jambu	200	7.3	14	24	--
	300	9.9		10	--
Marjelawat	200	6.8	15	26	--
	300	9.2		11	--
Banitan	200	7.3	14	24	--
	300	9.7		10	--
Mendarahan	200	6.6	15	26	--
	300	8.9		11	--
Margelang	200	6.8	15	26	--
	300	9.2		11	--
Api	200	6.3	16	28	--
	300	8.5		12	--
Kempas	200	7.0	14	25	34
	300	9.0		11	20
	400	10.9			9
Margaram	200	6.2	16	28	--
	300	8.6		12	--
Marakeladi	200	5.4	19	33	--
	300	7.0		14	--

1/ Langsat and the other eleven species at the bottom of the table are normally small trees which do not reach diameter of 500 mm.

and from 400 to 500 mm for each species. Then, assuming a constant growth rate for each growth period, I calculated the growth after periods of 15, 25 and 35 years. This method, although approximate, is probably accurate enough in view of the many uncertainties regarding competition. In this way I prepared Table 19.

<u>Estimating the amount cut in the next cutting cycle</u>

The evaluation is based on the amount cut per hectare. In the last logging, ITCI, GPI and KRTP cut on the average of 10, 9 and 11 trees per hectare respectively. In ITCI and GPI, species cut consist of red meranti, yellow meranti, white meranti and kapur, white KRTP red meranti, white meranti (kalunti), bagtikan and keruing.

On p. 59 I described the methods used to forecast future diameters of 20, 30 and 40 cm. Using the same methods, but working backwards, I calculated the present diameter of a tree which is expected to be exactly 50 cm in diameter 35 years hence. Then I counted the numbers of trees of that diameter or greater which will reach merchantable size (50 cm) in 35 years.

The results are presented in Table 20, which includes only those species which are commercially valuable at the present time. According to this table, the cut 35 years hence can be almost the same as the cut during the initial

Table 19. Future diameter growth by species and diameter on permanent plots of logged over forests in the three concessions of East Kalimantan tropical rain forests

Species	Initial diameter	Mean annual diameter growth	Diameter (mm) reached after		
			15 yrs	25 yrs	35 yrs
	mm	mm	mm		
Red meranti	250	9.0	403	530	676
	350	10.8	532	682	
	450	12.6	660		
White meranti	250	8.5	394	512	647
	350	10.3	520	658	
	450	11.2	613		
Yellow meranti	250	7.9	383	496	627
	350	9.7	514		
	450	11.5	643		
Bangkirai	250	7.8	381	482	622
	350	9.5	535		
	450	11.7	667		
Kapur	250	8.9	401	531	672
	350	10.9	535		
	450	12.9	667		
Bagtikan	250	8.7	399	537	695
	350	11.3	546	720	
	450	13.9	688		
Keruing	250	8.7	398	532	694
	350	11.1	541	709	
	450	13.5	680		
Resak	250	8.8	402	546	724
	350	11.7	554	740	
	450	14.5	701		
Nyerakat	250	8.2	389	510	651
	350	10.3	520	676	
	450	12.4	660		
Ulin	250	8.8	399		682
	350	10.9	535	694	
	450	13.0	670		

Table 19. (continued)

Species	Initial diameter	Mean annual diameter growth	Diameter (mm) reached after		
			15 yrs	25 yrs	35 yrs
	mm	mm			
Nato	250	8.2	389	506	669
	350	10.6	573	694	
	450	13.0	672		
Medang	250	7.7	380	498	642
	350	10.1	524	678	
	450	12.5	664		
Langsat	250	8.8	403	521	--[a]
	350	11.7	555	--	
Lelan	250	6.5	358	466	--[a]
	350	9.5	516	--	
Temberas	250	7.3	373		--[a]
	350	10.1	525	--	
Kayu arang	250	6.9	365	474	--[a]
	350	9.7		--	
Jambu	250	7.3	372	487	--[a]
	350	9.9	521	--	
Marjelawat	250	6.8	364	468	--[a]
	350	9.2	506	--	
Banitan	250	7.3	372	484	--[a]
	350	9.7	516	--	
Mendarahan	250	6.6	358		--[a]
	350	8.9	493	--	
Margelang	250	6.8	373	467	--[a]
	350	9.2	506	--	
Api	250	6.3	355	451	--[a]
	350	8.5	495	--	
Kempas	250	7.0	366	468	586
	350	9.0	456	632	
	450	10.9	635		
Margaram	250	6.2	354	448	--[a]
	350	8.6	498	--	

Table 19. (continued)

Species	Initial diameter	Mean annual diameter growth	Diameter (mm) reached after		
			15 yrs	25 yrs	35 yrs
	mm	mm	mm		
Marakeladi	250	5.4	341	407	--[a]
	350	7.0	466	--	

[a]Normally a small tree not reaching a diameter of 50 cm.

Table 20. Previous cuts and predicted future cuts after 35 years growth

Species and concession	Previous cut	Trees reaching harvestable size for the next 35 years cut	
		range	average
	--trees per ha--	-----trees per ha------	
ITCI concession:			
Red meranti		2 to 13	5
Yellow meranti		0 to 5	2
White meranti		0 to 3	1
Kapur		1 to 9	3
Total	10		11
GPI concession:			
Red meranti		1 to 11	6
Yellow meranti		0 to 4	2
White meranti		0 to 3	1
Kapur		0 to 3	1
Total	9		10
KRTP concession:			
Red meranti		2 to 11	3
White meranti		1 to 6	2
Bagtikan		0 to 5	1
Keruing		0 to 12	3
Total	11		9

logging. If we consider the fact that many species not logged at the present time may become merchantable in the future, the harvests 35 years hence may be even greater than those at the present time.

Limitations of previous growth studies

As was explained previously, there is a strong relationship between diameter and growth rate in all species. Unfortunately, this relationship has been ignored by many previous researchers in tropical forests. Several have chosen to present data on mean annual growth only. Such data are so dependent on diameter as to be of almost no value when comparing species or sites.

In 1956 Osmaston published a method of estimating age-diameter relationships in tropical trees without growth rings. The essential features of his method were as follows:

a. Establish permanent plots and measure diameter growth over an interval of several years.
b. Plot the growth rate over diameter and draw a smooth curve showing the relation between these two variables.
c. Using growth rates derived from the smooth curve, compute the number of years required to grow from 10 to 20 cm, 20 to 30 cm, etc.
d. Add these years together to obtain the estimated age of a mature tree of any given size, say 100 cm.

e. Divide the diameter of the mature tree by the estimated age to obtain the mean annual diameter growth during the life of that tree.

Osmaston's method appears valid and was probably the best available in 1956 when calculators were less sophisticated than in 1981. The plotting of many hundreds of data points was much more laborious than the calculation of regression equations on the TI-58 C calculator. Osmaston could have derived regression equations for the diameter-growth rate relationships from his smooth curves but did not. Such regression equations would probably not have been quite as accurate as my calculated ones, but would have been adequate for many purposes.

Sulit et al. (1962) also plotted data from Phillipine plots for growth in diameter against diameter, and drew smooth curves. They presented curves for two dipterocarp species, nato and karuing measured for 4, 22 and 37 years since logging. Their curves followed nearly straight lines for the diameter range 10-60 cm; at larger and smaller diameters the rate of diameter increase per unit of diameter decreased. Although they presented no regression equations, such equations can be estimated from their curves as follows, where Y, a, b, and x are mean annual diameter growth, Y-intercept, rate of increase in diameter growth and diameter, respectively, all measurements being in mm. Their regression equations are as follows:

$$Y = a + b X$$

$Y = 5.2 + .005 X$ for area logged 4 years previously

$Y = 0.0 + .02 X$ for areas logged 28 and 31 years respectively

He also presented such a curve (only slightly curvilinear) for all dipterocarps in virgin forest, the approximate equation being

$$Y = 0.8 + .005 X$$

The above data from Sulit et al. appear satisfactory except for the fact that they lumped data for two-several species, thus reducing the value of the data when forecasting. In another part of their paper, they reported average mean annual growth rates for 10 species. Those data are of limited value because they depend so heavily on the (unstated) diameters of the trees sampled.

Later, Wong (1973) attempted to use Osmaston's method to study growth in Sabah, Malaysia. Unfortunately his tables are so complex and poorly labelled, and the results of some of his calculations so puzzling to interpret that it is difficult to state the value of the study.

SUMMARY AND CONCLUSIONS

Tropical rain forest of East Kalimantan covers about 172,000 km^2 or about 85 percent of the total land area. It is the most important forest of Indonesia. Roughly 50 percent of Indonesian log exports are from this area.

Every year concession holders have to allocate the annual cut in such a way so that no abrupt reduction for the next series of cut.

Logging is done in virgin forests. Mature and overmature trees of exportable species above 50 cm in diameter are cut. The amount cut ranged from 3 to 22 trees per hectare. About 11 to 26 trees of exportable and locally commercial species are left per hectare. These trees consist of diameter between 200 mm and 500 mm. They have to function as the connecting link for the subsequent cut.

It has been a problem to determine the rate of growth in the tropical rain forests. Tropical rain forest trees do not produce annual rings. Whenever growth rings seem to be present, they are not clearly distinguishable. The only method for determining the growth of tree species is by laying out permanent growth plots in which the same trees are measured at interval of time.

As part of East Kalimantan Forest Service's long term forest management plan, Gadjah Mada University has established 79 one-hectare permanent growth plots. These plots were established in 1977, located in recently logged over forest throughout East Kalimantan.

In plot establishment, plot boundaries and trees along paths to the plots were carefully painted red to ensure that the plots could be found for subsequent measurement. All trees 100 mm diameter and up were numbered with aluminum tags nailed to the tree above the point of measurement (1.30 m). At the point of measurement was painted a ring at 1.30 m above ground level measured on the uphill side of the tree. For buttressed trees, the point of measurement was located at 20 cm above the buttress. Trees were identified as to species and their diameters measured with diameter tape to the nearest mm.

In 1980, I mapped all the numbered trees. I remeasured their diameters with diameter tape to the nearest mm, measured basal area of tree's competitors by the Panama Basal Area Angle Gauge, and for the dipterocarp species were measured the distances from the opening to the nearest dm.

I used program drum, a special attachment to the IBM 026 keypunch to punch more than 10,000 fortran cards. The card placed on the drum can be set up to allow the IBM 026 key-punch to duplicate automatically or skip unused columns of a card. I rearranged the contents of my file by species. I used sorting machine for this arrangement.

After the file had been rearranged by species, I performed all computations by using Texas Instrument TI Programmable 58 C calculator. I utilized this instrument because it can be afforded by people from concessions and forest service, so that they can follow my procedures. I summarized the procedure in the tabular form to make it ready to use.

I found that there is a relationship between initial diameter and diameter growth. The larger the initial diameter, the greater the growth rate. The rate of change in growth rate with diameter varied among species, varying from .018 to .030 mm growth rate per mm of diameter. So did the inherent growth rate, as measured by the Y-intercept in the growth rate - diameter regression formula. Members of the upper story of first layer generally had the most rapid growth rates for trees of small to medium diameters and the lowest rates of change in the growth rate - diameter ratio.

I also computed the effect of tree's competition on subject tree. The higher the basal area of competitors, the more intense the competition, and the greater the reduction in diameter growth of the subject tree.

I appraised diameter growth response of dipterocarp species under different crown release. My results indicated that opening by logging increased diameter growth of individual tree in residual stand.

I demonstrated how to estimate period of change from small diameter to large diameter. The data are presented in two forms: (1) the number of years needed for trees of 20, 30, etc. cm diameter to reach 30, 40, 50, etc. diameter, and (2) the diameter growth of trees of a given size during the next 15, 25, or 35 years. Such data are presented for each of several commercial species.

It is of interest to estimate the amount of cut for the next cutting cycle. To do this, I counted the numbers of trees on the study plots which will probably reach diameters of 50 cm or more in the next 35 years. On each of the three concessions it appears that the next cut will be about as heavy as the last cut.

The above discussions suggest that it is about the time to establish growth plots on every concession. These plots have to be adequate for monitoring and forecasting the operations. Cooperation between concessions - forest service - universities - and research institute will accelerate and strengthen the program.

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APPENDIX

Appendix 1. Common names used in this dissertation and their approximate scientific names and families

Common names	Scientific names	Family
Api	-	-
Bagtikan	Parashorea plicata	Dipterocarpaceae
Balau putih	Shorea lumutensis	Dipterocarpaceae
Bangkirai	Eushorea (Sub genus)	Dipterocarpaceae
Banitan	Polyalthia spp	Annonaceae
Jambu	Eugenia spp	Myrtaceae
Kapur	Dryobalanops spp	Dipterocarpaceae
Kapur tanduk	Dryobalanops lanceolata	Dipterocarpaceae
Kayu arang	Diospyros spp	Ebenaceae
Kempas	Koompassia malaccensis	Leguminosae
Keruing	Dipterocarpus spp	Dipterocarpaceae
Keruing tempurung	Dipterocarpus caudiferus	Dipterocarpaceae
Keruing hijau	Dipterocarpus grandi-florus	Dipterocarpaceae
Lalan	Santiria laevigata	Burseraceae
Langsat	Lansium spp	Meliaceae
Lempung abang	Shorea quiso	Dipterocarpaceae
Marakeladi	Polyalthia lateriflora	Annonaceae
Margaram	Linociera spp	Euphorbiaceae
Margelang	-	-
Marjelawat	-	-
Medang	Litsea spp	Lauraceae
Mendarahan		Myristicaceae
Merkabang	Shorea squamosa	Dipterocarpaceae

Appendix 1. (continued)

Common names	Scientific names	Family
Meranti almon	*Shorea almon*	Dipterocarpaceae
Meranti gisok	*Shorea gisok*	Dipterocarpaceae
Meranti merkuyung	*Shorea leptoclados*	Dipterocarpaceae
Meranti merah	*Shorea negrosensis*	Dipterocarpaceae
Meranti tembaga	*Shorea leprosula*	Dipterocarpaceae
Mersawa	*Anisoptera thurifera*	Dipterocarpaceae
Nyerakat	*Hopea* spp	Dipterocarpaceae
Nato	*Palaquium* spp	Sapotaceae
Red meranti	*Rubroshorea* (Subgenus)	Dipterocarpaceae
Resak	*Cotylelobium* spp	Dipterocarpaceae
Seraya melanti	*Shorea macroptera*	Dipterocarpacea
Temberas	*Memecylon* spp	Melastomataceae
Ulin	*Eusideroxylon zwageri*	Lauraceae
Urat mata	*Parashorea plicata*	Dipterocarpaceae
Urat mata hijau	*Parashorea tomentella*	Dipterocarpaceae
White meranti	*Anthoshorea* (Subgenus)	Dipterocarpaceae
Yellow meranti	*Richitia* (Subgenus)	Dipterocarpaceae

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