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CHAPTER 1

ENVIRONMENT

11. CLIMATE

111. Precipitation

Annual rainfall exceeds 2,500 mm throughout Sarawak and Brunei, except for a small enclave with lower precipitation in the interior of the NE. The mean annual rainfall increases from NE. to SW., and from the coastal plain to the mountainous interior (fig. 1).

Seasonality of precipitation is associated with the movement of the inter-tropical front. It is more pronounced in the SW. than in the NE. (fig. 1). The monthly rainfall is generally higher during the NE. trade from October to February. The seasonal variation is greater in the SE. and in coastal areas (fig. 2), irrespective of the amount of mean annual rainfall. The variation of daily amounts of rainfall and of sums of rainfall for shorter periods between different locations is very large, even if the distance between the locations is small. This is due to the relatively high proportion of convectional rain from rain storms.

Much of the rainfall comes from heavy rain storms. The relative intensity and frequency of rain storms are greater in the lowlands and during the SE. trades. According to JEEPS and LEONG (1965), at Kuching a rain storm with a rainfall intensity of 25 mm in 20 min. occurs once monthly on an average. In exceptional cases, rainfall may exceed 500 mm in 24 hours which causes extremely high rates of surface run-off and flooding. Storms with less than 5 mm yield are very frequent, but their total yield accounts for only a small proportion of the annual rainfall. KENWORTHY (1969) reports that such storms were common but accounted for only about 10% of total rainfall during a two-year observation period in Ulu Gombak F.R. near Kuala Lumpur. The general character of rain storms in that area is intensive storms at a rate of 25 mm per hour and above. Throughout Sarawak, the long-term mean monthly rainfall is above 100 mm. The absolute minima of recorded monthly rainfall for eight stations (fig. 2) shows that months with less than 100 mm occur at any time of the year, especially in the coastal stations, Talang-Talang islands, Miri and Bintulu. The frequency of months with less than 50 mm precipitation in three stations is shown in tab. 1. The frequency is less than one per decade in the strongly seasonal but high-rainfall station, Kuching. The frequency is more than twice as high at Baram (Marudi) where rainfall is lower but the proportion of convectional showers, higher. As a result, rainfall is less reliable and more variable. The frequency is highest at Miri with 0.32 per year. The mean annual frequency of months with less than 101 mm rainfall is 0.36 at Kuching, 1.42 at Miri, and 0.86 at Baram (Marudi). The frequency distribution of monthly rainfall shows more seasonality at Kuching than in the north. The frequency of dry months is greater in the north, where occurrences are also spread over a longer season.

SCHULZ (1960) has shown that, in the somewhat more seasonal climate of N. Surinam, sliding 30-days totals have an advantage over monthly figures for the ecological interpretation of rainfall patterns, because they avoid both the overlap of calendar-monthly records and the smoothing effect of averaging over the year. Sliding 30-days sums of rainfall were calculated for the stations Kuching Airport, Semengok F.R., Bako N.P., Miri and Long Lama. The data were supplied by the Public Works Department for the period July 1963 to May 1965. The lowest calendar-monthly rainfall during this period is 108 mm at Kuching Airport (July 1963), 101 mm at Semengok F.R. (May-July 1964), 93 mm at Miri (March 1964), and 195 mm at Long Lama (March 1964).

Only once during this period the recorded rainfall is below the 100 mm level (Miri, March, 1964, 93 mm). During the same two-year period, the 30-days sliding sum of rainfall falls below 100 mm twice at Kuching Airport, once at Semengok F.R., eight times at Bako N.P. and seven times at Miri (BRUNIG, 1969a, fig. 5). The relationship between recorded monthly rainfall and 30-days sliding sum minima is shown in tab. 2.

A calendar month in which the recorded rainfall is 100—150 mm will, in nine out of ten cases, have one or more days on which the 30-days sum falls below 100 mm. If this lasts for more than two weeks, the 30-days sum is very likely to fall below 50 mm. With the recorded monthly rainfall increasing, the chance of a 30-days sum of less than 100 mm decreases. It is about one in four if the recorded rainfall is 151 to 300 mm, and is practically nil above 300 mm.

The calculated frequencies of the 30-days sum of rainfall below 100 or 50 mm are based on a two-year observation period. The years were not unusual climatically, and the data give at least an indication of the scale and pattern at which dry periods are likely to occur in the area. The 30-days sum frequencies below 50 and 100 mm have been compared with the distribution of monthly recorded rainfall at Kuching (71 years), Miri (31 years) and Baram (22 years). The result indicates that the 30-days sum of rainfall will fall below the 100 mm level at least once or twice annually in areas with weakly seasonal heavy rainfall. This annual frequency increases to three or four in more strongly seasonal coastal areas and in areas with less than 3,000 mm annual rainfall.

On an average, once a year the 30-days sum falls below 60 mm. The corresponding MARTONNE-Index during such periods will be below 20 (margins are 64 mm at 28°C, 62 mm at 27°C and 60 mm at 26°C). This is considered to indicate an arid month.

During the two-year observation period, July 1963 to June 1965, the annual average number of days without recorded rainfall was 88 in Kuching, 155 in Bako N.P., 190 in Miri and 123 in Long Lama. The longest continuous period without rain was 20 days in Bako N.P. Again, the frequency of rainless days is higher and the tendency to prolonged rainless periods stronger during the SW monsoon and in stations close to the coast.

The general increase of rainfall towards the mountainous interior does not necessarily mean that rainfall increases with altitude. Little is known about the rainfall distribution along altitudinal gradients. ASHTON's observations in Brunei (1964c, pp.10-11), my own observations on the Merurong plateau, and RICHARDS' observation on the nearby Dulit Range (RICHARDS, 1936, p.342-343) indicate that downpours are less heavy but often more incessant on ridge crests, mountain tops, and plateaux. During several visits between 1958 and 1960, I frequently observed drizzle from low clouds on the Merurong plateau while heavy downpours from thunderstorms could be heard from the slopes 500 m below. The drizzling rain would often continue uninterruptedly for several days. Such prolonged drizzle has been frequently reported from exposed mountains at altitudes above 1,000 m (for example, by MEDWAY from the Klingkang range, Sabal F.R. (MEDWAY, 1960), and by ASHTON (1964c) from Brunei). At the same time, rainless periods are not uncommon on the mountains and bring pleasantly cool and dry weather with clear days and nights. Such periods have been observed by RICHARDS on the Dulit Range (l.c., eleven fine weather days) and myself on the Merurong plateau (six fine weather days followed by three days of drizzle on the plateau).

In addition to rainfall, effective precipitation may be obtained from fog, particularly during the more humid parts of the year. KEERFOOT (1968), in a review of the literature on mist precipitation on tropical vegetation, comes to the conclusion that mist precipitation in the humid tropics may be substantial, especially in hill locations and on fine-leaved vegetation. Unfortunately, there are no quantitative observations on mist precipitation on any type of vegetation in Sarawak and Brunei. Fog and mist drip in the humid tropics may be ecologically significant when soil moisture stress and atmospheric humidity are high (KEERFOOT, 1968). However, BAYNTON (1969) reports that extraction of water from drifting clouds by the canopy of an exposed ridge-top elfin woodland in Puerto Rico was less than 10% of the measured rainfall. Extraction by forest types with broad-leaved trees and in different topographical locations is probably much less, because the fine-leaved vegetation of elfin woodlands is much more efficient in combing fog and mist for water.

Dew fall could add to actual precipitation on stand surfaces. It could have survival value by resaturating leaf tissue in a critical situation. But usually, water is absorbed in such small amounts that it hardly contributes effectively to the daily waterbalance of trees (GAERTNER, 1963). In Sarawak, heavy dew fall often occurs during night on the canopy surface where radiative heat loss is largest. This may cause prolonged early-morning drip to the ground, but it is not known to what extent this drip is ecologically effective.

112. Temperature

The annual mean temperature is 26.7°C in Kuching and 27.2°C in Miri. The variation between monthly means is less than 2°C and synchronizes negatively with the seasonal rainfall pattern.

The mean daily maxima and minima vary about the monthly means by 3 to 5°C. Daily maxima may in very rare instances exceed 36°C. The diurnal temperature variation is about 6°C, the maximum range being about 10°C. The diurnal variation exceeds the seasonal variation of the daily means about three to five times.

The mean daily temperature drops with altitude by between 0.4 to 0.7°C for each 100 metres in the humid tropics (RICHARDS, 1964). This agrees with the rate of 0.5°C observed by ASHTON (1964, p.9) on Pagon Priok. Correspondingly, the mean annual daily temperature of the highest study sites at 1,100 to 1,200 m altitude (Bukit Skalap) is between 19 and 22°C.

humidity.

Wind affects the forest vegetation in many ways. Its most important effect in the tropical lowlands is on the heat exchange and thereby on the moisture balance of the forest stands. Wind may increase daily or periodical moisture stress, and also relieves heat stress on dry sunny days. On the other hand it may maintain adequate transpiration capacity during periods of high

113. Wind

Wind acts on plants mechanically and physiologically (WHITEHEAD, 1968). High wind velocities result in wood compression failures, break and throw of timber and damage to the roots. The interaction between canopy morphology and atmospheric exchanges will be further discussed in section 22.

Average wind speed in the area is low. Velocities and daily wind-runs are somewhat greater at the beginning, the peak and towards the end of the NE. trades. This may be important for maintaining transpiration rates during these periods of greater humidity and lower radiation. Localized tornados and frequent line-squalls connected with thunderstorms reach extremely high velocities and cause extensive break and throw of timber (ASHTON, 1964c, p.11; ANDERSON, 1964 b; BRUNIG, 1964). Even large trees can be seen swaying strongly during storms. This possibly contributes to the common compression failures and reaction wood formations in tall trees. Wind damage is of similar importance for the regeneration cycle of the forests as lightning damage (see sect. 116).

Ecologically important are the diurnally alternating land and sea breezes. The day-time sea breeze attains its greatest momentum at the time of greatest saturation deficit when first incoming radiation and somewhat later temperature are highest about noon. The breeze has considerable force near the coast, but diminishes inland where obstacles and local convective air movements absorb momentum. The penetration inland is consequently deeper on clear days with little convective cumulus formation. On such days, saturation deficits are relatively high which accentuates the physiological effect from the breeze. The diurnal valley and slope wind circulation systems act similarly on the forests. If elevation differences are great, wind speeds can be considerable and the cooling and drying effect of descending winds can be strong during clear periods.

114. Sunshine and Radiation

In 1964, radiation measurements were not yet available in Sarawak. The mean daily hours of sunshine are closely related to incident radiation. This relation can be used to estimate incident energy which is available for evapotranspiration and photosynthesis.

Mean daily hours of bright sunshine measured during 1955, 1957, and 1962 in Kuching, Bintulu, and Miri are given in tab. 3. The monthly and annual values agree reasonably with the sunshine maps of LANDSBERG (1965). The measured values differ from LANDSBERG's data in showing stronger E.-W. gradient and seasonality. The difference is large in January in Kuching due to orographic cloud-forming on coastal mountain barriers by the NE. trade. The average annual sum of hours of bright sunshine is 1,810 at Kuching, 2,190 at Bintulu, and 2,410 at Miri, In Uganda, RIJKS and HUXLEY (1964) measured 2,263 hours of bright sunshine during a year in which incident total solar and sky radiation at ground level were 151.4 Kcal/cm^2.

Tab. 15 of the Smithonian Meteorological Tables (1951) gives the regression of the ratio (average radiation to potential radiation received by a horizontal ground surface) on the ratio (actual hours of bright sunshine to potential hours of sunshine) for 11 stations in the U.S.A. This regression is likely to produce an over-estimate of ground radiation for Sarawak, because the average cloud system in Sarawak has a greater proportion of thick stratocumulus clouds. These clouds have relatively low transmission and higher reflection ratios than the average cloud system in the U.S.A. Considering this, the estimated radiation ratios for Kuching are 0.49 at the peak of the NE. trade (January), 0.69 during the peak of the SW. trade (June-August), and 0.61 for the year. The corresponding ratios at Miri are 0.63 (January), 0.76 (April-May), and 0.70 (year). The annual average ratio at Bintulu is 0.66.

With these data, an approximation of the average total annual solar radiation received by a horizontal surface at the ground is possible from tables 133 to 135, Smithonian Meteorological Tables, and from data given by SELLERS (1965, pp. 19-23 and fig.7). The estimate is 146 Kly at Kuching, 157 Kly at Bintulu, and 168 Kly at Miri. The latter are higher than the values on the maps by LANDSBERG et al. (1965). Brunei is on the map in the 135 Kcal/cm^2 belt and West Sarawak just above 140 Kcal/cm^2. WYCHERLEY (in litt., 1969) reported actually measured values of 142 Kly p.a. at Kuching, which agrees closely with my estimate and the LANDSBERG map. The disagreement between estimate and maps for the NE. may be due to an under-estimate of seasonality and sunshine by LANDSBERG.

RIJKS and HUXLEY (1964) measured 151.4 Kly p.a. total incoming radiation for 2,263 hours of bright sunshine in Uganda. Bintulu has 2,190 hours of bright sunshine and the estimated total annual radiation is 157 Kcal/cm^2. The difference is -3% for hours of bright sunshine and $+ 3.6\%$ for radiation. The world map of average annual solar radiation on a horizontal surface at the ground by BUDYKO (BUDYKO, 1963, reproduced by SELLERS, 1965, fig.8 on p.25) puts the whole area of Brunei and Sarawak just within the 120 Kcal/cm² line, which would seem rather low.

We may conclude, that the average annual total solar radiation received by a horizontal surface at the ground is about 140 Kly in SW. Sarawak and increases gradually to just over 160 Kly in the Brunei area. These values are slightly higher and show a much stronger gradient from SW. to NE. than on the two radiation maps. The under-estimate of the gradient on the maps is probably caused by the failure to recognize the seasonally very heavy cloudiness in SW. Sarawak.

115. Cloudiness

Cloud formation shows typically the following diurnal rhythm. In the early morning, humidity is high and, especially in flat valleys, low mist or fog is frequent and often dense about sunrise when gentle down-valley wind still prevails. The mist raises to a low cloud stratum about 7 or 8 a.m. Later, the sun penetrates and dissolves the low-cloud stratum usually before 10 a.m.

Any high-level stratus clouds, usually remnants of thunderstorms of the preceding day, will normally disappear before noon. Soon after about 10 a.m., wind direction changes. Sea breezes, up-valley or up-slope winds develop locally and interact with the over-all trade wind pattern. The forced convectional rise of the air and local convergences lead to the formation of low cumuli before noon, first above hills and mountain ranges. Cumulus formation is also rapid above dense high forest. Often cumulus fields mark the locations of large tracts of primary upland forests, while large river courses, coastal wet-padi and secondary bush remain clear much longer. Just before noon, short but intensive turbulences develop in the air layer between the forest canopy and the developing cumulus formation, several hundred metres above. This is particularly noticeable above the larger areas of peatswamp forest in the coastal plain where the sea breeze retains its speed for longer distances inland.

It is not unusual at this time of the day for long cloud plumes to develop in the lee of isolated but tall coastal mountains. A particularly impressive plume frequently forms at the top of Santubong mountain on days, when the sea breeze has great strength, height and humidity. Regular cumulus and plume formations at a time when potential evapotranspiration and incoming radiation rates are highest can be expected to have a strong effect on the vegetation on the tops and in the lee of the mountains which initiate these clouds.

After midday the low cumuli layer gives rise locally to tall and massive cumulus-nimbus clouds which may develop into heavy thunderstorms, often preceded by violent line-squalls. The thunderstorms frequently start above the slopes of the larger mountains and spread into the adjacent lowland.

The time of day of highest rainfall frequency varies between seasons and localities (SEAL, 1958). The generalized afternoon shower pattern is certainly common and rather typical, but variations, such as incessant and sometimes heavy rains through several days and predominantly night thunderstorms, are not uncommon especially during the NE. trade. Also, as described earlier, rainfall may not at all develop even if sea breezes or up-valley winds are strong. This may happen for several days or weeks and cause localized droughts.

116. Thunderstorms

Thunderstorms are frequent and often extremely heavy. Peak frequencies occur at the beginning and towards the end of the SW. trade and during the December-lull of the NE. trade (tab. 3). During peak frequency periods, any location can expect a thunderstorm to occur every third day. During thunderstorms, discharges are violent and almost continuous, but fortunately only a relatively small proportion of the discharges is between atmosphere and ground. But still, ground hits are sufficiently frequent and the resulting primary and secondary damages to forest stands are severe and extensive enough to make lightning one of the major environmental factors acting on the tropical forest ecosystem. It has been reported that lightning significantly affects the regeneration cycle of the forest vegetation (ANDERSON, 1964b; BRUNIG, 1964), and its effects may be accentuated by subsequent wind throw.

117. Atmospheric Humidity, Evapotranspiration and Waterbalance

117.1 Atmospheric Humidity

The annual mean relative humidity in the open at Kuching Airport is 98% at 6 a.m. and about 70% at 2 p.m. (SEAL, 1958). Variation from day to day and between seasons is considerable and the climate can hardly be characterized as having a uniformly high relative humidity. A calculation of saturation deficits from meteorological records for one year shows a stronger seasonality of the values for Kuching than for Miri (fig. 3a). The mean saturation deficit at 2 p.m., expressed in units vapour pressure, is fairly high throughout the year at both stations. Absolute monthly maxima of saturation deficit at 2 p.m. in Kuching is shown in fig. 3b. The range between minima and maxima is very small at 8 a.m. It increases steeply to 2 p.m., when the recorded range lies between about 8 millibar (July, 1963) and 26 millibar (July, 1964). The maxima represents conditions which are common during fine weather periods with low 30-days sum of rainfall. These values are not very different from those which characterize climates which are considered dry and very different from what is regarded an ever-wet equatorial rain forest climate.

RICHARDS (1964, pp. 169-170) produces evidence of similar diurnal changes of the saturation deficit for two days in Nigeria. The maximum saturation deficit at 2 p.m. is over 12 mm in the top-canopy of a rain forest. The undergrowth stratum experiences a marked rise of saturation deficit only on the day in the dry season.

117.2 Evaporation and Potential Evapotranspiration

The rate of evapotranspiration in relation to water availability and water transport capacity of trees is of prime importance for the survival and growth of individual trees.

Mean daily evaporation from class A pans in the open during 1963-1965 has been 5.4 mm per day (1,970 mm per year) at Kuching and at Miri. The monthly minimum was 4.7 mm per day in January, the maxima 6.1 mm per day in April and July. This equalled 46% of the mean daily rainfall during the period in Kuching and 66% in Miri. Monthly evaporation exceeded monthly rainfall several times, especially during the SE. trade. The pan evaporation of 1,970 mm compares with a potential evaporation of 1,740 mm (Miri) and 2,016 mm (Kuching) calculated from the regression on sunshine hours (BRUNIG, 1969a). The differences are relatively small. WYCHERLEY (1969) calculated potential evaporation after PENMAN from five years' standard meteorological records for Kuala Lumpur and from three years' solar radiation measurements:

Hours bright sunshine per day	6.5
Calories per cm^2 per day	435
Evaporation in mm per day	4.93
Precipitation in mm per day	6.94

The annual evaporation is about 1,800 mm and the rainfall 2,530 mm. WYCHERLEY (1969) gave the following data for Kuching:

Hours bright sunshine per day	5.1
Calories per cm² per day	390
Evaporation in mm per day	4.33
Precipitation in mm per day	10.51

The annual evaporation is 1,560 mm and the rainfall 3,780 mm.

Evaporation rates are affected by temperature of the evaporating surface, temperature and moisture gradients, and mass exchanges within the system, which in turn are altered as evaporation goes on. Class A evaporation pans differ in all these respects from natural evaporating bodies such as lakes (SELLERS, 1967, pp. 157-162) or vegetation. Pan evaporation is as a rule higher than that from lakes, but the ratio varies considerably with exposure of the pan and with size, depth, and environment of the lake. The common statement that rain forest evapotranspiration equals evaporation from open water surfaces as long as water supply is ample does not, therefore, help in estimating rain forest evapotranspiration.

HOLDRIDGE (1967, fig. 6) for example, assumes that evaporation from fresh water lakes is, by a defined and general curvi-linear relationship, higher than the evapotranspiration from climatic climax plant formations in the humid to semi-parched humidity provinces and lower in the perhumid to saturated humidity provinces. But such simple relationship probably does not exist either for lakes or for the vegetation.

117.3 Water Consumption in Forests

A very simple approach to express the relation between amounts of water supplied from precipitation and discharged through evapotranspiration is the MARTONNE index. This index expresses in a more direct manner than HOLDRIDGE's formula the degree of aridity as a relation of monthly or annual temperature to rainfall. Index values below 20 indicate arid conditions during the period, those above 60 wet or humid conditions. The mean monthly and the mean annual index values for Kuching, Miri and Marudi (Baram) are shown in tab. 1. In all cases, the values exceed 60, indicating ample water supply throughout the year.

Calculation of monthly index values from monthly rainfall statistics for Sarawak (Department of Civil Aviation and Meteorological Services, 1961) shows for Kuching that during seventy-two recorded years between 1875 and 1957, the monthly value of the MARTONNE index fell five times below 20, with a low of 7.3 in August 1877. At Miri the monthly index dropped below 20 thirteen times during thirty-one recorded years between 1917 and 1957, with a low of 1.0. If 30-days sum of rainfall were used for the calculation instead of monthly records, the frequency of arid periods would be greatly increased.

The marginal index value of 20 corresponds to 60.8 mm precipitation at a mean monthly temperature of 26.5°C to 61.7 mm at 27.0°C, and to 62.5 mm at 27.5°C. The annual probability that 30-days sum fall below these marginal values lies between 1 and 2 for most lowland sites in the area. The probability is therefore almost 1.0, that at least once per year arid conditions according to the MARTONNE index occur. These arid conditions may prevail for periods of several weeks (tab. 2, Bako N.P.).

Evapotranspiration rates of low vegetation from lysimeters are generally lower than the evaporation rates from Class A pans at the same site. But they are higher than from soil or water surfaces in lysimeter containers. The differences can be attributed to the differences of the roughness and exposure of the evaporating surfaces (SELLERS, 1967, pp. 165-166). Isolated clumps of vegetation may, as a result of the large surface exposed to radiation, attain very high evapotranspiration rates. The highest recorded daily rate is 14.66 mm from an isolated stand on Sudan grass, which consumed 866 langleys radiative energy, of which 90% could be obtained by the exposed and large surface from radiation, while only 10% needed to be supplied from the heat content of the air (VAN BAVEL and FRITSCHEN, cited by SELLERS, 1967, p. 166).

Little is known of the effect of leaf morphology, crown structure, exposure and canopy topography on evapotranspiration in tropical rain forests. The above example of an extremely high rate of evapotranspiration makes it likely that similarly high rates of potential evapotranspiration are possible for single or groups of emergent trees in tropical rain forests. The large surface exposed to radiation of such emergent units will lead to high rates of absorption and to correspondingly high rates of potential evapotranspiration. Absorption of advected energy and increase of air turbulence by emergent elements will add to the radiation effect on potential evapotranspiration rates.

The rates of potential evapotranspiration from climatic climax formations can be assessed from climatological data, because the rates are closely related to the radiation balance of the site. If radiation measurements are not available, the hours of bright sunshine can be used, as shown in sect. 114, to estimate the relative amounts of radiation received by a site. Evaporation rates have been successfully correlated to the annual mean daily hours of bright sunshine in Malaya (NIEUWOLT, 1965). Using NIEUWOLT's regression for the Singapore climate, evaporation should be at Kuching 1,880 mm in 1957 and 1,660 mm in 1962, and at Miri 2,020 mm in 1957, and 1,930 mm in 1962. Both stations had a recorded evaporation from Class A pans of 1,970 mm in 1957.

The agreement between the values is reasonably close. We may conclude that in Sarawak the actual annual evaporation from an open surface of shallow water, such as an evaporation pan, will lie somewhere between 1,600 mm and 2,100 mm, with a moderate gradient sloping west to east, but strong variations from month to month and day to day, in accordance with the variation of saturation deficits (fig. 4) and wind speeds (sect. 113). The relatively high observed pan evaporation in comparison to the calculated value for Kuching is most likely due to the high degree of exposure of the site of the meteorological station at the airport.

HOLDRIDGE (1967) uses biotemperature, instead of radiation, to compute potential and actual evapotranspiration of vegetation. The biotemperature for Sarawak is 26.7°C in Kuching and 27.2°C in Miri. This corresponds to 1,573 mm and 1,603 mm potential evapotranspiration respectively. According to HOLDRIDGE's calculations (1.c., fig. 6) the actual evaporation from vegetation and soil would be 46% of the potential evaporation in either station, and the transpiration 47% in Kuching and 45% in Miri. The total actual evapotranspiration would consequently be $46 + 47 = 93\%$ (1,463 mm) in Kuching, and $46 + 45 = 91\%$ (1,460 mm) in Miri. Total rainfall is lower at Miri and consequently water supply is less ample. Accordingly, HOLDRIDGE'S formula gives a lower rate of actual transpiration for Miri. On the whole, the HOLDRIDGE estimate seems to be rather low.

THORNTHWAITE and MATHER (1957) have developed a method of waterbalancing which has been widely used in tropical areas. The monthly waterbalances for lowland Mixed Dipterocarp forests at Kuching are given in tab. 4. The potential evaporation is related to the monthly mean daily temperature, which results in daily rates between 3.9 mm (January) and 4.9 mm (June). NIEUWOLT (1965) pointed out for Malaya and Singapore, that

THORNTHWAITE's formula gives values which appear too low for periods of ample sunshine and too high if sunshine is much below five hours per day. The values for January and June above support this view. The total annual potential evaporation according to THORNTHWAITE's formula is 1,728 mm which is very close to, but somewhat lower than the actually observed evaporation at Kuching.

All monthly balances in tab. 4 show a surplus of precipitation over potential evaporation. The surplus varies between 37 mm in July and 538 mm in January. Consequently, neither the soil moisture store would be drawn upon, nor would the tree transpiration be impeded. Consequently, the actual evaporation, including transpiration from the vegetation, equals the potential in each month, no deficit occurs, and a substantial amount of water is discharged into the drainage each month. However, the waterbalance looks significantly less favourable if instead of long-term means, a series of single monthly observations or 30-days sliding sum of rainfall are used.

The actual transpiration rate is within the range of air-temperatures, a function of the vapour pressure gradient from the more or less saturated leaf surface to the ambient air. Wind may reduce transpiration at higher velocities by cooling, but increases it at relatively low velocities by removing humid air from the surface vicinity. The generally low-speed breezes in Sarawak would be expected to effectively increase transpiration rates, especially from broad leaves, in tall forest vegetation. Tall crops with irregular surface may transpire more than the calculated potential evaporation (WIJK and BORGHORST, 1963). KENWORTHY (1970) used measured specific transpiration rates per unit area of leaf and sap flow velocity to calculate transpiration rates of trees. Accordingly, an emergent *Shorea curtisii* tree with LAI of 2.5 transpires 60% of the total transpiration of the canopy. This clearly demonstrates the important role of emergent elements in stand transpiration. According to LUTZKE (1969) estimates of tall-forest evapotranspiration from heat balances may be low by 14% if the air temperature instead of the potential temperature is used.

COSTER (cit. WALTER, 1960) assumes an annual evapotranspiration of 2,300 to 3,000 mm for tree plantations in tropical lowlands with 4,000 mm annual rainfall. This estimate appears to be somewhat high. Only 1,000 to 1,700 mm would be available for surface run-off and groundwater discharge which seems low for the very intensive and highly developed drainage systems in the equatorial tropics.

We may conclude that annual evapotranspiration rates from tall Mixed Dipterocarp forests with irregular surface is at least 1,700 mm, and possibly near 2,000 mm. In the latter case, the seasonal range of daily rates is 4.5 (Jan.-February) to 5.5 mm (June-July). This agrees closely with the annual rates of transpiration of 1,350 mm and evaporation of 450 to 500 mm estimated by KENWORTHY (1970) from the waterbalance during a two-year observation period in a tight water catchment under Hill Dipterocarp forest in Selangor.

Forests on relatively infertile sites are lower and simpler structured. Using HOLDRIDGE's assumed relationship between stand height, structure and evaporativity, and setting MDF (7 layers, H = 45 m) at 1.0 (2,000 mm), well-structured (6 layers, H = 40 m) kerangas forests would evapotranspire at a rate of 0.76 (1,520 mm), the poorest type of kerangas forests on SHP soil (5 layers, H = 28 m) at a rate of 0.45 (900 mm), and on PB soil in the lowlands (5 layers, H = 22 m) at a rate of 0.37 (740 mm). The average evapotranspiration from kerangas forests with a smooth canopy would be 1,200 mm, of which about 400 mm would be evaporation of intercepted precipitation and 800 mm transpiration. On better, well water-supplied soils, stand structure and evapotranspiration rates of kerangas forests will approach those of the lowand MDF.

HOLDRIDGE (1967) calculated the actual evapotranspiration from any land vegetation by multiplying the constant 29.47 with the top height in metres and with the climax association number. For well-structured kerangas forests with six poorly defined layers (see sect. 225) compared to seven in MDF and a top height of 40 m, the actual evapotranspiration would be calculated as 1,010 mm. The value for transitional types to Dipterocarp forests would be 1,475 mm and for the poorest members of the kerangas forests on SHP soil 570 mm. The results seem reasonable but somewhat too low.

The peripheral Mixed PSF (7 layers, H = 40 m) would accordingly evapotranspire at a rate of about 0.9 (1,800 mm), the tall *Shorea albida*-association, type 3.62, (5 layers, H = 50 m) about 0.8 (1,600 mm), the *Shorea albida* consociation, type 3.71 (4 layers, H = 50 m) about 0.7 (1,400 mm), and the interior-closed *Shorea albida*-padang forest, type 3.81 — 3.83 (4 layers, H = 39 m) about 0.5 (1,000 mm). For type numbers see Sarawak Inventory Code, 1961, and BRUNIG (1969c).

118. Climate Type

KOEPPEN (1923; also BLUETHGEN, 1964) includes the area in his type Afw'i; continuously wet, isotherm tropical rain forests climate with more than 60 mm rainfall in each month of the year and a weak peak of rainfall in early winter. LAUER's (1952) type Taefd: tropical equatorial continuously wet climate with twelve humid months according to the MARTONNE index agrees perfectly with the climate of the area as it is indicated by the official weather records. TROLL (1964) allocates the whole area to his tropical zone V 1: tropical rain climates with no or only short interruptions of the rainy period with at least nine and a half humid months.

The 1948 THORNTHWAITE classification (THORNTHWAITE and HARE, 1955) allocates the area to the megathermal province with a potential evapotranspiration over 1,140 mm (tab. 4) and the perhumid moisture province with a moisture index above 100 and with a large moisture surplus in each month of the year. HOLDRIDGE's (1967) life zone classification allocates the lowlands in the area according to the mean annual biotemperature and precipitation to the tropical moist and wet forest biomes in the humid to perhumid humidity provinces respectively. HOLDRIDGE confines true rain forests to much wetter humidity provinces than most other authors. True rain forests occur in the tropical lowlands only if the annual precipitation is more than 7,000 to 8,000 mm. This view agrees with the fact that in the lowlands of Sarawak, with a biotemperature of 28 °C, ecologically significant dry spells occur throughout the 2,000 — 5,000 mm rainfall zones. It would be inappropriate to classify forests in these zones as rain forests and the climate as rain forest climate, if this term implies that rain is a continuously and ample available environmental factor and, conversely, absence of rain with subsequent drought conditions not a typical feature of the ecosystem.

The same objection would apply to SCHIMPER's (1903) wet evergreen (rain) forest zone, which includes Sarawak and Brunei. SCHIMPER defines this zone as receiving more than 2,030 mm annual rainfall with consequently no or little water deficit at any season of the year. We have seen, that significant water deficits occur, with frequencies related to season, even in the 4,000 mm rainfall areas.

The rainfall and temperature characteristics of N. Sarawak and Brunei correspond closely to those described by WATTS (1955) for Singapore. The statement, however, that the Singapore climate type is truly humid and characterized by water surpluses throughout the year (NIEUWOLT, 1965; BLUMENSTOCK, 1958) is at least not true for the lowlands of Sarawak and Brunei. NIEUWOLT himself reports in a later publication (1966) that exceptionally dry years may occur throughout or anywhere within the Malayan equatorial lowland climatic zone. The more seasonal lowland climate of coastal S. Sarawak closely resembles that to the SE. coast of Malaya (RAMAGE, 1964; DALE, 1960; NIEUWOLT, 1965).

RICHARDS (1964) remarks that drought years are by no means unknown even far into the equatorial forest belt which extends 3° on either side of the climatic equator. But he considers drought condition in this belt as an exceptional event. He classifies the climate as non-seasonal, which he exemplifies by the hythergraph for Singapore (l.c., fig. 20). He later cautions, however, that "there are probably no land surfaces within the tropics with a complete non-seasonal rainfall". The most non-seasonal rainfall pattern within the equatorial belt of all stations included in table 12 of his book have Pontianak (Kalimantan) and Sandakan (Sabah). Both stations have similar climates as Kuching and Miri respectively.

WATTS (1955) finds only a small seasonal variation of rainfall at Singapore. Consequently, he considers that the growth of plants is practically continuous throughout the year and the periodicity of certain species unrelated to rainfall. But he also comments, that rainfall is not regular enough for vegetable farming and that during dry spells intensive watering is necessary, while root-drowning occurs during long periods of heavy rain.

BLUMENSTOCK (1958) regarded Singapore as a "good wet location" with only two months with less than 50 mm rainfall between 1931 and 1939. DALE found the monthly coefficient of rainfall variation to be 20-50% for SE. Malaya, compared with an annual variation coefficient of 10-15%. At Mersing on the SE. Malayan coast, the annual frequency of dry spells, defined as the sum of consecutive days with less than 0.01 in. rainfall, during twenty-four years has been 1.0 for fourteen days and more, 1.3 for ten days and more, and 4.2 for seven days and more (DALE, 1960). The corresponding figures for two years (1963-1965) at Kuching are 0.13, 0.64, and 3.6 respectively (BRUNIG, 1966).

Concluding, we may state that the diurnal and seasonal humidity features are very similar between the Singapore and N. Sarawak climates, and between the SE. coast of Malaya and the Kuching climates respectively. We also may conclude that a continuously wet lowland rain forest climate does not occur in the lowlands of Sarawak and Brunei, if the criteria are based on ecological factors rather than monthly and annual means of meteorological observations.

We have defined ecologically dry spells as consecutive days for which the sliding sum of P is less than 50 mm. Such spells occur regularly, and seasonally more frequently, throughout the study area. We therefore can confirm the opinion of RICHARDS that even in these most uniform equatorial climates, as defined by monthly averages, sufficiently large variability and seasonality of rainfall, sunshine and wind exist to create a seasonal pattern of ecologically significant moisture deficits.

The regular diurnal variation is much larger than the seasonal variation of temperature and humidity of air. Diurnal variation of precipitation is less pronounced and regular but still present in any season of the year (RAMAGE, 1964; DALE, 1960). The predominantly convectional origin of rainfall throughout most of the year produces a very strong variability of the spatial distribution of rainfall especially if short periods of time are considered.

The generalized "typical" seasonal and diurnal marches of weather parameters agree well with the description of rain forest climates by RICHARDS (1964) and SCHULZ (1960, pp. 14-99). The annual and diurnal variation is within the limits given by RIEHL (1954), who cites lower variability values only for very few areas within the tropics at the eastern edge of the Congo basin, at the west coast of Sumatra and the west coast of Malaya, Thailand and SE. Burma.

In Sarawak and Brunei little is known about the nature of climate in the upper lowland and submontane zones and about the microclimate on the exposed ridges and high plateaux. The few available observations indicate a generally higher and locally more gentle rainfall combined with lower temperature at higher altitude. Insolation, wind speed and humidity on bright days appear very similar to those described for the lowland climate. The effect of exposure and fog and mist frequency on radiation and waterbalances may be considerable at any altitude, but there is no information available on this.

In conclusion, we may therefore classify the lowland climate in Sarawak and Brunei broadly as wet equatorial lowland climate with low annual and monthly variability and weak seasonality, with rainfall predominantly from convectional showers and with dry spells of irregular length which are seasonally more frequent. Towards the upper limit of lowland forests the climate grades into a submontane equatorial diurnal climate with more gentle, prolonged rainfall and yet unknown seasonality pattern.

12. GEOLOGY

121. History and Pattern

121.1 The Geological History of Kerangas Sites

Sarawak is built of rocks which range in age from probably pre-Permian to Recent. It consists of two areas which had geologically dissimilar histories. The part west of the Batang Lupar is related to the continental part of SE. Asia and has been relatively stable throughout the Tertiary. The part north of the Batang Lupar is composed mostly of upper cretaceous and tertiary rocks and has been tectonically active during the periods when these sediments were accumulated to great thickness in the marine trough which has been named the North-west Borneo Geosyncline (WOLFENDEN, 1961a).

According to LIECHTI (1960) the whole area of Sarawak and Brunei has been part of the ancient Sunda shield which forms an extension of the Asian land mass and includes the Malayan peninsula, parts of Sumatra and the continental Sunda shelf below the South China Sea. The shield was formed of igneous and metamorphosed rocks during the Palaeozoic.

During the Mesozoic, periods of intensive folding and volcanic activity alternated with periods of relative inactivity but strong erosion of the uplifted land. The eroded material was sedimented in shallow marine troughs to the north and north-east. In the upper cretaceous most of the present Sarawak and Brunei areas were part of the great NW. Borneo geosyncline and covered by a shallow sea. Geosynclinal rocks in Pueh F.R., which today carry kerangas, have been accumulated in this trough. The continued heavy erosion of the uplifted landscape produced a very great thickness of the late cretaceous and tertiary sediments. During this whole time, only a small part of SW. Sarawak with remnants of the ancient Sunda shield remained above sea level.

During the middle and upper Tertiary, lifting of the geosyncline proceeded from SW. to NE. and exposed large tracts of marine and littoral deposits. The Oligocene saw the creation of the kerangas-bearing Plateau sandstone and Silantek formations in SW. Sarawak and of the more argillaceous Nyalau formation in central Sarawak. During the Miocene and Pliocene the formations Seria, Lambir, Belait, and Miri were accumulated in isolated sedimentation troughs in the north. Subsequently, during the Pliocene and early Pleistocene two large movements lifted the present upland part of Sarawak and Brunei above sea level. The newly formed land mass was subsequently subjected to three strong cenozoic erosion cycles. During late Tertiary to early Pleistocene the land connection between Borneo and Malaya was finally severed.

During the Pliocene and Quarternary, basalt, andesite, dacite, and rhyodacite lavas were extruded in central Sarawak. They now form conspicuous plateaux with eroded relics of volcanoes (WOLFENDEN, 1961a). The hypersthene dacite tuff plateaux of the Usun Apau massif with kerangas-like forest vegetation (BECKETT and HOPKINSON, 1961) belong to this formation.

The erosion cycles of the later Tertiary and early Quarternary produced a low-lying, undulating peneplain, which was subsequently uplifted and tilted, dipping north. Subsequently heavy erosion set in and removed the peneplain material except for very few, scattered and small remnants which remain perched in the underlying and uplifted tertiary formations.

The second, mid-pleistocene erosion cycle, which LIECHTI (1960) named Jerudong cycle, was initiated by a revival of strong erosion consequent to uplifting. The cycle ends with the formation of a mature landscape with broad valleys, which subsequently was subjected to a slight deformation.

The third erosion cycle is the holocene alluvial cycle which cuts deeply into the sediments of the Jerudong cycle. Of its deposits, only few and scattered terrace remnants have survived erosion and raising sea-level. The subsequent recent cycle and sedimentation actively continues to the present times. This cycle is responsible for the formation of the present extensive coastal alluvial and littoral plains with their varied geomorphology. The landform is a complex of low terraces, riparian flood plains, alluvial peaty swamps and recent mangrove swamps and sandy beaches, locally dominated by isolated relics and outcrops of older formations.

121.2 The Pattern of Geological Formations Carrying Kerangas

In western Sarawak, the strongly folded relics of the ancient continental Sunda shield, together with more recent formations, produce a very complex and varied picture of geological conditions. The most extensive kerangas sites are on the Plateau sandstone, which covers large tracts in the lowlands of the coastal Pueh F.R., Sempadi F.R., Bako N.P. and Santubong peninsula. In the interior, Plateau sandstone forms extensive and prominent plateaux and ranges which also carry much kerangas forests.

In Pueh F.R., the Plateau sandstone formation consists of feldspathic sandstone with rare partings of soft light-grey shale. It dips gently to moderately steeply from the flanks of the adamellitic (WOLFENDEN, 1961a) Pueh range until it subsides below the coastal and inland terraces in the north. The formation had been accumulated in a far-western extension of the NW. Borneo geosyncline, probably in late Cretaceous. According to HAILE (1961) there is some doubt whether the formation in this area is really true Plateau sandstone.

The tertiary Silantek formation forms a narrow belt at the foothill of the Klingkang Range and covers part of the Sabal F.R. The more arenaceous parent material of this formation on gentle slopes produced kerangas soils.

Between the two tertiary formations and the present beach remnants of pleistocene and holocene land surface are scattered in the form of irregularly shaped but always low mounds, ridges and free or encased terraces. These landforms often border present peatswamps beneath which they may dip in areas which subside. Terraces are scattered throughout W. Sarawak, but are particularly common and widely spread in the western part of Sempadi F.R., in the northern half of Pueh F.R., and in the low-lying lands in and around Siru F.R. Terraces may occur singly, scattered or in groups or chains which mark the old line or valley side. Locally, isolated terraces are found in the centre of deltaic mangrove, for example, in Sarawak Mangrove F.R.

The central part of Sarawak consists largely of late mesozoic and lower tertiary clay-rich sediments with some volcanic extrusions and intrusions. Only locally and rarely remnants of early pleistocene terraces with kerangas are found in this part.

The area further north has been formed by the uplift of the isolated miocene and pliocene sedimentation trough in which rather varied argillaceous or arenaceous materials had been deposited. The more important kerangas-bearing formations in Brunei and N. Sarawak are the miocene Belait and Meligan formations. The younger Belait formation consists of thick-bedded sandstone, which contains only little interlaminated clay and shale at the base and is mostly argillaceous near the top. The impressive Merurong plateaux, the vast synclinal Belait basin and the Sagan cuesta are formed by the Belait formation.

The older Meligan formation is predominantly thick-bedded sandstone and forms high table lands and weakly synclinal massifs which cover the northernmost part of the country from the Temburong-Trusan area to beyond the border with Sabah.

In northern Sarawak and in Brunei, few remnants of early pleistocene terraces cap the summits of tertiary formations by perching on the edges of synclinal sandstone cuestas. These terraces have been strongly tilted and dissected as a result of pleistocene orogeny.

The terraces of the older Jerudong subcycle lie about 60 m lower than the peneplain remnants. They frequently occur as encased, usually level to almost level and moderately dissected terraces along the sides of the present valley bottoms. Again 15 m lower are the otherwise morphologically similar terraces of the younger Jerudong subcycle. The terraces of both Jerudong cycles are scattered throughout Brunei and N. Sarawak. Their altitude ranges from about 250 m between the Jelalong and Melinau rivers in the interior to about 20 m on the coast. Jerudong terraces are particularly common in the upper Belait and the Medalam-Melinau drainages.

The terraces of the early Alluvial cycle lie about 3 to 6 m below level of lowest Jerudong terraces and about 5 to 7 m above the present alluvium. They are flat to moderately undulating low terraces which vary much in size and shape.

The landform of the present alluvium differs according to geologic origin of the environment. In the hilly or mountainous country of the interior the alluvium exists in two forms. Remnants of old erosion surfaces form broad and gentle valleys. More recent formations form narrow, steep and often deeply cut and steep-sided valleys with rapid-flowing rivers. In the former, kerangas appears to be common in the upper reaches of the Rejang (map. 2). Unfortunately, these areas could not be studied on the ground but only from the air and on aerial photographs.

The recent valleys broaden where the landscape opens to the coastal plain. It is in this zone that terraces of pleistocene to early alluvial origin are a particularly characteristic feature of the alluvial landscape. The coastal alluvial plain forms a discontinuous belt of widely varying width and irregular shape. It is largely covered by peatswamp, bordered by riparian fringes, sand terraces and mangrove formations. Locally tertiary sandstone outcrops raise a few metres to several hundred metres above the surrounding lowland of peatswamps, terraces and recent riparian fringes. The tertiary sandstone forms kerangas-bearing table lands or long ridges with kerangas on dip-slopes and on the crest.

The present coastline is either mangrove or sandy beach, depending on local tectonic movements and conditions of erosion and sedimentation. In areas of relative lifting, the recent beach formations are in the process of terrace-building. These terraces will be morphologically similar to the terraces of the early alluvial cycle and consist mostly of unconsolidated sand, often resting on older mangrove clay material. In areas of subsidence, but with active sedimentation of mineral parent material along the coast-line and rivers, long but usually narrow terraces may develop which alternate with depressions in which peat will develop. Further subsidence will eventually drown the terraces below the rising peat, unless floods continue to add mineral matter to the terrace surface which may happen along rivers.

[illegible] Parent Materials and Topography

The various geological formations differ characteristically and strongly in parent materials. The variation together with the effects of the described orogenic events, the high rainfall, the intensity of rainfalls, and of time has produced typical landforms by which the geological formations can be distinguished on aerial photographs with considerable reliability.

The kerangas-bearing tertiary formations consist generally of layers of siliceous coarse to medium-textured sandstone, alternating with argillaceous layers of clay/silt stone or of conglomerates. The consolidated sandstone components are thick-bedded in the Plateau, Belait and Meligan sandstone formation. The hard, protective sandstone layers of these formations give rise to extensive table lands or, if tilted, to sharp-edged synclinal cuesta landforms. The more argillaceous interbedded strata are chiefly exposed on frequently steep escarpments. The thickness and inclination of the sandstone strata determine the degree and amount of this exposure, which in turn determine the subsequent soil development. Very hard and thick sandstone strata produce prominent, exposed ridge crests and promontories which are so characteristic of the Dulit range, the Merurong plateau, the Klingkang range and the Bako N.P. The edges of these formations are often deeply dissected by erosion.

In some tertiary sediments, for example in the Silantek formation, the sandstone beds are thinner. Consequently, the succession of alternating arenaceous and argillaceous layers is more rapid and greywacke, shale and clay represent a larger proportion of the parent material, which produces a somewhat more gentle physiography. The often strongly cut and dissected sandstone beds may be reduced to isolated boulders, often only a few metres high and broad. The thin beds never give rise to the dramatic landforms which are so characteristic of the thick-bedded sandstones.

Locally, a conspicuous herring-bone physiography may occur as a result of tilting a formation consisting of thin sandstone beds interlaminated with clay. In some of these areas, the sandstone dip-slopes and exposed bouldery ridge tops may carry kerangas, if the sandstone is sufficiently hard and thick.

Other tertiary formations consisting of soft sandstone with interlaminated, often predominating, soft argillaceous strata produce irregularly undulating land surfaces with steep, short slopes, but generally low elevation. Increasing hardness and thickness of the argillaceous component lead to more rugged landforms with long, steep slopes and higher elevations. In both landforms, kerangas is absent or confined to minute enclaves on edaphically extreme sites.

The quaternary terraces consist chiefly of eroded and re-deposited tertiary sediments. The terrace formations exhibit characteristic differences between the products of the various cycles. The few surviving terrace remnants of the early pleistocene peneplain consist of a layer, several metres in thickness, of heavy, blocky clay with some embedded sand to sandy clay, overlying unconformably tertiary sandstone. The Jerudong terraces have typically a massive base of more or less well-assorted small boulders and gravel. Above this base lies rather abruptly, a sandy layer of a few to several metres thickness which locally contains layers and pockets of more clayey material. Younger terraces are generally more sandy and do not normally possess the more or less contemporary gravel base. Typically, they consist of unconsolidated medium to coarse quartz sand which may be several to many metres thick. The sand may contain a very small fraction of argillaceous, mostly kaolinitic matter throughout, or be interlaminated with layers or pockets of embedded clay. Some of the young sand terraces rest on mangrove clay or on wave-cut rock benches.

13. SOILS

131. Soil Development in Relation to Parent Material and Environment

In the tropical lowlands of Sarawak and Brunei, as elsewhere in the wet tropics, podzolization appears to dominate as process of soil development over laterization in most soils derived from tertiary and quartenary parent material outside flood plains. The intensity of podzolization and laterization processes and the direction of soil development are determined primarily by:

(a) texture, mineral composition, strike and stratification of the parent material
(b) nature and position of adjacent rocks which affect the site
(c) physiographic position of the site
(d) pattern of continued sedimentation and erosion
(e) microclimate conditions, especially those affecting the moisture regime
(f) chemical and physical effects from the vegetation, including microflora
(g) chemical and physical effects from animals, including micro-fauna, and from man.

About 90% of the lowland tropical podzols occur in humid climates with weak seasonality and large annual water surplus. The minimum moisture requirement for podzol development in the area is six humid months, provided groundwater influence counteracts climatic dryness (KLINGE, 1969b).

The time factor appears to be of lesser importance in the area because soils seem to reach a maturity very rapidly. Soils of apparently vastly different ages exhibit similar characteristics of maturity. Accordingly, the multiple correlation between physiography, nature of parent material, topographical position and upland soil type is close. Broad soil groups and associations can be interpreted with some reliability on aerial photographs. Heavy-textured clay-rich, well-drained tertiary sediments are associated with skeletal shale soils, lateritic loam and clay soils and RYP loam and sandy-loam soils. Prominent ridge tops of sandstone beds carry shallow skeletal humic sands, sandy SHP podzols, or strongly podzolic RYP loamy sands. Sandstone dip-slopes develop sandy RYP soils on soft argillaceous sandstones and siliceous conglomerates, and more strongly leached sandy HP on thick-bedded, hard, siliceous sandstone beds. The scarp slopes usually carry loamy to clayey RYP soils. Soil texture and degree of podzolization depend on inclination, nature of stratification and erosion pattern.

The soils on the plateaux of tertiary sandstone table lands are generally somewhat more clayey than the soils on the dip-slopes of the same parent material. The soils on the dip-slopes are strongly leached but humic illuvation layers are very weak or absent. Peat bog formation and gleying are strongest on level sites, but locally also present on gentle to moderately steep slopes.

The pleistocene terrace materials are in several respects not too dissimilar from the tertiary sandstones. They are extremely poor in bases and sesquioxides. They consist chiefly of quartz. The clays are predominantly quartz, with some mica, kaolinite and illite (ANDRIESSE, 1969). Consequently, the soils are low in fertility and generally more or less podzolized. The soils of the few peneplain relics are heavy clay GWP soils with a strong tendency to bog-formation and gleying. In places, the clay is covered by a thin layer of out-washed sand. The younger terraces consist of sandy, well-drained parent material which developed into medium deep to shallow HP and Clay-rich GWP soils developed on occasional clay pockets. Peat bog formation is common in the centre of large terraces if drainage is topographically and/or edaphically impeded. DHP develop on more recent terraces of almost pure quartz sand with excessive drainage. These soils are especially common along the edges of coastal terraces.

Ecologically closely related to the clay-rich GWP soils and the upland PB are the heavy bluish grey-brown clay soils with mor or peat accumulation which have been reported from submontane plateaux formed by ultrabasic and basic igneous parent material in the upper Rejang (BECKETT and HOPKINSON, 1961) and in parts of Sabah (MEIJER, 1965a).

Climatic peat bogs formation, according to GREEN (1963), occurs only in areas without potential water deficit. However, in Sarawak bog develops under extremely oligotrophic conditions not only on water-logged sites but also on sites which occasionally become dry. Shallow blanket bogs occur under primary kerangas vegetation on sandstone slabs throughout the lowland and submontane zone.

122. Classification of the Soils

122.1 Sarawak Classification Schemes

The first systematic classification of Sarawak soils has been produced by DAMES (1956 and 1962) who largely adopted the then current approximation of U.S. Department of Agriculture for classifying soils. The kerangas soils were divided into several main groups, groups, numerous subgroups, and series. The first main group "Sandy Soils with B_h" was subdivided into two groups. Group I, Underdeveloped Soils, included sandy soils with extremely weak profile development over sandstone (Bako series), recent beach sand (Anduan series), and non-kerangas riparian alluvials (Khebor series). Group II, Humus Podzols and Humus Groundwater Podzols, was subdivided into three subgroups according to hardness of the illuvation horizon and presence or absence of sesquioxydes in the illuvial horizon. Sixteen series were distinguished according to texture and the presence or absence of an A_3.

The second main group "Light Grey Podzolic Hydromorphs" was subdivided into eight series according to the amount of organic matter deposited on structural interfaces and in root channels of the illuvial horizon. Kerangas soils with peat accumulation formed a separate group which classified within the great soil group "Halg Bog Soils". In his 1962 classification, DAMES omits reference to humus-iron podzols. DAMES had to base his classification on relatively few observations, which consequently was not only necessarily fragmentary, but also somewhat imbalanced in favour of sandy kerangas soils.

ANDRIESSE (1962b) classified the soils for practical use in large scale soil surveys by combining landforms and soil types to broad and composite units which could be easily identified in the field and predicted from aerial photographs. A further improvement was the

1966 classification of Sarawak soils (Soil Survey Staff, 1966). Eleven great soil groups were subdivided into fifty-five families. Six soil groups include families with kerangas soils. The description of kerangas soils in sect. 133 is arranged in the order of this classification which is comprehensive, practical and flexible. It is essentially a land-use orientated classification, but recognizes pedogenesis as a primary classificatory principle. This introduces a certain weakness into the system, because in practice the groups Grey-White Podzolic and Podzols are often difficult to separate.

The families which include kerangas soils are the following:

Skeletal soils: the sandy Meluan soils on steeply sloping upland sites underlain by sandstone;

Grey-White Podzolic soils: the sandy Saratok soils on sandstones, the clayey Lubai soils on marine terraces, and the Triboh soils which are distinguished by strong textural contrasts between layers of the horizon;

Podzols and Groundwater Podzols: the Silantek soils with a weak B_h on sloping sandstones, the Bako soils with a strong B_h on sandstones, the Buso soils with weak B_h on alluvial terraces, colluvial fans and beach deposits, the Miri soils with strong B_h on mostly marine terraces where the pan rests either in clayey subsoils or on a wave-cut rock platform, and finally the Jerijeh soils with a weak B_{ir} on coastal terraces where basic igneous rock occurs close-by and the watertable fluctuates strongly;

Gley soils: the clayey Gerawat soils on gentle slopes of residual parent material;

Peat soils: the shallow Igan soils on light-textured subsoils, the shallow Mukah soils on heavy-textured subsoils, the deep-peat soils, and the high-altitude Mulu soils in the mossy forest formation.

Extensive areas of transitional forests between kerangas and Mixed Dipterocarp forests occur on sandy RYP soils with a marked albic horizon. These soils are included in the Matang family. Secondary kerangas forests may occur on originally much less podzolized families of the RYP. Secondary kerangas also occurs locally on Groundwater Laterite soils (Soil Survey Staff, 1966, p. 22).

132.2 Correlation to Other Classification Schemes for Tropical-Soils

D'HOORE (1968) compares the treatment of tropical soils in the USSR, USDA, ORSTOM and INEAC systems at all levels of classifications. The four systems differ at higher levels in the weights given to climatic, pedoclimatic, pedophysiognomic, physical and chemical features. At lower level the systems become increasingly similar.

Podzolic and podzol soils are treated in detail only in the USDA 7th approximation (USDA, 1967) and the comparison of kerangas soils is restricted to this system. The RYP soils belong to the ultisols. The skeletal soils and juvenile members of the HP catena correspond to part of the order entisol. The Deep Humus Podzols also belong to the entisols as a result of their deep B_h. This obviously is unsatisfactory because there is no pedogenetic or ecological reason to allocate DHP to a different order from MHP, which belongs to the order spodosols. Soils which have poor drainage belong to the suborder tropaquod. Tropaquods do not have a cemented albic horizon. Therefore, the suborder tropaquod is in Sarawak restricted to the typical GWP soils. HP soils with the B_h resting on a clay pan belong to the fragiaquods. Usually poorly to moderately drained HP soils with a hard, very finely textured quartz sand albic horizon are duraquods.

Soils of the suborder tropohumods are never saturated with water or, at least, show none of the characteristics of wet soils which are typical of soils such as the aquods. They have a spodic horizon (organic matter > 5% and an albic horizon (MUNSELL value < 3, chroma < 2) resting directly on it. They have no argillic horizon, no iron-cemented horizon and few iron-cemented nodules. These conditions seem to apply to HP soils on Plateau sandstones in Sarawak. Finally, the PB soils belong to the histosols.

133. Description of the Kerangas Soils

133.1 Characteristic Features of Kerangas Soils

The USDA 7th approximation to soils classification excludes colour as classificatory criterion because it proved impossible to relate colour to soil behaviour. But in Sarawak, kerangas soils are clearly distinguished from all other upland forest soils by their MUNSELL colour notation in the lower part of the main rooting zone. The hue values are generally below 10 YR, but the range is rather wide and overlaps over a broad area with soils of the MDF. Similarly, the range of value is broad but there is a marked peak of soil frequencies in the lower values. The most distinctive separation is in chroma. Kerangas very rarely has chroma above 4. Dipterocarp forest soils usually have chromas above 6, except in soils with a hue of 2.5 Y and yellower. Fig. 5 shows the differential distribution of kerangas and Dipterocarp forest soils. No clear distinction is yet possible between permanently water-logged kerapah bog soils and ANDERSON's peatswamp soils. Both groups overlap in MUNSELL colour notations and other field characteristics. Drier types of peat in kerangas have a generally browner hue than the wet peat bog soils.

Kerangas soils are texturally much less clearly distinguished from non-kerangas soils in spite of their very distinctive micromorphology (sect. 135.2). Early opinion was that the kerangas soils were sandy soils (BROWNE, 1952). Later, field observations showed that kerangas is more varied and includes also clay soils (DAMES, 1956), and that these clayey soils are very widely spread and common (BRUNIG, 1966). Some of the heavy-textured kerangas clay soils overlap widely in colour and texture with some soils in recent alluvium and on basaltic plateaux. In these cases, distinction in the field is easy by landform and nature of the parent material. A characteristic feature of kerangas soils, which is however shared by the peatswamp soils, is the predominance of lateral drainage, above an impervious horizon, of water, rich in organic matter. Water drained from kerangas of peatswamp is typically tea-coloured and acid to the taste through a high content in unsaturated humic acids and acid litter leachates. These so-called black waters have also been described from the Amazon basin (SIOLI and KLINGE, 1961; KLINGE and OHLE, 1964) and from other areas in the American, African and Asian wet tropics (RICHARDS, 1964; KLINGE, 1969) where peat or podzol soils occur.

133.2 Soils Descriptions

133.21 Skeletal Soils (DAMES: Assoc. 7, Lithosols)

DAMES (1956 and 1962) includes in the Skeletal soils shallow, bleached sands with mor accumulation on sandstone dip-slopes and dissected boulders and promotories. All other Skeletal soils are non-podzolic and either rocky or heavy-textured. None of them carry kerangas. The distinct ecological difference between the shallow sands and the other Skeletal soils and the close similarity to the sand GWP soils made me decide to include DAMES' sandy Lithosols in the GWP group. The shallow, well-drained Meluan soils, family of the soils classification 1966 (Soil Survey Staff, 1966, p. 5) are brownish and heavier textured than kerangas soils. The other families are still heavier and poorly drained.

133.22 Brown Forest Soils

These soils develop on base-rich parent material with balanced texture and do not include kerangas soils.

133.23 Lateritic Soils (DAMES: Yellow Latosol, Assoc. 1)

Lateritic soils are the most extensive soil group in the equatorial and tropical regions. The soils are generally red and yellow-coloured. They do not include kerangas soils, but degrade so rapidly after repeated burning, that secondary kerangas forests may establish and maintain itself on the site for a considerable time. An example is the secondary kerangas forests on red soils in Berakas F.R., Brunei.

133.24 Red-Yellow Podzolic Soils (DAMES: Red-Yellow Podzolic Soils, Assoc. 2)

The concept of the RYP group has changed with theories of genesis and advances in soil classification (McCALEB, 1967). They are lateritic-podzolic soils which are moderately to well-drained, have a thin organic A_o over a light red-yellow, bleached A_2 and a redder, more clayey and blocky-structured B. Parent materials are acid and siliceous. The soils are more susceptible to erosion than latosols (BENNEMA, 1967). In Sarawak, RYP soils cover about three-quarters of the land surface. They are rare in kerangas. Occasionally, diverse and complex-structured, primary kerangas forests are found on RYP with an albic horizon.

Examples

(1) Sempadi F.R., SP. 12, sq. 1. Plateau sandstone, gentle slope.

A_{oo}		Loose litter
A_o	3-0	Mor, well-rooted
A_{e1}	0-13	Moderately humic medium fine sand, 10 YR 7/3, well-rooted, top 3 cm shows signs of heavy leaching
A_3	14-25	Silty medium sand, 10 YR 6/4, few roots
B_1	26-72	Silty, weakly loamy sand, 10 YR 6/5, coarsely mottled 5 YR 5/6
C	72+	Sandy clay, 10 YR 6/2, coarse red-brown mottles 2.5 YR 4/5, very few roots.

Vegetation: Well-structured transition between MDF and kerangas forests. Invading mor-forming kerangas forest species (*Gymnostoma nobile*) produce disks of increased leaching and greying of the top-soil.

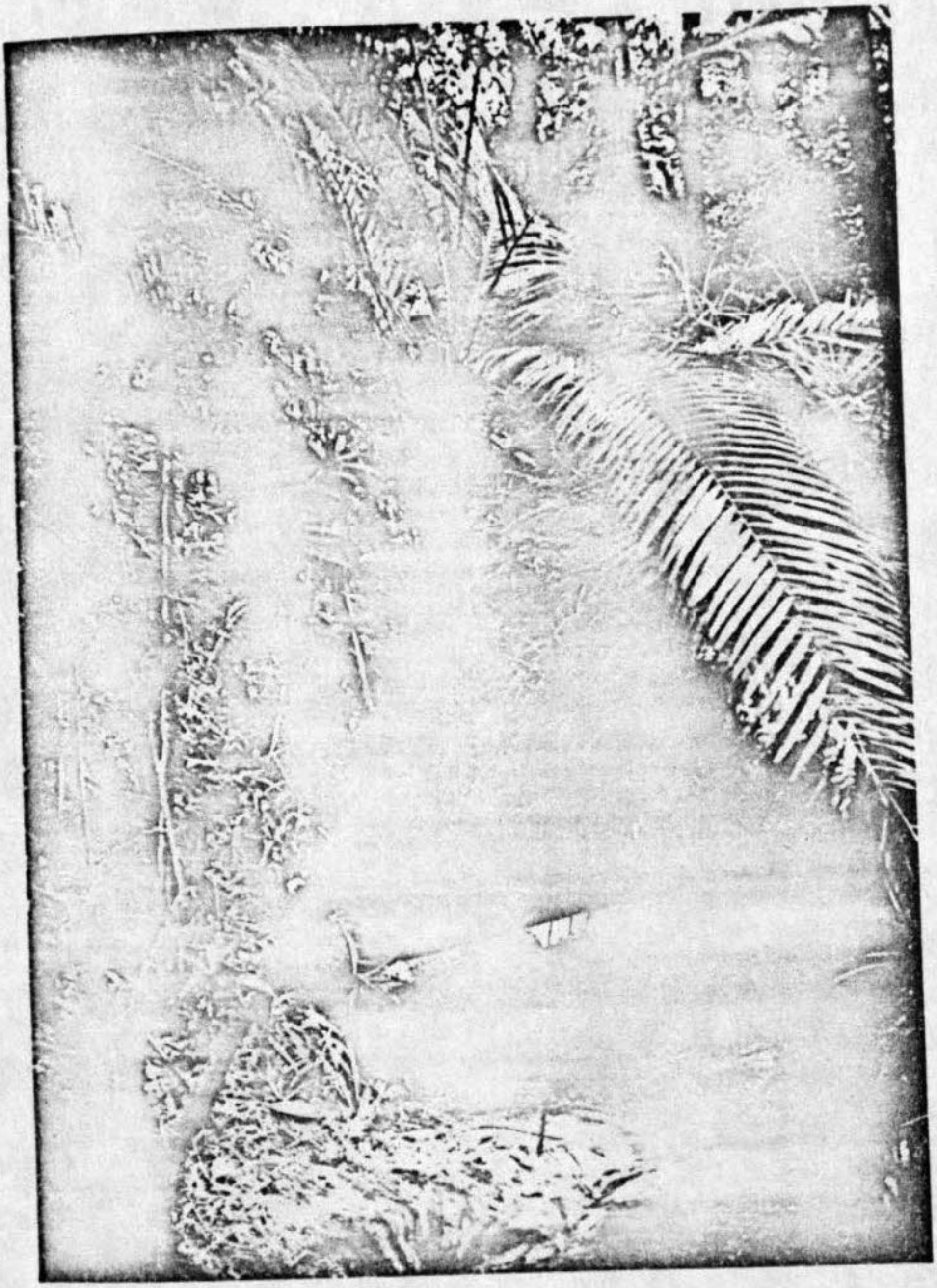

Plate 1. Humus-rich black water in a small stream flowing on sandstone between SP. 38 and SP. 39. The soil is SHP directly overlying the sandstone of a Belait formation dip-slope. The forest is kerangas type 532.1 (sect. 442) with *Agathis borneensis* the main dominant. The rottan palm is unidentified (coll. Li 5). The pandan on the stream-bank is *P. korthalsii Solms* (coll. S. 17491). Limbang Bako crownland.

(2) Sabal F.R., sampling area 1963, sq. 3, flat to undulating narrow step on a gentle slope, Silantek formation. Location of monolith SK II.

A_{oo}		Loose litter
A_{oF}		Leaf and wood debris mixed with grains of quartz, some moder
A_{oH}	3-0	Friable moder, 5 YR 2/2, numerous quartz grains, well-rooted
A_{o1}	0-5	Loose, moderately humus silty medium sand, 10 YR 7/3, few roots, c.e.c. 10.2 m.e. %
A_{e2}	6-12	Loose to slightly cemented silty, weakly humus medium sand, 10 YR 8/2, very few roots, c.e.c. 1.3 m.e. %, dry
A_3/B_h	13-32	Weakly cemented, silty, slightly loamy, moderately humus medium sand, 10 YR 5.5/3.5, c.e.c. 2.9 m.e. %, moist, few roots
B_{31}	32-50	Weakly cemented, silty-loamy medium fine sand, coarsely mottled, weakly humus infiltrated, base 10 YR 7/4, mottles 10 YR 5/4, c.e.c. 5.3 m.e. %, moist to dry
B_{32}	51-63	Weakly cemented, silty, weakly loamy, medium to fine sand, 2.5 YR 8/3 to 10 YR 8/3, some 5 mm large mottles 10 YR 5/3, few roots, c.e.c. 4.0 m.e. %
B_{33}	64-75	Angularly blocky loam, moderately rooted, with small humus spots and humus and clay films on interfaces and in root channels, base 2.5 YR 8/1, mottles 10 YR 6/4, c.e.c. 6.1 m.e. %
C	76-110+	Sandy, silty, plastic clay, base 10 YR 8/1, mottles 10 YR 5/4.

Vegetation: Shorea elliptica-MDF with large proportion of kerangas forest species. Dominant species: *Shorea elliptica, S. ovata, Dryobalanops beccarii, Dipterocarpus pachyphyllus, D. borneensis* and *Melanorrhoea beccarii.*

133.25 **Grey-White Podzolic Soils** (DAMES: Grey Hydromorphic Soils, Assoc. 5, and Bleached Soils)

The GWP soils have a clayey B instead of the spodic B_h of HP soils. The GWP group is genetically intermediate between RYP and the HP soils. The transition to either is gradual. The group is distinguished from the HP by the lack or very weak development of the B_h and from the RYP soils by a more strongly developed albic A_2.

The GWP soils differ from other kerangas soils by their high sand content in the top-soil but lack of B_h. Clay-rich soils of this group will only be kerangas if lateral water influx from sandy humus podzols or bog soils produces strongly oligotrophic conditions or if topogenic water-logging with strongly fluctuating water table creates very unfavourable conditions for growth. Heavy textured GWP soils often have gley-type mottling in the subsoil.

GWP kerangas soils are common on hard to soft, thin-bedded sandstone with interlaminated strongly argillaceous matter on plateaux and gentle dip slopes of tertiary sandstone formations. They are also common on more clay-rich terrace parent material, where final development is towards peat bog if surface drainage is poor.

An example (7) of a profile on dacite tuff is added because the soil appears related to GWP and the vegetation is a kerangas forest.

The soils classification 1966 subdivides the GWP soils in four families according to nature of parent material and texture of the B-horizon. In the following descriptions the examples are accordingly arranged.

(1) GWP soil on Belait sandstone with leached sand above clay subsoil.

Niah-Jelalong P.F. SP.48, sq.1, long 2° slope, 1 to 2 cm thick layers of sandstone alternating with 2-3 m thick argillaceous layers, 107 m altitude. MHP soils occur on the more arenaceous p.m.

A_{oo}		Loose litter, little moss on roots and fallen wood
A_o	5-0	Dense root mat with friable mor, 10 R 3/3
A_{e11}	0-3	Strongly humic fine sand, 2.5 YR 3/4, densely rooted, moist
A_{e12}	4-10	Humic, silty-loamy fine sand, 7.5 YR 5/4, poorly rooted, moist
A_{e13}	11-22	Humic, silty-loamy fine sand, 7.5 YR 5/4, few roots, moist
A_{e14}	23-25	Weakly humic, weakly silty-loamy sand, 10 YR 7/4, slight reddish-brown mottling, abruptly over:
A_{e2}	25-29(49)	Cemented, weakly silty sand, 10 YR 8/2, no roots, water table at base of horizon, irregularly over:
C(?D)	30(50)+	Plastic clay with sandy hard inclusions (?sandstone fragments) and scattered iron concretions (1-3 mm diameter), abundant gley-type mottling, very irregular in size, base 10 YR 8/1, mottles 7.5 YR 6/8, no roots.

Vegetation: well-structured Shorea albida—Dipterocarpus borneensis — Parastemon-forest, top-height about 40 m, much windfall.

(2) GWP soil on clay subsoil, high-altitude Belait formation plateaux.

Merurong plateau, SP.53, sq.4/5, 10° even slope, 50 below the N. edge of the plateau, 840 m altitude.

A_{oo}		Loose litter, moderate moss cover
A_o	(40)15-0	Fibrous raw humus, 7.5 R 2/2, well-rooted, max. depth below *Gymnostoma nobile*
A_e	0-25	Weakly humic fine sandy, weakly plastic clay-loam, 7.5 YR 5/2, irregularly coarse red-yellow mottles decreasing with depth, moderately rooted, gradually and irregularly into:
B_1	25-45(70)	Weakly fine sandy coarse mottled heavy loam, base 10 XR 6/2, mottles 5 YR 5/8 to 7.5 YR 6/6, few roots, gradually into:
B_3/C	45(70)-90(120)	Plastic clay, weakly gley mottled, base 10 YR 6/2, mottles 7.5 YR 6/6, very few roots
C_1	(90-120)-150	Plastic clay 10 YR 5/2
C_2	150-170+	Plastic clay, 10 YR 4/1, with depth increasingly harder and more strongly developed sub-angular blocky structure.

Drainage: Moderate, strong lateral water movement after rain, poor vertical drainage.
Vegetation: Tristania obovata — Palaquium leiocarpum — Gymnostoma-forest, well-structured, moderately distinct even top-canopy 25-30 m, no emergents.

(3) GWP soil with a weakly developed B_h over a textural B/C

Niah-Jelalong P.F., ulu Meluang, SP.48, sq.4/5, 2 to 3° slope lower part of a Belait formation dip-slope, 120 m altitude. The soil is transitional to SHP.

A_{00}		Litter, moss on roots and root mounds
A_0	2-0	Dense roots with sand and mor, 10 R 3/3
A_{e11}	0-2	Very loose, strongly humic sand, 2.5 YR 4/4, well-rooted, dry, c.e.c. 21.1 m.e. %
A_{e12}	2-9(10)	Friable humic sand, 5 YR 6/3, slightly moist, well-rooted, c.e.s. 4.0
A_{e2}	9-19	Slightly cemented silty, slightly loamy sand, 10 YR 8/2, moderately to poorly rooted, weakly humus mottled, c.e.c. 1.8, abruptly over:
A_3	19-22	Slightly compacted, silty, moderately loamy, slightly humic sand, rather irregular humus mottled, some yellowish spots, basic 10 YR 7/2, humus 10 YR 6/1, yellow 10 YR 6/6, moderately well-rooted, gradually into:
B_h/B_3	22-27	Slightly humic, silty, loamy sand, with few soft, in spots gritty, 1-2 mm iron concretions which are more common at 27 cm, basic 10 YR 7/6, iron 5 YR 5/8, no roots, abruptly over:
C_1	27-80	Plastic, fine sandy loam to clay, few indistinct grey mottles, grading irregularly, flame-like into grey sandy clay with yellow brown mottles and irregular purplish to red-brown veins along interfaces and some dead roots, base YR 8/2, mottles 7.5 YR 6/8 to 5 YR 6/8, c.e.c. 9.2.
Borings		
	80-110	Plastic, slightly sandy clay with abundant mottles, base 10 YR 8/2, mottles 5 YR 6/8, c.e.c. 5.8
	120-140	Plastic clay with few indistinct mottles, basic 10 YR 7/3.

Vegetation: Gymnostoma — D. borneensis-pole stand, main canopy at 30 m, with few emergent, large *Shorea albida* (max. height 37-40 m), much wind-break and some wind-threw.

(4) Shallow GWP sandy soil with B_h resting on sandstone p.m. This soil occurs locally on the steep dip-slopes or crests of hard sandstone, for example on the southern dip-slopes of Bukit Metaum north of the Merurong plateau (DAMES, 1956 and 1962), on the dissected ridge top of the Klingkang range and on steep slopes and tops of dissected promontories in Bako N.P. (DAMES, 1956; BRUNIG, 1965).

Example

Bukit Sagan, SP.35, sq.1, on the dip-slope of the summit syncline between a remnant peneplain terrace (SP.33) and the edge, 420 m alt., Belait sandstone formation.

A_{00}		Litter, little moss
A_0	12-0	Red-brown, friable mor with plant tissue, very strongly rooted, locally dense root mat

A_{e11}	0-3	Loose, very humic, red-brown greyish, well-rooted medium fine sand
A_{e12}	4-10	Loose, moderately humic, brownish-grey, medium fine sand, moderately rooted
A_{e13}	11-20(25)	Loose, weakly brownish-grey, medium fine sand with some sandstone fragments and fine white pebbles, few roots
C	20(25)+	White-grey, pale pinkish, hard sandstone.

Immediately after rain the soil showed rapid lateral water movement above C. Generally, drainage is good to excessive.

Vegetation: Very irregularly structured Melanorrhoea beccarii—Calophyllum spp.—Cotylelobium malayanum — Eugenia bankensis — Podocarpus-forest. H_T 35-40 m, 48 m on moist spots, declining towards edge. On clayey parts, *Dryobalanops beccarii* and *Shorea spp.* attain dominance.

(5) Medium deep GWP soil with a very weakly developed B_h over a textural B/C on terraces.

Pueh F.R., SP.6, sq.5/6, broad terrace of early alluvial or late Jerudong cycle, 7 to 12, above present sea-level. The soil is transitional to more heavy-textured PG soils which dominate in other parts of the plot.

A_{oo}		Loose litter, little moss
A_o	5-0	Well-rooted mor
A_{el}	0-17	Humic, brownish-grey, weakly loamy to loamy sand
A_3/B_t	18-48	White-grey, pale brownish, weakly plastic silty-loamy sand with humus colouration along interfaces of the coarse prismatic structural units
C	49+	Gradual transition to white-grey clay with moderately fine red, red-yellow and yellow mottles.

Drainage: Moderate vertical and somewhat better lateral drainage, probable strongly variable moisture content. A more detailed description of a profile within the same sample plot has been given by DAMES (1962, p.49).

Vegetation: Well-structured Shorea albida — Whiteodendron moultonianum — Diospyros polyalthoides-forest, max. height 35 m.

(6) Transition to Peat Bog.

A high water table persists almost continuously through the year on level sites in soils with heavy textures, or with humus-cemented subsoil, or where micro-relief impedes drainage. On these sites, mor accumulation changes the original GWP or HP soils eventually into peat bog. This development may be observable along catenas in the field.

Example

Merurong plateau, SP.55 and 57, sq. 1 to 3, 730-735 m alt. The almost flat slope rises from the banks of small slow-flowing streams in a peaty or rocky bed to the top of the peat bog. Beyond the almost level top of the bog the surface may descend to another stream or join to the foothill of the slopes rising to the plateau rim. The topography of the underlying clayey base suggests that sediments from the bordering streams have formed levees which initially impeded lateral water movement. Subsequent peat accumulation worsened drainage and accelerated the rate of bog formation. The sequence is illustrated in fig. 8a.

(7) GWP-type soil on dacite tuff.

Usun Apau plateau, eastern table land, 970 m alt., gently undulating plateau of weathered dacite tuff with occasional sand ridges and thick white clay deposits. The following description corresponds to profile 311 of BECKETT and HOPKINSON (1966).

A_{oo}		Litter, much moss on roots and on wet places on the ground
A_F	10-6	Decomposing litter
A_H	5-0	10 YR 2/2, slightly fibrous peat, containing a small quantity of coarse sand
A_e	0-70	5 Y 6/1, coarse sandy clay loam with few distinct root channels, live roots to 8 cm depth, structureless, non-sticky and non-plastic when wet, slightly hard when dry, rotting rock, carbonized roots and dammar fragments
C	71+	5 Y 8/1, very fine sandy clay loam, finely orange mottled, few coarse quartz fragments, structureless, slightly sticky and plastic.

Drainage: Water table at 53 cm depth.

Vegetation: Gymnostoma nobile — Agathis sp.-forest, distinct storeys at 10 m and at 20 to 30 m (emergents). The aerial photographs of the area show small open *padang* areas (BECKETT and HOPKINSON, 1966, p. 49).

133.26 Humus, Podzols and Groundwater Humus Podzols, (DAMES: Humus Podzols, Assoc. 6)

133.260 General Features and Distribution

In Sarawak and Brunei, HP and GHP soils are wide-spread on quarternary terraces and on tertiary sandstone formations. They occur at all altitudes and at all degrees of slope, and on strongly dissected terrain. The HP and GHP soils are distinguished from all other soil groups in the area by the presence of an humus indurated illuvial B_h but transition to GWP and RYP soils is gradual.

The formation of a B_h requires a porous, sandy, and acid siliceous parent material of sufficient depth. This condition occurs in arenaceous tertiary sediments and in quarternary sand terraces. The depth of the deposited or weathered sand layer must suffice for percolation to produce recognizable eluvial and illuvial horizons from lessivation and humus translocation. Periods of soil dryness favour the formation of humus pans by precipitating suspended humus colloids in the zone of the average groundwater table.

HP soils on level sites invariably have periodically high soil water tables which are perched on the B_h. By contrast, deep podzols are laterally and vertically well-drained. Perched soil water tables persist only for very brief periods and are of little or no significance to tree growth.

HP soils on sandstone dip slopes and boulders merge into sandy Skeletal or GWP soils if strong lateral water movement reduces and finally prevents the formation of a B_h. Increasing clay content of the subsoil leads toward a transition to the group Podzolic Gley soil. As long as a B_h can still be recognized in the field, transitional soils will be classified as podzols even if a gleying occurs in the top-soil. Generally, heavier texture is correlated with a weaker B_h formation.

HP soils on young holocene terraces have generally lower silt and clay contents than on older terraces. The p.m. of HP soils on sandstone is medium to fine loamy sand to sandy loam, from which clay is removed in the course of soil development by lessivation and destruction.

Generally, the quarternary parent materials of podzols are, for the same depth of the solum, poorer in bases, silt and clay than the tertiary parent materials. On both parent materials, shallow to medium deep Humus-Iron Podzols develop which in the field appear identical in their profile characteristics. Study of the profile by microslides reveals evidence of lessivation and iron deposition in the lowest part of the B_h.

The soils classification (Soil Survey Staff 1966, p. 20) first divides podzols by geologic origin of p.m. The mineral content and texture differs between tertiary and quarternary p.m. This would influence the general suitability for agriculture of the soils which are derived from them. But in the field profile characteristics and apparent site quality of HP soils of the same depth overlap so much between alluvial and residual p.m., that I do not use this criterion for primary division.

At the second level, the soils classification separates soils with B_h from soils with B_{ir}. My observations show that both types occur in intricate mixture on some more complex terraces. Reliable distinction in the field is very difficult. I therefore do not adopt this level of division either. At the third level, the soils classification distinguished five families by the type of the B_h which may be strongly or weakly developed or contain iron. My observations indicate that the nature of the albic horizon is a more important indicator of soil potential under forest. Therefore, I divide the HP primarily according to the depth of the albic horizon, and subsequently according to type of B_h and p.m.

133.261 Deep Humus Podzol

DHP soils have been termed Giant Podzols because of the extremely wide eluvial A_e. The eluvial horizon is at least 100 cm but commonly between 200 and 300 cm wide. Occasionally, it exceeds 600 cm. Medium to fine sandy parent material of homogenous structure and high porosity, and raised topographic position provide the excessive drainage required for the development of the giant A_e. Such conditions exist on narrow alluvial sand terraces and on the borders of older terraces with a deep sandy top layer. Recent alluvial terraces are usually not yet sufficiently raised above the drainage level and are too juvenile for advanced development of a wide A_e horizon.

The thickness of the B_h varies depending on drainage and stratification of the parent and underlying materials. The B_h may be few decimeters thick in a permeable soil with strong lateral drainage. It may reach a width of more than 1 m over impervious clay or gravel beds if lateral drainage is relatively slow. Below the B_h follow yellowish weakly loamy sand or older formations of argillaceous matter gravel, or wave-cut sandstone.

Example

1 km west of the Badas rail opposite Badas F.R., SP. 22, sq. 1. A narrow spur of the terrace extends EW. and separates the Shorea albida-consociation to the north from Mixed PSF

to the south. Altitudes are approximately 31 m a.s.l. in the Shorea albida-consociation, 33 m on the spur and 28 m in the Mixed Peatswamp forests. Dark-brown, humic water flows roughly south through a narrow gap in the spur about 30 m west of the sample plot. The B_h rises toward east and the soil changes to MHP in the centre of the terrace.

A[illegible]		Loose litter, scarce moss on roots and fallen wood
A[illegible]	10-3	Friable, 10 YR 3/4, matted mor with leaf debris and some quartz grains, strongly rooted
A[illegible]	3-0	Friable, 2.5 YR 3/6, mor with quartz grains, strongly rooted
A[illegible]	0-10	Loose, humic, medium to fine sand, 7.5 YR 7/4, good to moderately rooted
A[illegible]	10-25(30)	Loose, weakly humic, medium sand, 7.5 YR 7/3, moderately rooted
A[illegible]	50-70	Loose to very weakly cemented medium fine sand, 7.5 YR 8/1, with some reddish-brown humus infiltration, very few roots
A[illegible]	70-120	Loose to very weakly cemented medium fine sand, 10 YR 8/2, very few blotches of weak humus colouration, very few roots except some strong top roots, mainly of *Agathis borneensis*
A[illegible]	120-230	Weakly cemented medium fine sand, 10 YR 8/1, some coarse sand, very few vertical roots, dry
A[illegible]	230-280	Very weakly cemented, weakly humic infiltrated medium to coarse sand, 7.5 YR 8/2, humic blotches 5 YR 7/3, few vertical and lateral roots, moist
A[illegible]	280-290	Loose medium to coarse sand with prominent, irregular, more or less horizontal bands of humus colouration, which indicate periodic organic matter flushing, 7.5 YR 7/2, humic infiltrations 5 YR 7/3, very few roots, moist to wet, strong lateral water movement
B_h	291+	Hard to very hard, strongly humic medium fine sand, 2.5 YR 3/2, very few roots.

Vegetation: Well-structured kerangas forests, dominated by *Agathis borneensis* (top height 38 — 40 m).

111.262 Medium Deep Humus Podzol

The B_h of MHP soils begins at 30 to 100 cm depth. It is either a very hard continuous layer or a very hard to medium hard, irregular layer with loamy, yellow-brown soft inclusions. The B_h may rest on very different substrates. These include yellow, well-drained sand to loamy sand, and gravel, or finely textured, mottled clay-loam, or sandstone. In the last three cases, depth and nature of the B_h are largely determined by the depth and stratification of the underlying material. In deep, porous and sandy materials, accumulation of clay from lessivation often seems to initiate the B_h formation by acting as a barrier.

On terraces, the MHP occur typically on porous sands, often over somewhat heavy-textured subsoil. On tertiary formations they are common on relatively soft, arenaceous sandstones. MHP soils are much more heterogeneous than the Giant Podzols. The conditions of parent materials and topographical location under which MHP develops are much less limited. The following examples indicate the variability of MHP soils.

Examples

(1) Medium Humus Podzol with weakly developed B_h over C. Sabal F.R., sample 1963, sq.7/8, monolith SK I. Probably palaeogene Silantek formation with some Plateau sandstone colluvial, bouldry slope 5-10° N, 60 m altitude.

A_{oo}		Loose litter
A_f	7-2	Friable plant debris and moder, 5 YR 2/2, strongly rooted
A_H	2-0	Dense root mat with friable moder, 2.5 YR 2/2, c.e.c. 37.7 m.e.%
A_{e1}	0-7	Humic, loose medium fine sand, 2.5 YR 7/2, moderately rooted, c.e.c 1.4 m.e.%
A_{e21}	8-17	Very weakly humic fine sand, 10 YR 7/3, few roots, c.e.c. 0.7 m.e.%
A_{e22}	18-30	Loose medium fine sand, 10 YR 7/2, very few fine and medium roots, c.e.c. 0.3 m.e.%
A_{e23}	31-40	Loose, very weakly silty medium fine sand, 10 YR 8/1, with bleached and humus infiltrated sandstone fragments, practically no roots.
A_3	41-45(60)	Weakly compacted, slightly silty and humus-infiltrated medium fine sand, 10 YR 7/2, hardly any roots, c.e.c. 2.4 m.e.%, strong lateral water movement, which after heavy rain caused outflow of white sand from the bottom of the A_3
B_h	45(60)-(50)65	Irregular, humic-cemented medium fine silty sand, 10 YR 5/3, grading into:
C		Weathered and humus-infiltrated irregularly sized sandstone boulders and gravel.

Vegetation: well-structured Agathis borneensis—Gymnostoma nobile-forest. H_T 40 m.

(2) Medium Humus Podzol with moderately developed B_h over heavy-textured B/C. Sabal F.R. 200 m N and down-slope from the location of the previous example. The two soils are separated by an area of RYP soil (133.24, example 2, SK II). Gentle 2° slope, 45 m alt., Silantek formation, location of monolith SK III, sect. 135.2, ex. 2).

A_{oo}		Loose litter, moss on surface roots
A_o	5-0	Matted roots with fibrous mor 5 YR 2/2
A_{e11}	0-7	Loose, strongly medium sand, 5 XR 4/2, well-rooted
A_{e12}	8-25	Loose, weakly humic, medium sand, 7.5 YR 6/2, hardly rooted, mostly fine roots
A_{e21}	26-31	Loose, single-grain structured medium sand, 7.5 YR 8/2, hardly any roots

A_{e2}	32-40	Loose, very weakly silty, medium sand, 10 YR 8/2, few quartz pebbles to 1 cm diameter, no roots
B_h	41-50	Moderately hard, strongly humic silty, weakly loamy medium sand, 5 YR 3/2, few larger quartz pebbles and few humus infiltrated weathered sandstone fragments to 15 cm diameter, 5 YR 5/2, extending into:
B_h B_s	51-65	Moderately hard, humic, silty loamy medium sand, 7.5 YR 4/2, small quartz pebbles, few old fine-root channels in soil, mostly dead, and some live roots along humus-infiltrated interfaces
C D	65 +	Angularly fine-blocky, humic, loamy sand, 7.5 YR 4/2, numerous small quartz grains, many fine, dead roots, few living roots. The horizon shows vega-characteristics and is probably buried alluvial soil. A small stream flows in a flat valley with deep clay-loam above gravel and mud-stone, about 100 m NE. of the soil pit.

Drainage: good, moist in A_{e1}, wet in A_{e2}, dry in the cemented B-horizon.

Vegetation: well-structured mixed kerangas forests with dominant *Shorea pallidifolia, Shorea scaura*, and occasional *Gymnostoma nobile* and *Agathis borneensis*. Maximum height 45 m, but emergents more commonly around 35-40 m. A weak tendency to form continuous layers at 18-32 m and at 7-12 m respectively. Saplings rather dense, about 2-3 m high. Seedlings moderately numerous, dense on microknolls, scattered stemless palms.

(3) Medium Humus Podzol with well-developed B_h on Plateau sandstone.

Bako N.P., SP. 16, sp. 2, 50 m below scarp on moderately steep slope above Tanjong Dalima, 70-90 m a.s.l., exposed to western sea breezes (BRUNIG, 1961, p. 26-27).

A_{00}		Loose litter
A_0	(10) 5-0	Well-rooted moder with grains of quartz
A_{11}	0-9	Loose humic, greyish-brown well-rooted medium fine sand
A_{12}	10-35	Moderately loose, weakly cemented, grey-white weakly brownish-grey mottled medium fine sand, few roots, dry
B_h	(42)45-52(70)	Moderately cemented, strongly humic, silty very weakly loamy brown medium fine sand, very few roots, moist, irregular over:
C	52(70) +	Very hard weakly yellowish grey fine sandy, some quartz gravel, grading into weathered sandstone.

The drainage is good and lateral water supply ample.

Vegetation: complex kerangas forests transition to MDF, no distinct layers, top height 50 m.

(4) Medium Humus Podzol with weakly developed B_h over sandstone at high altitude.

Merurong Plateau, SP. 52, sq. 5, on a 3° even dip-slope, below the edge of the plateau, 750 m a.s.l.

A_{00}		Litter, moss scarce except on root mounds, surface roots and fallen dead timber

A_o	(20)10-0	Strongly rooted, matted mor, 10 R 3/2, technically peat, N 0.1%, loss on ignition 75.5%
A_{e1}	0-10(30)	Loose to weakly friable moderately humic, silty, weakly loamy, fine sand, humus mottled (panther pattern), base 7.5 YR 6/2, humus 5 YR 5/2, well-rooted, moist two days after rain, 2% C, 0.09% N, C/N 22, c.e.c. 4.1 m.e.%
A_{e2}	10(30)-40	Weakly cemented, weakly humic, silty, weakly loamy medium fine sand, moderately rooted fine sand, mottling very indistinct, base 10 YR 7/2, humus 10 YR 6/3, 0.6% C, 0.03% N, C/N 22, c.e.c. 3.1 m.e.%
A_3/B_h	40-45(60)	Slightly compacted, moderately humic, silty, moderately loamy fine sand, 7.5 YR 5/4, moderately rooted, irregularly on:
C	(45)60+	Grey sandstone with irregularly corrugated and clefted surface.

Drainage and water supply are good.

Vegetation: moderately well-structured kerangas forests, even top canopy at 30 to 35 m height, intermediate storeys distinct. The stand has been described by BRUNIG (1959 and 1960) under forest type "b": Gymnostoma nobile — Dacrydium beccarii — Podocarpus blumei — Shorea spp.-forest.

(5) Medium Humus Podzol with weakly developed B_h over a textured B_t.

Former Stapok F.R., Kuching, quarternary raised beach terrace. Mangrove and deltaic mud-clay, interbedded with sand layers are overlain by sand. The pit is located on the almost flat terrace centre at 20 m alt., location of monolith SK IV.

A_{oo}		Loose litter, little moss on roots
A_o	7-0	Matted mor, 2.5 YR 2/2, c.e.c. 78.1 m.e. %, densely rooted
A_{e1}	0-13	Silty-loamy strongly humic fine sand, 10 YR 6/3, c.e.c. 11.5 m.e. %, well-rooted
A_{e2}	13-25	Weakly cemented, very weakly humic blocky, fine sandy, silty loam, 10 YR 8/3, c.e.c. 4.3 m.e.%, moderately rooted
A_3	25-27	Moderately humic transition, 7.5 YR 6/2, c.e.c. 4.3 m.e.%, to:
B_h	28-38	Moderately cemented, humic, silty, strongly loamy fine sand, coarsely blocky, 7.5 YR 5/4. numerous dead roots along inter-faces, few life roots, gradually into:
B_t	38-45	Moderately cemented, fine sandy, silty humic loam, rectangularly coarsely blocky (7-10), 10 YR 5/3, humus infiltration along root channels and interfaces, c.e.c. 30.7 m.e.%, numerous dead roots, abruptly over:
C/D	45-62	Fine sandy, loamy clay, 10 YR 6/3, irregularly prismatic blocky (3-7 cm) structure, very numerous dead roots with strong humus illuvation in root channels, possibly a buried A-horizon of vega-character (see sect. 135.21, ex.4)

[illegible]	62-64	Friable to spongy, irregularly honeycomb-structured, strongly humic, fine sandy loam, 7.5 YR 3/2, abruptly over:
[illegible]	64-100+	Heavy clay, strong humus infiltration into root channels and along interfaces, base 10 YR 8/3, humus 5 YR 3/3, numerous dead roots, c.e.c. 19.3 m.e.%. This horizon probably is mangrove mud, which became C-horizon to the subsequently developed vega-soil.

Drainage: moderate to poor, depending on micro-relief and position in relation to terrace edge.

Vegetation: Agathis borneensis — Shorea pachyphylla-forest, heavily exploited.

(6) Medium Humus-Iron Podzol with well-developed B_h/B_{ir} over loamy-sand C.

Nyabau Block, Similajau F.R., sampling area 1959, centre of a quartenary sand terrace at 7 m alt. and 6 m above drainage level, about 2 km from the present beach, toward SW. encased to tertiary ridge. Location of monolith SK V.

Humus Iron Podzols occur locally on moderately porous quartenary terrace p.m. and on weakly clayey tertiary sandstone p.m. Humus Iron Podzols on terraces and on sandstone formations appear identical in the field. I did not observe Humus-Iron Podzols at altitudes above about 200 m a.s.1.

A_{oo}		Thin layer of litter
A_F	10-4	Litter debris and moder, 10 R 3/3, strongly rooted and somewhat matted, abundant hyphae and quartz grains
A_H	3-0	Friable moder mixed with sand, 10 R 2.5/2, strongly rooted
A_{e11}	0-8	Loose, humic medium sand, 2.5 YR 3/2, moderately to well-rooted, c.e.c. 11.0 m.e.%
A_{e12}	9-19	Loose, weakly humic, weakly mottled (panther pattern) medium sand, 5 YR 3.5/2, few roots, c.e.c. 9.0 m.e.%, gradually into:
A_{e21}	19-27(31)	Medium sand, 5 YR 8/1, very weak humus mottling around 20 cm, weak humus infiltration along root channels and interfaces, at lower boundary weakly cemented, c.e.c. 1.3 m.e.%
A_3	28-31(33)	Moderately cemented medium sand, 7.5 R 2/2, irregular and patchy humus colouration, few roots
B_h	32-43	Very hard (2.5 YR 2.5/2) to moderately cemented (7.5 YR 4/4) humic medium sand with strong humus infiltration along root channels and interfaces. Microslides of root channels show deposition of organic matter in successive thick layers. This is evidence of periodically heavy flushing of organic matter down the profile which precipitates during subsequent drying of the soil (BRUNIG, 1966). Very few roots. C.e.c. 6.9 m.e.%
B_{sir}	44-53	Moderately cemented, silty weakly loamy to loamy medium and fine sand, basic 10 YR 7/6, indurations common as concretions and irregular layers, 2.5 YR 4/8, live roots very rare, c.e.c. 14.7 m.e.%
B_{sir}/C	54-70	Silty-loamy fine and medium sand, 10 YR 7.5, c.e.c. 4.6 m.e.%, no roots, gradually into:
C_1	70-100	Loose, silty-loamy to weakly loamy fine and medium sand, 10 YR 7/4, c.e.c. 1.9 m.e.%
Boring	90-100	Loose, silty-loamy fine sand, 10 YR 7/4, c.e.c. 3.9 m.e.%
Boring	120-150+	Loose, silty, weakly loamy fine sand, 10 YR 8/3, c.e.c. 0.9 m.e.%.

Plate 2. Medium deep to shallow Humus-Iron Podzol in Agathis borneensis—Shorea albida-forest (type 513.2 in sect. 431.1). The profile is described in sect. 133.262, ex. 6. The pit is located in the centre of the terrace above and left of R.P. 21 in fig. 4. Microslides of this profile are reproduced in BRUNIG, 1968b, plates 12 to 16. Nyabau block, Similajau F.R.

Vegetation: Agathis borneensis — Shorea albida-forest, well-structured, top height around 50 m. The vegetation in surrounding peatswamp is a Shorea pachyphylla — Gonystylus bancanus-association, with some areas of dense pole stands, dominated by *Calophyllum obliquinervium* and [illegible] *curtisii.*

The loamy RYP on the slopes of the tertiary formation, with buttresses on the SW. flank of the cuesta, carries MDF.

133.263 Shallow Humus Podzol

SHP have a A_o of 10 to 30 cm width. They occur either on almost flat to moderately steep dip-slopes of very hard quartzitic sandstone beds or in the centre of old but well-drained terraces with an impeding clayey layer close to the surface. On tertiary formations, the B_h rests directly on sandstone, which it may permeate a few millimetres to several centimetres, on a heavy-textured argillaceous layer or, more rarely, on yellow sandy loam. On terraces, SHP development often starts under conditions of a high groundwater table, which determines the depth at which the humic matter is first precipitated. In the centre of large terraces SHP develops through continued build-up of organic matter on the B_h of a MHP.

The water capacity of SHP soils is small. Plant-available moisture is more than in deeper soils coupled to the rainfall pattern. This is accentuated on moderately steep dip-slopes and dip-slopes with good lateral down-slope drainage. On steep slopes or in dissected country drainage is so efficient that soils are at field capacity within a day or a few days after rain. Under such conditions, the B_h is often very weak or absent. The soil is then transitional to sandy GWP or Skeletal soils (sect. 133.25, ex.4, 5, and 6).

On level ground, drainage is always impeded by a more or less impervious subsoil. Lateral drainage conditions determine the moisture regime of the soil. Poor lateral drainage causes prolonged or permanent water-logging, which leads to the formation of peat bog.

The SHP soils are usually scattered in small patches on terraces or on the top of dissected sandstone. They rarely cover large areas. This may happen on long, gently to moderately steep sandstone dip-slopes.

Truncated MHP and DHP soils may secondarily develop into SHP. Examples of this development are common along edges of terraces which have been used for agriculture. Agricultural use destroys the organic surface matter, the mineral top-soil will be eroded and after the site has been abandoned, a SHP soil will develop under secondary tree vegetation.

Examples

(1) Shallow Humus Podzol on tertiary sandstone. Bako N.P. SP.15, sq.3, slope 5 to 7°, top of a massive Plateau sandstone bed, 200 m alt.

[illegible]		Loose litter, little moss
[illegible]	(25)10-5	Litter debris mixed with dark red-brown mor, strongly rooted
[illegible]	(20)5-0	Dark almost blackish red-brown mor, thickest under tall *Gymnostoma nobile* trees, frequent quartz grains, well-rooted, wet after rain
[illegible]	0-10	Loose, very strongly humic medium sand, well-rooted, moist after rain

A_{e12}	11-20(40)	Loose, mderately humic, medium sand, moderately to well-rooted, moist and increasingly wet with depth, after rain very strong lateral water movement immediately above the B_h, dry two days later
B_h	20(40)-21(41)	Strongly humic, weakly cemented medium sand
C	22(41) +	Grey-white, hard, irregularly corrugated and clefted sandstone. Locally in deep clefts, a weakly humic, weakly light brownish grey-white medium sand eluvial horizon is well-developed. The deep clefts contain more roots than A_{e2}-horizons under normal conditions.

Vegetation: a poorly structured Dacrydium — Gymnostoma nobile-forest, even top canopy at 24-30 m (BRUNIG, 1965, forest type 62).

(2) Shallow Humus Podzols on quarternary terraces.

The profiles are practically identical to those described as MHP (sect. 133.262, ex. 2 and 3) except that the A_{e2} is thinner and usually the B_h less well-developed. SHP soils on terraces are rarer than on the dip-slopes and cliff-tops of the sandstone formations.

133.264 Groundwater Humus Podzol

GHP soils are found on terraces with high groundwater table and very slow lateral water movement. The water-logging is permanent or almost permanent. HP soils can develop under such conditions and it is not necessary that the groundwater table recedes to below the B_h (DAMMAN, 1961).

Almost permanent perched water tables on top of the B_h over a frequently well-drained C or D are common on very broad terraces. Strongly fluctuating perched water tables are the rule in GWP and HP soils on normal terraces and on sloping sandstone. An almost permanent perched water table is, as far as site ecology and top-soil development are concerned, equal to a usually high but fluctuating groundwater table. The final stage of soil development on permanently high perched or groundwater tables will be a PB soil.

The GHP soils are rarer and more localized than the soils with a perched water table. They occur chiefly in the transition from recent, low beach or river terraces to peatswamp sensu ANDERSON (1961) or to keraph. They occur very rarely in the centre of large but relatively low pleistocene terraces. The GHP, under the climatic conditions in the area, will always develop into a PB, unless lowering of the drainage level in the surrounding country improves drainage.

Example

Anduki-Badas area, Brunei, SP.27, about 2 km inland from the present beach, on a very wide, flat and low (few metres above sea level) probably late pleistocene or early holocene terrace. The site is located between the recent terraces and the interior peatswamps.

The terrace surface shows cradle-knoll micro-relief. This may be caused by wind-throw of tall trees, or by the interaction of grouping tendency of plants and surface erosion from water run-off during heavy rainfall, or by both. The drainage is very poor. Water flows extremely slowly from the interior peatswamps towards the beach. The water table is less than 20 cm deep for most of the year, but may fall deeper during unusually long periods of drought. After six almost rainless weeks in February-April, 1958, the water table fell below 2-3 m depth in the adjacent Shorea albida-peatswamp, and peat burned to this depth during a fire. The depth of the water table in the GHP was not observed at the time. It is probable that the water table recedes to or even below the B_h during such excessively dry periods.

[illegible]		Loose litter, thick on the knolls, thin or absent in the intermittent channels and hollows
[illegible]	(20)10-0	Dark red-brown mor, well-rooted, many surface roots
[illegible]	0-35	In upper layer strongly humic to humic silty fine sand, 10 YR 6/2, numerous roots near top, decreasing downwards
[illegible]	36-50	Weakly humic, silty fine sand, 10 YR 7/3, few roots
[illegible]	51-92	Very weakly humic, silty fine sand, 10 YR 8/3, no roots
[illegible]	93-100	Humic, silty fine sands, 7.5 YR 4/2, no roots
[illegible]	100+	Medium hard cemented, in patches soft; strongly humic, silty, weakly loamy fine sand, 5 YR 3/2.

Water table 20 cm below surface of mineral soil 2 days after rain.

Vegetation: Shorea albida — Dryobalanops fusca-forest, poorly structured with distinct storeys. Uniform and dense top canopy at 40-43 m. Towards the interior, the forest changes gradually into Shorea albida-peatswamp forest, p.c.2. In this case, p.c.2 is probably the next stage of the successional development from recent beach terrace through GHP to deep peat bog in [illegible] landscape.

[illegible] Peat Soils (DAMES: Half Bog and Bog Soils, Assoc. 9)

Peat soils cover extensive areas in the coastal and sub-coastal lowlands of Sarawak and Brunei (ANDERSON, 1964 a). The peats are chiefly of two main groups. The topogenic peats of the coastal plain rest on light- to heavy-textured mineral subsoil. Only shallow peat of less than 100 cm depth has some agricultural potential. Deeper peats are suitable for forestry only.

The second group are the kerapah peat soils. It is impossible to separate the two groups on simple edaphic characteristics. The mineral subsoil under kerapah also ranges from fine sand to clay. Peat depth often exceeds 150 cm. Distinction is only possible by the whole vegetation—soil complex and its history, admitting a broad transitional zone of overlap between kerangas and some of the late phasic communities. Delimitation will much depend on the ranking of the criteria, in other words on more or less subjective judgement.

The most practical approach to distinction is by vegetation and site history. Kerangas peat or kerapah forests always develop along a succession which starts from dry-land kerangas forests. ANDERSON's peatswamp forest series typically start with the Gonystylus bancanus — Dactylocladus stenostachys — Neoscortechinia-Association, which often succeeds mangrove or some other littoral or deltaic vegetation. But Shorea albida-peatswamps may also develop from Shorea albida — kerangas on GHP in subsiding areas or on broad, flat terraces.

Kerangas peat or kerapah always originate from GHP, GWP or PG soils. The peat accumulates as a result of deteriorating drainage conditions. This deterioration is usually caused by the growing B_h. In some cases, newly formed topographical barriers may cause kerapah formation. Land subsidence will always lead to ANDERSON's phasic development, and not to kerapah. It will be shown later, that the phasic development of ANDERSON's peatswamps and the stages of peat formation on kerangas sites follow convergent pathways. Geomorphologically, both sequences lead to the formation of convex peat bogs.

The catena from a GWP soil to deep peat has been described in sect. 133.25, ex. 6. It represents a genetical sequence which can be observed on many terraces and plateaux throughout the country. The sequence is the same on GHP (sect. 133.264). WALL (1962, p.194) describes this catena in terms of soil genesis from GHP to deep peat.

The requirement of an almost permanently high groundwater or perched water table limits the chance for kerapah to develop. HP or GWP soils can become substrate to peat only in the centre of broad and level, poorly drained terraces or on flat to almost flat sandstone plateaux at higher altitude. Kerapah is particularly common on the older pleistocene terraces with level tops, especially on the Jerudong-cycle terraces in the Ingei-Melinau-Panderuan area in north Sarawak and Brunei. GHP soils in low-lying coastal areas will develop into deep peat bog unless drainage conditions improve. Drowned GHP soils are common in the coastal plains between Kuala Lawas and Kuala Kemena (Bintulu) and between the Sarawak Mangrove F.R. and Kuala Samunsam. Most of the low-lying kerapah lands between the raised terraces in Pueh F.R. is drowned kerangas. It is significant that the only site in Pueh F.R., which could be regarded as peatswamp sensu ANDERSON, occurs in the present alluvial plain on river deposits in the lower Samunsam valley.

A distinct soil family with peat formation are the blanket bogs on gentle to moderately steep, rarely steep sandstone dip-slopes. The peat either rests immediately on the hard sandstone or on a shallow sand layer overlying sandstone. The latter case could be regarded as a "drowned'" shallow sandy GWP soil. At altitudes around and above 1,000 m, blanket bogs may be up to 1 m thick. In the lowlands they are rarely thicker than a few decimeters. The family grades into the Mulu family of peat soils. This family occurs under mossy forest above 1,300 m alt. They are rarely more than 75 cm deep, more fibrous, spongy and less water-logged than the lowland peats (Soil Survey Staff, 1966). These characteristics also apply to blanket peats in the lowlands.

Blanket peat is also found on hard limestone in the lowlands and at high altitude. The vegetation on these limestone peats is floristically and structurally closely related to the kerangas vegetation (ANDERSON, 1965), especially to kerangas on blanket bogs and SHP on tertiary sandstone.

Examples

(1) Peat soil overlying GWP sand on sandstone.

Sabal F.R., sampling area 1963, sq.192, almost flat to gently sloping part of a moderately steep boulder-strewn slope, tertiary Silantek formation, 110 alt., area of peat about 0.06 ha. Several such small peat bogs are scattered in the sampling area. They all are shallow to medium deep and have developed either on more level parts of the slope; (sq. 192) or in wetlands along small streams; (sq. 142 and 143), or in troughs encased by sandstone boulders (sq. 188). In sq. 188 the 30-60 cm deep peat was relatively dry and rested directly on sandstone rock. In sq. 142-3 the 30-50 cm deep peat was wet overlying pale brown, yellowish-grey sand on sandstone, or on yellowish-grey sand over yellowish-white clay between 70 and 120 cm depth. No other differences could be observed in the field. The MUNSELL notation varies between 10 YR 4/3 and 6/4.

[illegible]		Loose litter, some moss
[illegible]	60-0	Fibrous peat, 10 YR 6/4 at bottom, well-rooted, moist to wet
[illegible]	0-30	Very humic, 10 YR 6/4, medium fine sand
[illegible]	31-40	Weakly humic, 10 YR 6/2, medium fine sand
C	40+	Irregular, humus-stained surface of sandstone bed.

Drainage: somewhat impeded by topography. Strong seepage from upslope. Water table about 30 cm below surface of A_0, probably periodically fluctuating.

Vegetation: Whiteodendron moultonianum — Ganua curtisii — Calophyllum obliquinervium-forest with rather dense undergrowth and broken top-canopy. In spite of the small area, the stand is floristically and structurally distinct from surrounding kerangas forests on sandy GWP soil. A similar peat bog in sq. 486 (fibrous, well-rooted peat deeper than 120 cm, 10 YR [illegible]) with cradle-knoll micro-relief carries a Melanorrhoea beccarii — Ganua curtisii — Tristania [illegible] — Whiteodendron moultonianum-forest, also with rather dense undergrowth and broken top-canopy.

[illegible] Peat soil on drowned HP over gravel on a quarternary terrace.

Location — Medalam drainage, proposed Mulu National Park, SP. 31, interior of a large pleistocene terrace, even slope dipping 1-2° from the terrace edge towards the centre. Sample location at the edge of an extensive almost flat peat bog, 183 m alt. The peat depth increased from the bog margin where the terrace slope dipped below the peat, to a depth of more than [illegible] m in the centre.

[illegible]		Dense litter, no moss except on roots and on larger pieces of timber
[illegible]	120-0	Red-brown fibrous peat, very wet and oozing, well-rooted at top, roots diminishing downwards but still present at bottom
[illegible]	0-20	Light brownish-grey, strongly humic medium-fine sand, some quartz pebbles
[illegible]	21-25	Grey-white, weakly humic, weakly compacted medium fine sand, some dead roots
[illegible]	26+	Very dark blackish-yellow red-brown cemented medium fine sand with gritty quartz pebbles, over:
C, D		Clay/gravel.

Very poor drainage, water table at 7 cm depth after rain, only slowly falling during several rainless days.

Vegetation: moderately well-structured Shorea albida — Melanorrhoea beccarii — Palaquium [illegible]-forest, situated intermediate between a Gymnostoma nobile-bearing forest (SP. 28) on [illegible] MHP at the terrace edge and an open wet padang (SP. 29 and 32) which leads into a Shorea albida-forest on raised bog in the terrace centre.

(3) Peat soil in a blanket bog on tertiary sandstone.

Merurong plateau, upper slope of Bukit Skalap, SP. 54, on a 10-15° slope, Belait Sandstone, 1,125 m alt.

A_{00}	75-70	Dense, thick moss, some litter
A_{01}	70-60	Crumbly-friable, 7.5 R 2/2 mor, well-rooted
A_{02}	60-40	Peat, oozing, 10 R 3/2, well-rooted
A_{03}	40-60	Peat oozing, wet, 2.5 YR 3/2, moderately rooted
A_{04}	60-70	Peat, soupy-oozing, 5 YR 3/3, some fine sand and silt, weakly rooted, very wet
D	70+	Yellowish-grey sandstone.

Vegetation: irregularly grouped, low (max. 20 m) Gymnostoma nobile — Tristania elliptica — Palaquium rostratum-forest, transitional between the kerangas forests of the plateau and the elfin woodland which covers the ridge crests about 50 m above SP. 54.

133.28 Podzolic Gley Soils (DAMES: Grey Hydromorphic soils Assoc. 4)

In the lowlands true Gley soils are, due to their moisture regime and chemism, more favourable to plant growth than kerangas soils. Anthropogenic site degradation may occasionally lead to the establishment of lowland kerangas forests on Gley soils. In primary kerangas forests, Gley soils are very rare because the forests require a more or less thick top-layer of sandy material. This surface layer then qualifies the soils as GWP or HP soils, even if the subsoil is heavy-textured clay. Consequently, the leached top-layer of sandy material must be very thin if the soils are to classify as Gley soils. Because of the presence of this leached, thin white sand top-layer, I call these soils Podzolic Gley soils.

BRUNIG (1965) described the localized occurrence of Gley soils with little surface organic matter under probably old secondary high kerangas forests and under padang vegetation in the Bako N.P. DAMES (1962, pp.46-47) described a Gley soil profile from a kerangas forest on a terrace in the Sarawak Mangrove F.R., and considered Gley soils common in kerangas in lowland West Sarawak. According to my own observations, true Gley soils are generally very much rarer in lowland kerangas than GWP and HP soils.

PG soils in kerangas are more common and more widely spread above 500 m altitude. They are found on old, pleistocene terrace remnants or on Plateau and Belait sandstone formations. On the latter case, PG soils mostly occupy gentle to moderately steep, concave slopes. Locally, on these sites, very tiny open padang areas with very stiff, plastic clay soil are scattered in the kerangas forests. The padang soils are either PG soils or truncated PG soils.

Examples

(1) Podzolic Gley soil on quarternary terrace.

Bukit Sagan, SP. 33, sq. 2, terrace remnant of the early pleistocene peneplain, tilted and perched on the summit of the Sagan syncline, 435 m alt. The soil pit is situated on a gentle slope between the centre and the edge of the convex terrace. The soil at the highest point of the terrace is more sandy and therefore GWP. It seems that orogenic tilting has brought underlying sandstone boulders very close to the surface in some parts of the terrace which increased [illegible] sand content of the soil. At the edge of the terrace, the soil grades into a red-yellow [illegible] podzolic clay-loam with a very thin moder surface layer (SP. 34). Towards the rim of the syncline the terrace gives way to a SHP soil on sandstone (SP. 35).

[illegible]		Loose litter, moss on fallen timber and surface roots
[illegible]	(10)5-0	Root mat with red-brown mor
[illegible]	0-20	Dark grey light-brownish, humic, silty, fine, sandy loam, moderately rooted
[illegible]	20-25	Grey-white sandy, silty sticky clay, very few roots
[illegible]	26-180+	White-grey, yellow and red-yellow mottled plastic clay, roots extremely rare, with depth mottling and roots disappear and the clay becomes evenly grey.

[illegible] is generally poor, but due to topography, lateral water movement in the uppermost top-[illegible] probably adequate.

[illegible]: Dacrydium pectinatum — Shorea revoluta — Tristania obovata-forest, poorly struc-[illegible] strong layer formation, uniform, relatively dense top-canopy at 20-25 m, very few [illegible] to 33 m on more steeply sloping ground, distinct sub-layer at 7-10 m. At the edge of the terrace the forest grades into MDF (SP. 34). At the rim of the synclinal dip-slope, the [illegible] fades out and the forest grades into a Melanorrhoea beccarii — Calophyllum — Cotylelo-[illegible] malayanum kerangas forest, H_T 40-45 m, on shallow sandy GWP soil (SP. 35).

[illegible] Podzolic Gley soil on tertiary sandstone.

[illegible] Plateau, SP.53, sp.3, 5° dip-slope, 50 m south of the northern edge of the southern [illegible] 845 m alt. There may have been some disturbances from wind-fall, which is indicated by [illegible] irregular micro-relief and a piece of *Ternstroemia* timber found at 50 cm depth in [illegible] pit about 30 m further downslope. Further downslope, the soil grades into GWP soil [illegible] 133.25, example 2).

[illegible]		Litter, little moss
[illegible]	(30)15-0	Mor, 7.5 R 2/2, maximum thickness in root mounds and tree groups, well-rooted, 1.1% N, loss in ignition 87%, pH 3.2
[illegible]	0-20(35)	Weakly to moderately humic, fine sandy clay-loam, 7.5 YR 5/2, slightly plastic, moderately rooted, moist 0.16% N, 2.6% C, C/N 16, c.e.c. 10.1 m.e. %
[illegible]	(25)20-35	Slightly fine-sandy clay, coarse gley mottling, base 10 YR 6/2, mottles 7.5 YR 6/6 at edge, 5 YR 5/8 in centre, few roots. 0.06% N, 0.55% C, C/N 9, c.e.c. 8.6 m.e. %
[illegible]	35-55(65)	Plastic, strongly silty, fine sandy clay, base 10 YR 6/2, mottles 5 YR 6/6, few roots, dry, pH 3.6. 0.08% N, 1.0% C, C/N 11, c.e.c. 9.0 m.e. %.

[illegible]

70-90	Plastic clay with gley mottling, base 10 YR 5/2
90-110	Plastic clay, very few mottles, base 10 YR 6/1, hardly any live roots

110-130	Plastic clay, very few mottles, base 10 YR 5/1, hardly any live roots
130-150	Plastic clay, 10 YR 5/1—4/1, no roots
150-170	Plastic, subangularly blocky, dry clay, 10 YR 4/1.

The lateral drainage along the surface is good, but internal drainage is very poor. The mor accumulation close to trees and tree groups indicates active surface wash-off of organic matter.

Vegetation: moderately to poorly structured Gymnostoma nobile — Palaquium leiocarpum — Tristania obovata-forest with a fairly uniform, dense top-canopy at 25-30 m. *Cotylelobium malayanum* occurs near the rim. Further downslope the forest grades into the poorly structured Gymnostoma — Dacrydium-forest on shallow sandy GWP soil (SP. 53-55) or on SHP soil (SP.51 and 52).

133.29 Other Soils which may bear Kerangas Forests

None of the other soil groups of the soil classification, 1966, includes kerangas soils. But a few soil groups include soils which can degrade sufficiently after misuse that a secondary forest vegetation may develop which contains kerangas forest elements. Also some soil groups contain sandy soils which may be early stages of a genetical catena to Humus Podzols. Examples can be found among the recent beach deposits.

Groundwater Laterites can carry an open woodland with kerangas forest elements if repeated burning and sùrface erosion have degraded the site sufficiently to give the kerangas forest species a competitive advantage.

The *Recent Alluvial Soils* include beach deposits. These deposits do not immediately carry kerangas forests. The initially high content of iron and bases is continually leached. If no fresh sedimentation rejuvenates the soil, kerangas forest species may invade and accelerate HP soil development. Leaching and podzolization will be increased if the site is raised relative to the drainage level of the surrounding land, which at present happens in many places along the Sarawak coast in areas of orogenic uplifting. Conversion of these coastal sites to agriculture advances the invasion of kerangas species and of podzolization. As a result, kerangas forests will be established on soils which are more juvenile than kerangas soils normally are.

134. Catenas and Soil Development in Kerangas

134.1 Definition and Applicability of the Catena Concept

A soil catena is a repeated succession of different soils on the same geological parent materials. The soils differ from each other by features of relief and drainage. The members of the catena may or may not be genetically related.

ASHTON (1964 c, p. 15 ff) has given examples of the ordered variation of soil and related vegetation characteristics across topographical features, such as valley-ridge-valley sequences in Mixed Dipterocarp forests. ANDERSON's peatswamp series are less easily defined by geomorphological features, but topographical relationships permit the abstraction of a generalized catena river bank — raised peat dome — river bank.

Similarly in kerangas, sequences of different soils can be recognized across quarternary terrace landforms and across tertiary plateaux and cuestas. These soils sequences repeat themselves in a characteristic pattern. This pattern can conveniently be generalized in the form of catenas of kerangas soils, or of kerangas soils alternating with soils of the Mixed Dipterocarp or peatswamp forests. Examples of kerangas catenas are given in figs. 7 and 8.

5.3.2 Catenas on Tertiary Formations

The tertiary landform catena valley — dip-slope — crest — scarp — valley is related to the analogous catena in MDF described by ASHTON (1964c) and will include MDF, if site conditions are favourable. Steep scarp slopes with argillaceous p.m. carry LS or RYP soils with MDF. Dip-slopes of hard, thick-bedded sandstone will carry kerangas or transitional forests (fig. [illegible]).

The typical kerangas catena sequence on Belait and Plateau sandstone cuesta formations is GWP and MHP on the lower dip-slope, shallow sandy GWP soil towards the ridge top, skeletal soil on the ridge top and a RYP soil on the scarp slope. Podzolization will not always decrease downslope. The stratification of tertiary p.m. or sandy colluvial or remnants of encased terraces can produce lighter-textured top-soils and stronger podzolization on the lower slope.

WOOD and BECKETT (1961) describe a catena in low, hilly country in Similajau F.R. (mid-tertiary Nyalau formation). The foothill is occupied by a low-level kerangas soil with heavy-textured subsoil which the authors regard as lower members of the Yellow Loam (Dipterocarp) series. The lower part of a gentle seaward slope carries a MHP with a thick B_h. On the upper slope the profile gradually becomes shallower and the B_h thinner. The forest on the foothill is kerangas which gradually changes into Dipterocarp forest about half way up the slope where the B_h fades out. The soil on the reverse slope is a yellow loam. A different catena runs across the junction between country rock and an encased terrace. This catena also shows "how as the lighter material feathered out upslope, the depth of the humus B horizon and its sharpness decreased until near the Kerangas-Dipterocarp boundary, the soil profile differed from the normal yellow loam profile only in showing enhanced litter and A_1 horizons" (ibid., pp.231-232). No direct information is given on the parent materials in the first catena. My own observations in the area suggest the possibility that in both cases the lighter material on the lower seaward slopes may be terrace remnants. An indication in this direction is the altitude of 5 m reported for the lower seaward slope sites which coincides remarkably well with the 5 to 7 m level of quarternary terraces in the area. Similarly, KLINGE (1965) explains the stronger podzolization on lower parts of slopes in Amazonian campina-like forests by the presence of light-textured river sediments on the foothills.

The nature of the p.m. seems to be the dominant factor which determines soil development on tertiary sediments. The inclination of dip- or scarp-slope appears to be much less important. Shallow GWP sands are frequently found on steep scarp-slopes, which are usually associated with red-yellow soils. GWP soils are especially common on steep scarp-slopes of very hard and thick-bedded Plateau and Belait sandstone. Humic illuvation horizons are normally associated with less steep slopes. Humic material supply from decomposing litter must exceed potential lateral eluvation in order to accumulate humic matter in the soil. Consequently, very steep slopes and very pervious material will not as a rule be favourable for the formation of humic soil horizons.

Gentle dip-slopes, especially on the Belait and Silantek formations, may carry RYP and Clay soils. These soils are often intricately mixed with GWP and HP soils, if the p.m. and topography vary accordingly. Vegetation variation in such cases corresponds closely to the pattern of soil variation.

Kerangas soils and kerangas soil catenas on tertiary formations show great variability, of which the following examples give some indication.

Examples

(1) Regular sequences on tilted Plateau sandstone with podzolization stronger towards the ridge top.

Sempadi F.R., Plateau sandstone in a series of low and broad, parallel ridges, approx. alt. 30-40 m.

Vegetation: Agathis borneensis — Ganua curtisii — Whiteodendron moultonianum-forest (SP. 11), *A. borneensis* preferably on foothill.

(a) Lower dip-slope, 3-5°

A_{oo}	8 — 5	Loose litter
A_o	5-0	Well-rooted, dark, red-brown mor
A_{e1}	0-20(30)	Humic yellowish-brown-grey sand, well-rooted near top of horizon
A_{e2}	(30)20-35	Moderately cemented grey-white medium fine sand
B_h	35-36(40)	Very weak and discontinuous silty humic medium fine sand
B_t	(40)36-55	Brownish-yellowish sandy clay-loam, with few rust-coloured concretions, gradually into:
C(D)	56-75(80)	Sand loamy clay, gley mottling, gradually into:
	80-90+	Sandy grey clay, coarse sand content increasing with depth.

Water table at 60 cm depth.

(b) Upper slope and broad ridge top

A_{oo}	12-9	Loose litter
A_F	8-3	Well-rooted red-brown mor
A_H	2-0	Root mat with quartz grains and friable moder
A_{e11}	0-10(25)	Loose, grey-brown, humic medium sand
A_{e12}	(10)25-30	Weakly cemented, slightly humic, weakly brownish grey-white medium sand, few roots
A_{e2}	30-40(45)	Cemented, greyish white medium sand, very few roots
B_h	(40)45-50(60)	Hard to moderately hard cemented, blackish red-brown weakly loamy medium sand, few roots
B_3	(50)60-90	Brownish yellow sandy loam with humus infiltration along interfaces, very few roots
C(D)	90+	Yellowish white-grey sandy clay with few dead roots.

Water table at 80 cm depth.

(c) Scarp-slope, 8-12°

Light-textured RYP soil (DAMES, 1962, p.34, profile 224/229 D), poor quality MDF (BRUNIG, Inventory Reports on Sempadi F.R., 1955, unpublished, Forest Department, Kuching).

(2) Regular sequence on coastal Plateau sandstone Pueh F.R., low and broad hills of Plateau sandstone between S. Bedaun and S. Blinsah, approx. 1 km W. of beach.

The catena on the low ridge is very similar to that described in ex. (1) above. The broad flat ridge tops carry shallow to medium deep Humus Iron Podzols. The B_h lies over a light brownish, yellowish-grey silty weakly loamy sand with iron-colourations. The vegetation is a Shorea albida — Gymnostoma nobile-forest (SP. 8). On the slopes the soil is a medium deep Humus Iron Podzol. The B_h is noticeably softer, more irregular and at greater depth than on the crest. *Gymnostoma nobile* and *Shorea albida* are less dominant which also indicates less podzolized conditions.

The surrounding bottomland is either well-drained recent beach (SP. 7) or riparian fringe terraces, or submerging terraces with GHP grading into PB. The narrower ridges closer to the coast carry Dipterocarpus pachyphyllus — Shorea elliptica — MDF on sandy RYP soils.

(3) Complex catena on tilted Belait sandstone.

Niah-Jelalong F.R., moderately steep to almost flat synclinal dip-slope south of Sungai Meluang, between 65 and 200 m alt. Relative thin-bedded sandstone alternating with medium thick argillaceous layers. On the foothill occur some narrow encased river terraces of the S. Meluang valley. The catena is complex and irregular, but can still be defined as catena because it is not only repeated within the Niah-Jelalong F.R., but also elsewhere on similar topography and p.m. (e.g. Sabal F.R.). The example illustrates the amount of site, soil and vegetation diversity which can be expected at small-scale pattern on variable physiography, heterogeneous p.m., and conditions of differential erosion and re-deposition within the area.

Sequence from the Meluang river up-hill:

(a) Encased terrace, 5 m above river-level, the terrace flank to the river carries MDF on deeply leached sandy RYP soil.

(b) The top of the 30 m wide and some 100 m long encased terrace carries sandy GWP and MHP soils over a textural B, which grades into plastic clay at greater depth (Shorea albida—S. pachyphylla-forest, SP. 47).

(c) Moderately steep dip-slope, buttressed on terrace edge, with MDF on RYP or on steeper mid-slope sections on Red-Yellow Lithosol.

(d) Gentle dip-slope of the syncline with undulating surface, ridges very broad. The lower dip-slope carries MHP over yellow loam over clay (Shorea albida—Gymnostoma nobile—Falcatifolium angustum-forest). On the broad ridge medium GWP sands over yellow loamy sand over clay (Shorea albida—Gymnostoma nobile—Dipterocarpus pachyphyllus-forest).

(e) Even section of the gentle lower dip-slope without ridges, intricate mixture of soil types and associated vegetation types.

(i) Podzolic light yellow sandy loam under MDF.

(ii) Shallow leached sand on gley-mottled clay (Shorea albida—S. pachyphylla—Gymnostoma nobile-forest, SP.48-1 and 4.8-4/5).

(iii) MHP over sandy clay (Shorea albida — Dipterocarpus borneensis — Gymnostoma nobile-forest with many stilt-roots, SP.48-2/3).

(f) The moderately steep mid-slope consists of:

(i) Strongly dissected parts of the slope which carry Red-Yellow Lithosol under MDF.

(ii) Even but steep parts of the slope carry a podzolic sandy brown-yellow loam under MDF or, without noticeable difference of the soil surface topography, a MHP with very weak B_h at about 40 cm depth over plastic grey clay with sandstone fragments (Shorea albida—S.pachyphylla-forest).

(g) Moderately steep upper slope:

(i) 10 cm leached sand over 30 cm brown-yellow loam over brown-yellow sandy clay, at 140 cm depth grey sandy clay (over-mature Shorea albida-Gymnostoma nobile-forest, (SP.50-3), slope 12°.

(ii) MHP ,B_h at 40-80 cm over loamy sandstone at 2 m (Calophyllum spp.—Palaquium spp.-forest with few slender *Agathis borneensis* and *Falcatifolium angustum*, SP.49-1), slope 5°.

(iii) Moist slope hollows with deeply bleached humic, loamy sand over sandstone at 2 m (Gymnostoma nobile—Shorea albida—S.pachyphylla-forest, SP.49-2).

(h) Broad ridge top of the rim of the syncline, 200 m alt. The soil is a bleached podzolic humic loam, overlying irregular sandstone at average depth of 1 m (Shorea ovata—Dipterocarpus borneensis—Agathis borneensis-forest, SP.50-1).

(i) Steep to very steep scarp on the opposite side, descending into the Sungai Jelalong valley, strongly red-yellow coloured slay lithosols under MDF.

(j) The same slope on moderately steep parts carries strongly podzolic, sandy red-yellow loam above a red-mottled, slightly plastic layer at 50 cm depth, under a MDF of different composition and structure.

(4) Regular sequences on high plateaux.

Merurong Plateau, SPs 51 to 57, Belait sandstone formation, thick-bedded hard sandstone 730 to 1,200 m alt.

The SW. plateau is a large, shallow basin with an uptilted edge towards west, where Bukit Skalap forms the summit ridge. The S., E. and N. slopes dip towards the more or less flat centre which is drained towards E. by a black-water river. The NE. plateau is generally flatter, with 800 m max. alt. The following catenas can be recognized on both plateaux:

(a) From the centre towards northern and southern edges:

(i) Peat bog in the almost flat centre of the plateau (Shorea albida — Gymnostoma nobile-forest, SP.57) (sect. 133.25).

(ii) SHP or GWP sand on the dissected spurs and lower slopes which lead towards the edge (Dacrydium spp.-Gymnostoma nobile—Palaquium leiocarpum-forest, SP.51).

(iii) MPH on the moderately steep slopes near the edge, clay content increasing up-slope, (Gymnostoma spp.—Shorea spp.-forest, SP.53).

(iv) Broad ridge tops of the rim carry strongly humic podzolic brown-yellow loam soil under MDF. Exposed rocky crests carry shallow GWP soils with a thick cover of litter, humus and moss. The forest is low, somewhat gnarled, and is a transition between (ii) and mossy forest. The more sheltered depressions and drainage channels along the edge carry gley-mottled bleached sandy clay soils under tall submontane forest (Gymnostoma spp.—Agathis beccarii-forest, SP. 53 and 56).

(v) The upper scarp slopes have strongly coloured lithosols with MDF, rock out-crops are common.

(vi) The scarp slope is interrupted by cuesta-like steps and spurs. The successive dip-slopes carry kerangas forests on SHP and GWP soils, e.g.: Dryobalanops rappa — Shorea — Tristania pole-forest on the unstable, very shallow GWP sand of the southern 45° slope of Bukit Sangit. Mosses, *Nepenthes spp.* and *Pinanga spp.* are abundant on the ground. The forest is very similar to the forest which covers the upper dip-slope of Bukit Patam in the Ulu Ingei, Brunei, at much lower altitude.

The soil profile on this slope has been described by DAMES (1962, p.66, profile 164-166 D) who classified the soil as lithosol because of its shallowness. I prefer to include this type of soil in the GWP group for ecological reasons, because all other lithosols are non-podzolic and their vegetation do not belong to the kerangas forests (sect. 133.21 and 133.25).

(b) From the centre towards the western summit ridge:

(i), (ii) PB and SHP as in (a) before.

(iii) 70 cm deep blanket bog on the gentle to moderately steep upper slope of the summit ridge at about 1,000 to 1,150 m. alt. (Gymnostoma nobile—Tristania—Palaquium —Podocarpus-forest, SP. 54).

(iv) Moss forest on the Summit crest with *Dacrydium spp., Shorea monticola* and *Vatica sp.*, nov. SK 326.

(v) MDF on the scarp slope, similar to (a).

131.3 Catenas on Quarternary Terraces

All terraces are still in a continued process of building-up or eroding, lifting or submerging. The development will be determined by the original chemical and physical nature of the deposited material, and by the direction and speed of topographical changes as a result of erosion and tectonic movements. Particularly important in this respect is the position in relation to the drainage level of the environment. The older holocene and pleistocene terraces have generally reached greater maturity of development. Many have already been completely removed by erosion. Others have drowned below peatswamps in subsiding coastal areas and in more static, broad alluvial plains. The presently more conspicuous members have been raised above the surrounding drainage. They now form encased or isolated, more or less level but dissected plateaux which raise a few to more than sixty metres above the surrounding present valley bottoms. The older base material below the terrace may have become exposed in the course of erosion. It often consists of stratified boulders and gravel with lenses and layers of finer argillaceous material. In other cases, the base is sandstone which is usually less exposed.

As a result, terraces exhibit a great variety of topographical position, p.m. and base materials. In spite of this, soil development on the terraces shows considerable uniformity. The reason is that the p.m. is always extremely deficient in most minerals but quartz. The repeatedly resorted and redeposited medium fine sands, loams and clays vary in texture, but relatively little in chemical composition. Consequently, soil development is overwhelmingly determined by soil texture and drainage. As a result, soil genesis and catena are closely correlated and can be reduced conveniently to few seral types. The most common and typical terrace kerangas catena is the sequence bottomland — terrace slope — terrace top — terrace slope — bottomland (fig. 4). Successive terraces of several levels and different ages may combine to one catena sequence (fig. 7a). Another common sequence is the catena Groundwater Podzol — Peat Bog — Groundwater Podzol in low-lying coastal areas (fig. 8b), which is related to the sequence of peatswamp forest phasic communities. The complex geomorphological relationships are illustrated in fig. 7d in a very simplified manner, which relates development and catena sequences of site and vegetation to pedology and tectonics.

Examples

(1) Raised coastal terraces.

Similajau F.R., south of Sungai Setuang. The sequence starts at the present beach with terrace level I at 2-3 m alt. (SP.46). It continues to terrace level II at 5-7 m alt. This level is up to 300 m wide. The average distance from the beach is 160 m (SP.45 on the terrace edge, SP.43 on the terrace top). Then follows terrace level III at 12-15 m alt. The distance from the beach is 0.3 to 2 km. The final terrace level IV is at 30 m alt. and about 1 to 3 km from the present beach (see fig. 7a). All levels except level I are moderately dissected. Sandy valleys meander between the irregularly shaped terraces and often separate different terrace levels. These bottomlands are usually occupied by early stages of GHP, similar to level I. The kerangas forests on the valley bottoms is also similar but more mixed and mature than on the terrace level I.

The terraces are, towards the interior, encased by Nyabau formation sandstone. The ridges run generally SE. to NW. and carry Cotylelobium burckii — Gymnostoma nobile — Dipterocarpus borneensis-forest on shallow GWP soils and MDF (*Dipterocarpus pachyphyllus, D. sarawakensis, Dryobalanops beccarii, Shorea pallifolia, S. glaucescens*) on RYP soil.

The following sequence shows the development from unconsolidated ferrugineous sand through a medium deep GHP on a low terrace, MHP on the slopes, DHP on the edges of a raised terrace, and MHP on the terrace top (fig. 7a). Eventually, the MHP develops into a SHP and finally into PB if drainage is sufficiently poor in the terrace centre.

(i) Present beach, 15 m wide.

Slightly humic, ferrugineous sand, Casuarina equisetifolia-belt (BRUNIG, 1969, type 1.1).

(ii) Dune, 5 m wide.

Small, steep sand dune, raising 2-3 m, open scrub with much *Oncosperma horrida* and *Pandanus tectorius*.

(iii) Recent beach terrace, level I, 60-100 m wide.

Alt. 2-3 m, almost flat except for undulating microrelief (SP.46-5).

A_{oo}		Sparse loose litter
A_o	(5)2-0	Root web with loose moder and quartz grains, 7.5 R 2/2
A_{e11}	0-5(20)	Loose, moderately to locally strongly humic medium fine sand, 10 R 4/2, much disturbed by wild boar

A_{e12}	(20)5-40	Loose, slightly humic yellowish brown-grey, indistinctly mottled, medium sand, 5 YR 4/3, moderately well-rooted, to a depth of 30 cm disturbed by wild boar
A_{e2}	40-60	Wet medium fine sand, 5 YR 5/3, few roots
A_3/C	60+	Yellowish-brown beach sand, unchanged to 1.5 m depth.

Drainage: water table at 60 cm ten days after rain, some lateral water movement from terrace level II (S.) to beach (N.). The high water table is apparently maintained by the beach dune, which acts as a drainage barrier.

Vegetation: poorly structured, two-storied, single-dominant Shorea materialis-forest. Locally *Dryobalanops rappa* attains dominance in this site type, similar to the extensive Dryobalanops rappa-forest in Anduki F.R., Brunei.

(iv) Terrace level II, seaward 10-15° slope.

At lower mid-slope the soil is a medium deep Humus-Iron Podzol (SP.45-1).

A_{oo}		Loose litter, little moss on roots
A_o	6-0	Plastic-friable, well-rooted humus with some quartz grains, 7.5 R 2/2
A_{e1}	0-25	Strongly humic, weakly mottled medium fine sand, 2.5 YR 3.5/2, moderately rooted, moist, gradually into:
A_{e12}	25-60	Moderately humic, irregularly humus-mottled, medium fine sand 7.5 YR 5/4, moist to wet, gradually into:
A_{e2}	60-70	Weakly humic, indistinctly coarsely mottled, very slightly cemented medium fine sand, 7.5 YR 6/4, humus 5 YR 4/3, hardly any roots
A_3	71-73(75)	Discontinuous, irregular layer of humic, very wet coarse sand with strong lateral water movement
B_h	(71)75-90	Strongly humic, moderately hard, cemented medium fine sand with some quartz pebbles, 5 YR 3/2 to 2.5 YR 3/2
B_3	90-110+	Loamy sand, 7.5 YR 5/4, moist, very few roots, becoming rapidly lighter coloured and less loamy with depth.

Drainage is good, laterally very good.

Vegetation: transition from Shorea materialis to Agathis borneensis-forest.

(v) Top of terrace level II.

Up-slope from (iv) the B_h is lower relative to the soil surface and a DHP extends about 50 m from the edge towards the terrace centre. Then the soil changes gradually back to MHP. The lowering of the B_h at the edge may be the result of corrosion caused by accelerated lateral drainage after the terrace was up-lifted.

A_{oo}		Litter, few tufts of moss
A_F	5-4	Leaf debris, roots, and quartz grains
A_H	3-0	Loose moder, 7.5 R 2/2, and sand, many roots
A_{e11}	0-15	Loose quartz sand with granular moder, 10 YR 8/2, well-rooted, dry

A_{e12}	16-20	Moderately loose, humic medium fine sand, 7.5 YR 8/2, moderately rooted, moist
A_{e13}	21-43	Very weakly cemented medium fine sand, 10 YR 8/2.5, few roots
A_{e21}	44-95	Weakly cemented, in patches humic medium fine sand, 10 YR 8/1.5, hardly rooted, dry
A_{e22}	96-150	Weakly cemented to friable loose medium fine sand, 10 YR 7/1-2, roots extremely rare, moist
A_3	151-160	Weakly humic, medium fine sand, 10 YR 4/3, very wet with strong lateral water movement above the B_h
B_h	161-181	Hard, strongly humic, medium fine sand, 7.5 YR 3/2 to 2.5 YR 2/1.

Drainage: very good to excess, perched water table in A_3.
Vegetation: coastal Agathis borneensis-forest with some *Shorea materialis* in the top canopy, tendency to distinct storey formation, maximum height of *A.borneensis* 40-45 m (SP.43).

(vi) Slopes of terrace level III.

On the seaward side the soil is a MHP with Agathis borneensis — Shorea materialis-forest. On the landward side the soil is a strongly podzolic brownish RYP soil with *MDF* (*Dipterocarpus pachyphyllus, D. sarawakensis, Anisoptera grossivenia*) which contains kerangas elements (*Agathis borneensis, Gymnostoma nobile,* but not *S. materialis* which is socially replaced by *Mangifera havilandii*).

(vii) Edge and slope of terrace level III.

The terrace level III buttresses distinctly by a 10-20° more or less abrupt slope on level II. In places, the two terrace levels are separated by meandering valley bottoms. Distance from beach 1.2 km. The top is almost level to 1-2° dipping SE. The altitude is 12-15 m and the terrace emerges ca. 9-10 m above surrounding valley bottoms.

The soil at the edge is a MHP with a moderately hard to very hard, more than 60 cm thick B_h at 85 cm depth. The top of the B_h raises towards the centre at a rate of 0.2 m per 100 m and the thickness of the B_h increases from the edge towards the centre of the terrace.

Drainage: good near edge, poor in centre.

Vegetation: at the edge a tall Agathis borneensis — Gymnostoma nobile-forest, well-structured, top height 45 m.

(viii) Top of terrace level III.

Similar to the change on terrace level II, the HP is more shallow in the centre. Vertical as well as lateral drainage are impeded. The difference between the soils of terrace levels III and II is very much smaller and less easily defined than between levels II and I.

Vegetation: the well-structured, tall forest of the terrace edge changes gradually into a more simple and more noticeable stratified Shorea albida — S.pachyphylla — S.havilandii-forest in the centre. *Agathis borneensis* first becomes smaller and then eventually fades out (SP.44-5). The difference in vegetation between levels III and II is greater than in soil characteristics.

(iv) Terrace level IV.

This terrace level again repeats the previous patterns of the catena. GHP at the base is followed by MHP on the flanks, and by MHP to SHP in the poorly drained centre. The peat accumulation is locally deeper than on the lower levels, especially where drainage is poor. An example is a 60 m wide terrace, 5.5 km east of Kuala Similajau. The terrace is encased between kerangas bottomland with GHP and a broad ridge of Nyalau shale with podzolic lateritic soil under MDF.

The vegetation on the bottomland is Anisoptera grossivinia — Durio carinatus — Whiteodendron moultonianum-forest. On the terrace slopes, a transition from kerangas forests to MDF with *Dipterocarpus pachyphyllus.* On the top of the terrace the MHP carries a Shorea albida—S.pachyphylla—Gymnostoma nobile-forest.

(2) Submerging coastal terraces.

Pueh F.R., ulu Samunsam-sungai Undan area. On both sides of the sandy river levees follow sequences of low pleistocene terraces with HP over sand (SP.5), or over a textural B (SP.1 and 5). More rarely, the terrace soils are shallow leached sand which grades into a gley-mottled clay subsoil (SP.6; also profiles 64, 67 D of DAMES, 1962, p.49). Between the terraces lie flat PB areas. The mineral soil below the peat indicates that these bogs are drowned parts of an originally higher terrace landscape. Distinct terrace levels, such as were described from Similajau F.R., cannot be recognized. Instead, the surfaces of the terraces dip gently and submerge gradually below the surrounding peat bogs.

(a) Low terrace with Humus Podzol (SP.3).

Very gently, 1-2° sloping, MHP soil, 12 m alt.

A_{00}		Loose litter, some moss
A_F	12-5	Leaf debris, dense roots and friable mor
A_H	4-0	Wet friable mor and root mat some quartz grains
A_1	0-10	Humic, soft, yellow brown, medium fine sand with numerous roots
A_2	11-34(40)	Cemented and hard to dig, white-grey medium fine, few roots and old root channels, wet to very wet. Abruptly over:
B_h	(30)40+	Blackish red-brown hard to very hard, strongly humic, slightly silty-loamy medium fine sand.

Drainage: poor.

Vegetation: Dryobalanops fusca—Whiteodendron moultonianum—Palaquium ridleyi-forest with strong tendency to form a dense and uniform top-canopy. Maximum height 45 to 50 metres.

(b) At the base of the terrace, the ground dips below peat bog. The soil changes.

A_{00}		Loose litter
A_0	35-0	Red-brown wet peat, fibrous on top, more granular at bottom
A_1	0-20+	Humic, brownish grey, at 20 cm depth moderately cemented, medium fine sand.

Vegetation: Poorly structured Gymnostoma nobile — Calophyllum sclerophyllum — C. rhizophorum-forest, much wind break. Maximum height 40 to 45 m.

(iii) 100 m further into the peat bog the soil becomes deep peat (SP.4 and 5). 150 cm peat, very wet, over 20 cm soft sand over cemented whitish-grey sand. Vegetation as in (ii), but somewhat less wind-break.

(3) Catena on pleistocene terraces of the Alluvial and Jerudong cycles further inland.

There is apparently no consistent and significant difference between the soils on the terraces in the coastal plain and the terraces further inland at somewhat higher altitude. The remnants of the peneplain, of which I have examined only one example on Bukit Sagan (set. 133.27) seem to have heavier, clayey p.m., which differs from the light-textured material of the younger terraces.

The catena described in the following example is typical for the extensive area of pleistocene terraces which stretches as a broad belt from the middle reaches of the Baram river to the middle reaches of the Temburong river. This belt, together with the coastal Gunong Pueh and Siru F.R. in West Sarawak, contains the bulk of lowland kerangas terraces in Sarawak and Brunei (see maps 1 and 2).

Examples

Terrace complex between the Melinau river and the ulu Ingei, SP.28 to 32. The transect runs from sungai Melinau for about 3 km at 305° toward the ulu Ingei (see fig. 7b).

(i) Recent sandy river terrace on the bank of sungai Melinau with mixed, well-structured riparian forest. Alt. 135 m.

(ii) Limestone ridge, 18 m high, 50 m broad, with dry mor soil on top and a yellow, stiff loam on the lower slopes.

(iii) Moat-like valley bottom between limestone ridge and base of terrace. Alt. 137 m.

(iv) Steep slope to terrace level I, thin podzolic yellow-brown sandy loam under MDF. The shallow soil lies on poorly assorted boulders and gravel which form the terrace base.

(v) Top of terrace level I, 1-2° sloping E., micro-relief apparently caused by wind-throw (SP. 30), alt. 165 m.

Soil: sandy MHP with a weak and indistinct B_h at 45-50 cm depth over greyish-yellowish moderately cemented silty sand between boulders at 60 cm. Wet two days after rain.

Vegetation: moderately well-structured Shorea albida — Mixed kerangas forests. Better structured near edge where *Shorea revoluta* replaces *S. albida.*

(vi) Slope to terrace level II, similar to (iii) but slope shorter.

(vii) Terrace level II, 180 to 185 m alt., extensive flat, basin-like plateau, surface dipping from edge 1° W.

Soil: from edge for 150 m MHP similar to terrace level I, but with a more strongly developed B_h. On small raised mounds the B_h forms a hard pan at 25-40 cm depth (SP. 28). In one pit near the edge a layer with pieces of charcoal was found at 22 cm depth. This is the only charcoal found in a soil pit in kerangas high forest outside the Bako N.P. (SP. 17, see also BRUNIG, 1965). There is no evidence of its origin. It is possible that the charcoal was washed down from the nearby limestone mountains where the dry peat surface sporadically burns during dry spells.

At 150 and 200 m distance from the edge the dip increases slightly to 2°. The B_h gradually hardens into strongly cemented humic pan. Above the pan, lateral water movement is strong after rains.

Vegetation: At the edge, the forest resembles that on level I, except that *Gymnostoma nobile* is somewhat more frequent. As the transect proceeds inwards (SP. 28), the vegetation shows more distinct stratification. Dense pole stand at 10 m, open but regular main canopy at 30-33 m, very few large emergent *Shorea albida* at 40 m height. All emergent and on level I. Further on, beyond 200 m from the edge of terrace level II, the mineral soil dips beneath a peat layer and, as far as borings show, the subsoil is more clayey. The sequence from dry land to peat is shown by profiles from SP.31, 29 and 32 which are spaced along the transect at 100 m intervals.

PEAT CATENA ON PLEISTOCENE TERRACE

Topography	Edge	Flank of peat dome	Interior
Locality	SP. 31 (182 m a.s.l.)	SP. 29 (182 m a.s.l.)	SP. 32 (182 m a.s.l.)
A_{00}	Loose litter, little moss	Loose litter, much moss on root mounds, bare hollows with stagnant water above surface	Loose litter, moss on fallen timber
A_0	(70)120-0 cm, very wet, water table at 7 cm depth, red-brown fibrous peat, well-rooted in upper layer	(90)60-0 cm, very wet, red-brown fibrous peat, more granular-soupy and redder at bottom	Deeper than 1.5 m, red-brown peat, dried and more fibrous than in S.P.29 near top, soupy toward bottom, well-rooted in upper part, few roots near bottom
A_1	0-20+ cm, humic, soft sand over sand	0-10+ cm, wet, cemented silty fine sand	Wet, cemented sand, difficult to penetrate
Vegetation	Mixed kerangas forests. Moderately well-structured, weak tendency to two-storey stratification. *Shorea albida* and very few *S. scabrida* emergent, top height 40 m. Some windthrow among emergents.	Open to very open irregularly grouped pole stand, *Mesua* spp. dominant, height 10-12 m, few moribund emergent (H 28-33 m). *Shorea albida, Dactyloclados stenostachys Combretocarpus rotundatus.* Some *Shorea albida* saplings in pole stand.	Dense pole to small timber stand, moderate grouping tendency, two-storied, with poles at 10-15 m and uniform, rather dense top canopy at 25-30 m. Top canopy dominated by *Calophyllum* spp. and *Shorea albida*, under-storey by *Mesua* spp.

Beyond SP. 32, the peat surface rises slightly and the top-soil appears drier. The peat depth is about 1.0-1.5 m, *Shorea albida* again increases in size and the forest changes gradually into a Shorea albida — Calophyllum spp. (2)—Gonystylus bancanus-forest, H_T 30-35 m, raised root platform, much wind-throw. The type extends along the transect for about 250 m when the surface raises by about 1-2 m and the peat becomes shallower, and gives way to a strongly humic MHP soil. The forest is similar to the forest close to the edge in SP.28. A short slope downward carries a well-structured forest with *Shorea albida, S. revoluta* and *Gymnostoma nobile,* followed again by flat PB with Shorea albida-forest, which continues to the end of the terrace. The terrace descends by a steep slope with MDF to a moat at the foot of a limestone ridge.

Some of the terraces in the area, especially those near the Terikan-Medalam confluence and in the ulu Ingei, are encased. The soil changes gradually from the HP on the terrace into medium-textured RYP or yellow soils under MDF on the tertiary scarps. If a dip-slope buttresses on the terrace, the soil is HP or light-textured RYP soil under kerangas forests (*Agathis borneensis, Dryobalanops beccarii*) or under poor, transitional MDF.

135. Kerangas Soils as Vegetation Sites

135.1 Soil Mineral Content

135.11 Plant-Available and Total Nutrient Content

Kerangas is by definition infertile land. More specifically it is land on which rice does not thrive (BROWNE, 1952, p. 70). The low fertility may be due to deficient supply of water or nutrient, or both.

ANDRIESSE (1962a) has compared the nutrient status of tropical podzols in Sarawak with RYP and red-brown LS soils. Differences were within the normal tolerances for errors of analysis. He concluded that actual nutrient availability may be dependent on some yet unknown process which is not sufficiently correlated to analysis results for available nutrients at the exchange complex. Acidity was not associated with observed field fertility. Periodic drying and wetting of soils is known to cause the pH-values to vary considerably (LOETSCHERT, 1963). Variation may be in the order of two units (WALKER in discussion to RICHARDS, 1965, p. 205). Any correlation between pH and fertility would be obviously difficult to ascertain.

Similarly the data from analyses of a wide range of soil samples by DAMES (1962) produced little reliable evidence of significant differences in the contents of plant-available nutrients. Total nutrient contents were not analysed. Kerangas soils appear to have a wider C/N ratio and less phosphorus and magnesium content, but the number of presently available observations is too small to confirm this difference. RICHARDS (1965, p. 198) found some indication that total nitrogen was slightly lower in kerangas soils, but there was no evidence of a difference in ammonia or nitrate. He also suspected that dried and shipped samples may have undergone changes and not given very dependable results. Also, the figures for total and extractable phosphorus and for calcium and potassium did not produce significant differences between the soils in kerangas and MDF. Among the kerangas soils, the DHP had the lowest nutrient content per unit weight of soil.

RICHARDS analysed peat samples from various places in the neighbourhood of SP. 22 to 27 in the Badas-Anduki area and near Marudi. The samples also did not show consistent nutrient availability gradients which could reliably explain the very great difference in the standing biomass between the peripheral and central peatswamp vegetation. However, there is some indication of decreasing total and extractable phosphorus and nitrogen in top peat layer from the perimeter to the interior. The C/N ratio increases correspondingly from about 21 to above 27. In concluding, RICHARDS suggests, that in spite of the inconclusive results, the availability of nitrogen and/or some other nutrient, such as phosphorus, may be the factor mainly responsible for the productivity gradient in the peatswamps.

GILLILAND (1959) assumes that nitrogen deficiency is critical in the nutrition of the padang flora in the Bako N.P. which BRUNIG (1965) described as secondary kerangas vegetation. GILLILAND believes that this is due, at least in part, to the original poorness of the tertiary sandstone p.m.

SCHULZ (1960, pp. 122 and 125) finds that differences of available nutrients between strongly bleached sands and less bleached loams in Surinam are too small to explain the large difference in vegetation luxuriousness, but suspects that the bleached white sands have a generally lower nutrient content. HEYLIGERS (1963) could not confirm such differences in a later investigation and suspects that physical parameters, above all those affecting drainage, may give more important indications of fertility than the conventional agricultural methods of chemical soil analysis.

BECKETT (in lit. of 21.6., 1966) points out that ratios between K, Ca, Mg, and Al may be more significant than the absolute levels of plant-availability of individual nutrients.

In the present study facilities permitted only very few soil analyses. A series of analyses of the nutrient content of a variety of kerangas soils in the Bintulu District gave inconclusive results. Only the general statement that "these soils are typical of the poorer (sandier) hill soils in being very low in all nutrients, and what nutrients there are being chiefly located in the organic matter confirms the general poorness of these soils, but not any differences between them. The samples are also typical in being very acid (pH 4.0-4.5) and having low values for c.e.c., particularly in the sandier profiles, indicating a kaolinitic type of clay minerals" (pers. comm. from Mr. DESMORE, Soil Chemist, Kuching, dd. 19th Nov., 1959).

All results of the kerangas soil analyses were combined and are reproduced separately for each soil group in tab. 5. Also included in tab. 5 are the results of RICHARDS' (1965) peat sample analysis. The peats were collected from above the water-table in the peatswamp forests between the Anduki (SP. 27) and the Badas (SP. 22 to 26) terraces. My samples were analysed by the Soils Laboratory, Department of Agriculture, Kuching, by the standard methods used in the years 1959 to 1961. RICHARDS' samples had been analysed at Bangor, U.K.

The pH differences are not consistent with differences in p.m., or texture or organic matter content, and do not clearly associate with differences in fertility. Obviously plants must, under the climatic and evolutionary conditions of the area, have become adapted to the very high acidity of most soils and consequently to low nutrient and high hydrogen levels in the soil solution.

Nitrogen and phosphorus decrease from RYP to GWP and HP soils. Correspondingly, the C/N ratio increases. The c.e.c. is relatively high in the HP soils as a result of the relatively high content in organic matter, and in the GWP soils as a result of a high clay content. The only difference in base saturation, which seems to be somewhat consistent, is the relatively low value for magnesium in the GWP and HP soils.

The change of nutrient content with depth shows the same trend as in extra-tropical podzolic and podzol soils. The change seems closely related to organic matter content and to texture. The highest nutrient contents occur in the A_0 and A_{011} horizons, the lowest in the

A_{e2}, and a small increase is noticeable in the B_h or B_t horizons. The contents in available nutrients are of the same order reported for HP in other parts of the tropics (KLINGE, 1969). The pH value in the A_{e1} and B_h of HP soils is usually smaller than in the A_{e2}. This is probably due to the extremely low exchange capacity of the almost pure quartz-sand A_{e2} horizon which is consequently low in exchangeable hydrogen ions. The same applies to the A_{e2} in sandy GWP soils. The kerangas HP and sandy GWP soils appear lower in available nutrients than comparable soils in cool-temperate climates. LEYTON (1954) produces data for some heathland soils in Britain, which show consistently higher contents for all major nutrients. The C/N ratio in the Sarawak podzols is greater than in comparable Humus-Iron Podzols and Gley Podzols in NE. Germany reported by TOELLE (1968, tab. 3). The ratio is also higher than those in comparable horizons in free-draining oxysols under tropical moist evergreen forests in Africa, reported by NYE and GREENLAND (1965, p 59). NICHOLSON (1962) reported differences in nutrient status between "padang type sandy podzols" and "degraded red earth" in Sabah, which in scale are similar to the, however insignificant, differences in tab. 5.

The two peat samples from the Merurong plateau (tab. 5d) are very poor in all nutrients. Phosphorus is even lower than in the other types of kerangas soils, even if the different reference basis (total content of ash) is considered. BLACK states that the only soils from which loss of fertilizer phosphorus by leaching is significant on a short-term basis are sands and peats which have little tendency to react with phosphorus (BLACK, 1968, p. 563). On the other hand, this low level of reaction will make the little phosphorus in organic soils more easily available. It has been suspected that phosphates in organic form may be fixed much less than inorganic phosphates (IGNATIEFF and LEMOS, 1963). The combined effect of low level of fixation and the correlated, if small, susceptibility of phosphorus to long-term leaching in soils, where the main chemically active component in the top-soil is very acid peat or mor, may have reduced phosphorus contents but may also enable the maintenance of a reasonable level of cycling in spite of the extremely low levels of phosphorus in kerapah and sandy kerangas soils. LUDECKE (cit. BLACK, 1968, pp. 563-4) has demonstrated a decrease in total phosphorus content in New Zealand soils with increase of rainfall from 410 to over 1,000 mm, indicating losses of phosphorus by long-term leaching.

The results of analyses of the lowland peatswamp samples by RICHARDS (1965) seem to indicate that the lowland peatswamp forest peat of the samples is somewhat better supplied with nitrogen, especially in the more peripheral Alan forest, than the high altitude kerapah plot samples from the Merurong plateau (tab. 5d, PSF 19 and 5).

Available nutrients may be a poor measure of nutrient-related soil fertility in tropical soils and total cation content may be more indicative (ANDRIESSE, 1962a). There are few data published yet on total nutrient content in tropical podzols. WOOD and BECKETT give the following values for total cations present in composite samples of the A_o and A_{e1} of several kerangas soils in m.e. per 100 g of soil:

A_o K 0.42; M_g 6.70; Ca 6.80

A_{e1} K 0.25; M_g 4.15; Ca 4.70.

They also mention that the cation content of the A_{e2} in a kerangas soil on a beach terrace is extremely low (WOOD and BECKETT, 1961, p. 226, footnote), which is not surprising in view of the almost absence of an effective exchange complex in this horizon. The above values are very much lower than the means of twenty temperate zone soils in New Jersey which BLACK (1968, p. 211) reports as K 46.7; Mg 42.3; Ca 17.3 m.e. per 100 g of soil.

The total nutrient contents in the A_0 horizons of the British heathland podzols studied by LEYTON (1954) are of the same order as the contents reported by WOOD and BECKETT (1961) for Ca and Mg, but there is a noticeably lower content of K in the kerangas soils (0.42 m.e. per 100 g as compared with 5.0 to 8.8 in Britain).

Recently, ANDRIESSE (1969) published data from chemical analyses of one humus podzol on old alluvium, one humus podzol on quartzitic sandstone and for comparison one grey-white podzolic soil on carbonaceous shale, which generally confirm the extremely low contents in the exchangeable and total nutrients. The differences between the profiles are relatively small. The terrace soil with a sandy clay-loam to sandy clay subsoil is somewhat richer than the residual soil over white medium-textured sandstone. Generally, the exchange capacities and contents for exchangeable bases lie within the ranges given in tab. 5c, except for magnesium for which ANDRIESSE's figures are higher. Unfortunately, ANDRIESSE gives no description of the vegetation on any of his profiles.

The available evidence indicates on a whole that kerangas soils have lower contents in total and so-called available nutrients than the RYP and LS soils under MDF. Observations of STARK in Surinam and Amazonia, Brazil, point into the same direction. He found that the mineral horizons of lateritic soils and the plants growing on these soils were richer in the total content of biologically essential mineral nutrients than the plants and the comparable horizons in the mineral soil of podzols. In the forest and savanna types studied, there appeared to exist a general correlation between litter depth, organic matter content of the surface soil, total mineral nutrient content, and the stand height and species diversity of the vegetation. Especially in the Dimorphandra-forest with a up to 1 m thick litter layer along creek margins most of the mineral nutrient store is contained in the organic matter on the soil surface (STARK, 1970). In the kerangas soils, the PB and sandy GWP soils are poorer in available nutrients than clayey GWP and sandy MHP and RYP soils. SHP about equals sandy GWP soil. DHP soils appear extremely poor on a volume unit basis, but it must be remembered that the profile and rooting depth is several times greater than in other soil types.

135.12 Mineralogical Composition

In mineralogical composition the terrace soils, as far as the few data show, differ notably from poor and leached residual non-kerangas soils. Mineralogical analyses by the Soils Laboratory, Royal Tropical Institute (report in Agric. Dept., Soils Lab., file T9/JPA/d, dd. 11.11.1961) show that the sandy top-soil on a quarternary raised beach terrace soil is a zircon association with zircon, rutile and anastase as principal minerals, while the clay subsoil contains a higher proportion of tourmaline and belongs mineralogically to the zircon-tourmaline association. By comparison, one poor RYP soil profile on miocene sandstone and shale is a zircontourmaline association at the top and bottom of the profile, with a zone of 100% alterites, including leucoxene, in the middle. Another highly leached, poor yellow latosol on tertiary sandstone is an andalusite-tourmaline zircon association with increasing andalusite content (50 to 85 %) with depth.

ANDRIESSE reports that the alluvial terrace materials consist largely of crystalline quartz. The clays also are mainly quartz with small amounts of mica, kaolinite and illite. The heavy mineral association of the sand fraction consists of zircon, tourmaline, rutile, anatase and brookite. The content of opaque minerals is above 60%, and ilmenite is dominant. In the p.m. of iron podzols, a high concentration of hornblende is typical and may be the source of the iron oxides. Sedentary p.m. of podzols may locally contain orthoclase, but this could not be established with certainty. The heavy mineral associations are very similar to those in terrace p.m. Generally, the podzol p.m. in Sarawak is high in quartz, very low in weatherable minerals and clay, and low in sesquioxides (ANDRIESSE, 1969, p. 202-3).

Kerangas soils seem to be low in minerals which are associated with the level of mineral nutrient reserves and nutrient availability to plants. In the available data is some indication that the mineral content of the p.m. of podzols differs from that of RYP soils. We may therefore, in accordance with ANDRIESSE (1962a), suspect, that there may exist a difference in mineral availability between kerangas soils and the poor members of the Dipterocarp forest soils in spite of the somewhat inconclusive evidence of convential analyses of plant-available nutrients at the exchange complex itself.

135.13 Soil Colour as an Indicator of Differences in Chemism

Differences in colour generally indicate that two substances differ in their chemical composition. It would, therefore, be of some significance if the colour of kerangas soils would differ consistently and clearly from Dipterocarp forest soils. Fig. 5 shows the MUNSELL colour notations at the base of the A_{e1}, on an average between 20 and 30 cm depth. The data are from 500 square-chain recording units in Sabal F.R., the 55 single sample plots and from profile descriptions by DAMES (1962), BECKETT and HOPKINSON (1961), WOOD and BECKETT (1961) and ANDRIESSE (1969). The distinction between RYP and Skeletal soils under MDF and the HP and GWP soils under kerangas is very obvious and clear. Alluvial Gley soils under riverain forests are located on the right of the lithosols and mountain gley-type clays (beyond 10 YR 9/4 to 2.5 Y 8/2-4). Red Lateritic soils under MDF occupy the region left of the RYP soils (beyond 7.5 YR 7/6-8) and centre around 2.5 YR 5-6/6-8. The A_o of HP soils would lie near the bottom of the diagram below the Red Lateritic soils in the region of 2.5 YR 4-5/0-2, and continue left into the dark red-brown chroma. The distribution of the MUNSELL colour notations clearly separates kerangas soils from all other soils (see also sect. 132). Therefore, we may suspect that the chemism of kerangas soils differs accordingly.

135.2 Micromorphology and Texture of Kerangas Soils

135.21 Micromorphology

The difference in micromorphological features between strongly bleached brown loam and podzol soils in the Amazon has been discussed by ALTEMUELLER and KLINGE (1964). The strongly bleached brown loam profiles did not show clay accumulation within the investigated profile depth. In contrast, humus podzols showed clay accumulations and new formations of minerals below the B_h. One of the described podzol profiles is obviously a DHP with a black-brown to reddish brown, ferruginous humic soil B_h in 3.5 m depth. The B_h also contains clay remnants from a prior brown earth phase. Below the B_h, the brown earth character becomes predominant and the iron content of the clay fraction decreases. Continued clay transport downwards is evidenced by accretions of clay. The B_h of a SHP soil had no colloidal iron-hydroxide, but abundant clay minerals. Beneath the B_h, evidence of secondary formation of kaolinite and hydrargillite was found.

In order to study the relationship between horizons and between profiles of kerangas soils in Sarawak in some more detail, seven monoliths were collected from typical profiles which represent the range of the major kerangas soils. Micro-slides and the clay fraction were investigated in some of the monoliths at Reinbek. Soil samples from the same profile were sent to the Soils Laboratory, Department of Agriculture, University of Oxford, for physical and chemical analysis, but were not analysed.

The following is a summary of an informal report on the micro-slides (v. BUCH and SCHMIDT-LORENZ, 1966). The result of the clay analyses will be discussed in sect. 135.3.

(1) Medium Humus Podzol with weakly developed B_h, m SK I, Sabal F.R., sample area 1963, sq.7/8. For profile description see sect. 133.262, ex. 1.

The micro-slides of the A_e show a single-grain structure of quartz. A small amount of organic matter has been mechanically arrested between sand grains in the A_{e1}. Roots in the A_{e1} have much ectotrophic mycorrhiza. The eluvial A_{e2} consists of single grains, no humus, and contains much opaque material. The B_h/C layer shows signs of strong lateral eluvation of organic matter.

(2) Medium Humus Podzol with moderately developed B_h.

Monolith SK III, Sabal F.R., 50 metres N. of the NE. corner of sample area 1963, 200 m N. of monolith SK I and 100 m. N. of monolith SK II (see below, ex. 6). For profile description see sect. 133.262, ex. 2.

The micromorphology of the A horizon is identical with the A in SK I, but the subsoil shows indication of lessivation, which are absent in SK I. It is uncertain whether the lessivation had been developed in a different profile from which the top-soil was subsequently eroded and later replaced by sandy colluvium.

As in the previous profile, fungus hyphae are common, but also extend into the B_3. Some unidentifiable organic substance has been encrusted in secondarily crystallized silica in the A horizon.

(3) Medium Humus Iron-Podzol with hard B_h.

Monolith SK V, Nyabau Block, Similajau F.R., sampling area 1959, centre of a quarternary sand terrace, 7 m alt., 6 m above present drainage level, S. and E. bordered by the peaty alluvium of a small river, SW. encased to tertiary ridge, N. dipping into a coastal peatswamp which extends from the terrace to the 1-2 km distant beach. For soil profile description see sect. 133.262, ex. 6.

The A_{oo} shows plentiful marks of animal frass and faeces and has a dense root mat. The A is again characterized by single quartz-grain structure. Granular pieces of black-brown organic matter are irregularly distributed. The organic matter is separated from the quartz grains and does not form coatings. In the cemented A_3 very small quartz fragments are abundant. There is no evidence of silica gels and secondary silica crystalls, which had been observed in example (2).

The B_h shows irregular humus illuvation. Recent illuvation seems concentrated in clefts and old root channels. The walls of large root channels show humus deposition in successive, thick layers. This indicates that the humus colloids must have been precipitated in flushes followed by drier conditions (see sect. 111 and 117). At 44 to 53 cm depth, dark brown relatively older sesquioxides mixed with few traces of clay and light reddish-yellow younger sesquioxide gels are irregularly deposited in a matrix of quartz grains. Some of the gels show brighter lines, which may be cracks, caused by alternating wetting and drying. Further down, clay illuvation is noticeable which most likely has originated from lessivation. There is no indication of any change of p.m. from A to C. Throughout the profile the soil is a sand matrix of irregularly angularly shaped quartz grains mixed with numerous very small splinters. Edges are mostly rounded. Organic matter, clay and sesquioxides are illuvated and deposited in narrow passages, channels are clefts of the illuvation. The clay in the subsoil is fairly evenly distributed. It is uncertain whether the increased clay content is exclusively due to lessivation or to some extent due to the formation of secondary clay minerals from the components of clay destruction in the top-soil.

(4) Medium Humus Podzol with B_h over B_t.

Monolith SK IV, former Stapok F.R., centre of the gently undulating quarternary terrace. For profile description see sect. 133.262, ex. 5.

The A horizon is distinctly different from the previous profiles. The single-grain structure is replaced by a more layered and aggregated structure. The quartz grains are very irregular and strongly rounded, with clay filling gaps. The B_h is denser than the B_h in example 3 and illuvated organic matter and bulky clay is more distinctly aggregated in inter-spaces. Root channels are again lined with layered humus sedimention.

The B-layer rests abruptly on a fine sandy, loamy clay layer at 38 cm depth, which consists of yellow-brown, irregularly shaped mineral grains. Fungus sclerotia and concentrated, bulky humus flocculations fill some of the clefts in the mineral soil matrix. Clay is also irregularly distributed in the matrix of coarser material. This is in contrast to example 3, in which the clay is more or less evenly dispersed within the single-grain coarser matrix.

The soil structure changes again abruptly at 60/65 cm depth. Fine irregular quartz grains are scattered in massive darkish clay which shows strong evidence of layering and lateral flow movements. Amorphous organic matter fills numerous old root channels. The structural change represents the transition from mangrove mud at 65 cm through a brief alluvial phase at 38-60 cm to the sandy kerangas terrace. During terrace formation, the sandy top-soil was deposited, subsequently probably partly eroded and the remnants eventually podzolized to the present condition.

(5) Secondary Humus Podzol.

Monolith SK VII, Bako N.P. near SP.17, centre of the Plateau Sandstone plateau, gentle 5° slope dipping N., 75 m alt., 60 m E. of sungai Sloar.

The vegetation is a Dacrydium pectinatum— Gymnostoma nobile — Cotylelobium burckii-forest, uniform top-canopy at 15-18 m, H_T 40 m on the lower slope, 33-35 m on the upper part of slope, undergrowth moderately dense, some unhealthy looking saplings of *Dipterocarpus borneensis,* moderately abundant *Eugeissona insignis* and *Paphiopedilum hookeri,* scattered sedges on the ground. Simplicity of structure and condition of ground-flora indicate old-secondary status. The soil profile is briefly as follows:

A_{oo}		Loose and sparse, sedge leaves
A_o	7-0	Red-brown mor, well-rooted
A_{e1}	0-15(20)	Loose reddish-brown grey humus sand, moist, well- to poorly rooted
A_{e2}	(15)20-35	Moderately loose yellowish-grey sand with weak reddish-brown mottling, moist
A_3/B_h	35-40	Reddish-brown-yellow slightly cemented sand, moist
B_t/C_1	41-65	Slightly cemented, angularly blocky, fine sandy loam, humus infiltration along interfaces and in old root channels, dry
C_2	66+	Soft-friable, increasingly loamy, light yellow sandy loam, humus illuvation along interfaces, dry, with depth more clayey, over irregular sandstone surface.

In the micro-slides, marks of animal activity are abundant in the A_o horizon. The A_e is a matrix of very irregular, unsorted mostly fine-grained mineral grains with moderately rounded edges. A small amount of aggregated clay in some narrow passages appears dark in polarized light. The mineral grains are less uniform and the proportion of non-quartz mineral grains is greater than in the HP profiles (examples 1-3). From 20 cm depth downwards, the amount of illuvated granular organic matter decreases and the amount of the more uniformly distributed clay fraction increases. The clay fraction is much greater than the colour and macroscopic features of the horizon suggest. At 40 cm, the structure is very heterogeneous. Sesquioxides and, it appears, also clay and humus are deposited in small clefts along the old sedimentation interfaces. At 75 cm the structure resembles typical "brown loam", except for some illuvation which is still noticeable in cracks and clefts.

The profile shows stronger podzolization than the clay and mineral contents of the soil suggest. Historical and vegetational evidence will be discussed in later sections which indicates that the present vegetation is a secondary kerangas forest. The original poor type of MDF has probably been burnt for gambier-growing or accidentally at some time during the second half of the nineteenth century. Subsequently, species from adjacent kerangas forests invaded and initiated podzolization.

(6) Red-Yellow Podzolic soil.

Monolith SK II, Sabal F.R., sampling area 1963, sq. 3. For profile description see sect. 133.24, ex. 2.

The A_{e2} is very similar to SK I and III, except that the matrix of irregular, rounded quartz grains is cemented by irregularly aggregated, humus-stained clay material. Very fine mineral splinters are again common. The A_3/B contains some more larger quartz grains and abundant very fine splinters. Pore space is ample but with increasing depth, pores become blocked and filled with amorphous mineral and organic matter, together with some coarser particles of organic matter.

The B_3 at 62 to 75 cm depth is much more irregularly structured and the range of strongly rounded mineral particles is wider. Clay is abundant and relatively evenly distributed through the soil. Illuvation of small amounts of granular and larger amounts of diffuse organic matter can be recognized in areas which are accessible through clefts and cracks. The evidence of micro-slides is insufficient to decide whether the clay fraction in the B_3 has been originally present in the p.m. or, if at least part of it, has been added by lessivation from A_e. The plastic grey-white clay C below 75 cm points to the former, the conspicuous humus illuvation in the B_3 to the latter. There is a possibility that the A_e is a sandy colluvial which has been eroded from surrounding sandstone boulders, or from the upper portion of the slope of the Klingkang range.

The microstructure of this soil is distinct from the very unbalanced structure of LS soils, which is characterized by large, angular minerals scattered in a matrix of fine-structured, rather homogeneous, dense red-brown material.

135.22 The texture

The soil texture in kerangas varies much between different soils and within profiles. Previous opinions that kerangas soils were exclusively sandy (BROWNE, 1955), are incorrect. The cause of the greater variation within the kerangas soils is firstly due to p.m. It was shown above that areas of clayey kerangas soils are found on thin-bedded tertiary sandstones with interbedded siltstones, mudstones or shales. Kerangas clay soils are also common in depressions between lines of raised beaches. They also occur on clay pockets on top of littoral and alluvial terraces. Clay soils also develop from originally more sandy terrace soil if the top-soil is eroded and a more clayey subsoil becomes exposed. This condition is not rare on quarternary terraces and also occurs on thin-bedded tertiary sandstones. Predominantly sandy and uniformly textured throughout are shallow GWP and HP soils on hard, gently to steeply dipping sandstone beds and on the tops of broad boulders. HP soils on holocene beach terraces are often sandy to loamy sandy down to the underlying D horizon. But, in contrast to the shallow GWP sands on sandstone, the clay fraction increases somewhat with depth and a moderately marked peak of clay content occurs in the lower B_h and in the B_3, which is most probably the product of lessivation.

Secondly, the variation of texture is also due to the wide range of topographic conditions under which kerangas and kerapah occur. This range has formerly been underestimated. Processes of differential erosion and sedimentation within the kerangas sites and differential exchange between the kerangas sites and their environment greatly increase the textural complexity. An example is the complex pattern of soil types in the Niah-Jelalong area, SP. 47 to 50 (sect. 134.2).

The great amount of variation within and between the profiles of the various soil groups, subgroups, and series of the kerangas makes it almost impossible to distinguish kerangas soils clearly from other soils on a purely textural basis. Fig. 6 shows the distribution of the A_{e1} horizons in a textural diagram. As in fig. 5, the A_{e1} has been chosen because it is the lower level of the main rooting sphere of the forest vegetation. It could be expected that even small textural differences in this horizon should influence noticeably growing conditions for the forest vegetation.

The distribution shows the expected concentration of HP soils in the left corner (sands, sandy loams). The only GWP soil is from SP. 50 and belongs to the sandy clay loam class. The bulk of the GWP group on more arenaceous p.m. would be in the classes of sands and sandy loams. The GWP soil described by ANDRIESSE (1969) falls on the boundary between loam and clay. The PG soil from the Merurong plateau (SP. 53) is in the clay class, which would be expected in this soil group.

The RYP soils under MDF (e.g., Sabal sampling area, 1963; WOOD and BECKETT, 1961, profile 8; ASHTON, 1964c, profiles 7, 18 and 19 in fig. 9) overlap texturally with the sandy kerangas soils. The gley kerangas soil is texturally in the area of the alluvial clays and the clay latosols and lithosols of ASHTON (1.c., fig. 9, profile 21 and B 7 to 12). A textural distinction of kerangas and MDF soils is therefore not possible. The same is true for kerapah and peatswamp forest soils (see sect. 133.27).

Textural change within the profile of kerangas soils is typically either very weak and the profile uniformly sandy, or the change is strong and often abrupt. The sandy top-layer may be a few centimetres to several decimetres deep. It changes gradually into more heavy-textured material if the p.m. remains the same. Changes are sudden and boundaries distinct if the substrate changes (e.g., the sandy MHP over alluvial loam over mangrove clay in the former Stapok F.R., described in sect. 133.262, example 6, and 135.22, example 3).

Exceptional cases of kerangas soils without sandy top-layer are some PG and truncated GWP clay soils. Such soils are texturally close to clay lithosols with which they also share similar topographical positions.

The comparison between kerangas soils and MDF soils in Sarawak indicates that it is the combined effect of the primary factors soil texture, soil stratification, soil depth, topographical position and mineralogical composition which is responsible for the obvious differences in fertility between kerangas and Dipterocarp forests, rather than any single factor alone. The interaction of the primary factors determines soil colour, soil aeration, soil water and nutrient cycling regime. The last two in turn directly affect stand characteristics. Under such conditions it would be unlikely that any single factor, such as soil texture, could be a suitable criterion for deliminating kerangas soils.

135.3 The Clay Fraction

The organic matter of tropical soils is one of the most important links in the complex chain of the nutrient cycle. In kerangas soils the greater part of the available nutrients is associated with horizons having a relatively high content of organic matter as chief absorption and exchange complex. As we have seen, some kerangas soils also contain substantial amounts of soil material in the clay fraction at any depth of the horizon. The nature of this fraction is, therefore, of some ecological interest.

Clay, similar to humus and mor, affects the physical and chemical soil properties in a number of ways. An important function of the clay fraction is that of slowing water movement. Consequently, it affects the nutrient cycle and the moisture regime of the site. Another important function is that of an absorption complex. LIECHTI (1960) remarks that the terraces consist of material which had been redeposited several times and which is almost exclusively quartz in the fractions clay, silt, and sand. Such material obviously would have little value as absorptive complex. ALTEMUELLER and KLINGE (1964) suspect from refraction in micro-slides of an Amazonian HP that the clay fraction in the B horizon consists of kaolin and hydrargillit, minerals which could be expected to occur in this strongly weathered material. They also mention that, in the soil studied, a white-clay bed occurs below a depth of 80 cm.

WOOD and BECKETT (1961, p. 225, prof. 5) had analysed the clay fraction in a HP soil on the seaward slope of a low hill, 15 m above sea-level, 400 metres from the beach in Similajau F.R. The A_{e2} contained a high percentage of quartz and some kaolin. The clay fraction of the B_h was 95% kaolin, 5% gibbsite, traces of vermiculite, anatase and quartz. The clay fraction of the underlying B_t (58-66 cm) consisted of 60% quartz, 20% mica, 20% chlorite and traces vermiculite, gibbsite and quartz.

SCHMIDT-LORENZ analysed the clay fraction in the 7 monoliths from kerangas soils. In addition he analysed one monolith (SK X) which Dr. ASHTON collected in MDF on Gunong Lundu. The monoliths covered the more important kerangas soil groups except GWP soils. The micromorphology of the monoliths has been described in sect. 135.21, except for monolith VI, which has been collected in a secondary padang in Bako N.P.

	Monolith Soil	Geology	Profile described in:
SK I	MHP on sandstone	Silantek	133.262, ex. 1
SK II	RYP on sandstone/clay	Silantek	133.24 , ex. 2
SK III	MHP over B_t	Silantek	133.262, ex. 2
SK IV	HP over alluvial loam and mangrove clay	Quart. terrace	133.262, ex. 5
SK V	MHP over sand	Quart. terrace	133.262, ex. 6
SK VI	Clayey PG	Plateau Sandst.	—
SK VII	Secondary MHP	Plateau Sandst.	135.21 , ex. 5
SK X	Deep brown loam	Igneous	—

The x-ray analysis of the clay fraction in the B horizons had the following results (SCHMIDT-LORENZ, 1966):–Weathered aluminium silicates are absent or occur in traces. Three-layered clay minerals occur in all profiles but mostly in insignificant amounts. Kaolin predominates in all profiles except in VII, in which this fraction represents only 30% of the clay fraction. Unaltered illite occurs in small amounts in I, III, V and VII. A large proportion of illite, up to 40%, is present in VI. Widened illite derivates, which contract if K is added, occur in all profiles, but in substantial amounts only in IV, V and VII. Secondary chlorite is particularly common in the RYP soil of monolith II, in a small enclave of MDF surrounded by kerangas forests.

Non-silicates in the clay fraction are chiefly quartz and some iron oxide. 40% of the clay fraction are quartz in SK I, 25% in SK IV, and 15% in SK III. Gibbsite occurred only in SK X, which contained considerable amounts. Montmorillonite occurs in traces in SK III and SK IV, which both show vega features in buried alluvials in the C/D horizons.

This result is of considerable interest because it shows differences in the clay minerals which closely conform with vegetational differences. The clay fraction in the B horizons of HP on terraces (SK IV and V) and tertiary formations (SK I and III) consist predominantly of kaolin and to some degree of quartz. The vegetation on the sites of all these monoliths is a well-structured mixed kerangas forest with *Agathis borneensis*. Monolith SK III is somewhat extreme in that its quartz content is relatively low and montmorillonite is present. The present topographical position of monoliths SK I and SK III is very similar, but SK III rests on clay-loam with vega character and SK I directly on sandstone (see 133.262, ex. 1 and 2; 135.21 ex. 1 and 2). The vegetation around monolith SK III is distinctly more diverse and exacting (Shorea pallidifolia — Shorea venulosa — Shorea ovata-forest, H_T 45m) than the vegetation around SK I (Agathis borneensis — Melanorrhoea beccarii — Gymnostoma nobile-forest, H_T 40m).

Secondary chlorite is common in SK II at the expense of quartz and kaolin. The forest around the location is a small enclave of transitional MDF with *Shorea elliptica* and *Dryobalanops beccarii*, H_T 45-49 m (see 133.24, ex. 2). Monolith SK X from typical MDF on igneous p.m. differs from SK II in its high content of gibbsite.

The stagno-gley clay soil of monolith SK VI has sediment character and probably developed on an interbedded clay pocket or on down-washed material. In the profile, illite is very common (40%) besides kaolin and quartz. The vegetation around monolith SK VI is secondary, open padang. The most likely natural vegetation on the site would be a well-mixed and well-structured kerangas forest, probably dominated by Dipterocarps and Sapotaceae, or a transitional MDF with a strong kerangas element.

The secondary podzol of SK VII, which is located near SK VI and near SP. 17 on the main plateau in the Bako N.P., differs from all other kerangas profiles by its low content of kaolin in the B_t/C, and the relatively high content of widened (14 Ångström units) illite and illite derivates. This relates the profile to the stagno-gley of the nearby monolith SK VI in secondary padang and supports the opinion that both vegetation and soil types are equally secondary. Gold had been mined in the nearby valleys and apparently the plateau has been prospected for centuries. During the nineteenth century, gambier has been grown at many places on the plateau. It is therefore not unlikely that the original vegetation has been destroyed and replaced by secondary kerangas.

The results show the general deficiency in typical kerangas soils of clay fractions which are efficient absorptive compiexes. Therefore, as ANDRIESSE (1969) also emphasizes, the exchange complex in the HP soils and light-textured GWP soils is mainly a function of the organic compounds. In fine-textured GWP and RYP soils the clay fraction plays a more important role as exchange complex and may, to a large measure, determine fertility and growth potential of these soils.

13.5.4 Micro-organism

RICHARDS mentioned the possibility that the kerangas soils may have microbiological conditions which differ from those in Dipterocarp forest soils. Such differences could affect the availability of nutrients, especially of nitrogen (RICHARDS, 1965, p. 203).

The micro-slides of kerangas soils show abundance of fungus hyphae in the organic surface matter and frequent ectotrophic mycorrhiza formations. This agrees with the abundance of the genera *Agathis, Dacrydium, Vaccinium, Tristania, Eugenia, Lithocarpus, Quercus*, and *Castanopsis* in these forests. So far, micro-slides from MDF soils have not shown the same abundance of mycorrhiza formations, but the formation of ectotrophic mycorrhiza on Dipterocarps on sandy loams and granite-derived soils is well-known (SINGH, 1966). BEVERIDGE (1953) mentions the occurrence of mycorrhiza in kerangas in Menchali F.R. on the east coast of Malaya. STARK (1970) observed abundant hyphae and mycorrhiza (91% of spp.) in the litter and in the surface layer of the mineral soil in HP soils in Surinam and Brazil. The mycorrhiza may be important in maintaining an efficient nutrient cycling by directly linking decomposing litter with the roots. The scarcity of plants in the fire savannas may be partly due to the inability of mycorrhiza to develop in the absence of organic matter at the soil surface.

Mycorrhiza in *Agathis australis* SALISB. is associated with increased phosphorus uptake and a small but significant fixation of nitrogen (MORRISON and ENGLISH, 1967). Mycorrhiza also stimulates water uptake by the roots, which may be important in the periodically dry kerangas soils.

Some kerangas tree species, which do not form ectotrophic mycorrhiza, often have other types of root micro-organism associations. *Podocarpus spp.* have root nodules which harbour nitrogen-fixing micro-organisms (BAYLIS, 1969, BECKING, 1963). Similar nodules are common in *Gymnostoma* and *Casuarina*. No study has been made of leguminous kerangas species in this respect. Generally, the family is not as well-represented in kerangas forests as in the American Wallaba forest (RICHARDS, 1964), but locally *Pseudosindora leiocarpa* or *Koompassia malaccensis* may be among the leading species of a stand.

Nothing is known of the role which blue-green algae in the soil and on the plant surfaces may play in the nitrogen cycle on and in kerangas soils. The potential of these organisms in tropical areas has been emphasized by SHIELDS and DURRELL (1964). Results by DICKINSON and DOOLEY (1967) show that the micro-flora is very limited in cut-away peat probably as a result of restricted availability of substrates, severe nutrient deficiency or adverse physical conditions. Drainage does not improve conditions very much because the water content remains high due to high hygroscopicity, if rainfall is high, and due to poor internal drainage in peats. This points to a possibly important limiting factor in kerapah and peatswamps, which would be difficult to ameliorate efficiently by silvicultural means.

Signs of intensive animal activity within the surface organic matter are common in all micromorphologically studied profiles. The accumulated surface litter and humus of kerangas soils provide the relatively most favourably living space for micro-organisms in an otherwise adverse environment. The more and better living litter accumulation provides, the greater will be the micro-organism activity and the break-down rate will increase until an equilibrium is reached. This interaction may explain the curious fact, that the depth of surface organic matter is about 5 to 7 cm (excluding freshly fallen leaves) with little variation between sites. Greater depth occurs on very dry sites, extremely oligotrophic soils and under conditions of almost permanent water-logging. In all cases, the conditions are extremely unfavourable for growth of micro-organisms.

A notable feature of kerangas sites is the almost complete absence of leeches. This is probably due to the general scarcity of mammals in kerangas forests more than to the acidity of the oligotrophic humus or the frequent drying of the soils. Leeches can be extremely abundant along game tracks in moss forest with very acid raw humus, but they are absent in water-logged kerapah. All this points to a general poorness of animal life in the kerangas forests, possibly related to its more sclerophyllous nature and generally lower nutrient status. The probably rather specialized micro-fauna and micro-flora in kerangas soils is probably a contributing factor, by limiting the flow along the food chain at an essential point.

135.5 Soil Moisture

The texture of the kerangas soils is coarse to fine sands (HP), loamy sand to sandy clay (RYP), sand or sandy clay-loam (GWP), clay (PG), and sandy clay-loam to clay (LS) (fig. 6). In the mineral soils, humus content is generally low and between 0.3 and 3.5% in the A horizon. Surface mor or humus are on an average 5-7 cm and rarely more than 10 cm deep, except in kerapah peats.

Light-textured, mor-covered kerangas soils have high infiltration and percolation rates. Substantial surface run-off occurs in slope positions and in very intensive showers in which precipitation rates exceed infiltration or water-holding capacity of the soil. The infiltration water is laterally drained above duripans or fine-textured subsoil material. Almost stagnant, perched water tables may saturate the soil over prolonged periods, if the underlying hard-pan or clay layer is impervious and the topography flat. Evapotranspiration and, however slow, vertical and lateral drainage will, even under extreme conditions of water-logging, reduce the level of the perched water table and eventually reduce the soil moisture content below field capacity during dry spells. This has important implications for soil development, especially humus deposition, and for tree growth.

Clay soils are water saturated most of the time and contain practically no air during prolonged periods of heavy rainfall. Sandy loams and sand will still retain air-filled pores during super-humid periods. Excess of water and lack of oxygen in the finely textured soils favours anaerobic micro-organisms and reduces nitrification, nitrogen fixation, and redox potential. It increases CO_2-content and reduces root growth and uptake of nutrients and water. BEVERIDGE (1953) suspects that high water table and poor aeration are responsible for the poor height growth of stands on MHP in the coastal Menchali F.R., Malaya.

According to BOELTER (1965) it is likely that dense, decomposed peats have a low rate of water conduction and low specific water yields. This would mean that perirhizal zones of high water tension could develop fairly rapidly in blanket peats and possibly also in raised kerapah bogs during a dry period. Unfortunately, information is not available on the moisture conditions and water availability in these and other types of peat soils in Sarawak. For the kerangas mineral soils, the water availability can be estimated with reasonable reliability from the known water capacities of soils of different texture.

The water availability of some of the major kerangas soil types has been calculated from observed maximum rooting depth (see sect. 222), soil texture and organic matter content. The results are given in tab. 6. Field capacity and water content at approximate wilting point differ strongly between soil types. The maximum contents of plant-available water range from 60 mm in SHIP in a Gymnostoma nobile—Whiteodendron moultonianum—Cotylelobium burckii-forest to 552 mm in DHP in Agathis borneensis — Shorea spp. — Dipterocarpus borneensis-forest. The latter is probably an overestimate because much of the A_0 horizon is practically free of roots and water in this area would not be fully and easily available to the stand. The almost pure quartz sand A_2 horizon in these soils occupies about two-thirds of the 3 m depth down to the hard-pan. The reduction of water availability as a result of poor rooting in this horizon could be substantial and might amount to anything between one-third to one-half of the calculated 52 mm. The depletion of the water supply by evapotranspiration is discussed in sect. 226.

The heat flux into the soil depends, to a large measure, on the shading of the soil surface by plant canopies. The radiation balance at the soil surface decreases with increasing plant mass of the stand. Stands with low basal area and low leaf area on the shallow PG, SHIP and PB soils have relatively more energy available at the soil surface for evaporation from the soil. The thick litter and humus layer on these soils, which contrasts strongly with the scarcity of cover in many types of MDF, is in this situation a useful protection against water loss from evaporation. This would be particularly important in open stands on shallow clayey PG soils with thin or no sandy top-soil. Without litter such soils would rapidly evaporate soil moisture during dry spells.

136. The Effect of the Vegetation on Soil Development

Tropical rainforest on upland sites is generally notoriously lacking in surface accumulation of organic matter on the soil. Kerangas forest is distinguished by an ever-present accumulation of organic matter on the soil surface, which is usually 5 to 10 cm deep, but occasionally much deeper. This layer of litter and dark red-brown raw humus is a characteristic feature of kerangas soils, which in the area is only shared by mossy forest and some types of limestone vegetation. This surface layer reduces erosion, increases infiltration, maintains soil moisture at higher levels and increases leaching, especially in sandy soils. The translocation of mineral and organic substance in the soil by percolating water produces the effects which are commonly associated with podzolization. Seepage water from kerangas has a high content of humic acids which gives it the characteristic tea colour and acid taste described from peatswamp and kerangas areas in many parts of the tropics.

BEVERIDGE (1953) mentions that the litter of *Shorea materialis* was much scarcer than that of *Hopea nutans* on the same HP soil and site type in Menchali F.R., Malaya. He concludes that the decomposition rate is less in the latter species, which has a thinner and less coriaceous leaf. The commonness of a spodic horizon under kauri pine (*Agathis australis*) is well-known (Soil Survey Staff, USDA, 1967, p. 19). *Agathis* in Bornean kerangas has been characterized as podzolizer (WHITEMORE, 1966). Planted *Gymnostoma nobile* on a red-yellow gley-type loam near Kuching produced mor accumulation of several centimetres and caused considerable top-soil bleaching within fifteen years. In another area (SP. 12) a mature single tree of *Gymnostoma nobile* in a small gap of natural MDF produced noticeably increased bleaching of the RYP soil. PAGEL lists among the requirements for the formation of montane humus podzol soils in the tropics the presence of a vegetation which produces acid humus, respectively raw humus (PAGEL 1963, p. 101). It was therefore suspected that the leaves of some kerangas species may have properties which could reduce either decomposition rates and initiate or increase podzolization.

Dr. W. R. C. HANDLEY, Commonwealth Forestry Institute, Oxford, had tested aqueous leaf extracts of European woody species and found a correlation between the tannin content and the raw humus forming capacity. Leaves of species containing condensed tannins are more likely to give rise to raw humus than the species containing hydrolysable tannins. But it seems that the presence of condensed tannins does not automatically lead to the formation of raw humus. The nature and amount of mineral bases in the litter or in the soil may also be involved in the process of decomposing leaf protein and releasing nitrogen (HANDLEY, in litt. 19.8.64). DAVIES et al. (1964) found more active gelatine precipitation by leaf extracts from sites with raw humus accumulation than from mull soils. Extracts from green leaves were more active than extracts from brown leaves. Leucoanthocyanin content within a species was about 50% higher on raw humus soils than on mull soils and apparently related to nutrient supply, especially of P and N. HANDLEY (verbal comm.) also stressed the importance of the Ca content in the soil.

The amount of protein-precipitating tannins and phenolic substances in the leaves seems to be associated with the amount of organic matter accumulation in the stand. These substances, therefore, may be regarded as indicators of the likelihood that a species may give rise to raw humus formation. The most likely process involved is that these substances make leaf protein less accessible to microbial decomposition by masqueing the protein with tannin or phenolic substances, as originally suggested (1954) and reassessed by HANDLEY (1961). For example, indication of protein masqueing has been found in soils from Wallaba forest (HANDLEY, in litt. 1968). LEWIS and STARKEY (1968) found that protein tannin complexes attained a resistance to decomposition which was generally a function of the resistance to decay of the tannin component.

HANDLEY's test consists of precipitating gelatine from an aqueous solution with an aqueous leaf extract and to identify the presence of tannin by a colour reaction with $FeCl_3$. The higher the tannin content of the leaf the more rapid and intense is the precipitation of the gelatine (DAVIES et al., 1964; HANDLEY, 1961). Leaf extracts from forty-three of the more common species in kerangas and of a few species from MDF were analysed by HANDLEY's standard test method. ASHTON subsequently tested 119 species from Dipterocarp forests and produced the combined result for the 162 MDF and kerangas species in appendix II and tab. 10 of his memoir (1964 c). In both kerangas and MDF series, the correlation between pH of the extract and the precipitating activity is not significant. There is a weak correlation between soil conditions, pH and precipitation intensity. These relationships are not consistent among the various species and therefore difficult to interpret.

In the kerangas series, for example, *Alseodaphne insignis* from RYP soil had a more acid extract (pH in $H_2O = 5.1$) than from SHP, but the extract from the podzol had a stronger precipitating capacity. The leaf extract of a planted *Gymnostoma nobile* from a MHP, which had for many years received heavy applications of wood ash and household refuse, had a pH of 4.5. Protein was precipitated as finely dispersed coagulate and sedimentation was very slow. In comparison, leaf extract of the same species from a non-fertilized MHP had a pH of 3.8 and precipitated a coarsely-bulky coagulate which settled rapidly. This difference of reaction is probably soil-related, and may significantly contribute to the rapidity of peat accumulation under oligotrophic conditions on kerangas and peatswamp sites.

Details on the reaction of the forty-three tested species have been described elsewhere (BRUNIG, 1968b, pp. 59-62 and tab. 4-5). The conclusion was that all tested species from kerangas sites were actively protein precipitating, but differed in coagulating power and sedimenting speed. All extracts contained tannin. There was some indication that species from MDF had a somewhat lesser precipitating power but the five tested control species were too few for any definite conclusion. The high potential mor-forming capacity of kerangas species is obviously of considerable silvicultural importance.

It was therefore decided to analyse the nature of the tannins in leaf samples of *Gymnostoma nobile*, *Dacrydium pectinatum*, *Agathis borneensis* and *Shorea albida* fom natural kerangas forests. The first two species have an equally strong precipitating capacity and were known to produce deep litter and mor accumulation in natural and secondary forests and in plantations. *Agathis borneensis* seemed to be less mor-forming in natural forests and leaf extracts had precipitated protein as a less bulky and more slowly settling, fine precipitate. *Shorea albida* was chosen because it is not a particularly strong mor-forming species on kerangas, but an important dominant in the more advanced peatswamp phases. Its protein precipitating power is slightly stronger than that of *Agathis borneensis*, but considerably less than that of the first two species. All four species are plantation species of some promise.

The analyses were kindly arranged and results interpreted by Dr. HANDLEY. The following dried leaf samples were sent:

Gymnostoma nobile	:	4 trees of different ages from HP on three kerangas sites
Dacrydium pectinatum	:	2 trees from two of the sites above
Agathis borneensis	:	1 about 30-year-old tree from SHP, two collections in 1963 and 1969 respectively
Agathis sp. (probably *A. loranthifolia*)	:	composite samples from several 25 years old trees in a plantation near Baturaden, Java, at 750 m alt.
Shorea albida	:	1 young tree from near *A. borneensis* above.

The results were (HANDLEY, in litt. var., 1964 to 1969) that the tannin content differed markedly between species, between individuals of different ages and between sites. The highest tannin content had a mature *D. pectinatum* from a dry site (6.7% of dry weight), while a young tree of the same species contained 4.8%. *G. nobile* contained 2.7% (young tree on tertiary sandstone), 4.3% (mature tree on tertiary sandstone and young tree on quarternary terrace) and 4.?% (mature tree on quarternary terrace). *Agathis borneensis* had 2% grey-green tannin which was in a first analysis in 1964 determined as only containing hydrolysable tannin. Repetition of analysis in 1969 on new material produced pale reddish-brown condensed tannins. It is now certain that *Agathis* produces condensed tannins. But it is not clear whether the original and later reconfirmed result was due to some mistake, or whether the particular tree had produced only hydrolysable tannins due to some unknown cause. This would have been the first record of a conifer producing only hydrolysable tannin.

The tannin of *A. loranthifolia* produced anthocyanidins on hydrolysis and is a condensed tannin, similar to that in the 1969-samples of *A. borneensis*. The *Shorea albida* sample had 2.1% of dry weight condensed tannin, which in quantity and nature would agree with its characteristics as a moderately strong mor-forming species on HP soils. The relatively low degree of raw-humus accumulation under natural *A. borneensis* may, as HANDLEY suggests (in litt. of 19.11.1969), be due to a more rapid decomposition of the relatively soft needle-leaves by the soil fauna. Micro-slides of the usually well-drained soils under *A. borneensis* showed abundant faeces of micro-organisms in the top-soil (BRUNIG, 1968).

While the condensed tannins of the five species cannot yet be characterized in detail, they seem to agree in many respects with the tannins known from such mor-forming species as *Calluna vulgaris* in temperate regions. The results of the analyses and precipitation tests at least show that considerable amounts of tannin are present in tropical tree species and that the quantities appear strongly correlated with species, age and site and with the amount of raw humus accumulation observed under the tree species in the forest.

The characteristic raw humus formation in kerangas forests may therefore be explained as the result of a complex interaction between properties of the tree species, stand development, site, soil, and most probably micro-organisms. The initial low base content of kerangas soils and their susceptibility to drying-out leads to higher tannin contents and acidity, which in turn accelerates the podzolizing and bleaching processes. An equilibrium between accumulation and decomposition on well-drained, but not excessively dry sites appears to be reached when the raw humus layer is between 5 and 10 cm thick (see sect. 135). However, on excessively shallow, or extremely base-poor, or very dry or almost permanently water-logged sites, the accumulation of mor will continue and eventually lead to the formation of a peat bog in form of a blanket peat or a wet peat mor.

Colonizing of abandoned, large clearings on base-poor lateritic or quartz-rich RYP and yellow podzolic soils by strongly mor-forming kerangas species, such as *Dacrydium spp.* and *Gymnostoma nobile,* has been observed to cause intensified leaching and raw humus accumulation. On marginal soils, a secondary podzol may consequently develop under a secondary kerangas forest which may then be regarded as a stabilized desclimax. SP. 17 in Bako N.P. is an example. These developments sound a warning that replacement of natural forest on kerangas soils and on some MDF soils carries a great amount of risk of soil degradation.

The Sabal data have been evaluated in a pilot analysis in which the frequency and dominance of the more important species were listed by square units and MUNSELL colour notation on an IBM-1620 computer. The result indicated close correlations between species distribution and edaphic factors and species associations. Consequently, a more extensive analysis is being undertaken in cooperation with Dr. ASHTON's group, which includes a study of grouping tendency of top-storey trees, species associations and species/site relations of all enumerated trees. The structure of the canopy was studied during a year at the Forestry College, Syracuse, in 1968/69. Evaluation of ground data and air-photo features was combined to produce standardized canopy diagrams and to relate them to site factors. Some of the results are discussed in sect. 226.

22. PHYSIOGNOMY AND STRUCTURE

221. Life Forms and Growth Forms

Life form spectra in the kerangas forests are essentially the same as in MDF and in the closed-forest communities of PSF. Secondary kerangas forests, especially on the poorer sites, are more akin to the open final phases of PSF development.

Phanerophytic trees dominate kerangas forests by number of species (849) and phytomass. Epiphytes are the second most numerous life form with more than 100 species. Their contribution to the biomass is relatively small and rises above 5% only in some open and exposed communities. Only 55 species of lianas were recorded during the study and most of these in disturbed, open or marginal communities. Chamaephytes are few in number of species and individuals, except on certain wet sites where especially Araceae and pandans are more numerous. Cyperaceae, ground orchids, ferns and fern allies may locally abound in open secondary vegetation (BRUNIG, 1961 and 1965). Hemicryptophytes, geophytes and therophytes, are absent (tab. 7).

The number of tree-type phanerophytes is 79.6% of the species in kerangas compared with 67.4% in PSF. The difference is small and almost exclusively caused by the smaller share of lianas in kerangas (4.5%) than in PSF (17.7%). The number of epiphytic species (9.9 to 8.1%) and chamaephytes (5.0 to 7.7%) are practically equal.

The number of meso- and microphanerophytic trees increases in the open, wet kerapah communities and on exposed hill tops. Habitually shrubby species, such as *Vaccinium spp., Rhodamnia linerea, Baeckea frutescens* and several rubiaceous and melastomataceous species are conspicuous features of the vegetation in some of these localities. Other species which are normally megaphanerophytic develop dwarf forms on sites with extreme nutrient and water deficiencies. Polster forms also occur on such sites (BRUNIG, 1961). *Calophyllum nodosum,* which is normally a medium-sized tree, forms polster plants on rock padangs in Bako N.P. One polster was observed to fruit several times during seven years without growing in size.

The range of crown shapes in the kerangas forests lies within the range of crown shapes in other types of tropical rain forest. But there are differences in the frequencies of crown types along ecological gradients which distinguish the kerangas forests from MDF and PSF. Elsewhere, I described eight generalized crown types in the top canopy of tropical rain forest communities (BRUNIG, 1970). These crown types are reproduced in fig. 12b. In kerangas, types c, f and g are particularly common, while types a, b, d, and e are less common and restricted to special site conditions. The distribution of the crown types within the kerangas and kerapah forests will be discussed in some detail in sect. 226.3.

The ratio crown diameter to stem diameter of top-canopy trees has been studied for emergents in part of the Sabal sample area. The ratio in metric units ranged between fifteen and twenty for different species. Variation within species was wide and, due to this and the small sample size, any differences between species were obscured. Only *Agathis borneenis* had a consistently lower ratio between 12 and 15.

I know of no information on ratios in peatswamp forests. My own measurements in Shorea albida-consociation forest at Tanjong Kranji indicate mean ratios about 20 and less variation than in kerangas. The ratios in kerangas appear to be more variable and on an average somewhat smaller than ratios which I measured in MDF. The ratios for fully emergent trees differ between species but seem constant throughout the diameter range of each species. The ratios apparently are smaller for trees which have not yet attained top-storey position and for senescent trees, but measurements are too few to permit any definite conclusions.

222. Roots

The aspect of many kerangas forest stands is dominated by the great frequency and strong development of stilt-roots, while buttresses are absent or poorly developed. RICHARDS (1936, pp. 27-28) commented on this feature and the possibility that the degree of stilt-root development is, in some species, related to site conditions. PAIJMANS (1970) found in four rain forest stands on different sites in New Guinea, that development of buttresses is more or less erratic in many species. He also found that stilt-roots develop regularly in some species, but occur only in occasional individuals in others. He suspected an increase in stilt-rooting on gullied slopes to be due to surface erosion and very humid soils.

In kerangas, *Gymnostoma nobile* produces very high, steep stilt-roots on wet PB on terraces, on SHP with persistently high water table, on shallow soils with periodically strong lateral water-flow on slopes and on sandstone boulders. Stilt-roots are lower on medium deep, but wet to moist soils. Stilt-roots become rare if drainage improves and are almost absent on well-drained, medium to very deep sandy HP and GWP soils. Occasionally, individual large trees of *G. nobile* have narrow, high and strongly fluted buttresses on terrace soils with moderately poor drainage. The equally strong stilt-root formation on wet PB on flat terraces and on shallow GWP on boulder tops suggests that tree statics are involved.

Generally, common and strong stilt-root formation in kerangas stands may either be the results of local predominance of habitual stilt-rooters, especially on wet sites, or of the response of facultative stilt-rooters, such as *G. nobile*, on sites with impeded drainage or broken, bouldery substrate. Habitual stilt-rooters, such as *Calophyllum sclerophyllum*, *C. flavoramulum*, *Ploiarium alternifolium* and *Xylopia coriifolia* are locally common on wet PB and determine the stand physiognomy. Variability of stilt-root formation of a species may be very great even within a restricted and uniform site. *Palaquium leiocarpum* is locally common and in places dominates the top canopy of kerangas forest on the Merurong plateau (BRUNIG, 1959 and 1960). Some trees have very high and numerous stilt-roots. Others have very few, low and almost buttress-like, fluted stilt-roots. It often happens that among neighbours of equal size one has extremely high and numerous stilts and the other none at all. This cannot be explained but at least, site does not seem to be an important factor (ref.: collections SK 320 and SK 321). *Xylopia coriifolia* which is common in SP 57, produces high stilts only in the square 2. This sub-plot is on medium deep peat in the unstable transition zone from the interior open low forest (square 1) to the high forest on the shallow peat nearer to the river levee (57 — 3 in fig. 8a). Small trees have relatively fewer and lower stilts than large trees of the species.

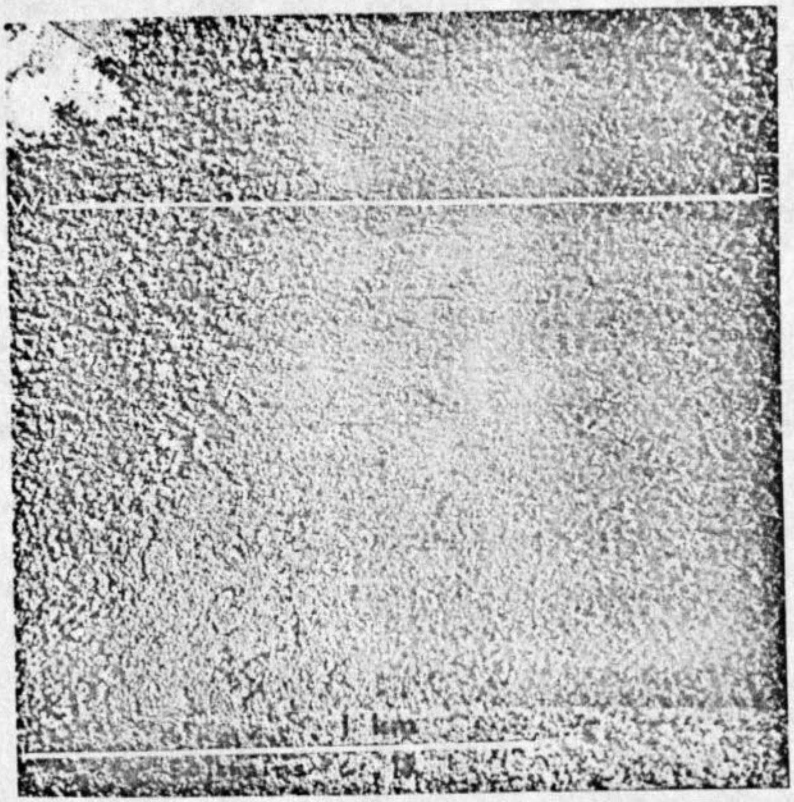

Plate 3. Coastal quarternary terrace with catena from mixed PSF (left) in the west through Shorea albida — Gymnostoma nobile-forest of types 511.1, 512.11, 512.13 and 513.2 (see sect. 441) into riparian forest in the east. The line W — E marks the transect in fig. 8b. Dalam sampling area, Lambir F.R.

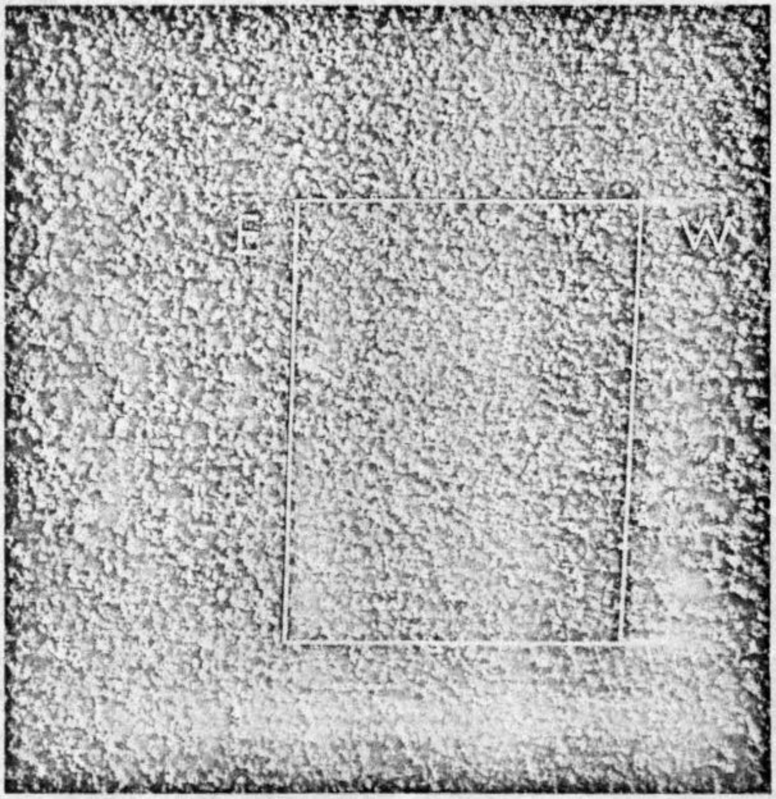

Plate 4. Kerangas forest on a conglomeratic and colluvial tertiary foot-hill. The rectangle marks the Sabal sampling area, size 20 x 25 chains. The arrows mark the E — W transects illustrated in fig. 12a. The types in the kerangas forest are 521.3, 522.1 and 524.9 (see sect. 426). The last type is transitional to MDF which occupies the top-right corner of the sampling area (see fig. 12a). Sabal F.R.

RICHARDS (1952, pp. 59-74) could not find a correlation between stilt-root development and water regime of the site at Moraballi creek. According to him, stilt-rooting in rain forests is particularly common among under-storey species. The capacity to stilt-foot formation is inherited but the degree of actual stilt-root development is also dependent on the local environment. These observations agree well with my observations in kerangas forests. Stilt-rooting appears to serve more than one function and incidence of development is correspondingly complex and variable.

Buttress formation in kerangas forests is conspicuously less intensive than in MDF. ASHTON (1964 c, p. 44) suspects that the absence of buttressing in kerangas forests is largely related to the rarity of the larger members of the Dipterocarpaceae. He states that trees of Dipterocarp species in kerangas forests bear buttresses just as large as trees of the same size in other Dipterocarp species in other habitats. My observations in kerangas seem to confirm this view. An example is *Shorea albida*. In PSF, the species produces very high and broad buttresses on the large alan trees of the peripheral communities, but relatively low and narrow buttresses on the alan bunga trees of the dense interior communities. On kerangas medium-sized emergents of the species have low, but broad buttresses, irrespective of drainage conditions. On some sites, the species grows into very large trees. These sites are usually reasonably well-drained and well water-supplied. The large trees invariably have high and broad, steep buttresses similar to those developed by the species in peripheral PSF. This may be related to size or to age and size. Trees on relatively unfavourable sites in kerangas may grow old more quickly and die before they reach the size at which prominent buttresses are formed.

CORNER (1952) states that buttresses are usually not present in trees which possess a strong tap-root. This is true for *Agathis borneensis.* Data are insufficient to confirm that it is also true for other kerangas species with columnar boles without buttresses. Several common kerangas species of the genera *Calophyllum, Ganua, Palaquim, Tristania* and *Gonystylus* have neither stilts nor buttresses, and apparently no strong tap-roots. It may well be that abundant vertical roots functionally replace a tap-root in these species.

The study of rooting intensity and root-tip density in the soil is difficult and costly. In the present study, available resources limited observations to a study of the roots on wind-thrown and therefore exceptional trees and of number, sizes and condition of roots at various depths in soil pits. Roots in kerangas soils appear to be more strongly concentrated in the A_o and A_{e1} horizons than in sandy soils of the MDF. Penetration into the B and C horizons of kerangas soils is poor. Rooting intensity in these horizons is somewhat greater only in sandy DHP and sandy RYP soils. *Agathis borneensis* has a beet-shaped tap-root with thin strap-roots reaching deep into the B, and more rarely into the C horizon. These roots are probably important for the water supply on the excessively drained DHP soils which the species favours, possibly as a result of its requirement for deep rooting space and the competitive advantage which an obligate deep-rooting habit by a tap-root confers on such sites. On the same site, *Gymnostoma nobile* has a much shallower but wide-spreading root system similar to the system developed by the species on its usually shallower soil habitat. WEBB (1959, p. 559) reports a correlation between root system and crown volume. Similar to CORNER's statement above, he observes that species with columnar stems are generally deeper rooting. This appears certainly true in *Agathis borneensis* with its long, narrow crown and deep tap-root, and *Gymnostoma nobile* with its spreading, flattish mature crown and shallow root system.

Observations indicate that maximum rooting depth of stands is related to soil texture and drainage in the various horizon. Maximum rooting depth is less in fine-textured and wet soils, and greatest in the coarse-sandy DHP. Table 6 shows the ranges and means of observations of deepest living roots in forty-eight soil profiles in Kerangas. ASHTON's (1964 c, pp. 15-26) soil description from MDF indicate similar relations between rooting depth and soil texture. FREEZAILLAH and SANDRASEGARAN (1969) report that concentration of roots in *Pinus caribaea* plantations in Malaya in the top-soil is much more intense in soils with a periodically high water table and in podzols with a concentration of nutrients in the surface organic matter. Deepest rooting occurred in well-drained sandy loams and clay-loams with relatively high contents of available nutrients throughout the profile. The rooting intensity in natural stands on kerangas soils conforms with this pattern of maximum intensity in the relatively nutrient-rich surface layers and low intensity in the eluvial and illuvial horizons at greater depth. Maximum rooting depth is related to soil texture and drainage conditions, which effect water supply and aeration. The high frequency and relatively high proportion of dead roots in the deeper soil horizons is most likely the effect of periodically high water tables and points at the importance of oxygen supply through adequate aeration. The channels of dead roots of the present vegetation as well as those of former vegetation in buried profiles (e.g., monoliths SK III and SK IV) of finely textured GHP, HP and GWP soils probably fulfil an important function in improving vertical drainage.

223. Leaves

RICHARDS (1936, p. 28; 1964, pp. 85-87) suspects that the leaves in kerangas forest on sandy soil may be smaller, thicker, and harder, than leaves in MDF on loam. He refers to BEWS who regarded the rain forest type of leaf as xeromorphic and connects its characters with a low specific conductivity of the wood for water which he believed to be characteristic of tropical and subtropical evergreen trees. This is unlikely to be true, certainly not in lianas. The leaf xeromorphy of many upland top-canopy rain forest trees is conspicuous. Recently, RICHARDS (1965) pointed at the possible role of nutrient deficiency in kerangas soils in producing xeromorphic leaves in kerangas forests. VAN STEENIS (1948, p. 29) reports two examples of reduced sizes of leaves formed during the dry season in Java. In one case, the leaves also developed a brown colouration. WEBB (in discussion to RICHARDS, 1965, p. 205) draws attention to results of studies in Brazilian campinas which indicate nutrient status as limiting factor responsible for the development of "xeromorphic" vegetation in the campos cerrados.

GENTRY in a study of several short transects in different stands of wet and dry tropical forests in Costa Rica found differences in leaf sizes which were difficult to interpret because of the effect of the small sample plot size on the frequencies of large trees which possess compound leaves and small leaflets. Results indicated that there were differences which might be related to water supply and to the need for heat dissipation by emergent trees. But the problem appeared very complex and further factors must be considered as playing a part in determining leaf physiognomy (GENTRY, 1969).

In the field, average leaf sizes of stands in kerangas and kerapah appear noticeably smaller than those in MDF or Riparian forests. Leaf sizes also vary markedly within a species in relation to social status and site. This variation is obviously related to environmental gradients. *Dacrydium pectinatum/elatum* and *Shorea retusa*, for example, show considerable reduction of leaf size from more mesic, fertile sites to more xeric, infertile sites. In other species, leaf sizes seem to vary less and relationships to environmental gradients are less noticeable.

WEBB (1959) used leaf size spectra together with other physiognomic features as criteria in his classification of Australian rain forests. Leaf sizes are generally smaller at higher latitude, or higher altitude, or on soils with insufficient nutrient or water supply. A classification based on leaf sizes in addition to life forms and stand stratification should, consequently, give better results than conventional procedures of correlating woodland types and climatic features.

If leaf size is, in fact, correlated in a simple manner to nutrient and/or water supply, leaf size spectra of primary forest stands should be a good parameter for separating MDF, PSF and kerangas forests. Within the kerangas association group they should indicate ecologically distinct subunits related to site differences. 1,367 herbarium sheets of 507 tree species were selected by random from the kerangas collection. On each sheet, length, width and length of the drip-tip were measured of three intact leaves. The leaf surface was estimated by multiplying the product of greatest width and length with 0.7457. The mean leaf surface per sheet and species was calculated and summarized for WEBB's modified RAUNKIAER leaf size classes. Of the 50 species 3.2% were macrophylls, 31.6 mesophylls, 39.2% notophylls, 24.2% microphylls, 1.0% nanophylls and 0.8% leptophylls. There was a higher percentage of mesophylls among understorey species (33.7%) than among top-storey (24.1%) species. The trend was reverse in notophylls (39.6 and 45.4%). The proportions in the macrophyll, microphyll and nanophyll classes did not show any clear trend. Leptophylls were restricted to the top-canopy. The leading, more common and dominant species in kerangas forests are microphylls (45.7%), notophylls (31.4%) or mesophylls (21.8%). Nanophylls and leptophylls each are less than 1% of all species, but leptophylls contribute more than 10% to the basal area of the kerangas forests. The microphylls represent 24.2% of all species, 45.7% of the leading species and approx. 39.5% of the basal area of the kerangas forests. Mesophylls are 31.6% of all species, 21.8% of the leading species, and contribute less than 20% of the total basal area in kerangas forests.

In comparison to the mixed rain forests leaf size spectra reproduced by RICHARDS (1952) the kerangas forests have a significantly higher proportion of microphyllous species. This proportion is even higher if basal area proportions are compared instead of species percentages. Number of species or basal area per leaf size class each alone poorly expresses the ecological importance of high dominance in the former and of a great number of species in the latter. Therefore, both parameters were combined in a leaf size index which reads

$$L = 1/2\ (G\ \% + Sp\ \%)$$

where G % = percentage of stand basal area in the respective class,

Sp % = percentage of species in the respective class.

Tab. 8a shows the variation of the leaf size index values among plots on different sites. SP.27 on a GHP has a peak in the mesophyll class due to the dominance of *Shorea albida*. SP.28 on MHP on a terrace has the highest value in the notophyll class (38.7%), a good representation of mesophylls (36.1%) but few microphylls. SP.52 on a slope with SHP on the Merurong plateau is very similar, except for a greater value in the microphylls. SP.22 on a DHP on a terrace resembles the previous two plots, except for the absence of leptophylls and the higher value for microphylls, as a result of the dominance of *Agathis borneensis* in the plot. SP.17 with old secondary kerangas forest on a secondary MHP has much leptophylls and relatively few mesophylls. This is a typical feature of secondary kerangas forest. It contrasts significantly to the large leaf sizes in secondary growth on the better MDF and PSF sites.

SP. 29 to 54 in tab. 8a are on PB soils. Notophylls shows a strong dominance on the lowland sites (SP. 29 and 32). The classes microphyll, nanophyll and leptophyll increase with altitude (SP. 40 to 54). Leptophylls represent 36.1% of the basal area in the highest plot, SP. 54. The relatively high value in the mesophyll class in SP. 57 is caused by *Shorea albida* which is also a common top-canopy tree in the lowland plots SP. 32, 29 and 27). The averages of HP soils (SP. 27 to 17) and of the PB soils (SP. 29-54) show a slightly higher representation of larger leaves on the HP and on altitude-related increase of leptophylls on PB soils. There is little difference in the nano-, micro- and notophyll classes between HP and PB soils.

The leaf size index values were computed separately for the understorey C-layer, the intermediate B-layer and the top-canopy A-layer of 8 selected sample plots. The results are presented in tab. 8b. The plots cover the whole range of kerangas sites and kerangas stand diversity. SP. 37 is transitional to Mixed PSF. The top-storey is dominated by microphyll species but there is a pronounced trend toward dominance of noto- and mesophylls in the lower strata. The stands on DHP on the edge of terrace in SP. 22 (Badas) and 43 (Similajau) show the same trend but somewhat less markedly. SP. 43 has a high proportion of nanophylls in the understorey which is due to the high dominance of habitually understorey species with nanophyll leaves of the genera *Hopea, Eugenia* and *Garcinia.* The high value of mesophylls in the A-layer is due to the high dominance of *Agathis borneensis.* SP. 44 is next and inland of SP. 43 in the catena on coastal quarternary terraces (see sect. 134.3). Microphylls are dominant in all layers of SP. 44 and a weak trend toward smaller leaves in the top-canopy is recognizable. Leptophylls are represented by a few codominant *Gymnostoma nobile* in the A-layer. The high-altitude SP. 40 and 57 on PB soils have very characteristic leaf size spectra. In SP. 40 *Dacrydium* is very common and the top-canopy is dominated by microphyll and leptophyll trees. The under storey is predominantly noto- and mesophyllous. In SP. 57 the A-layer is dominated by the mesophyllous *Shorea albida* which reduces *Dacrydium* to a moderately common codominant. The understorey consists mostly of micro- and notophyllous species. The sites of SP. 40 and 57 are climatically very similar, but SP. 40 has deeper peat on a peneplain terrace base than SP. 57 has on a sandstone plateau close to a river course. The relationship between the two plots is comparable to that between Shorea albida-dominated peripheral phasic communities and interior padang communities in PSF. The dominance of *Dacrydium* puts SP. 40 in an analogous position in relation to other kerapah forests to that which the Dacrydium-Campnosperma type in ANDERSON's Lawas SP. 51 (ANDERSON, 1961, pp. 98-102) occupies in relation to the Shorea albida-communities. In SP. 27, *Shorea albida* is strongly dominant on the submerging coastal GHP soil and consequently the leaf size index for mesophylls 75.9% in the A-layer. The two lower storeys are pronouncedly micro-/notophyllous. The reverse trend is shown in SP. 17. The original noto-/mesophyll MDF has been replaced by secondary kerangas forest which is now dominated by *Dacrydium pectinatum.* It is likely that the species had initially colonized the open site, a process which in places can still be observed in the park. These examples may suffice to show that the common trend from larger to smaller leaf sizes from ground to canopy surface also exists in some kerangas stands, but that the trend may be reversed as a result of species vicarism or catena-related site development.

The leaf size representation is rather similar in the mixed kerangas forest on MHP in SP. 28 and ASHTON's upper hillsides with sandy RYP soils in Andulau, except for the presence of lepto- and nanophylls in SP. 28. This affinity to MDF on sandy RYP soils, with the leptophyll exception, applies to almost all stands in the centre of the ordination in the X/Y-plane.

There is little affinity between the spectra of any kerangas stands and the spectra of MDF on the lower hillside with LS soils or the ridge-tops with shallow clay lithosol. The nearest to the spectrum of the ridge-top stand in Belalong is the SP. 54 on a blanket PB at high altitude.

I have no information on leaf size spectra in PSF. But I would suspect that the Mixed PSF will be closely related to the notophyll-dominated kerangas type represented by SP. 29, 32 and 37. The *Shorea albida* phasic communities should correspond closely to SP. 27 and 31. The floristic composition of the phasic communities further to the centre of the peatswamps is similar to SP. 57. Consequently, leaf size spectra should be similar. As mentioned earlier, the aberrant Lawas peatswamp communities have a close affinity to SP. 40 and 54. The positions of the phasic PSF communities in relation to the kerangas sample plots in the X/Y-plane of the ordination (fig. 13a and sect. 243) also support the assumption that the described similarities represent ecological affinities.

The measurement of drip-tips on the 1367 herbarium sheets had the following results. Drip-tips were formed by 85% of the 507 species. There was a slight increase in per cent species with drip-tips and in length of drip-tips from the A-layer downward to the C-layer (BRUNIG, [illegible], tab. 7b). In the top-canopy 76.3% of the species had drip-tips with a mean length of [illegible] mm. In the C-layer 88.2% of the species had drip-tips and the mean length was 0.91 mm. The B-layer species were intermediate. This trend may become obscured and almost disappear in stands on dry sites which possess a distinctly separated understorey of relatively small-leaved species with very short or without drip-tips (SP. 43, 51, 57).

[illegible] Number of Species and Diversity

[illegible] Species Richness

RICHARDS (1952, pp. 240-247) reports that the Wallaba forest on bleached sand (podzol) near Moraballi creek is distinguished from forests on richer soils by an extremely large number of trees per area unit and a high individual/species ratio. Similarly, his kerangas forest plots in Sarawak also have fewer species and more trees per area unit than his plots in [illegible] on yellow loamy soils. Generally, this structural dissimilarity is greater between forests on different soils within a floristic region than between forests on similar soils in different regions of the same climatic zone.

ASHTON found at Andulau that "the individual/species ratio increased with decreasing 'physiological' depth of soil in valleys and with increasing xeric conditions on the hills." The individual/species curves were lower in his kerangas plot at Badas than in any of his Mixed Dipterocarp plots, except on shale lithosol on the Belalong ridge site. The floristically richest stands in his areas were on the most fertile, clay-rich, relatively well-drained soils (ASHTON, [illegible], p. 40 and fig. 21).

In the present survey, the mean number of individuals above girth limit is 380.4 per 0.1 hectare kerangas forests. The corresponding average number of tree species is approximately [illegible]. The ratio of total individuals to number of species in all plots varies considerably between families. Among the more important and common families it is low in the Euphorbiaceae (39), Annonaceae (52), Anacardiaceae (63), Dipterocarpaceae (66), Guttiferae (68), and in the Conifers (75). It is medium in the Myrtaceae (122) and Sapotaceae (140), and high in the Casuarinaceae (270). The ratios are necessarily much smaller for individual stands of smaller area extend such as the single plot. They may within stands be larger for certain strata than for the whole stand. LAMPRECHT (1969, p. 55) suggests that the reverse ratio species/individuals may vary about a "normal value" of 1/5 to 1/10 in tropical forests depending on species richness, but also on sample area and minimum girth.

The mean number of species per 100 individuals > 2 cm d had been computed for all plots from SP. 20 to 57 (BRUNIG, 1968b). The lowest values are 19 (SP. 40, PB) and 28 (SP. 29, PB). The highest values are 51 (SP. 30, MHP), 55 (SP. 44, MHP; SP. 47, GWP) and 63 (SP. 50, GWP sand on clay). The mean of the kerangas plots SP. 20 to SP. 57 is [illegible]. The plots in the transition to MDF all have relatively high values between 55 (SP. 38), [illegible] (SP. 34), 60 (SP. 35) and 69 (SP. 42). The increase of the number of species per 100 individuals from peat soils to relatively fertile loam soils is negatively correlated to the environmental gradient which is represented by the Y-axis in the ordination.

ASHTON (1964c, p. 38 and fig. 20) constructed species/area curves for trees over 12" girth in groups of five one-acre plots. His curve for five kerangas forest plots is initially steeper and, throughout the range shown, above his Belalong MDF curves, but below the curves for Andulau. It seems that differences in tree density determined the initial slopes of the curves more than differences in floristic richness. Consequently, the information value of the differences between species-area curves is rather limited.

Only if stands have a similar structure will simple species/area curves produce direct information on differences in floristic diversity. The majority of the kerangas sample plots is reasonably similar in structure. The rates of increase of recorded species in twenty-seven sample plots of 0.2 ha each have been plotted over square-chain units on semi-logarithmic paper. Straight lines have been fitted to the data by least-square computation. The closeness of fit is greater and the standard deviation per cent smaller, if the sites between the five recording units are relatively uniform and if the stands are mature and little disturbed. The amount of standard deviation decreases generally with number of species per plot (tab. 9). but the coefficient of variation about the regression mean does not exhibit this trend and shows more clearly the effect of heterogenity independent of total number of species. Larger coefficients indicate greater irregularity of the stand composition as a result of stand disturbance and/or site differences between recording units.

The species-area lines of a selection of stands representing the range of site conditions in the kerangas forests are shown in fig. 9a. The soils are secondary MPH (SP 17), dry shallow HP (SP 15), dry MHP (SP 43), moist MHP (SP 30) and deep, loamy RYP in the transition to MDF (SP 38). The slope of the species-area line is determined by the ratio of initial number of species to total number of species. The slope expresses the rate of species additions as the area is enlarged. The slope of the lines increases with the improved soil conditions. The ratio of initial species number between the poorest and the richest primary forest plot is 1 : 1.8. The ratio of number of species in 100 consecutive individuals is 1 : 1.3. This compares with a ratio of total number of species of 90 : 240 = 1 : 2.7, and a corresponding ratio of the tangent of 1 : 5.7 Comparison to the densities (N/0. 2 ha in the last column of fig. 2) shows that species richness and rate of species addition are not related to density. The tangent of the species-area lines and the mean variation coefficients were calculated for 27 of the 55 stands. The mean variation coefficients were 0.9% on peat bogs (4 stands), 1.4% on HP and GWP soils (17 stands) and 2.7% on deep RYP and bleached sandy clays (6 stands). The mean species ratio between poorest and best site is 1 : 2.2 for one recording unit and about 1 : 3.5 for whole plots (5 units.) The corresponding ratio of the coefficients of variation is 1 : 5.7. The variability, therefore, increases more rapidly than the number of species and appears to be primarily related to site heterogeneity (BRUNIG, 1973).

A high starting point but a low inclination show relatively species-rich, but very uniform stands. This type is represented by SP 27 in fig. 9a and corresponds to the type of species-area line given by LAMPRECHT (1969) for an andine cloud forest in Venezuela. High starting point and steep inclination such as in SP 38 (fig. 9a) indicate relatively high richness in species and relatively large heterogeneity of stands between recording units. Continued steep increase in number of species possibly indicates insufficient size of sampling for an estimate of total number of species. This applies to the sample plots 52, 20, 47, 38, and 37, which are all on relatively clay-rich, moist to wet, well-drained soils. The sites in these plots, except for SP 37, are reasonably homogeneous. Three of the plots (SP 37, 38 and 52) carry kerangas forests which are transitional to more complex Mixed Peatswamp and Mixed Dipterocarp forests respectively, which would partly explain the steep inclination of the species-area line.

Fig. 9b shows the same general trends of the species-area lines and species/individual relation along transects of 10 recording units (405 m² squares) in the Sabal sampling area. The actual numbers of species in the transects are not too different, except for the low number in transect 450, but the differences widen as additional units are added. Transect 216 is on soil. The site is relatively homogeneous. The species-areas line is reasonably straight and closely fitted by the observations per square. With increasing depth and chroma of the soil rooting zone (right column of fig. 9b) the slope of the lines steepens and the effect of soil heterogeneity becomes increasingly more evident by a tendency of the lines to bend upwards, for example in SP 15 and 3 in transitional forest to MDF. The apparently aberrantly low position of transect 450 on a reddish-yellow clay soil in MDF is caused by the extreme dominance of *Dryobalanops beccarii* Dyer. This species regenerates profusely below parent trees and shows a strong tendency to clustering on shallow but moist clay and sand soils. The result is a low species richness in the respective stands. The shape of the species-area in fig. 9b demonstrates the importance to restrict sampling plots to areas of uniform site conditions. Comparison of numbers of species per 0.1 ac recording unit (= 1 square chain) in figs. 9a and 9b shows the large increase of species recorded per unit area which is achieved by lowering the sampling diameter limit from 10 cm in 9b to 0.8 cm in 9a.

BLACK et al. studied the relationships between total number of species, frequency of individual species, and plot size in the Amazonian forest. They compared the number of recorded species in successive "octaves" of frequencies with a log-normal distribution according to PRESTON (GREIG-SMITH, 1964, pp. 139-140). The distributions are reproduced in tab. 10, together with distributions in four forest types in British Guiana (BLACK et al., 1950, p. 424, using their own and data of DAVIS and RICHARDS, 1934). The authors comment that in all but one single plot — the plot at Belem —, the octave represented by one or two individuals contains the largest number of species. Accordingly the distributions are all truncated at the modal octave or on the right of it. This indicates that many of the rarer species have been missed. The same distributions have been calculated separately for eight kerangas sample plots which have been chosen to represent the range of diversity scatter shown in figs. 10a and b (sect. 223.2). The distributions are similarly truncated in seven plots, but not in SP. 27 (GHP on a holocene terrace with *Shorea albida* strongly dominant) and SP. 47 (GWP on a holocene terrace, no marked single-species dominance). The numbers of species in the kerangas vary little among the first few octaves, and less than in Tefé. This indicates that probably more than half of the species in the vegetation represented by each single plot has been recorded. In addition, the distribution has been calculated combinedly for all fifty-five kerangas and kerapah sample plots. The frequency is highest in the 16 — 32 octave and approaches normality (see tab. 10). This indicates that also many of the rarer species have been recorded. Completion of the log-normal distribution on the left of the veil line gives the total number of tree species in kerangas forests as 856 (BRUNIG, 1973). We can conclude that the survey has produced an adequate estimate of the number of the tree species of the kerangas forests in Sarawak and Brunei.

224.2 Species Diversity Within And Between Stands

Species richness can be high even in a homogeneous vegetation and within-stand diversity may be low even if species number is high. This is the case if each species contributes an equal share to the diversity measure. The diversity share may be expressed by such parameters as number of individuals, basal area, biomass or productivity. Between-stand diversity may similarly be low, if the species occur in all stands at roughly equal proportion of the parameter.

In kerangas forests, a considerable number of the 774 recorded tree species have very low frequencies. 206 species occur only in one plot, about two-thirds (532) of the species occur in less than eight plots. Only thirty-three species occur in more than half the fifty-five plots. The highest frequencies are 40 (*Diospyros hermaphroditica* and *Canthium didymum*), 41 (*Garcinia sarawakensis* and *Ganua curtisii*), 44 (*Melanorrhoea beccarii*) and 45 (*Palaquium ridleyi*). There is no species which occurs in all fifty-five plots. This suggests that the diversity in kerangas forests may be relatively high and higher than previously thought.

The total basal area of all fifty-five sample plots is 414.7 m^2. *Agathis borneensis* contributes 34.9 m^2 (8.2%), *Shorea albida* 29.6 (7.1%) and *Gymnostoma nobile* 17.7 m^2 (4.3%). The first species is somewhat over-represented as a result of an excessive proportion of sample plots in the Agathis borneensis-bearing forests at Badas. The two other species are correspondingly under-represented. But it is generally true that in kerangas relatively few species contribute relatively much to the basal area, and very many species very little. The ten most dominant species together contribute 147.2 m^2 (34.7%) of the basal area. The 70 (9%) leading tree species in the sample plots together contribute 277.5 m^2 (67.0%) of the basal area.

In order to express diversity quantitatively, an index has been developed which incorporates some of the more important characteristics related to diversity. The index is the sum of the species per cent in a plot of all species recorded in the kerangas forests, the per cent standard deviation about the species-area line, and the tangent of the species-area line (fig. 9) multiplied by 100. Its first term expresses species richness, the second term the variation in species composition between square-chain units within the plot, and the third term the gradient of increase of number of species as new square-chain recording units are added. The maximum value of the index is 300.

The index has been calculated for 27 0.2 ha plots. The indices range from 16.8 in SP. 17 (old secondary kerangas forest) to 86.9 in SP. 37 (transitional forest between kerangas and mixed peatswamp). The association between index values and soil p.m. or soil type is loose (tab. 9). Index values increase gradually along the gradient of landform forest-soil type units (BRUNIG, 1969c), when the units were arranged from flat, poorly drained sites to increasingly more hilly sites (fig. 10a).

SPEARMAN's rank correlation coefficient has been calculated to test any correlation between the ranking of plots according to diversity index, total species number, tangent of the species-area line, and standard deviation about the regression. The correlation coefficients indicate a highly significant rank correlation between total numbers of species and tangent of the species-area lines (r_s = 0.866, sign. at 0.1% level) and between the diversity index and total number of species (r_s = 0.894, sign. at 0.1% level). There is no correlation between the rankings according to total number of species and standard deviation about the regression, and between the latter and the tangent of the species-area lines (r_s = 0.312 and 0.353 resp.). This points at the possibility that the standard deviation about the regression may be due to factors other than the species richness, such as site heterogeneity between recording units within plots. The mean square deviation could be substituted by the standard deviation in the index. Consequently, the weight allocated to diversity factors other than species richness increases, and with this the value of the index as measure of the combined vegetation/site diversity.

No correlation of rank exists between the altitudes of the twenty-seven plots, their species richness (r_s = 0.107) or their index of diversity (r_s = 0.207). This appears to support the general opinion that altitude exerts little influence on the vegetation in the equatorial lowland some below 1,000 m a.s.l., and that any effect is masqued by other more effective site factors. So far, conclusions are that the total number of species and the floristic diversity of stands change with site factors related to soil group and physiography. There is no clear evidence of change along the altitudinal gradient. Species richness and stand diversity are larger on more clayey soils and in rougher topography. Both are also larger in communities which are transitional to the more complex MDF and Mixed PSF. The number of species and the index of diversity also change in relation to successional gradients and catenas.

The old secondary kerangas forest in SP. 17 has the lowest diversity index value (fig. 10a). The value increases from the single-dominant stand on GHP (SP. 27) to the edge of the raised terrace (SP. 23 — 25). It also increases from lower level (SP. 43) to higher and older levels (SP. 44) of raised beach terraces. The reverse trend is initiated if excessive moisture starts peat development on the Merurong plateau. The index value first increases from SP. 53 (relatively dry, exposed) to SP. 52 (lower hillside with balanced water regime), and then falls to SP. 51 (beginning of peat formation) and reaches the lowest point in SP. 57 (peat bog). A significant association between stand diversity and moisture conditions has also been found by WHITTAKER (1965) in forest and woodland communities in the U.S.A.

A diversity index which is solely based on number of species and number of individuals has been suggested by McINTOSH (1967) for quantitative data:

$$ID = \frac{N - \sqrt{\sum_{i=1}^{S} n_i^2}}{N - \sqrt{N}}$$

where N = Number of individuals in the sample

n = number of individuals per species

This index has the advantage of being independent of sample size. It expresses the species-related observed diversity (numerator) as a proportion of the absolute maximum diversity (denominator) at a given N. The values range from 0, if there is only one species, to 1, if the number of species is equal to the number of individuals. Diversity is then at a maximum. The index is sensitive to dominance pattern through the second-power term in the numerator. It is therefore a useful indicator of diversity in forest such as the kerangas forests, where species and group dominance patterns are a characteristic but variable feature.

Forty stands were selected in thirty-seven sample plots which represented the major kerangas catenas described earlier (sect. 134). The stand included the whole range of leaf-size spectra and index of diversity previously discussed. The index was calculated for all trees over 1 cm d. The results are represented in fig. 10b.

The actual diversity/absolute maximum ratios range from 0.577 in SP. 40 (PB on high-altitude terrace) to 0.957 in SP. 50 (standy GWP clay on low hill). The actual diversity expressed as per cent of maximum possible at the given number of species ranges from 64.6 (SP. 40) and 75.2 (SP. 43) to 98.8 (SP. 33-1. clay) and 99.1 (SP. 50). Of the forty stands, twelve are above 95%, 29 above 90% and only 11 (28%) are below 90% maximum possible diversity.

The index values appear associated to the successional status of the stands, but the trend is not uniform. Low ratios occur in stands which are in an active phase of primary (SP. 43 and 28 at terrace edges) or secondary succession (SP. 17), or which have reached a mature stage (SP. 29, 31, 32, 40). Within the coastal terrace catena, high values are found on the young GHP behind the beach in Similajau F.R. (SP. 45 and 46). Diversity index values decrease along the gradient to the DHP sites with *Agathis borneensis* stands (SP.43) and rise again to about 95% of the maximum on the well-drained MHP on the highest terrace level (SP. 44). The diversity index value of the pronouncedly single-dominant Shorea albida — Dryobalanops rappa-forest on GHP in Anduki — Badas (SP. 27) is rather close to the values of the more mixed stands of early coastal catena in Similajau F.R. (SP. 45 and 46) in spite of significant differences in species composition. The pleistocene terrace catena SP. 30-28-31-29-32 is associated with a decrease in diversity from the margin of the lower terrace level (SP. 30, transitional to MDF on the terrace flank) through the plateau rim (SP. 28) to the raised PB of the higher level terrace (SP. 31-29). The diversity continues to decrease with raising peat in spite of a slight increase in species number in SP. 32.

On the Merurong plateau the index is highest in the relation to the maximum possible in tall forest near the edge of the plateau (SP. 53), and in the transition between slope and flat plateau (SP. 52). It is lowest in the early stages of peatswamp succession (SP. 57-3 and 55), and in the Agathis beccarii dominated forest on almost flat MHP (SP. 56). Intermediate index values occur in the forest on the rocky ridges on the plateau (SP. 51), on the blanket bog of the highest slopes (SP. 54) and in the open pole forest on flat PB of the plateau centre (SP.57-1). These relationships suggest that, in this case, the index values are determined by a rather complex interaction between site stability, especially erosion, soil fertility, successional phase of the stand and chance dispersal of species.

Similarly, in Bako N.P. the distance from maximum is relatively small and nearly the same in the low pole forest on the plateau (SP. 15) and in the tall Shorea flava-dominated transition to MDF on the rocky slopes (SP. 16). The index value is smaller and the distance to the maximum considerably larger in the Dacrydium-dominated old secondary forest on a secondary MHP (SP. 17).

The highest index values and smallest distances to the maximum occur among the undisturbed stands on RYP soil (PS. 35, 38, 42, 50), on the GWP sand-over-clay soil of a riparian encased terrace (SP. 47) and on the PG sand-over-clay soil in the old pleistocene peneplain remnant on Bukit Sagan (SP. 33-1).

The index values are obviously affected by chance of species distribution, stage of stand and site development and present edaphic, physiographic and edaphic site conditions. In fig. 10b, a general but weak trend is noticeable from low values in young stands on HP, PB and secondary HP soils to higher values and shorter distances to the maximum line in stands which are successionally more mature, occur on transitional sites and have low degrees of dominance and consequently high species richness.

The ranking of stands according to the relative index values is closely correlated ($r = 0.617$ at 38 d.f.) to the ranking of the plots according to species richness. The correlation to the ranking according to the previous index of diversity is weaker, but still significant at the 5% level ($r = 0.515$ at 22 d.f.).

For eleven of the forty stands, the diversity was also calculated for the trees which formed part of the canopy. Including all top-canopy trees in the sample plots, numbers of individuals ranged from 41 (SP. 37) to 103 (SP. 40). In six plots, the actual diversity reached over 90% of the maximum possible for the number of species and trees (SP. 15, 16, 23, 27, 47, and 17), and two plots had values of 89% (SP. 22 and 37). Dominance of *Agathis borneensis* reduced the relative diversity to 82.0 % in SP. 43 and to 65.2% in SP. 44. The relative diversity in the top-canopy was 84.3% in SP. 17, compared with 88.8% in the whole stand, and 70.4% in SP. 40 compared with 64.2 in the whole stand. The top-canopy of both stands includes *Dacrydium pectinatum* as a common dominant species. But SP. 17 on secondary HP has a somewhat more diverse understorey, including a few apparently invading elements of the Dipterocarp forest. In contrast, SP. 40 on a developing PB has a strong tendency to species dominance both in the top-canopy (*Dacrydium*) and in the undergrowth (*Palaquium spp.*) In SP. 43 the relative diversity in the top-canopy is greater than in the whole stand (82.0% compared with 75.2%). This is the result of the strong dominance of a few nanophyll species in the understorey (see sect. 223). In SP. 44 the trend is reversed and the understorey is more diverse than the canopy which is strongly dominated by *Agathis borneensis.* SP. 44 is transitional to the Shorea albida-dominated forest on the highest level of the terrace sequence. This partly explains the different and more complex species composition and pattern in the understorey which increases the diversity for the whole stand. The diversity of the top-canopy in the remaining plots is practically the same as for the whole stand and is in all cases above 90% of the maximum possible with the exception of SP. 23 (85.6%) which is strongly dominated by *Agathis borneensis.*

We can conclude that the kerangas sample plots show a conspicuous gradient of diversity, as expressed by species number, species increase with area, and variation of species increase with area, which is closely related to the landform-forest-soil complex and to the Z-axis of the ordination. Diversity expressed according to McINTOSH in terms of number of species and individuals is, through the species term, related to the earlier diversity index (r_s = 0.515 at n = 41). The diversity relative to maximum possible shows a weak trend with soil conditions. The primary interrelationship in this case appears to be between relative diversity value and successional phase, respectively degree of stand maturity. The position of SP. 40 (relative diversity 64.2%) is unexpected and appears aberrant. The site is a terrace remnant of the old pleistocene peneplain. The stand and the site show no signs of recent disturbance. The stand therefore should have a higher diversity value. It may be possible that in this case some unknown factor works toward single-species dominance which is positively related to time and reduces diversity. Such factor could be allelopathic effects in connection with strongly impeded drainage. It is noteworthy that the stand also shows an extremely strong tendency to dominance among the understorey specie. Within the kerangas forest sample plots, this occurs again only on the excessively drained HP soils on young coastal terraces (SP. 43, Similajau F.R., and SP. 7, Pueh F.R.).

The ecological implications of the various forms of diversity and the relationships between floristic and structural diversity parameters and productivity of stands are further discussed in BRUNIG (1972).

[illegible] Frequencies, Dominance and Stand Stratification

[illegible] Breast-Height Diameters

WINKLER (1914, p. 203) described what he called 'heath forest' as a rather dense stand of mostly slender 20 — 30 m high trees in which big trees, mostly of *Agathis borneensis,* were rare. Any gaps were filled by a dense pole crop. Similarly, POSTHUMUS (1937, p. 506) described a kerangas forest on the Luwai terraces as a low uniform stand of slender trees below which was little undergrowth. In contrast, an Agathis borneensis-forest stand studied by RICHARDS (1936, p. 29) contained more trees in the 41 — 61 cm d class than a stand in MDF in the area. The number of trees above 61 cm d was equal. DIELS and HACKENBERG (1926) recognized the wide range of variability of stand curves between stands on different kerangas sites. They mentioned that the scrub-like structure of a Dacrydium-forest on the crest of a sandy hill contrasted strongly to the luxurious Agathis borneensis-forest on the slopes. BROWNE (1952, p. 64) stated that "compared with Mixed Dipterocarp forests of better soils, it (i.e., kerangas soils) usually carries only small timber, but there is considerable variation and in some areas fairly large trees are not uncommon."

ASHTON's (1964c, pp. 43-44 and fig. 33-35) girth histogram of Agathis borneensis-heath forest at Badas is not strikingly different from some of the histograms of MDF. Differences are: the density in the smallest girth class in Badas is noticeably greater than in the Belalong MDF stands on clay-rich slope soils, but there is less difference to the Andulau MDF stands on more sandy soils; trees above 107 cm d in the heath forest are fewer than in any of the Dipterocarp forest stands; the histograms for forest on the shale lithosols of the Belalong ridge-crests are similar to those for Badas heath forest though there is a greater density of higher girth classes in the former. The MDF on the lower slopes appears to support considerably more large trees, and slightly more small trees than the steeper upper slopes.

The information on d-distributions from the present survey of fifty-five relatively small single plots does not lend itself easily to a mathematical analysis of differences between species, stands and forest types. This is aggravated by the tendency of some species to occur at high densities in some plots on certain sites and in certain stand strata. The following discussion of d-distribution is therefore restricted to descriptive comparison between sample plots. The conclusions conform with the information on d-distribution in the larger size classes from more extensive inventories in kerangas forests in Pueh F.R., Sempadi F.R., Sabal-Balai Ringin F.R., Kakus-Pandan P.F. and Similajau F.R.

Generally, the largest diameters of trees in kerangas forests occur on well water-supplied soils and on sites with somewhat impeded drainage or accessible groundwater supplies. In the fifty-five sample plots, the largest trees occur in SP. 1 and 7 (MHP on low terraces with high groundwater table), SP. 27, 45 and 46 (GHP on holocene coastal terraces), SP. 28, 30 and 31 (MHP and PB on pleistocene inland terraces with impeded drainage). The most severely truncated distributions occur on poorly water-supplied periodically dry soils (SP. 9 and 15) or on soils with almost permanently stagnant water at the soil surface. The variation of the frequency distributions in different size classes on different sites is shown in fig. 11a for the whole stand and for some of the most dominant species.

The frequency distribution in SP. 10 (fig. 11a, bottom row) in MDF on a loamy LS resembles the distributions in ASHTON's Belalong hill-side plots. There is no single dominant species and the decline of frequencies with diameter is gradual. The gap in class 11 (101-110 cm d) is probably due to the small size of sample for large trees. The transitional forest in SP 16 was a higher tree and lower basal area density. There is a weak dominance of *Dryobalanops beccarii*, a larger frequency in the small sizes and a distinctly lower frequency in the larger sizes. These differences between SP. 16 and 10 are relatively greater than the difference in stand top heights of about 7 m (see fig. 15a). The site in SP. 17 originally probably carried a forest similar to SP. 16, but the present secondary kerangas stand is distinguished by a marked dominance of *Dacrydium pectinatum* and a much narrower size range. SP. 38 on a moderately steep to gentle, dissected sandstone dip-slope has high densities in the 2-20 cm range, about the same densities as SP. 10 in the 21-60 cm classes, and fewer trees above 60 cm. There are distinct differences between SP. 22, 26 and 23 in Badas on DHP at the edge (SP. 22) and in the centre (SP. 23) of the western terrace and on a low and broad sand dune east of Badas F.R. (SP. 26). SP. 22 has lower densities in the smaller sizes, but more large trees. SP. 23 has fewer large trees and more small trees. This trend is characteristic for the difference between terrace edges and centres. SP. 26 is intermediate between these two plots which would be expected. The stand is distinguished by the extremely high density of *Agathis borneensis* in all size classes.

The sequence SP. 46, 45, 43 and 40 in Similajau F.R. is another example of the coastal terrace catena. Sites and soils along the catena have been described in sect 134.3, ex. 1. The stand of the early stage behind the beach has high densities in the smaller size classes but few emergent trees of large size, which are mostly *Shorea materialis*. SP. 45 on the succeeding slope of the terrace level II has fewer trees in the intermediate size classes, but larger-sized trees are more common. This tendency increases weakly to the terrace top. As in Badas, *Agathis borneensis* reaches highest density and largest size on the DHP soil of the terrace margins. SP. 44 in the centre of terrace level III differs mainly in having fewer large trees as a result of the decline of *A. borneensis*.

A very marked bi-modal frequency distribution is shown by SP. 27 on a GHP south of Anduki F.R., Badas (see also sect. 232). This type of stand curve is characteristic for kerangas stands on rapidly changing sites. Often the change is due to rising groundwater table. In SP. 27 local submergence impedes drainage and initiates peat development on the sandy GHP soil. In the course of this change, *Shorea albida* replaces *Dryobalanops rappa* as dominant and eventually forms an almost uniform, dense top-canopy of large but not very tall trees. *D. rappa*, which is an exclusive single-dominant further to the coast on younger stages of the GHP-series (comparable to SP. 45 and 46), is reduced to codominant and dominated position in SP. 27. Markedly, bi-modal stand curves are common in the stands with dominant *S. albida* and codominant *Gymnostoma nobile* and *D. rappa* on submerged peat-covered GHP and GWP soils in Pueh F.R. Similarly shaped bi-modal stands curves occur in *Dryobalanops fusca* single-dominant stands on MHP on low coastal terraces west of Sematan in Pueh and Siru F.R. An example is SP. 7 in fig. 11a.

The change from an asymmetrical uni-modal frequency distribution to a bi-modal distribution along a catena is also shown by the sequence SP. 21, 28, 31 (fig. 11a, second row from top). SP. 21 is on a low pleistocene terrace with undulating surface in the Ulu Ingei. The stand is structurally and ecologically related to the stand in SP. 30 on the lowest terrace level in the Ulu Mukaau below and east of SP. 28. SP. 28, inside of the margin of the highest terrace level, has poorer drainage than SP. 21 and 30. Drainage worsens towards the terrace centre. Finally PB develops in conditions of almost permanent water-logging. Further on, the PB surface rises and *Shorea albida* becomes dominant. The large *S. albida* trees produce a distinctly bi-modal stand curve in this part of the terrace catena (fig. 11a, SP. 31). A break-down of the diameter classes into 2.5 cm d classes does not change this type of distribution. Large-scale inventories of similar stands on similar sites have also produced bi-modal frequency curves over size classes. We can conclude that the bi-modal distributions are no artefact due to sampling size but an expression of the peculiar structure of the stands in relation to site and status. This is the same situation as in the *Shorea albida* and related forests in PSF where the modality of stand curves is an efficient parameter for use in forest type classification (BRUNIG, 1969c). The feature could well be used locally in kerangas forests to delimitate strata along the catenas.

The uni-modal asymmetrical stand curve is also characteristic for terrace sites with sandy GWP soils on clay if drainage is moderate (SP. 33 on Bt. Sagan; SP. 37, Temburong river valley) to good (SP. 47, Niah-Jelalong P.F.). The uni-modal stand curves on SHP with strongly fluctuating soil water content (SP. 15, Bako N.P.) or in old secondary kerangas (SP. 17, Bako N.P.) descend more steeply as those on more favourable soils. The distinct uni-modality could be an artefact due to a masqueing effect of the relatively wide 10 cm diameter size classes. But a break-down of the frequencies into 2.5 cm classes still maintains the uni-modal curve type of stand curves, which proves its reality.

An exceptionally steep slope of a uni-modal stand curve occurs in the sample plots SER 1-6 on the corroded summit plateau of the Bt. Serapah limestone massif. The biggest tree is only 24 cm in diameter. The tree density is very high (N=14,940 per ha above 0.8 cm d) and the slope of the distribution curve, correspondingly steep (BRUNIG, 1968, tab. 13).

The effect of topographical slope position on the frequency curve is shown by the sample plots in Niah-Jelalong P. F. For example, the stand in SP. 50 (fig. 11a, top row) near the rim of the tertiary synclinal dip-slope has more medium-sized trees (10-20 cm d) and fewer trees above 50 cm d than SP. 47 at the base. The stand is somewhat stunted, probably as a result of the closeness to the ridge-top. Some of the big but short trees of *Shorea albida* (30 to 110 cm d) appear almost moribund. The effect of topographical position and soil development at high altitude on the stand curves is shown by the catena on the Merurong plateau (SP. 51-57) and Bumbong rumah (SP. 40) in the top-row of fig. 11a. SP. 51 on a MHP on the undulating plateau has a higher density of small trees than SP. 53 on a moderately steep slope near the plateau margin. Otherwise the curves are similar. SP. 56 on a gentle slope on the plateau is distinguished by a greater number of large trees due to the presence of *Agathis beccarii* on the more favourable site. The smaller size classes are correspondingly less well represented. SP. 57 and 40 are both on raised peat bogs but their stand curves differ. The densities in the smaller sizes are greater in SP. 57, where *Shorea albida* produces a tendency towards a bi-modal distribution. SP. 40 on a peneplain terrace is dominated by *Dacrydium* sp. while *S. albida* is absent. The stand curve is distinctly uni-modal and the density is higher in the 30 — 50 cm d classes than in SP. 57. The stand curve in SP. 54 on a blanket peat of the summit slope of Bt. Skalap, Merurong plateau, is rather similar to the curve in SP. 40 without the few emergent *Combretocarpus rotundatus*. The smaller maximum size in SP. 54 is most probably due to the exposed position of the stand and the poorness and drainage conditions of the soil. The distribution is intermediate between SP. 40 with ample, and SP. 15 with frequently deficient water supply.

LAMPRECHT emphasizes that undisturbed natural forests usually have a distinct "selection forest" structure. In other words they have a uni-modal, strongly asymmetrical frequency curve with the mode far on the left. But individual species may deviate from this rule which is contrary to conditions in managed selection forests (LAMPRECHT, 1969, p. 58). The above distribution together with the clear evidence, that most of these stands are undisturbed (see sect. 231) indicates that deviation from the selection forest or so-called LIOCOURT geometric series is very common in undisturbed natural forests under more severely limiting site conditions. Results of peatswamp and dry-land forest inventories in Sarawak and Brunei confirm the widespread deviation from the hypothetical "normal" size-class frequency distribution in undisturbed natural tropical rain forests. More will be said on the stand curves of single species in sect. 232.

223.2 Basal Areas

The frequency distribution of number of individuals in d-classes for a stand, or for individual species, generally indicates the intensity of regenerative activity (fig. 11a and sect. 232). The basal area distribution in d-classes indicates the contribution of the different size classes to the stand biomass. It somewhat exaggerates the contribution of trees with smaller diameters or crowns because it does not include the effect of the third dimension "height" and tree shape generally (see sect 261). Basal area histograms, more than N-distributions, over-emphasize the ecological importance of very large single trees which happen to be included in a relatively small sample. The basal area of a species in a stand indicates the biological success of the species better than simple presence and absence data or frequencies.

The total basal area of trees > 1 cm d in the sample plots in kerangas forests varies between 16.9 (SP. 29) and 88.0 m^2/ha (SP. 31). The weighted mean basal area is 36.48 m^2/ha, with a standard deviation of 1.601. The true mean of the sampled kerangas stand population is between 33.3 and 39.7 m^2 at $p = 0.05$ and between 32.2 and 40.8 m^2 at p

= 0.01. The mean of 36.5 m² is about 10% above the pantropical mean basal area in natural tropical high-forests according to the estimate of DAWKINS (1959). Generally, variation of total basal area between adjacent square-chain units is small and considerably less than in MDF or Mixed PSF. The coefficient of variation of basal area per unit area between different localities or between different forest types and forest quality classes are of the same order in kerangas forests as in Mixed PSF and in MDF, but are larger than in Alan bunga forests (BRUNIG, 1958). In the Sabal sampling area, basal areas above 10 cm d per square-chain (404.7 m²) ranged from 0.3 m² (7.5 m²/ha) to 2.4 m² (60 m²/ha) in MDF (49 squares) and from 0.71 (17.7 m²/ha) to 2.1 m² (52.2 m²/ha) in kerangas forests (451 squares). The variation coefficient naturally rises more steeply in kerangas than in MDF if the minimum diameter limit is raised, because the tree population diminishes more rapidly with size in kerangas.

The basal area distribution over d varies strongly between different types of stands in kerangas (fig. 11b). The distribution is rather even in the one sampled MDF stand (SP. 10). A more markedly uni-modal distribution with a weak second peak in the classes 7 and 9 occurs in the transitional stand (SP. 16). The poor kerangas stand in SP. 15 is strongly uni-modal with steep declines on both sides of the model class 11 — 20 cm d. The more markedly single-dominant stand (*A. borneensis*) in SP. 43 has the largest value in class 8 and a corresponding weak depression in classes 3 to 5. The depression in the intermediate size classes is much more pronounced in SP. 27 where the strongly dominant *Shorea albida* represents 57.7% of the stand basal area and is the only species above class 10. The intermediate storey of this stand is strongly dominated by *Dryobalanops rappa* (10.0% G) which, similar to *S. albida* shows a peculiar distribution gap between classes 4 and 9. SP. 27 has the second largest basal area (74.7 m²/ha) of the fifty-five plots. Most of the other plots with large basal areas show similarly a strong single-species dominance in the top-canopy. Of the eleven sample plots with basal areas greater than 50 m²/ha, four plots are strongly dominated by *S. albida,* 1 by *A. borneensis,* 1 by *Dacrydium beccarii* and 1 by *Combretocarpus rotundatus*. Only three plots show merely moderate dominance of the leading species with less than 20% of the stand basal area. All plots with large basal areas have moist to very wet soils. Four plots are on peat and two on PG soils, which indicates a preference for infertile substrate. High-basal area stands with moderate dominance are on well water-supplied RYP and on GWP sandy clays on moderate to steep slopes, indicating a favourable water regime and reasonable fertility.

Nine sample plots have basal areas below 30 m²/ha. Only two of these are stands with a distinctly dominant leading species representing more than 20% of the stand basal area. In both cases, *Shorea albida* is the dominant species. The one plot is in a kerangas stand near the terrace edge where *S. albida* fades out and soil conditions appear unstable (SP. 28, MHP with microknoll relief). The second plot is in the centre of the transition zone from wet kerangas to extremely wet kerapah at a point at which the dry-land kerangas (SP. 31) had already deteriorated but the Shorea albida-kerapah (SP. 32) is just about to form. Similarly, one of the two low-basal area plots in Pueh F.R. is situated in a transition from *Dryobalanops fusca* forest on a low dune into the *S. albida* kerapah of the large central basin. The other six plots are in mixed stands on heavy clay soils of pleistocene terraces (SP. 33, 36 and 37) and on alternately dry and wet sandy HP soils on sandstone dip-slopes (SP. 8, 9 and 15).

The sample plots on the undulating, broad top of the limestone massif of Bukit Serapah have a mean basal area of 45.2 m²/ha, with a range from 35.2 (plot 4, broad top of the NW. ridge above vertical scarps) and 57.4 (plot 2, flat plateau-like shoulder of the SE. ridge). The basal area increases from size class 0.8 — 1.5 cm d (0.3 m²/ha) to a peak in the 9 — 10 cm d class (1.6 m²/ha). Then it descends steeply to 19 cm d and forms a weak second peak in the 23 — 24 cm d classes. The relatively high basal area in these plots is the result of the very high density of relatively small trees. The biomass of the stands is small in spite of the large basal area because the heights are low. There is a distinct main canopy between 12 and 15 m. Emergent trees average 17-19 m and very few reach beyond 20 m.

For comparison, FOX (1967) reported a mean basal area above 10 cm d of about 28.5 m²/ha in 2.8 ha MDF in Sabah. NICHOLSON (1962) reported a mean basal area of about 32 m²/ha from research plots in Sabah. The standard deviation per cent was 7.4 and 13 respectively. The figures seem somewhat low even if 10 m² are added for the sizes below 10 cm d.

Very large basal areas are associated with very different site conditions. Either water supply exceeds consumption and discharge, peat is formed and the stands are strongly dominated by well-adapted species. Or in other cases, water supply is adequate to abundant, the soils deep and well-textured and the stands mixed and relatively complex. Very small basal areas seem associated with periodically insufficient water supply on shallow, sandy or stiffly clayey soils or with a transitional position of the stand under conditions of rapid vegetational change and site instability.

The contribution to stand basal area and biomass differs between species of different social status and different abundance in the stands. The pattern of the different contributions is characteristic for stands and can be expressed as curves of the per cent basal area contribution in sequence of species ranking. The species in stands with strong dominance would produce a sigmoid shape of this so-called dominance-diversity curve with a characteristically steep initial decline. Stands with a greater degree of species diversity (sect. 223.2) have relatively flatter curves than stands with a smaller degree of species driversity. The curve of a stand with a diversity equal to the maximum possible diversity would be a straight line parallel to the abcissa. Four stands were selected from among the sample plots to demonstrate the range of curve variation within the kerangas forests. The curves were calculated from the per cent basal area contribution and are shown in fig. 11c. The curves are arranged in order of increasing diversity from left to right. An exception is SP. 27, which would have a higher diversity than SP. 15 according to fig. 10b, but not according to fig. 10a. This discrepancy of position is the result of the different weight of numbers of individuals and of basal area in the two indices.

The very steep slope in the upper portion of curves of SP. 27, 43 and 40 is the result of a marked single-species dominance. In the mid-range of the curves, the degree of steepness corresponds to the effect of intermediate species on the stand diversity. There is a small general decrease in inclination from SP. 40, 27 and 43 (low within-stand diversity) to SP. 15 and 16 (high within-stand diversity). The lower part of the curves is occupied by the rare species. The rare species contribute very little to the total basal area which generally causes the curves to decline more steeply in this range. Similar results were obtained by WHITTAKER (1965) in stands of different diversities in the U.S.A. He used net annual productivity (NAP) to construct his sigmoid dominance-diversity curves of forest stands. This results in a somewhat less steep initial slopes because trees contribute to biomass or coverage relatively more than to NAP. Otherwise, the shape of the dominance-diversity curves is the same. WHITTAKER observed that his core forests with high species diversity have sigmoid distributions of moderate slope throughout. The same communities have log-normal distributions when plotted by PRESTON's method on octaves of basal areas. The previously discussed frequencies of species in octaves of number of individuals (sect. 224.1) suggest that this would also happen in the kerangas forests. The dominance-diversity features of various types of kerangas forest stands in comparison to Mixed Dipterocarp and Amazonian terra firma forest stands are discussed in more detail elsewhere (BRUNIG, 1972).

The stand basal areas are the result of an interaction between species availability, species adaptability and competition capacity on the particular site, site properties and time. Very large stand basal areas are likely to occur in single-dominant stands on sites with more extreme properties which offer special advantages to adapted and competitive species. Very low basal areas are likely to occur on more xeric sites with shallow soils, which cannot sustain high biomass, or at certain stages of rapid succession. Therefore basal areas alone are no reliable indicator of site productivity and soil fertility in kerangas. The same is true for peatswamp forests, where the largest basal areas occur in the Shorea albida-consociation (ANDERSON, 1961; BRUNIG, 1969c) and not in the peripheral mixed associations which occupy clearly more fertile soils.

The basal area or dominance of a species is some measure of its ecological importance. As an importance index, basal area is biassed in favour of species like *S. albida* which tend to occur as large trees but few individuals. Bias is also associated with density of a species because it overrates the importance of some of the frequent understorey species. Both these measures have been combined with frequency (occurrence in plots) to an Importance Value Index of a species (CURTIS and McINTOSH, 1951; CURTIS, 1959). The highest index value in kerangas has *Palaquium ridleyi* (86.3 of a possible 300), followed by *Melanorrhoea beccarii* (83.9) and *Ganua curtisii* (78.5). The great heterogeneity of sites and vegetation and the general species richness of tropical rain forests generally cause excessive weight to be put on frequency. The relative effect of dominance and density in the index is reduced for the same reason because hardly any species obtains a high rating in these parameters. (BRUNIG, 1966, pp. 90-91). As a result neither the species with highest density, *Whiteodendron moultonianum* (N=1,304) nor the two species with the highest dominance, *Agathis borneensis* (G=34.9 m^2) and *Shorea albida* (G=29.6 m^2) are among the twenty species with the highest Importance Value Index. The species with the highest IVI, *Melanorrhoea beccarii,* characteristically is a species with a very high frequency (forty-four plots out of fifty-five). Eight of the twenty leading species are normally understorey species, six are normally intermediates to codominants and only six are typical topstorey species. This again is the result of bias due to overrating frequency. The IVI consequently has a rather low information value in complex tropical forests. LAMPRECHT (1969) and GREIG-SMITH (1964) similarly criticized that the IVI is composed of parameters of very different nature and weight.

225.3 Tree Heights and Layer Formation

The top-heights of undisturbed stands in the kerangas forests vary between 50 and 18 m. Fig. 11d shows the height relations of forty-eight stands in forty-six sample plots in order of decreasing top-height. The tallest stands occur in the lowlands on well water-supplied sites. The stand with the maximum recorded top height of 50m (SP. 3) is on a low dune transitional to peatswamp in Pueh F.R. *Dryobalanops fusca* (12.3% G) is the leading emergent species. SP. 46 is on GHP of a recent beach terrace in Similajau F.R. Leading emergents are *Shorea materialis, S. scabrida* and *Dryobalanops rappa.* SP. 16 with emergent *Dryobalanops beccarii* and *Shorea flava* is transitional to MDF in Bako N.P. The SHP soil is rather unfavourable, but this is compensated by the slope position which improves water and nutrient supplies. Similarly, SP. 8 on a broad, gently descending ridge in Pueh F.R. is near MDF and shows transitional feature. SP. 5 is similar to SP. 3 except that the drainage of the low-dune site is more effective. SP. 21 is on a board and gently undulating terrace. The forest intermediate between

MHP on the terrace flank and Shorea albida-kerapah on the flat. The soil has a high water capacity and drainage is moderate to poor. Decreasing stand height towards the right of fig. 11d is associated with increasingly more unfavourable water regime of the soils. Either water availability of the soil decreases, as in SP. 33, 36A on clay and in SP. 9, 15 on sand, or peats develop which may be very wet (SP. 32, 29, 57-1) or excessively drained (SP. 54). There is also an ill-defined increase in altitude towards right.

The sample plots on the limestone massif of Bukit Serapah are not shown in fig. 11d. The stand top-heights of the emergent trees are between 17m (plot 6, exposed top of 7 m wide NW. ridge) and 20 m (plot 4, depression on the ridge with shallow loamy rendzina soil). The heights correspond to the lowest stand heights on sites with very unfavourable water regime and strongly oligotrophic soils in kerangas (SP. 29, 54. 57-1).

Emergent species with a relatively wide site tolerance, such as *Shorea albida* and *Dacrydium pectinatum*, are also among the species reaching maximum heights in kerangas stands. *Shorea albida* is up to 50 m tall on favourable kerangas sites (SP. 8, 5, 21), 35 to 43 m on soils with either topographically impeded drainage (SP. 27, 31, 1), or relatively strong drainage (SP. 22, 49), or low water availability (SP. 6 on clay). The height is reduced at high altitude or in exposed positions even if soil conditions are favourable. In SP. 57-3 (730 m altitude) maximum height is about 35 m and falls to 20 m in SP. 57-1 where drainage is strongly impeded and the peat deep. Similarly, *Dacrydium pectinatum* reaches a top-height in the lowlands of about 37 m in SP. 17-5 (secondary MHP on lower slope in Bako N.P.), 32 m in SP. 17-1 (secondary MHP on the drier upper slope), 29 — 30 m in SP. 15 (SHP on upper slope). At higher altitude, *Dacrydium spp.* reaches 25 m in SP. 40 (raised peat with MHP on hummocks, 15 m in SP. 57-1 (PB) and 12 m in SP. 54 (blanket peat). Height trends in *Combretocarpus*... *Tristaniopsis*... *...stoma nobile* are much the same as in *Dacrydium,* and appear chiefly related to water supply, drainage, exposure and altitude. The combined effect of moisture availability and exposure can be observed in Bako N.P. where tree heights of *Ixonanthes reticulata*, *D. pectinatum*, *C. ...*, *Shorea ovata* and *Calophyllum nodosum* decline rapidly from tall kerangas on MHP (SP 17, type 61 of BRUNIG, 1965) to pole forest on SHP (SP. 15, type 63 and type 66) and finally to low, shrubby growth on rock padang and exposed boulders (type 71). Under extreme exposure and periodic dryness, otherwise tall tree species occur as stunted, gnarled trees and finally as cushion forms on natural and fire padang sites in Bako N.P. (BRUNIG, 1957a).

The height/diameter ratio declines generally from left to right in fig. 11d, indicating a tendency to more stunted growth with more unfavourable site conditions. This tendency is noticeably more marked in the bigger size classes than in the undergrowth classes.

The histograms in fig. 11d also show the variation of integration of layers in the stands. The number of layers varies between four (SP. 29) to seven (chiefly in the taller stands to the left). The layers are distinct in thirty of the forty-eight stands. Eighteen stands, chiefly on the left, are fully integrated and layers cannot be recognized visually. Distinct gaps between layers occur in stands which are strongly dominated by a single species or by an ecological species group (SP. 21, 27, 47, 26, 22, 57-1, 31, 40, 33, 29), or in stands which are in a rapid successional or ... development (SP. 46, 17, 31, 55, 29, 57-1 to 57-3). The ground vegetation of mosses, ferns, herbs, tree seedlings, stemless palms and pandans is always regarded as one layer.

The stands in the sample plots on Bukit Serapah have a distinct and dense main canopy about 12 m high, with few emergents about 15—20 m, a distinct small-pole layer at 4-5 m and an indistinct sapling layer. Including the ground-vegetation, five layers can be distinguished. The general structure of the tree stand resembles closely SP. 54 on the high-altitude blanket bog.

226. Stand Physiognomy in Relation to Site

226.1 Xeromorphic Features

GRIEVE (1953) lists the following eleven morphological and structural modifications characteristic of Australian sclerophylls: broad, leathery leaves; microphylly; acicular (needle) leaves; aphylly (phyllodes); winged stems; spiny stems; sunken stomata; cutinization; strong development of tannins and resins; strong development of palisade mesophyll; formation of hairs, scales, waxy blooms on surface. Singly or in combination most of these modifications are characteristic for species and stands in kerangas as well as in the interior peat-bog forests. Only spiny stems are almost completely absent from kerangas forests.

Xeromorphic characteristics of tropical rain forest leaves have occasionally been explained by an assumedly low specific water conductivity of tropical woods (BEWS, cit. by HOWARD, 1969), but this would at least not apply to woody lianas which frequently exhibit equally xeromorphic habits of the leaves. GRIEVE (1953) mentions the relatively low average rates of transpiration during summer in southern Australian sclerophylls and states that this is probably true for sclerophylls in other parts of the world. COUTINHO (1962) reports that many species from a tropical rain forest at Paranapiacaba (P = 3 600 mm, no dry season but periodic drought) have efficient stomatal adaptations comparable to those of so-called xerophytes in arid climates and in the tropical American caatingas. In contrast FERRI (1961; 1962), in a comparison with severed leaves from an American caatinga and normal rain forests, found equal transpiration rates and a generally slow stomatal reaction in the former. Various authors relate the scleromorphy of savanna vegetation in Latin and US America to low nutrient contents and high acidity in the soils rather than to water availability. LOETSCHERT (1969) reviews the literature on the relation between xeromorphy and nitrogen nutrition of peat-bog plants. He concludes that the more xeromorphic plants were also less well nitrogen-supplied.

BEADLE found that in the rain forest vegetation of Australia xeromorphy as a result of high lignification, heavy cutinization, silification, or a combination of these, may occur in any rain forest species. Adaptation to low fertility accentuates xeromorphic characters through a reduction in leaf size. The low-fertility xeromorphs are not xerophytes. The degree of xeromorphy can be reduced in many taxa by the addition of phosphorus and nitrate (BEADLE, 1966).

Milky juice is suspected by OPPENHEIMER (1960) as an adaptation to xeric conditions, but he warns that the problem is still open to discussion. In the kerangas forests, latex-producing species of the Sapotaceae alone represent about 10% of the biomass in the formation. Species which contain copious viscious latex or resin in stems and leaves together represent about 58% of the total biomass of the kerangas forests. We have seen earlier (sect. 136) that the species in kerangas forests have on an average a higher leaf tannin content than the species in MDF, but that tannin content within a species varies with soil base status. We may conclude that the common xeromorphic features of the kerangas vegetation is most probably the result of a complex interaction of several site factors, which may differ between different sites. In the following, some of the more easily observed features and their possible association with site factors will be discussed.

226.2 Leaf Sizes and Albedo

Average leaf sizes of forest stands are generally larger in stands on sheltered sites with ample and sustained water supply than on sites where moisture deficits are frequent. Large

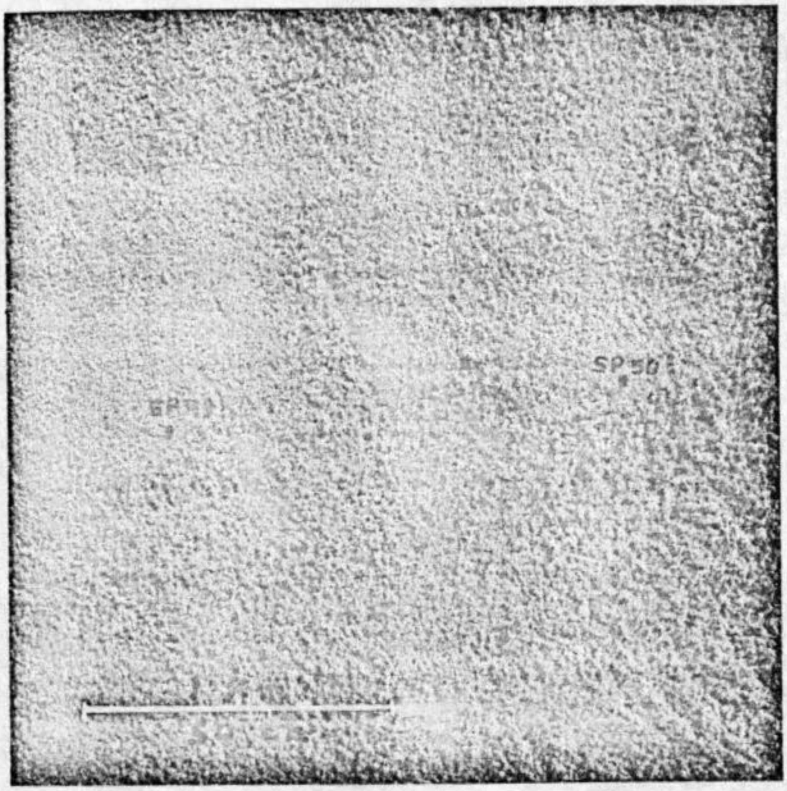

Plate 5. Kerangas forest on a gentle to moderately steep dip-slope, Belait formation. The catena from a terrace in the valley of s. Meluang (beyond the upper margin of the photograph) to the rim of the syncline near SP. 49 and 50 is described in sect. 134.2, ex. 3. The kerangas forest in the picture is mainly types 523.1 and 532.1 (sect. 432.2) with some type 523.1 (sect. 432.11). Niah — Jelalong P.F.

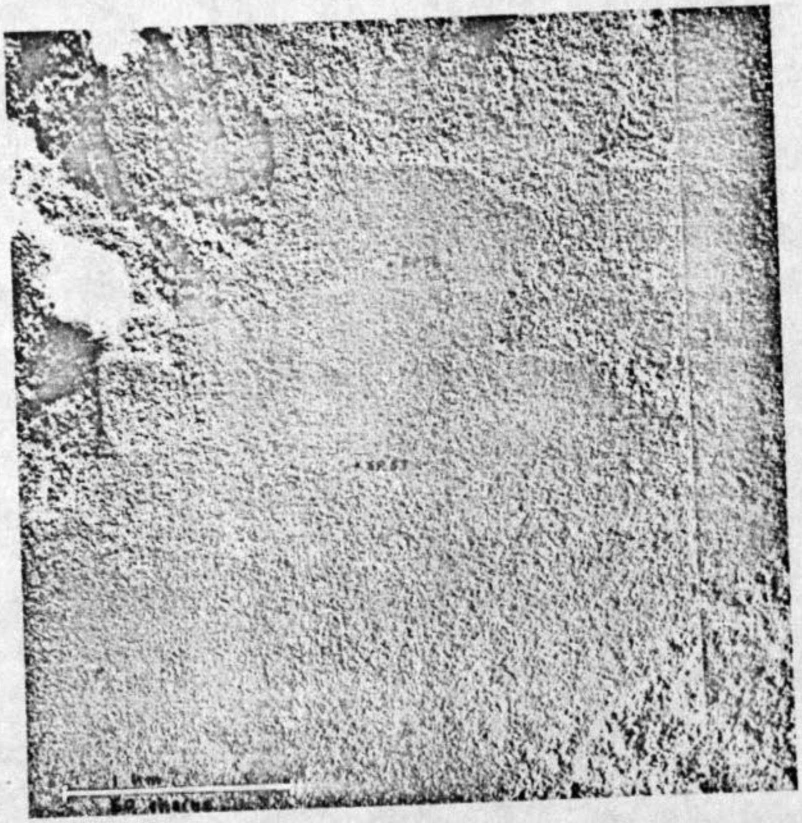

Plate 6. Kerangas and kerapah forest on a (?) Belait sandstone plateau at 700 m altitude, with cuesta formation in the top — left corner. The catena is illustrated in fig. 7c (No. 1—11) and in fig. 8a, and described in sect. 134.2, ex. 4. The forest types are described in sect. 432.2. Merurong plateau.

leaves on dry sites usually exhibit alternative features which prevent overheating in the presence of high radiation and low moisture supply. One common feature is glistening leaf surfaces which are common in all layers of kerangas forest stands. Especially, flushing leaves are often thickly covered with resins (e.g., *Gardenia resinifera, G. pterocalyx, Agrostistachys borneensis*). In other cases buds and emerging leaves lack a particularly reflectant and protective resinous or waxy cover, but are protected by stipules or more or less dense hairs. HOWARD (1969) observed in an elfin forest in Puerto Rico that, in the majority of woody species, young leaves have some form of protection. The same applies to kerangas forests in Sarawak.

Reflectivity as a result of a whitish leaf surface is frequent among many species of common emergent trees (e.g., *Shorea albida, Vatica brunigi, Xylopia coriifolia, Euphorbia sp.* S 6446, *Elaeocarpus euneurus*). Highly reflectant pale whitish-green leaf or frond surfaces are common among ephiphytic orchids, ferns and ant-harbouring dicotyledons in kerangas forests. Some common emergent species have reddish pigments in the mature, dark green leaves which improves the radiative exchange with respect to cooling (e.g., *Ploiarium alternifolium, Tristania stellata* and other species of the genus, *Whiteodendron moultonianum, Ganua curtisii, Melanorrhoea inappendiculata*). The abundance of anthocyanin in epiphytic *Vriesea sintenisii* seedlings and its survival value under exposure to light and low humidity in elfin forests in Puerto Rico has been demonstrated by WAGNER et al. (1969). Similarly, the common kerangas top-canopy parasite *Dendrotrophe varians* is conspicuous by its dark red leaves.

The effect of albedo on the heat balance and the transpiration rate of leaves is in direct relation to the fraction of reflected radiation. The kerangas and kerapah forests have a noticeably larger albedo on aerial photographs. This is most likely related to a larger per cent reflected incident radiation which has survival value by maintaining low transpiration rates without overheating under conditions of strong illumination and low moisture store. In addition to surface reflectivity, also leaf form is an important factor in this respect.

Many of the more important species in kerangas forests have roundish, strongly curved ovate or oblong leaves. The curvature of the surface is usually longitudinal and lateral. In many cases the leaf margins are strongly rolled-in. Examples are *Melanorrhoea inappendiculata, Vatica cuspidata, Calophyllum sclerophyllum, Ganua curtisii.* HOWARD (1969) reports the same phenomenon from the elfin forest on Pico del Oeste and suspects that some selective value could be attached to this growth form. Another important factor in regulating leaf temperatures is the leaf dimension.

The frequencies of different classes of leaf sizes on different sites in kerangas and MDF has been described in sect. 223. Leaf size influences the thickness of the atmospheric boundary layer and the effects of wind speed on the layer. The thickness of the layer affects external diffusion resistance and rate of heat exchange. Other conditions being equal, larger leaves have thicker, more persistent boundary layers. Consequently, larger leaves have greater temperature differences between leaf surface and ambient air. Conversely, the strongest coupling between leaf surface and air temperature is found in needle-leaves and in cylindrical, thin phyllodes (LEE, 1967). The importance of the combined effect of reflection and conduction for cooling leaf surfaces has been emphasized for *Ficus elastica* Roxb. by LOOMIS (1965). SLATYER (1967) has shown that the heat transfer coefficient k_h is dependent on the effective leaf width down wind and that a cylindrical leaf under conditions of perpendicular air movement has a greater capacity for heat dissipation than a flat broad leaf.

The advantage of smaller leaf sizes in reducing surface temperatures in situations with high radiation and water deficits has been discussed elsewhere (BRUNIG, 1970). Leptophyll leaf habit can effectively reduce the temperature of the leaf. At a wind speed of 45 cm min^{-1} at noon on a bright day with a net radiation of 1.27 ly min^{-1}, a 5 cm broad leaf had to transpire $7.8 \cdot 10^{-4}$ g cm^{-2} min^{-1} to reduce its radiation-determined surface temperature of 52°C to 40°C (5°C above the ambient air temperature of 35°C). This rate corresponds to a transpiration rate of 0.5 mm per hour if the leaf area index is 1, 1.0 mm for LAI 2, and 1.5 mm for LAI 5. Such rates are by no means excessive, but would be very difficult to maintain if soil moisture tension is high. Cooling by efficient removal of the boundary layer through wind-enforced convection is, under such conditions, essential. This conclusion agrees with the opinion that, in terms of control of leaf temperature, convection is the most important process, transpiration commonly is next and re-radiation is least important (MILLER, 1967). The importance of leaf size and reflectivity for temperature control by the plant is emphasized by the fact that almost all of the heat transfer of a tree is through its leaves (TURRELL and AUSTIN, 1965). Therefore, ecological significance may be attached to the fact that the frequencies of leaf size classes in kerangas stands show the previously described association with ecological gradients related to energy and water regime. (sect. 223 and fig. 13a).

GATES compares changes of transpiration rates from single leaves at different leaf sizes, wind speeds, temperatures and humidities. In warm air, convective cooling at various wind speeds will reduce the water pressure within the leaf. This effect is stronger than the simultaneous reduction of external boundary layer resistance to diffusion of water vapour. As a result, transpiration is reduced under the conditions of relatively high atmospheric humidity which are common in Sarawak. Evapotranspiration from vegetation in tropical humid regions may at times under certain conditions be less with wind than without. Wind will in these areas cool vegetation directly and increase air mixing. If increased air mixing reduces humidity in the canopy, increased evapotranspiration could result. As a result of these compensating effects, it is likely that the effect of wind on evapotranspiration from vegetation in warm-humid climates will be relatively smaller during humid conditions (GATES, 1965, 1966 and 1968). The advantage of smaller leaf sizes for cooling under such circumstances is obvious. The general prevalence of species with small leaves in kerangas forests and their particularly strong dominance on sites with unfavourable water regime suggests a functional relationship between leaf sizes and periodic moisture deficiency on some sites in the kerangas forests.

Therefore, the previously described leaf area index (sect. 223) was plotted in the ordination of sample plots (fig. 13a). The ordination will be described in detail in sect. 243. The leaf size index values were calculated for each sample plot and plotted at the SP coordinate in the X-/Y-plane. The values of the most common notophyll class and the most uncommon nano- and macrophyll classes did not exhibit any recognizable trends. The intermediate classes leptophyll, microphyll and mesophyll showed patterns of variation which appear related to site factors. The proportion of the microphyll class is largest on deep, porous sands which are excessively drained but retain some water reserve in the deeper soil layers which are accessible to deep-rooting species. Characteristic for such sites is the microphyllous, deep-rooted and gregarious *Agathis borneensis*. Leptophyll values are largest on sites with extremely fluctuating water regime. The soils are either sandy SHP soils on sandstone or shallow clayey GWP. The mesophyll class shows a marked dominance on the lowland deep-peat soils. This is largely due to the high dominance of *Shorea albida* or, on the wetter sites, of *S. pachyphylla*. The second centre of high mesophyll values is associated with the well water-supplied and fertile riparian soils below the belt of MDF at the bottom of the lower right-hand quadrant. The pattern of the index values of the three classes in the ordination confirms generally the trends of leaf size pattern described in sect. 223 for selected sample plots.

ASHTON's MDF plots except those on shale lithosols have a predominance of mesophylls and notophylls combined. Mesophylls exceed notophylls on the mesic clay-loams on the [illegible] hillsides. Microphylls predominate on shale lithosols. A change of leaf sizes from relatively damp to relative dry soils can be observed in all sampling areas (ASHTON, 1964c, p. 44 and fig. 37). The basal area percentage of leaf size classes for three sites in Belalong and Andulau and the leaf size index values in kerangas indicate that significant differences exist between MDF and kerangas which support the conclusions on site-leaf size relationships which were interpreted from fig. 13a (sect. 223).

In Australian rain forests, leaf sizes are smaller at higher latitudes and altitudes, and on soils of lower moisture and nutrient status. The evergreen sclerophyllous habit may be an adaptation to highly erratic rainfall under conditions of permanently limited moisture, because extreme pressure deficits require rigid sclerophyllous leaves (WEBB, 1959). A general association of xeromorphic development and nutrition, especially with phosphorus and nitrogen, has been described in Australia (RICHARDS, B.N., 1965; WEBB, 1968). However, the only rain forest species, *Araucaria cunninghamii* Ait., which could be introduced to sclerophyll forest sites by fertilizing, has much in common with the species in the dry sclerophyll forest (RICHARDS, B.N., 1967). This is certainly true for its leaf and twig morphology, which resembles that of *Dacrydium pectinatum*.

Little is known of the nutrient regime in kerangas forests on podzols and related soils in the tropics. It was said earlier (sect. 135) that HP, PB and GWP soils are very low in most minerals. Sandy HP soils also are extremely low in adsorptive complexes and exchange capacity. The difference of nutrient status and adsorptivity between kerangas soils and brown earths and lateritic soils, carrying luxurious MDF in Sarawak, is smaller than the striking differences in the vegetation seem to suggest. The smaller biomass turnover rate in kerangas (see sect. 261) would accentuate the difference and the combined effect may go some way in explaining why kerangas differs so strikingly from MDF. The inferior site fertility may also in part explain why the degree of evergreenness is greater on kerangas than on MDF sites. In this respect ASHTON (1967) also suggests that soil fertility may be involved. MONK (1965) found a greater degree of evergreenness on the less fertile soils in Florida, which may be an adaptation to the need for conserving the nutrient store of the site.

We can conclude that the distribution of leaf size spectra of the stands in the ordination reflects conditions of site which appear at least partly associated with the water regime. It is, however, also evident that soil fertility may also be important. This is indicated by the increase of mesophylls from the centre of the matrix downwards. It is known that the nutrient status of the soil could affect leaf size variation within a species and between stands. STONE ([illegible]) observed criteria resembling drought effects in pine such as short yellow needles, on sandy, nutrient-deficient sands which had sufficient plant-available moisture even in dry summer. For example, in Sarawak *Dacrydium pectinatum*, after transplanting from a sandy rock padang in Bako N.P. into well-watered pots with sandy but more humic soils, produced much longer [illegible] on new shoots. This immediate and very drastic change was probably the result of improved supply of water and nutrients (BRUNIG, 1965, p. 295). The general relationship between leaf physiognomy and site fertility is recognized by the Iban who considers land as good [illegible] land if the canopy of the natural forest is "daun hitam", i.e., if the canopy is darkgreen and heavily shading (RAGAI, pers. comm.).

[illegible] Crown Structure

The crown shapes in tropical trees appear uniquely adapted to the peculiar radiation environment (DOHRENWEND, 1969), and seem to bear relationship to the moisture regime of the ecosystem. The more common and characteristic types of crown shapes in the lowland forests of Sarawak and Brunei are shown in fig. 12b. Excluding the effects of convection, evapotranspiration and leaf geometry, the diurnal march of crown surface temperatures in relation to air temperature follows the general trend indicated by the broken lines below the crowns. Midday is indicated by the position of the stem.

The flat crowns (a) and (b) are characteristic for early successional, exacting species, such as some *Baccaurea* and *Macaranga spp.*, with large, relatively thin and easily fluttering, often highly reflectant leaves. Typically, these species are rapid-growing, deep-rooted, short-lived and occur in low and relatively dense, uniform stands on moist to wet, fertile soils. In kerangas, this type is restricted to rare occurrence on well-watered more fertile mineral soils at the margins to other forest types.

The composite cone (f) receives almost equal amounts of incident radiation irrespective of the inclination of the sun. In emergent trees, the cone also intercepts a high rate of adjective energy. In lowland kerangas this crown type is represented by *Agathis borneensis*. If root-accessible water supply in the soil is adequate, the species will occupy an emergent position. If supply is marginal, the species is confined to codominant canopy position. The crown type is absent from very dry sites and from MDF. The composite sphere (c) is characteristic for large emergents in near climatic climax MDF. This shape evens the daily march of the radiative load in an equatorial climate and permits ample light penetration and ventilation. It intercepts less diffuse and thermal radiation than the oblong crowns of lower strata in the same stands. The composite broomstick (g), by vertical arrangement of the short-needled twigs or phyllodes, reduces interception of radiation during the most critical period of the day at noon. Reradiation to the zenith is rather inefficient with this geometry, but the usually darker green colour of the twigs assists in this respect. This crown type is characteristic for *Dacrydium spp.* and *Gymnostoma nobile*, which are common on excessively drained, periodically dry SHP, sandy GWP and shallow PB soils. The broomstick crown is typical and common in low and frequently open stands in exposed positions. Examples are the padang and cliff-tops of Bako N.P., the rim of the syncline of the Klingkang range and the exposed margins of the Merurong plateau.

The cauliflower type (d) is characteristic for *Shorea albida, S. pachyphylla* and *Dryobalanops rappa* in stands with high basal area and high tree density in kerapah and peatswamp. The crown shape compromises between the composite sphere, which evens radiation load, and the umbrella type, which reduces canopy surface roughness (sect. 226.4) and increases albedo. It is common in peatswamp forests on sites with rather fluctuating water tables but rare and probably at most moderate water deficits. In kerangas, the cauliflower type occurs locally on well water-supplied GWP and PB soils, but is absent from dry sites.

The oblong or irregularly spreading crowns of trees in the understorey are well adapted to the low wind speeds and high proportion of diffused, uneven light in the understorey. Locally, adaptation to exacting energy flux regimes in the understorey is by leaf sizes rather than by crown shape, which causes the reversal of the common trend towards larger leaf sizes at lower height in the stands which has been described in sect. 223.

226.4 Canopy Structure

The structure of the canopy of forests changes along site gradients. In tertiary landform, tall MDF with large predominantly composite-spherical crowns and irregular canopy surface occupies deep soils with adequate water supply, preferably on scarp and lower dip-slopes. In the same formations, kerangas forests with smaller crowns, lower heights and more uniform canopies occupy more shallow soils and peat bog. The canopy surface pattern (figs. 7a-c) and size vary on aerial photographs sufficiently for identification and classification of types.

In holocene terrace landscape, the roughest canopy types occur in the peatswamp and riparian forests which often surround recent alluvium and in the MDF on terrace flanks and adjoining tertiary landforms. The more uniform canopy with smaller crowns occurs on the terrace plateaux. The general pattern of canopy types and associated changes in topography and soil are shown in fig. 7a.

The pattern is similar on pleistocene terraces (fig. 7a, centre, and fig. 7b). A common feature on more extensive old terraces is the opening and lowering of the canopy in areas where impeded drainage leads to PB formation (fig. 8a and kerapah types in figs. 7a and b). An analogous development occurs on level parts of sandstone plateaux (fig. 7c, No. 2). In contrast, the canopy on blanket peats of sandstone dip-slopes is typically very uniform and dense (fig. 7c, No. 4), resembling the vegetation on the exposed ridges (No. 5) and on tops of limestone hills (fig. 7b, right). For example, the canopy in SP. SER 1-6 on the summit plateau of Bukit Serapah is very dense and even. Microphyll species (*Cotylelobium malayanum, Tristania obovata, Decaspermum fruticosum*) or species with very coriaceous, reflectant leaves (*Hopea andersoni, Vatica coriacea, Diospyros hermaphroditica*) dominate. There is a distinct increase in canopy height and in surface roughness from ridge-top (surface mor) to hill-side (clay-loam rendzina). Locally on summits of limestone at low altitudes also *Gymnostoma nobile* occurs and may become dominant (ANDERSON, 1965), emphasizing the close structural resemblance to the poorer types of kerangas forests.

Surface roughness and height of the stand canopy generally decrease along the gradient from MDF on deep soils to kerangas forests on SHP and to kerapah forests on PB soils. Similar gradients can be observed from lowland to mountain sites. The very consistent pattern changes in PSF from the perimeter to the centre have been described elsewhere (BRUNIG, 1970a).

The canopy surface roughness affects energy and matter exchanges principally in two ways. Firstly, the geometric shape of emergent canopy elements determines the daily heat load from incident direct solar radiation. The heat load on emergent single or groups of crowns can be estimated by the ratio interception by emergent element/interception by horizontal surface (Q_E/Q_H). The ratio depends on the height and diameter of the emergent element and deviates from 1 (= horizontal surface) in relation to the size of the emergent units in the stand canopy. In the forenoon and afternoon at a zenith angle of the sun of 45° the ratio is about 3 in riparian forests, 2.8 in MDF, 2.7 in moist kerangas (Agathis-bearing), 2.5 in kerangas on MHP soil and below 2 on SHP and periodically dry PB soils (BRUNIG, 1970a, fig. 1). The reduced heat load on the emergent trees in kerangas is obviously an advantage if moisture supply becomes critical.

Secondly, the surface topography determines the aerodynamic roughness, which in turn affects energy and matter exchanges at the surface. Greater irregularity and height variation of the canopy surface increase its aerodynamic roughness and consequently the amount of turbulence from free and forced convection. Increased turbulence in turn reduces atmospheric resistance to heat and vapour fluxes from the plant surface. Consequently, a greater amount of sensible and latent heat can be dissipated per unit area and time. Therefore, greater aerodynamic roughness will be associated with a larger value of the ratio evaporation/incident net radiation. Conversely, a smoother and more uniform canopy will have a smaller aerodynamic roughness, the turbulent and convective exchange processes will be less intensive, and the external diffusion resistance will be greater. As a result, the potential evapotranspiration rate will be lower in stands with smoother canopy surface.

The main structural parameters which affect the aerodynamic roughness are:

(1) top height of the emergent trees or groups of trees
(2) the distance between these emergent elements
(3) the diameters of these emergent elements
(4) the range of sizes of the latter two parameters
(5) the average height above ground at which the canopy of the stands can be assumed to be closed.

These parameters were measured on large-scale aerial photographs in a number of stands in kerangas and PSF. The means and mean ranges were calculated and used for constructing standardized canopy profile diagrams. These profile diagrams are a pictorial representation of those canopy surface parameters which effectively contribute to the aerodynamic roughness of the stand. Examples of such profiles in various types of MDF and kerangas are illustrated in fig. 12c. The increase in smoothness of the canopy from mesic and more fertile sites to relatively xeric and more oligotrophic sites is immediately apparent. The same trend is equally noticeable in actual stand profiles. Examples are given in fig. 8b of a coastal terrace and in fig. 12a for an inland kerangas stand on tertiary parent material. In both cases, the positive association between aerodynamic roughness and site quality is as marked as it is in the standardized profile diagrams in fig. 12c. The same pattern is also noticeable in the crown projection map of the Sabal sampling area in fig. 12a. The more irregular patterns with larger individual and groups of crowns are associated with deeper, more loamy and more reddish-yellowish soils, for example in the top-right corner of the area (western tail of the E-W transect no. 24 with dominant *Dryobalanops beccarii* = No. 100, *Dipterocarpus pachyphyllus* = No. 98 and *D. sarawakensis* = No. 99). The numerical values of the parameters which were used to construct the profile diagrams are given in tab. 11, which also gives some tentative values for PSF phasic communities at Tanjong Kranji, Saribas, for comparison.

Further, an attempt has been made to express the aerodynamic roughness by the estimator z_o. This estimator has been calculated from the same parameters which were used in constructing the standardized canopy profile diagrams. The following formula gave the best results, that is the best fit to data from other climatic regions and the best gradient in relation to corresponding site gradients (BRUNIG, 1970a):

$$\log z_o = \log (h_T - d) + \log (\Delta r) + \log (\Delta t) - 2.94$$

where h_T = top height of emergent roughness element

d = zero plane height estimated as the average height of the more or less closed intermediate canopy

t = distance between the tops of emergent roughness element

r = diameter of emergent roughness element

Δ = mean range of the respective parameter.

The values range from 565 cm in MDF, type 42, to 157 cm in kerangas, type 52 on SHP. The trend of the z_o-values indicates that the canopy surface roughness and its correlated aerodynamic roughness decrease in the same manner along the ecological gradients as the heat load estimator Q_e/Q_H. The estimator z_o of the aerodynamic roughness is largest on mesic sites and smaller on more xeric sites. In a similar manner, it also decreases from low to high altitude and in PSF from the perimeter to the centre of the peatswamps.

The trend of z_0-values along the PSF gradient of phasic communities is very similar to that from mesic MDF to xeric kerangas communities. The lowest calculated values occur in the P.C. 4 (forest type 381). This forest type corresponds structurally closely to the kerapah forest on kerangas peat. The aerodynamic roughness estimator z_0 has not been calculated for open Padang Peatswamp forest (P.C. 6 or forest type 39) because suitable data or aerial photographs were not available. According to LAMBERT (1970) increase of spacing, approaching savanna conditions, would tend to decrease surface roughness. It could then be expected that the values for open padang in PSF and in kerapah would be lower than those for types 38 or for 51 on deep PB soil.

This association between canopy surface roughness, exchange processes and site indicates the possibility of a functional significance of stand morphology. Consequently, it is a useful guide in defining constraints on silvicultural stand manipulation on critical sites. It also offers an opportunity to classify natural forest vegetation on aerial photographs in an ecologically meaningful manner.

The assumption, that the described patterns of surface roughness change is ecologically significant, is supported by the previously discussed changes in leaf sizes and albedo along the same ecological gradients. Again, along the gradients the density of leptophyll species with phyllodes (*Gymnostoma nobile*) and needles (*Dacrydium spp.*) and generally upright position of leaves and twigs increases. This improves cooling capacity of the canopy and reduces evapotranspiration rates under conditions of high radiation, low wind speeds and lack of soil water. The ecological advantage in kerangas sites is obvious. Similarly, in East Africa canopies become smoother and podocarps and cypress replace broad-leaf forest species in the montane sclerophyll forest type where precipitation is suboptimal, but incidence of solar radiation and of occult atmospheric moisture are high (KEERFOOT, 1968).

Transpiration rates increase with stand leaf area to about LAI 3 provided the soil surface is dry and does not evaporate. Pronounced upright arrangement of leaves slows the rate of this increase and delays the peak to about LAI 6 (COWAN, 1968). A smaller LAI of a stand generally increases downward radiation fluxes and decreases upward vapour fluxes. The rates of light penetration suggest that the LAI is generally smaller in kerangas than in MDF or Mixed PSF and Alan forest. The lower LAI would then be an advantage on sites on which deficient water supply periodically restricts transpiration. The advantage is even greater if the reduced LAI is due to wider spacing, as in the open padang woodland of white-sand terraces or in the open peat-bog savannas of ANDERSON's phasic community 6, PSF type 39.

2.6.5 Stand Physiognomy in Relation to Moisture Availability

ASHTON had first drawn attention to the phenomenon, "that the gradient in structure, and to a lesser but significant extent in floristics, from Mixed Dipterocarp to Savanna forests in south-east Asia is parallel to the gradient from Mixed Dipterocarp forest on yellow podzolic soils to Heath forests on shallow podzolic soils studied by ASHTON in Borneo; this suggests that the climate is not the only differentiator. The main difference is that the heath forests are yet more evergreen than the Mixed Dipterocarp forests". He also points out that on the most fertile soils in MDF, mostly derived from basalt, there is a marked increase in deciduous species, though there is never a shortage of available water, and a decrease in floristic richness and an increase in single-species dominance. The optimum habitat does not therefore carry the most complex vegetation (ASHTON, 1967). In the previous sections we have suggested that moisture requirements and availability may be decisive factors in determining stand physiognomy, especially the canopy surface morphology. It was especially suggested that availability of water in relation to incoming and intercepted energy is likely to exert a significant influence on the development of stands on the various kerangas sites. This would require that water deficits in fact occur in kerangas forests.

A forest stand will evapotranspire and extract soil water close to the rate of potential evapotranspiration until the portion of available water is exhausted which is held at soil moisture tensions of less than 2 atm. In sandy soils about 70% of the total plant-available moisture is held at less than 2 atm., in loam about 50% and in clay only about one-third. The depletion curve in sandy soils is approximately linear between 0 and 2 atm., strongly concave to 10 atm. and depletion virtually stops between 10 and 30 atm. In clay-loam and heavier soil, the depletion curve is more concave throughout its range and depletion continues at higher rates beyond 10 atm. (ZAHNER and STAGE, 1966).

Free water in the plant tissue of a tree stand is equal to about 25% of the wood volume at full saturation. Stands in the various types of kerangas forests would according to their biomass (tab. 14a) contain between 50,000 and 250,000 litres free water per hectare. Optimum MDF would contain between 200,000 to 250,000 l/ha. The evapotranspiration rates in the different forest types in Sarawak has been discussed in sect. 117.3. The rates appear reasonable in relation to pan evaporation and estimated evaporation from free water surfaces. Rough estimates have led to the conclusion, that transpiration of normal agricultural crops may range from 0.8 to 1.2 of free water evaporation for fields of large horizontal extension. Much larger average values are unlikely, because the energy for vaporization would not be available. But larger values may occur through the "oasis" effect in smaller, exposed plots (WIT, 1958). Emergent units in the forest canopy could be regarded as small plots in this respect, if they are exposed. We may therefore adopt the transpiration rates estimated in sect. 117.3 without too great a risk of overestimating. The transpiration rates for bright days with normal wind conditions were 3 mm in kerangas pole forest on SHP (SP. 15) and 5 mm in Agathis borneensis-forest on DHP (SP. 43). The stand water store equals about two days transpiration in the pole forest and five days in the Agathis forest. Optimum, tall and rough-surfaced MDF would transpire 6 mm on a bright day and the stand water store equals the consumption of three to four days. The rooting depths and corresponding amounts of plant-available soil water are given in tab. 6. Assuming for the sake of simplicity continued maximum evapotranspiration rates, the minimum number of dry and bright days can be calculated which are required to completely exhaust the available water store in the stand and in the soil. The result is thirty-tree days for MDF on RYP and thirty-one days on LS. In kerangas the number of days required are sixteen on SHP, forty-seven days on MHP, 115 days on DHP and fifteen days on PG clay soil. The estimate for the stand on the DHP is probably too high because only part of the soil volume is actually accessible to the plants through roots (see sect. 135.5). Also, the generally poor water conductivity of fine sands in HP will accentuate water stress and cause rapid development of perirhizal zones of soil water tension if transpiration rates are high (TINKLIN and WEATHERLEY, 1968).

The following is an example of estimated water depletion in two kerangas stands in Bako N.P. (SP. 15 and 16) during the period, March to June, 1965. The Kerangas forest type in SP 16 is transitional to MDF (type 532), nearly 50 m tall (fig. 11d, serial no. 3), predominantly mesophyll (fig. 13a, bottom) and of high aerodynamic roughness. SP 15 is Kerangas forest type 521, only about half the height of SP 16 (fig. 11d, serial no. 43), predominantly microphyll (fig. 13a, centre) and the canopy is aerodynamically smooth. Rates of evapotranspiration and amounts of water store are 5 mm and 138 mm in SP. 16, and 3 mm and 101 mm in SP. 15 (fig. 14). In addition, the effectiveness of rainfall in recharging the water store must be considered. FREISE (1936) measured 33% throughfall, 27% stem-flow and 40% interception in a subtropical rain forest in Brazil. This corresponds closely to the 57% total average interception (including stem-flow) reported by CLEGG (1963) from Puerto Rico. DABRAL and RAO (1969) measured 54.6% throughfall, 7.2% stem-flow and 38.2% interception in a dense *Shorea robusta* plantation in India. KENWORTHY reports that 450 to 500 mm are intercepted and evaporated annually from the trees in a MDF in Ulu Gombak F.R. near Kuala Lumpur. His observations indicate that stem-flow is of little importance except in the largest and most intensive storms. Evaporation from the soil surface seems to be in the order of 1% of total rainfall. Annual transpiration is calculated as 1350 mm. The average transpiration per day is 3.65 mm. Only 3-4% of the rainfall (100 mm) were lost in surface run-off. Over 90% of the rainfall (2,500 mm) were therefore estimated to be available for nutrient uptake and cycling within the system in the study area (KENWORTHY, 1969 and 1970). We may conclude that average mixed tropical rain forest intercepts between 25 and 35% of the annual rainfall. The amount is most likely less in the poorer types of kerangas and peatswamp forests which have a lower leaf area index, lesser canopy depth and smaller biomass.

Intercepted water is evaporated and is therefore not simply waste. Intercepted water contributes usefully to total evapotranspiration and temperature control. Some of the intercepted water may, through the leaf surface, enter the plant. It may eventually even be discharged from the roots into the soil. However small these amounts are, in critical situations they may have survival value. More generally, interception reduces direct soil recharge from rain, especially from light showers during dry spells. Interception rates during such showers are determined by the amount of water required for wetting of the tree surface, which requires 0.4 mm for a mature *Fagus silvatica* L and 1.8 mm for *Picea abies* Karst. Figures from tropical rain forests are not available but would most likely be considerably larger due to the abundance of epiphytes, the roughness of bark, the depth of leaf-filled canopy and the high leaf area index in undisturbed natural rain forests. Considering the reported annual interception rates of 25 to 40% and the rainfall pattern in the area, a wetting rate of 3 to 4 mm or more does not appear excessive. A shower of less than wetting rate will not effectively recharge the soil. These high rates of interception and the rapid evaporation of surface water from showers by subsequent sunshine (RIEHL, 1954) reduce both the proportion of effective rainfall and the damping effect of showers on transpiration during fine-weather periods.

In the example of the two sample plots in Bako N.P. a flat and conservative rate of interception of 3 mm is deducted from each shower. No allowance is made for surface run-off, which would occur in intensive down-pours as soon as the precipitation rate exceeds the infiltration rate. In doing this, undue bias in favour of creating drought conditions is avoided. The amount of rainfall available for recharge is shown as shaded columns in fig. 14.

Water store is at capacity on both sites on the 8th April, 1965. Depletion exhausts the store on the 25th May in SP. 16. The deficit period lasts for twenty-seven days to the 20th June. If interception is not deducted and the total rainfall considered effective, exhaustion would still occur on 7th June. The amounts of recorded monthly rainfall (fig. 14, bottom line) show that rainfall during this period was not exceptionally low. It appears therefore that typical MDF cannot maintain full activity on a loam soil and with a rooting depth of 70 cm on soil and stand water store alone. In SP. 16 additional water supply comes from seepage down-slope. In contrast, observation of the water flow in soil pits has shown that the soil in SP. 15 is at field capacity and without noteworthy lateral recharge about twelve hours after heavy rain. The much lower transpiration in SP. 15 has prevented a water deficit to develop in spite of the shallow soil (B_h at 30/40 cm over sandstone at 50/60 cm) and the correspondingly shallow rooting. Increasing transpiration to the value of 3.65 mm, which KENWORTHY calculated as annual average for MDF in Malaya, would lead to exhaustion of the water supply in SP. 15 on about the 15th May.

We can conclude that a more complex stand with larger leaves would not be able to survive on this site, or at least not function efficiently. It is very probable that such stand would, during the dry and bright period in the example, transpire at a considerably higher rate than the Malayan annual average. Moisture supply, therefore, would be a critical factor in the ecology of this stand.

During the same period from April to June, 1965, the 30-days sliding sum of total rainfall (including interception) dropped below 100 mm first on 9th May and stayed below for two days. The sum lingered just above 100 mm until the 28th May and then fell below 100 mm for twenty-six days with a minimum of 69 mm on 20th June. The recorded monthly rainfall during this period was 360.5 mm in March, 238.7 mm in April, 100.7 mm in May and 145.2 mm in June, which does not reveal that periods of dryness occurred during this period. The trend of the depletion curves in SP. 15 and 16 indicates that a risk of water stress to develop in kerangas and MDF exists if the 30-days sum drops below 100 mm and approaches 60 mm. The frequency of such occurrences during the two-year period was 9 at Bako N.P., 10 at Miri and 4 at Kuching airport (comp. tab. 2 and sect. 111). It is very likely therefore that periodical water deficiency is no uncommon phenomenon in lowland equatorial rain forests of Sarawak and Brunei.

At equal rates of evapotranspiration, moisture stress develops more rapidly in kerangas on shallow sand or heavy clay soils. Critical moisture tensions develop less rapidly in deeper sand and balanced loam soils. However, as the feeding roots of trees in HP and GWP soils seem concentrated in the top-soil layer, moisture stress may develop even earlier than the calculations above suggest which are based on observed maximum rooting depth. Early water stress has been reported for shallow-rooted *Hevea brasiliensis* in plantations on loam soils by GUHA (1969), who concludes that soil moisture deficit is likely to be a limiting factor for productivity in rubber plantations. It seems possible that in MDF in Sarawak, similarly critical water tensions develop on average RYP soil in flat country, if the 30-days sum falls below 100 mm and thereafter little or no effective rain occurs for another seventeen days. Surface run-off in heavy down-pours reduces recharge and aggravates the situation. GUHA (1969) considers permeability of Malayan soils at 15-45 cm depth low enough to cause substantial loss of water from high intensity rains of Malaysia.

Water deficit in a plant can be the result of slow absorption not only from dry but also from poorly aerated soils (KRAMER, 1964). Nothing is known about aeration and CO_2-concentrations in the kerangas and MDF soils in Sarawak. Observed periodic water-logging in PB and clayey GWP and PG soils is probably associated with poor aeration. The similarity between kerangas forests on clayey PG soils and sandy SHP soils points at the possibility that both soils are ecologically not too dissimilar. The soil-water: aeration regime may be a significant factor in this respect. WANNER (1970) found in Bako N.P. that in shallow depressions in the alluvial forest type 42, Oncosperma — Salacca — Artocarpus-forest, water drained slowly and the soil respiration was only half of that in adjacent but better-drained spots. This points at significant differences in the aeration regime of sites with different drainage conditions.

SCHULZ had tried to explain differences in the vegetation in North Surinam by differences in the soil texture, aeration and moisture regime. Sandy clay soils would be inadequately aerated if filled up to capacity during the rainy season. Sandy soils on the terrace plateaux are better aerated but reach a level of 60% of field capacity if the 30-days sum of precipitation falls below 30 mm. The correlation between wilting point, soil texture, and moisture availability is particularly poor in these light-textured sandy soils. Water stress is suspected to occur at low 30-days sums on the terraces (SCHULZ, 1960, pp. 151-156). HEYLIGERS found that, on the white sand terraces of North Surinam, distance from the nearest water course, surface topography and relief of the underlaying granitic bedrock show a closer relation to vegetation differences than other site factors, including texture of the soil. His dry savanna forest is found on well-drained soils. The wet savanna occurs on white-sand soils in which the water table is permanently or at least periodically near the surface. Both types possess xeromorphic physiognomy. These vegetation types seem to reflect moisture conditions of the soils on which they occur (HEYLIGERS, 1963, pp. 67-69).

226.6 Spatial Pattern of Tree Distribution in Stands

POSTHUMUS (1937) mentions that the trees in the Luwai terrace kerangas show a grouping tendency in the terrace centres. The same observation can be made on terraces and plateaux in Sarawak and Brunei. Grouping is less noticeable on sites with adequate and reasonably balanced water regime than on periodically dry or permanently wet sites. Grouping of individuals as a deviation from random to a less dispersed pattern is very marked in the undergrowth on shallow HP, GWP and PG soils, especially on sandstone dip-slopes (SP. 9, 15). Grouping in the undergrowth and among top-canopy trees is very noticeable on sites with impeded drainage, especially if the canopy breaks open (SP. 29, 30, 32, 57). On these sites, meandering hollows often separate distinct groups, especially on very wet sites, resembling the micro-relief in some types of PSF. There is no evidence yet for the cause of this phenomenon. Seedling distribution suggest that there may be a correlation between surface drainage pattern and grouping through the deposition of seeds and litter outside the channels on the mounds. This is quite common in kerangas on soils which possess impervious layers close to the surface or which suffer from topogenic water-logging. It is also known from similar sites in mixed hardwood forests in north-eastern U.S.A. (RICHARDS, N.A., 1969).

In some kerangas stands, coppice regeneration is common especially among species of Fagaceae, Myrtaceae and Melastomataceae. As a result, small single-species groups of poles develop from the sprouts which noticeably increases the grouped aspect of the stand. The feature seems particularly common on sites with imbalanced water regime or with excess of water.

Outside kerangas, strong grouping has been observed in SP. SER 1-6 on the broad summit of Bukit Serapah. This is partly due to the dissected nature of the corroded limestone substrate which underlies the surface peat and partly due to the large proportion of coppice regeneration. Tree seedlings are common on the micro-knolls of limestone outcrops, but almost absent on the intermittent meandering depressions, in spite of frequently better soil conditions.

The grouping tendency is easy to observe among the undergrowth trees up to about 5 m height. The wider spacing and taller growth of larger trees makes it difficult to assess presence and degree of grouping. Distance or coordinate determination and quantitative analysis are necessary which both are expensive and difficult. For this reason the distribution of individuals within recording units was only studied in the Sabal area. In all other sample plots, grouping tendency was merely visually assessed qualitatively for the undergrowth within recording units in the three classes: (1) weak grouping (apparently random), (2) moderate grouping, (3) strong grouping. It became apparent that local disturbances through windfall or lightning and minor site variation due to micro-relief and soil changes (clay-pockets) strongly affected the distribution of size classes, individuals and species. The resulting pattern of undergrowth distribution alone is already extremely complex. The result of the qualitative assessment is therefore not more than a very general indication that average undergrowth pattern varies between sample plots and that this variation seems to be in some manner related to site conditions. Of the fifty-one plots for which detailed pattern descriptions were made, twenty-five are in class 1, thirteen in class 2 and thirteen in class 3. The strongly grouped plots are on HP (3), GHP (1) and PB (9). Eight of these plots are at high altitudes. The apparently near-random distributions are typical for the better drained but well water-supplied sites in the lowlands and the transitions to MDF. The pattern in the understoreys is not necessarily reflected in the top-canopy. The understorey in SP. 43 is in class 1, while the emergent trees are strongly grouped, especially *Agathis borneenis*. Conversely, the understorey in SP. 40 is strongly grouped, while the dense and uniform canopy of *Dacrydium sp* does not exhibit a grouping pattern which could be recognized from the ground.

The pattern of crown distribution within kerangas and MDF stands on different sites shows characteristic differences (fig. 12a) which promises to be useful in quantitatively classifying stands on aerial photographs. A study of the canopy pattern in the Sabal sampling area is being undertaken at present. The results are not yet available and will be reported elsewhere.

23. DEVELOPMENT AND REGENERATION

231. The Ecological Status of Kerangas Forests

Wide-spread human interference with the evergreen caatinga of tropical Latin American lowlands is evidenced by charcoal and pottery fragments in the soil (SCHULZ, 1960; HEYLIGERS, 1963; KLINGE, 1965). The kerangas and padang vegetation of the Bako N.P. shows many signs of past fires in the vegetation and soils (BRUNIG, 1965). The tall kerangas forest in SP. 17 proved to be a secondary subsere after complete destruction of the original MDF on RYP soil. Outside the Bako N.P., a soil pit in tall and apparently undisturbed kerangas forest on the Melinau terraces is the only pit which showed any evidence of fire. A piece of charcoal and carbon colouration were found just above the B/C in 27-30 cm depth in soil pit ME 1-1 in SP. 28. None of the other pits in the plot produced similar evidence which makes lightning strike or down-wash from the nearby limestone massifs the most likely sources.

It was clearly desirable to obtain more reliable information on the historic development of kerangas forests. Peat samples were therefore collected from encased PB sites in the sampling area on the Dalam F.R. terrace, on the Melinau terraces (SP. 31) and on the Merurong plateau (SP. 54, 55 and 57-2). Further collection in the Sabal sampling area and in Pueh F. R. were intended but impossible due to the political situation in the border area during 1962/63. The pollen content of the samples were analysed by Mr. J. MULLER, at that time palynologist at B.S.P., Seria. The objective was to check if any successional trends or disturbances could be detected from changes in the pollen content. The findings were briefly reported at the symposium on ecological research in humid tropics vegetation, Kuching, 1963 (MULLER, 1965). The following is an extract of MULLER's more detailed reports to me with my own ecological interpretation added. A summary of the pollen counts is reproduced in fig. 16. The absolute counts for all species have been reported elsewhere (BRUNIG, 1966, tab. 15).

The profiles can be divided into the lowland terrace samples with high percentage of pollen from species of *Calophyllum* and Sapotaceae. The high-altitude kerapah samples from the Merurong plateau have throughout a high percentage of *Gymnostoma*, fewer Sapotaceae and very little Calophyllum. The pollen diagram of the holocene Dalam terrace shows first an increase and then a decrease in Calophyllum. Gymnostoma is common throughout and increases markedly to the top. Dacrydium is much less common and changes are slight, with a small decrease in the upper layer. Dipterocarps first increase and eventually fade out towards the top, while Shorea albida shows a consistently low percentage throughout, similar in pattern to Combretocarpus. Ferns and miscellaneous species decrease towards the top.

This corresponds closely to the pattern of species dominance in the area. MDF is gradually replaced by transitional forest with Dipterocarpus lowii, Dryobalanops rappa and various Shorea spp. which towards the terrace centre in the north-east grades into kerangas forest, which is according to WOOD (1965), a Gymnostoma—Dacrydium—Shorea albida-association on the centre plateau and an Agathis-bearing subtype along the rim and on raised ground. The forest generally becomes poorer in species and denser in the main canopy towards the terrace centre. A few open patches, which are caused by lightning and wind-throw, regenerate to Gymnostoma nobile and Dacrydium pectinatum and do not indicate a transition to a different phase of succession. In contrast, open patches in stands in the catena on the older Melinau terrace accelerate observably the succession to succeeding stages.

The basal area distribution of Gymnostoma nobile among the sixty sample plots on the Dalam terrace shows only a weak correlation to peat depth. The species is absent or very rare on sites without peat or mor (MDF transition), but the scatter of basal area values over increasing depth of peat does not produce a significant regression. The largest basal area dominance values (33 to 41 m^2/ha) are, however, restricted to plots with more than 70 cm peat. There are only two plots with 26 to 30m^2/ha G. nobile on sandy HP with less than 25 cm peat. Shorea albida basal area values have a similarly wide scatter. The species is also rare in plots without peat, but in contrast to the previous species highest dominance values (8.1 to 18.0 m^2/ha) are restricted to plots with less than 30 cm peat. Dacrydium pectinatum is distributed similar to Shorea albida. The species avoids the deep peat and generally poorly drained sites on the Dalam terrace.

The sample from SP. 31 on the pleistocene Melinau terrace shows a decline of Gymnostoma pollen from base to 70 cm which agrees with the relative dominance of the species along the catena SP. 30 — 28 — 31 — 29 — 32. The increase upward from 70 cm cannot be explained and may be related to a local disturbance. The increase of Combretocarpus rotundatus points to changes in drainage conditions rather than catastrophic events as being the cause. The increase in Calophyllum pollen to the top parallels the change of relative basal area dominance along the catena. The low variation of Sapotacease pollen also agrees reasonably well with the surfaced trend along the catena SP. 30 (4.8%) to SP. 28 (6.5%), SP. 31 (5.1%), SP. 29 (11.4%), and SP. 32 (6.2%). Combretocarpus is absent from the early parts of the catena. It occurs first in SP. 29 (60 m W. of SP. 31) and increases with raising bog surface to 7.3% relative dominance in SP. 32. The Shorea albida type pollen closely repeats the trend of relative dominance of Shorea albida along the surface catena SP. 30 (27.4%) — SP. 28 (42.5%) — SP. 31 (82.2%) — SP. 29 (36.4%) — SP. 32 (14.9%). Just beyond SP. 32, S. albida gains strong dominance and forms an almost pure top-canopy on the raised peat.

SP. 55 on the Merurong plateau is close to a stream in a depression with shallow peat (25 cm). The change of pollen content resembles surface trends in that Gymnostoma declines and Combretocarpus increases in the course of peat development. The sample of blanket bog on the summit slope of Bt. Skalap (SP. 54) shows no trends related to surface features. The observable changes may either reflect chance alternation of species if successional changes ended with the establishment of the blanket bog, or may reflect successional trends which are not reflected in the surface catena.

The pollen content of the sample from SP. 57 reflects the vegetational changes along the catena P. 51 (SHP soil), 57-3 (PB perimeter), 57-2 (PB slope of dome) to 57-1 (PB centre of bog). *Calophyllum* increases in the course of peat development from SP. 51 (0.4%), SP. 57-3 (10.5%) to SP. 57-1 (28.7). *Gymnostoma* pollen is most common at the base and decreases gradually to the top of the peat. *Gymnostoma nobile* is the most common species by number of trees in the top canopy in SP. 57-3 (perimeter of PB), is represented by moderately frequent saplings and poles in the understorey of SP. 57-2 (flank of PB) and is a rare small pole in the open centre of the peat bog (SP. 57-1). *Shorea* type pollen is absent in the profile. *S. albida* is the largest and most dominant (about 1/3 of G) species in the topstorey of SP. 57-3 and occurs as moderately common emergent tree in SP 57-2 and 57-1. Pole-size regeneration is very rare at the perimeter, moderately common on the flank and moderately rare in the centre of the peat bog. The absence of the pollen from the profile suggests that *S. albida* may be a recent arrival on the site. The *Dacrydium* pollen is common at the base, rare in the mid-portion and more common again at the top. Similarly. *Dacrydium spp*. decrease from SP. 51 (SHP) to 57-3 (bog margin), and increase again toward the open forest of the bog centre (SP. 57-1). The decline in *Melanorrhoea* pollen agrees exactly to the variation of dominance of *M. beccarii* along the catena from SP. 51 to SP. 57-1. The dominance of Sapotaceae in SP. 51 and 57 is almost equal, but there is a noticeable decline within SP. 57 from the margin to the centre of the bog. Also, Sapotaceae are much more common on the slopes above SP. 51 (SP. 52 and 56). The changes in the pollen profile therefore conform the vegetational changes in the course of successional development from HP to PB soil.

The strong increase of *Eugeissona insignis* in the profile in SP. 57 is difficult to interpret. The increase is neither repeated in the profiles SP. 55 and 54, nor does it correlate with changes in the frequencies of fern pollen. This excludes the possibility of a general change of conditions on the plateau favouring *Eugeissona, Vaccinium* and ferns which all prefer open sites. The most likely reason is probably the local development of a river course. *Eugeissona* is very common along river courses on the plateau. About 20 m NE. of SP. 57-3 and 80 m S. of SP. 57-1 flow small streams lined with *Eugeissona insignis.*

The decrease in *Vaccinium* pollen and fern spores is possibly related to increasing density of vegetation. *Vaccinium sp. nov.*, S 8725, is common in the open centre of the peat bog but rare elsewhere. The decline of *Vaccinium* pollen in the profile therefore cannot reflect successional trends in the course of peat formation but must be due to other conditions.

In concluding, the pollen frequencies show a degree of agreement to species dominances along corresponding kerangas peat bog catenas which seems to justify the conclusion that the development of these peat bogs has originally initiated on kerangas sites. We can further conclude that the vegetation at the time when peat formation started was similar to the vegetation which at present occupies the HP and GWP soils surrounding the peat bogs. We also can conclude that the surface peat samples are a fairly good sample of the present vegetation on the bog and seem to be very little contaminated in spite of the commoness of wind-pollination in kerangas species (*Gymnostoma, Dacrydium, Agathis*). Finally we can conclude that the kerangas forests in Dalam, on the Melinau terraces and on the Merurong plateau are primary. There is no reason to assume that the kerangas forests in other areas, which are very similar to the studied stands, are not primary. In fact, there is some evidence that the kerangas vegetation may even be relatively ancient. According to MULLER (1972) spores of *Lycopodium cernuum* and *Dacrydium* and *Casuarina* pollen types show a marked increase in frequency in the lower part of the Miocene. "It is of course tempting to suppose that this reflects the first extensive development to the typical, highly adapted kerangas vegetation" (l.c., p. 11).

The pollen profiles corroborate the evidence from the surface catenas that the characteristic kerangas species have occupied the poor sand or clay soils from the start of forest vegetation development. Kerangas forests are neither secondary successions to man-made disturbances, nor are they products of prolonged site deterioration caused by the effect of the vegetation on the soil. Kerangas species may also occupy available better sites outside their natural range if competing species are absent. An example is the aberrant kerapah in Kayangeran F.R., Lawas. They also may invade such sites after complete destruction of competing vegetation. An example is SP. 17 in Bako N.P. and the kerangas on LS soil in Berakas F.R. in Brunei. It may happen that subsequent soil development is irreversible. Soil degradation may then prevent re-establishment of the original vegetation type. As a result, kerangas species and kerangas forest communities may maintain themselves permanently on the aberrant site, even if the contemporary size class distribution of top-storey species seems to indicate rapid changes in species composition.

232. Natural Regeneration in Kerangas Forests

Natural kerangas forests are edaphic climax forests which are in a state of apparent dynamic equilibrium of mortality and regeneration. Change of environmental factors may initiate or maintain a successional development. The examples of peat bog formation under conditions of impeded drainage and of replacement of MDF by a secondary kerangas have been described in previous sections. WOOD (1965) in a report on the Dalam area concludes on the evidence of the strongly negative (sensu DAWKINS, 1959a) stand curves and the low seedling frequencies of *G. nobile, D. pectinatum* and *S. albida* that these species do not regenerate and that invasion by the Dipterocarp species from the southern part of the block is likely.

The pollen profile from a 1.2 m deep peat bog in the centre of the Dalam terrace has been described in the previous section. The results offer some interesting information on the status of the three species discussed by WOOD (1965). In the profile, *G. nobile* is increasing, *D. pectinatum* stagnates for some time, but decreases slightly in the top-layer. This may possibly be the result of an inability to compete successfully with *G. nobile* during late stages of peat accumulation and deteriorating drainage. *S. albida* lingers on at low frequency and does not change appreciably through the profile. In contrast, the suspected invaders decline steadily after an initial rise during the early phase of site development, which according to WILFORD (1959) happened about 6,000 years ago. We can conclude that the present stand curves alone are poor indicators of the regenerative activity of the tree species. This conclusion is supported by results of the other pollen samples which show that species have maintained or increased dominance during many thousands of years through successional stages which are represented in local catenas. In the present stands, the species have in most cases strongly negative stand curves and seem not to regenerate. The continued existence of such "senile" age structures of species is possible if no other species is decidedly more successful on the site to regenerate.

The most effective factors inhibiting regeneration in natural forests are low illumination, water deficiency and allelopathic effects. Light conditions are rarely the primary limiting factor for the regeneration of the dominant species in kerangas. Stand illumination is relatively better than in MDF, especially about noon. Accordingly, top-canopy epiphytes are often common in the lowest strata of kerangas forest. The presence of certain epiphytic ferns and orchids on the lower parts of stems or on root mounds is indicative for certain local kerangas forest types. An example is the common occurrence of *Coelogyne pandurata* Lindl. at man-height on the stems in open pole forest in Pueh F.R. (BRUNIG, 1963). A similar high density of epiphytes in the lower stand strata of Wallaba forest is reported by RICHARDS (1952, p. 121).

Water supply is more likely a critical factor. We have seen that drought conditions occur quite frequently while feeding roots are concentrated in the top-soil. The surface layer of litter and of oligotrophic moder and mor aggravates the adversity of the situation for the seedling. WOOD (1965) in his report on the Dalam area considers "that the forest floor conditions become the limiting factor to regeneration, the excessive accumulation of organic matter from the slowly decomposing Ru (*Gymnostoma nobile*) phyllodes and Sempilor (*Dacrydium pectinatum*) needles preventing seedling rooting from getting sufficient moisture or any nourishment from the mineral fraction of the soil". Particularly for strongly light-demanding top-storey species, the forest floor environ may locally be deficient in light, and morphological adaptation to this condition is of relatively low efficiency. But it is likely to be more significant that the forest floor, especially in the less dense stands, is an extremely exacting environment with respect to moisture availability, transpiration and temperature control. The situation becomes even worse in the intermediate storeys of the stand where radiation increases, wind-speeds are low and competition of adapted intermediate-storey species is severe. The severity of micro-climate in this zone is most likely contributing to the common gap in the stand curve of emergent tree species even if seedlings are abundant. Species and individuals will have a competitive advantage which are capable of passing through this zone quickly by rapid height growth on the expense of lateral growth. The speed and vigour of root penetration through the surface litter and mor is not the only limiting factor for the establishment of regeneration in such areas as the Dalam terrace. *Agathis borneensis* develops a strong and vigorous tap-root. The species is common along the free and well-drained parts of the rim of the terrace, but trees of any size, including young seedlings, are completely lacking in the interior, even where light and drainage conditions appear favourable.

The possible role of the leaf tannins and sclerophyllic leaf morphology on litter decomposition has been discussed earlier. High levels of terpenes, aromatic oils, phenols or tannins in the leaves not only deter animal consumers, but may give a species a competitive advantage over other species, which at some stage of their development are sensitive to high concentrations of tannins in the litter leachates. Conversely, high concentration of allelopathic substances can have autotoxic effects. On first sight, this may seem a disadvantage. Considering limitations on densities on periodically dry sites potential autotoxidity may not be a disadvantage because it may help to control population size in face of a periodically severely limiting environmental factor. The high levels of tannins in the twigs of *Gymnostoma nobile* and *Dacrydium pectinatum* could play a role in the regenerative behaviour of the species on such sites as the Dalam terrace. Increased leaf tannin content on infertile sites (sect. 136) would give an additional competitive advantage to species which are adapted to the exacting site conditions.

In fifty-one sample plots, seedling and sapling densities were recorded in 1 m^2 random samples. At the beginning of the survey the social status of each enumerated tree was recorded in five classes. Preliminary evaluation suggested so large a variation and complexity, that the information gain was out of proportion to the effort spent. The recording of social status was subsequently abandoned. The variation of seedling frequencies between and within plots was very large and bore no apparent relation to the stand curves of the larger trees in the stand. Seedling frequencies changed drastically with time in spots which were observed over a number of years in Bako N.P. The recording of regeneration was continued to the end of the survey.

but no statistical evaluation of the records was attempted. Tree seedling numbers per m^2 varied between 0 and above 100, within plot means between 1.5 and 55. The corresponding figures for saplings to 1.5 m height are 0 to 20, and 0.3 to 5, and for saplings to 5 m height 0 to 9, and 0.2 to 3. Palms and pandans are excluded from the figures. The figures are for all species, including understorey as well as top-canopy species. The proportion of top-storey species is very variable, and there are considerable differences between stands, sites and species.

In the state of "dynamic equilibrium" seedling and small sapling regeneration of dominant top-storey species fluctuates strongly. The population may be abundant or scarce at any time. Examples are *Eperua falcata* in the Wallaba forests described by DAVIS and RICHARDS (1933-1934) and *Agathis borneensis* in SP. 26 (sandy DHP, Badas), *Shorea albida* in SP. 6 (clay GWP, Pueh F.R.). In both SPs, the dominant emergent species has a distinctly positive stand curve down to seedling size. At the time of survey seedlings and saplings were frequent (above one seedling per square metre in grouped pattern). In other stands on similar soils and sites regeneration of the same species at the time of survey was scarce with few patches of greater density (SP. 22, 25, 43, Nyabau sampling area). In these stands, *Agathis borneensis* has a strongly two-peaked stand curve with a gap commonly between about 10 and 30 cm d. Seedlings occur in groups and patches which seem superimposed on a matrix of widely scattered single individuals. The distribution appears strongly affected by micro-relief, soil variation and difference in stand condition. A similar pattern with locally profuse regeneration in more open spots and a wide scatter of individuals is shown by *Dryobalanops rappa* (SP. 1, 3, 7). The species has a strongly two-peaked stand curve with a gap between about 20 and 50 cm d in all enumerated stands. Occasionally three-peaked curves occur in areas where spots with profuse regeneration are abundant, probably as a result of repeated local disturbances or perhaps a change in social status of the species in the course of succession.

Similar patterns of stand curve and consequently possibly similar pattern of regeneration and growth can be observed in species or species groups which dominate the upper part of the intermediate canopy below the emergents. For example, *Cotylelobium burckii* and *Gymnostoma nobile* have a two-peaked stand curve (peaks at 1-2 cm d and at 30-40 cm d) below emergent *Shorea albida* in SP. 28. A similar curve is produced by *Dryobalanops rappa* as intermediate below *Shorea albida* in SP. 27 on GHP. The dominant *S. albida* itself also shows a markedly bi-modal distribution in this plot. All four species had only very little seedling regeneration which consisted mostly of scattered individuals at the time of enumeration in late 1958 after an extremely dry period earlier in the year. Species which are intermediates on better sites, such as *Gymnostoma nobile, Dacrydium spp., Ganua curtisii, Palaquium leiocarpum* and several Myrtaceae, may dominate the smooth and uniform top-canopy of stands on very unfavourable sites where such tall emergent species as *Shorea albida* or *Agathis borneensis* cannot thrive. The species do not, however, produce the two-peaked stand curve which is so characteristic for the emergent species on better sites.

In concluding, regeneration of the top-canopy species in kerangas forests seems to follow a similar pattern of small and large scale variation in space and time as in MDF. Natural regeneration on podzols is therefore feasible with the same restrictions which operate in MDF, but may be somewhat more hazardous as far as the existing and expected density of seedlings of desired species is concerned.

Successful natural regeneration of forests on podzol soils has been reported for Wallaba. Ecologically, the regeneration from seedlings of *Eperua falcata, E. grandiflora* and *E. jenmani* is not a great problem. RICHARDS reports a seedling density in his representative plots of 1.8

per m², which is ample, and that the species are light demanding and react quickly to release. Difficulties in regenerating are mentioned by VIEIRA (1967) as a result of felling damage and fire. Similarly, the natural regeneration of such gregarious species as *Dryobalanops rappa, D. fusca, Agathis borneensis, Dipterocarpus borneensis* and many of the intermediate species represents no great ecological problem on optimum sites and requires relatively small stand manipulation. Difficulties arise on less favourable sites and in late successional stages, where regeneration may be scarce at any time except for short periods immediately after heavy seed production.

233. Silvicultural Possibilities for Regenerating Kerangas Forests

In Menchali F.R. on the Malayan east coat, regeneration in kerangas forest stands dominated by *Shorea materialis, Hopea nutans* and *H. mengarawan* respectively, was abundant in 1906, scarce in 1931 and abundant again in parts of the reserve in 1952. The 1906 regeneration may have resulted from felling the original timber crop. Seed-fall occurs every few years, but seedlings stagnate unless the canopy is drastically opened. Growth response by the seedlings is in direct relation to the amount of felling and consequently to top-canopy opening. Girdling of the understorey in unworked forests does not stimulate growth of seedlings or new regeneration, and was a waste of time and money in Menchali F.R. (BEVERIDGE, 1953). Removal of part or of the whole of the understorey has also proved largely ineffective in MDF in Malaya and in the Philippines. It seems to be equally ineffective in kerangas forests. Only drastic reduction of the density in the top-canopy seems to improve conditions of water and light supply sufficiently to effectively stimulate growth of existing regeneration.

Little quantitative information exists in Sarawak on the responses of kerangas species to changes in the light, water supply and competition conditions through silvicultural measures. Intermediate *Agathis borneensis* trees have been observed to respond well by increased diameter growth to removal of the emergents on Bukit Urang, Bintulu (LAW HONG CHIAW, verbal comm.). Data on 19 *A. borneensis* trees of 20 to 80 cm d were supplied by J. R. PALMER (letter dd. 24.9.1970) from research plot 21, Nyabau Block, Similajau F.R. The trees had a mean annual diameter b.h. increment of 0.40 cm during the period 1951 to 1956. Variation of means between trees and of single observation between years is considerable. Increments are consistently larger in 1955 and 1956 and very low in 1951 and 1952. Annual rainfall has been 14% below average in 1951,just above average in 1952, 17% below average in 1953, and above average from 1954 to 1956. It is possible but cannot be proved that a correlation between growth and rainfall exists in this case. All trees retained their dominance class (3 or 4) through the observation period. Only one tree was in the lowest class. This tree also had the lowest mean annual diameter increment of 0.13 cm.

Seedlings may react unfavourably to rapid and drastic opening of the canopy in kerangas if the operation is followed by a bright and dry period. Not only are the shade leaves of evergreens particularly sensitive to change, but also the roots: shoot ratio in shaded plants is normally smaller than in open-grown plants. The consequently greater susceptibility to drought is further increased if the seedling roots are concentrated in the A_0 of HP and GWP soils.

According to my own observation in 1959/60, height growth of seedlings of *Agathis borneensis* responded well to increased light in the Nyabau sampling area around research plot 21, but the response was much less than in associated *Gymnostoma nobile, Tristania obovata* and in some Sapotaceae. This capacity of intermediates on better sites to take the lead on canopy-opening is a disturbing feature in kerangas forests because most of these intermediates do not grow to large diameters and many have rather heavy or otherwise less desirable timber

The species concerned are chiefly *G. nobile, Whiteodendron moultonianum, Tristania spp.*, resp. *T. obovata, Lithocarpus sp.* S 12027, *Ploiarium alternifolium, Ganua curtisii, Palaquium leiocarpum* and other species, *Eugenia spp.* and *Melanorrhoea spp.* Some, such as *G. nobile*, are also ecologically undesirable on forest soils because of their tendency to accumulate raw-humus. On the other hand, *G. nobile* seems a good codominant associate because of its light crown, probably low water requirements and possibly small draw on the soil nutrient store, especially in nitrogen. The high tannin content of the phyllodes makes the species suspect of being possibly allelopathically active and a potentially aggressive component in a mixture.

In Sarawak, success in the few cases of post-exploitation stand manipulation in kerangas to favour desirable light-weight conifers and light to medium-weight broad-leaved species has been poor. Many of the common but undesirable top-storey and intermediate storey species are more aggressive, more frequently seeding and more efficiently dispersing and germinating than the desired species. Examples have been mentioned above. Their competition with the final crop trees is often severe and requires expensive silvicultural treatment. The decision on the feasibility of natural regeneration in kerangas forests with good stocking of *Agathis spp., Dryobalanops spp., Shorea spp., Dacrydium pectinatum* or other desirables will finally depend on the relation between the cost of removing competition and the expected revenue from the stand. This relation is likely to be unfavourable on all kerangas soils except moist MHP, DHP and transitional RYP soils. On the latter soils, natural regeneration is feasible provided the stocking of the desirables is adequate. Especially favourable are stands with a high density of *Agathis spp.* and at the same time low density of aggressive species such as *Gymnostoma nobile* and *Tristania spp.* Also favourable are heavy stands of *Shorea albida* and/or *Dryobalanops rappa* on GHP and of *Dryobalanops fusca* on MHP. Less productive sites or stands of low stocking density of desirables will not justify the expenses of natural regeneration for the production of saw-and veneer-timber. Locally, the growing of special products of small dimension in short rotations may be feasible on poorer types of podzols and podzolic soils, provided the desired species are dominant and aggressive and do not require expensive silviculture for establishment and tending.

The silvicultural possibilities for growing a crop of medium light-wooded species on kerangas by natural regeneration appear therefore restricted to stands on the better soils and sites in which the desired species are gregarious. For these stands the following treatment is tentatively suggested. Poison-girdling of undesired species in the A-layer several years ahead of exploitation, followed by one fairly drastic poison-girdling down to 10 cm d after harvesting to favour regeneration of the desired species and to reduce competition for water. Stands without a high stocking of a single or a group of desirable species can only be managed economically if the production goal is pulpwood or boardwood. The method would then be complete harvest of the growing stock and natural regeneration to an unspecified mixture without silvicultural treatment.

If natural regeneration for timber production is unsatisfactory, because the desirables fail to regenerate adequately, the only alternative remains planting. The risk of drought excludes assisted natural regeneration on kerangas sites.

Little is yet known about risks to natural regeneration on kerangas sites. Fire hazard is certainly high. After several weeks of drought, ground fires have completely destroyed naturally regenerated sapling to small timber stands of *Shorea albida* and *Dryobalanops rappa* in Sarawak and Brunei.

In Wallaba forest in Surinam about 5,500 seedlings were counted as survivors after exploitation. Of these more than 95% were subsequently destroyed by fires which spread from charcoal kilns. Growth of survivors was generally slow. Annual height growth averaged 30 cm for seedlings and fell off strongly in saplings. Annual diameter growth was between 2 and 3 mm until a d.b.h. of 30 cm was reached, after which it declined first slowly, then more rapidly. The rotations required for growing saw-timber at this rate and the low volume production even in young stands would make natural regeneration of Wallaba uneconomic even if the considerable fire hazard on the quickly drying sites could be substantially reduced without extra costs. This conclusion also applies to sites of comparable productivity in kerangas.

Large scale wind-break and wind-throw has occurred in dense pole stands of naturally regenerated *Dacrydium pectinatum* on submerged podzols and humus podzols near Lawas. Wind damage will be a strong hazard to all dense and uniform stands in an equatorial climate where heavy squalls are frequent. The damage is not restricted to visible break and throw, but strong swaying of the slender stems in uniform stand is also likely to affect timber quality. Growing the crop at wide spacing is one possible remedy, but the control of density would be prohibitively expensive in most naturally regenerated kerangas stands.

It has been shown in sect. 224.2 that stand diversity in most types of kerangas and kerapah is near the maximum possible for the number of available species. Any silvicultural measure aiming at natural regeneration and improvement of stands is therefore likely to reduce diversity and increase the tendency to dominance of single species or ecological groups of species. In this respect, kerangas and kerapah are rather similar to MDF. The ecologic, as well as the economic consequences depend on the species which are favoured by the silvicultural measures and may range from extremely undesirable, if, for example, strongly-mor-forming and heavy-wooded species are favoured, to very desirable, if species increase in dominance which produce a medium-light commercial timber and a palatable litter which is low in tannins and decomposes rapidly.

However, in concluding, it appears that the predominating problem of natural regeneration as of silviculture generally in kerangas forests is not ecological. It is the question of economic feasibility which will finally decide whether natural regeneration is possible or not.

24. STRATIFYING KERANGAS FORESTS

241. Species Distribution

Some of the more common species in kerangas forests show peaks of dominance along the X-, Y- or Z-axis of the ordination (sect. 243). The classification described in sect. 242 is partly based on this fact. Other species seem to be more uniformly distributed. Some of the rarer species are noticeably more common on certain sites or in certain associations. Others do not exhibit preferences or they are so rare that this cannot be recognized. Fig. 13c shows the dominance distribution of a sample of seventeen species along the X-axis. Seven of these are among the leading species with the highest Importance Value Index. They are *Melanorrhoea beccarii* (IVI=83.9), *M. inappendiculata* (73.1), *Gymnostoma nobile* (60.5), *Cotylelobium burckii* (57.5), *Dipterocarpus borneensis* (50.1), *Shorea albida* (48.2) and *Litsea palustris* (51.0) (BRUNIG, 1968a). The last species is an example of fairly even if discontinuous distribution in kerangas and kerapah along the X-axis. *M. inappendiculata* shows a weak peak on the well-drained sites in the centre. *M. beccarii* is more common on sites with peat formation and at higher altitude. *G. nobile* behaves similarly, but is noticeably absent from the centre plots with either well-drained but relatively fertile soils on sites in the transition zone to MDF (SP. 1, 16) or on clayey PG or GWP (SP. 37) soils, or on wet GHP when peat has not yet formed (SP. 46, 27). WOOD (1965) reports that the species is a prime indicator for kerangas in Dalam F.R. but that it was not found on wet kerangas with clay. He suspects that this is due to drainage and competition. The species is locally conspicuously rare or absent, probably for historic reasons of dispersal, even if suitable sites are available. An example are the Ingei-Melinau terraces (SP. 20, 21, 28-32) except that the species is more common in SP. 28 on MHP of the margin of the higher terrace level. On summits of limestones, *G. nobile* is locally the most prominent dominant on mor soils (ANDERSON, 1965), but for example is absent from this habitat on Bukit Serapah.

C. burckii is concentrated on lowland sites and has its greatest dominance on sites near the rims of terraces or sandstone plateaux where the soil becomes periodically dry. The rarer *C. malayanum* appears to prefer better water-supplied soils, but requires some exposure or stand instability to be able to compete successfully. The species has a marked peak at higher altitudes and is common on moist, loamy soils near ridge crests. *Dipterocarpus borneensis* is restricted to lowland sites and has its greatest dominance on relatively fertile, usually well-drained but moist soils. The distribution of *Shorea albida* is not unlike *G. nobile*. The species is rare or absent both on excessively drained sites and from relatively fertile sites. WOOD (1965) mentions that the species is widely spread in Dalam F.R., but does not extend into dry kerangas with clay, probably due to dryness and hardness of the soil. *S. albida* is less montane than *G. nobile*. At high altitude it has only been found once on a peat bog on the Merurong plateau (SP. 51). It is strangely absent from the peat bog on the Bumbong rumah (SP. 41), and also from the lowland peatswamp at the base of the mountain (ANDERSON, 1961).

Agathis borneensis (32.3) is concentrated on the excessively to well-drained but deep terrace soils (SP. 22, 43, 26, 44), and less common on moderately drained medium deep sandy terrace soils (SP. 5, 20, 47), and on dip-slope GWP soils (SP. 39, 50). *A. beccarii* (4.0) is restricted to sites with relatively well-drained MHP and PG soils above about 500 m alt. *Combretocarpus rotundatus* (15.3) is absent from sites on which any of the two *Agathis* species occurs. The range of the species is restricted to GHP and PB soils. In Bako N.P. it is rare in open vegetation of types 71 and 72 but more common in the secondary fire padang type 8 (BRUNIG, 1965). On the Merurong plateau and Bungo range the species is found in mossy forest on ridge tops, again preferring more open habitats. *Dacrydium pectinatum* (22.6) is in the lowlands restricted to very shallow soils which periodically become severely dry (SP. 9, 15). WOOD (1965) reports a "definite thinning out of the size classes in the wetter soils, particularly in the wet kerangas clay site" in Dalam F.R. It is, like *Gymnostoma nobile,* favoured by natural (SP. 1, 6, 57-1) or man-caused (SP. 17) stand disturbance. Locally, the species may become dominant on SHP or MHP on lowland terraces, if a perched water table causes peat accumulation (Dalam F.R., Lawas F.R.). The main range of *D. pectinatum/D. elatum* is submontane. It occupies well-drained HP (SP. 41) as well as poorly drained PG (SP. 33) and PB soils (SP. 40, 57), preferably on plateaux.

Ploiarium alternifolium (32.8) shows a similar distribution peak at high altitude. At low altitude it is restricted to peaty, wet HP or to very shallow HP soils (SP. 9, 39). On more favourable sites the species occurs usually in stands in which disturbance from wind-break is common (SP. 3, 4, 6, 50). In SP. 41, favourable conditions of disturbance, shallow HP and unbalanced moisture regime jointly give the species such advantages over competitors that it attains 22.4% relative dominance. In the Sabal sampling area, *P. alternifolium* occurs in twenty-one squares out of 500 (4.2%). Sixteen of these squares form one cluster. Seven squares are on peaty GWP and PB soil (unit IV, tab. 13). Thirteen squares are on moist MHP soils (unit III, tab. 13). Outside the area, the species is common in some of the wetter parts of secondary kerangas on SHP and GWP soils around Kuching (BROWNE, 1955, pp. 334-335). It is locally common and characteristic in the padang types 71, 75 and 8 in Bako N.P. (BRUNIG, 1965) on wet, water-logged soils and rocks with deep, water-carrying cracks.

Dipterocarpus pachyphyllus and *D. lowii* are examples of rather exacting species with very localized distribution. The former occurs on MHP transition to RYP in the coastal part of Similajau F.R., but is restricted to RYP clay-loam in the Sabal sampling area. *D. lowii* occurs locally on clayey GWP on encased terraces and on sandy RYP on sandstone dip-slopes.

Dryobalanops fusca (7.2) occurs locally in the Sematan-Lundu area of West-Sarawak. Its range is restricted to well-drained MHP soils on low coastal terraces. Some of the sites appear suitable for *Agathis borneensis*, but the species does not occur together with *D. fusca*. *D. rappa* (31.0) has a much wider geographic and ecologic range. It is locally common and dominant on wet GHP and early PB stages, extending into DHP and MHP on adjacent higher terraces. It is gregarious on SHP on steep sandstone dip-slopes (Bukit Batu Patam and Bukit Metaum). The third kapor in kerangas is *D. beccarii* which occurs only in two sample plots (SP. 16, 38) on a mosaic of SHP and RYP soils with adequate supply of water and possibly nutrients from slope water. In the Sabal sampling area the species also occurs on a similar mixture of MHP and RYP soils but is more severely restricted to RYP loams and clays (tab. 13). *Shorea elliptica* in the same area is closely associated with *D. beccarii*. The other distributions in tab. 13 give further examples of species with very weakly marked ecological optimum (*Tristania obovata, Shorea ovata, Dipterocarpus borneensis*). Some species show greater dominance on the moist to wet sites of unit IV (*Ganua curtisii, Calophyllum sclerophyllum, Melanorrhoea beccarii*). One group of Dipterocarps avoids all the poorer sites on soil units IV and V. Some species do best on the well-drained MHP/GWP and SHD soils of units II, III and V, but are poorly represented in IV (*Agathis borneensis, Cotylelobium melanoxylon, Shorea ovata, S. venulosa, Vatica cuspidata, Palaquium multiflorum*). Some species do well both on moist humic GWP/PB soils and on dry SHP soils (*Shorea rugosa*), and some are most common in the driest soil group V (*Gymnostoma nobile, Cotylelobium burckii, Shorea ovata, Tristania obovata* and *Palaquium multiflorum*).

These examples may suffice to demonstrate that tree species in kerangas forests are of widely different ecological requirements and behaviour. The distinction of ecological groups of species with different ecological optima among top-canopy species is therefore possible and can be used for vegetation classification. A certain difficulty arises from the fact that an indicator tree, palm or herb species may be common in one part of the country and be absent from another. The use of the tree species as indicators is further complicated by the fact that the ecological behaviour and the relative competitiveness of a species may not be the same throughout its range. The value of understorey and ground vegetation species for classifying vegetation in a relatively small area has been demonstrated in Bako N.P. (BRUNIG, 1965).

242. Forest Type Classification

Pre-war inventories did not distinguish forest types except the very broad types MDF, PSF and kerangas. The development of more sophisticated methods of inventory during the fifties stimulated interest in forest type classification. Eighteen forest types were distinguished in a report on the survey of 26,000 ha forested area in Sempadi F.R. in 1955-56. The types were defined by commercial timber stocking, range of tree sizes, species composition, soil and general site conditions. Five kerangas forest types were distinguished by species composition. Two types were dominated by *Agathis borneensis* and *Gymnostoma nobile* respectively. Three types had no distinctly dominant species and were separated by the volume of growing stock and proportion of meranti timber. A 1.2% two-line per block randomized inventory in Pueh F.R. was stratified by means of basal area diagrams which showed basal area dominance per size class and species or species group. However the variability of species distribution and dominance was so great, that it was impossible to subdivide PSF, MDF and kerangas on the basis of the diagrams into types which would bear clear correlation to differences in site conditions (BRUNIG, 1961.) As an alternative, the area was stratified into topographic units which were further subdivided into forest types by ground vegetation, stand composition and soil type. Altogether five types were distinguished in kerangas, two in kerapah and three in MDF (BRUNIG, 1963).

In Bako N.P., twenty-five vegetation types were defined by topography, stand physiognomy and characteristic species (BRUNIG, 1957a). The classification was subsequently elaborated for the kerangas and padang vegetation. Six kerangas types, five natural padang types and one fire padang type were identified and defined by landform, soil group and type, vegetation physiognomy and composition. Listing of species indicated common and characteristic species and typical species combinations in the various stand layers of the main types. Subtypes and variants were distinguished mainly by ground flora species and related to differences in soil type and water supply. Such simple classification was practical because the area of the park is relatively small, and geologically and floristically relatively homogeneous. Classification from frequency lists of species is feasible under such conditions.

In describing kerangas on the east coast of Malaya, BEVERIDGE (1953) distinguished three subtypes by dominant species. His Shorea materialis-subtype is similar to my SP. 45 and 46 on a recent beach terrace. His Hopea nutans — H. mengarawan-subtype occurs on the more permanently dry sandy dunes and is related to my SP. 7, except for the presence of *Dryobalanops fusca* in the latter. Seasonally flooded kerangas sites carry a Dipterocarpus — Calophyllum-subtype. The classification is based on a combination of topographical features and species composition. The area is small, the stands are few and the classification consequently efficient.

A comprehensive classification of forest types is included in the "Forest Survey and Inventory Code, 1961" and has been later published (BRUNIG, 1969c). The following main types are recognized at the association-group level: beach forest, salt water-swamp forest, peatswamp forest, mixed Dipterocarp forest, kerangas-kerapah forest, riverain forest, montane and other specialized forest types. At second level, units are distinguished by topographic features. The topographical criterion compounds the effect of differences in the geological substrate by separating areas of different geology and consequently different physiographic aspect in aerial photographs. Stratification by geological substrate at this level should be done if suitable geological maps are available. ASHTON (1973, unpubl. msc.) emphasises the correlation between species distribution and geological formation in Sarawak. At third level, separation is by canopy morphology and albedo in air-photo interpretation or by stand structure in field classification. At the lowest general level 4, subdivision is by species presence, species dominance and stand curves. Timber quality and commercial stocking are only loosely associated with the units at level 4 and prediction with adequate precision for management planning requires further stratification into local categories defined by relative dominance of species, defectiveness of timber, diseases, stand damage and, resulting from these, productivity in terms of commercial growing stock. Indicators among the tree or ground flora species may be locally useful in classifying at this fifth level of the scheme. At all levels of the classification, it is important to recognize that both vegetational and environmental factors are continuously distributed in space and time. The delimination of vegetational or site units in the classification is consequently more or less arbitrary, which is indicated by the frequent mentioning of transitional status in the classification. Final decision on delimiting types will always depend on local conditions and on the objectives of classifying. In the following, the main features of the classification at levels 2 to 4 are described in the form of a key for the kerangas and kerapah forests (main type 5). The values given for crown diameters d_k and aerodynamic roughness z_o are tentative and further research is needed before delineation by z_o-values could be applied in forest inventories. The units described at classification level 4 (designated by first decimal) are not exhaustive but only examples of the more common communities. Further subdivision at level 5 by quantity and quality of growing stock and by soil type will be necessary in most cases for forest management and land-use planning.

CLASSIFICATION OF THE ASSOCIATION GROUP 5

Classification Level 2: *Topography within stand*

Flat to almost flat 51
Undulating to moderately hilly 52
Hilly to bold 53

Classification Level 3: *Stand structure*

51 On aerial photographs canopy uniform, dense, tone dull medium grey, little variation in tone, crown diameter in top-canopy d_k 2-8, av. 4 m, aerodynamic roughness z_o 100-200 cm. In field data, uni-modal stand curve and largest d between 40 and 100 cm 511
Not so 512

512 Intermediate canopy uniform, dense, tone dull medium grey, overtopped by tall emergents, usually single, rarely in groups, very rarely merging into small closed stands, lighter toned than the intermediates. Emergent crowns compact, often cauliflower-like, d_k 10-25, av. about 18 m, z_o 400-500 cm. In field data, bi-modal stand curve, largest d above 100 cm 512
Not so 513

513 Irregular canopy structure, much variation in crown sizes and tone, grouping moderate, top-canopy d_k 5-12, av. 7 m, z_o 200-400 cm. In field data, stand curve uni-modal or weakly bi-modal, largest d 100 to 100 cm.

52 On aerial photographs canopy uniform, but more uneven and better integrated than in 51, dense, tone light grey to dull medium grey, top-canopy d_k 2-7, av. 4 m, z_o 100-250 cm. Stand curve steeply uni-modal, largest d about 40 cm 521
Not so 522

522 On aerial photographs intermediate canopy as in 521, but overtopped by emergents of various tones and shapes. Irregularly star-shaped, medium dark grey or cauliflower light grey emergent species recognizable and locally conspicuous. But on a whole, the variation of crowns is moderate and there is not a consistently lighter tone among the emergent than among the intermediates, d_k 6-12, av. 8 m, z_o 250-350 cm. Stand curve weakly to moderately bi-modal, more rarely a strongly developed second peak about 100 cm, largest d about 100, rarely 120-140 cm 522
Not so 523

523 On aerial photographs intermediate canopy medium dull grey, dense, overtopped by emergents, of lighter tone and of cauliflower type. Emergents d_k 10-20, av. 16 m, z_o, 300-500 cm, stand curve more or less strongly bi-modal, largest d about 140 cm 523
Not so 524

524 On aerial photographs well-integrated, irregular top-canopy structure, crowns vary in shape, type and tone nearly as much as in MDF, type 42, but crown diameters and heights are smaller, d_k 5-18, av. 10 m, z_o 300-450 cm, largest d about 140 cm 524

53 On aerial photographs the canopy is uniform and dense, tone light to medium, dull grey, individual crowns more difficult to identify than in any other type, small to very small, d_k 2-8, av. 3 m, z_o 100-200 cm, but topography rough. Stand curve very steeply uni-modal, rarely with a moderate second peak, d usually less than 35 cm, occasional emergents to 50 cm 531
Not so 532

532 On aerial photographs the canopy is irregular and varied in crown size and tone, light grey to dark grey, grouping moderate to strong, top-canopy d_k 5-13, av. 7 m, z_o 200-450 cm. Stand curve moderately steep uni-modal, largest d usually less than 70 cm, very rarely individual trees, larger than 80 cm d .. 532
Not so 533

533 On aerial photographs, canopy intermediate between 532 and 521, more uniform than 532 but more irregular than 521, sites distinguished by topography (long, gentle to almost flat dip-slopes), d_k 4-12, av. 6 m, z_o 200-300 cm 533

Classification Level 4: *Species composition*

511 Kerapah and transitional kerangas/kerapah forests, soil PG, GWP, HP with impeded drainage and PB. Usually single species as dominant emergent species, or groups of closely related species. Dominance usually strong but occasionally only moderate to weak:

.1 *Gymnostoma nobile* leading dominant species, dominance at least 10% of G or canopy projection.

Example: SP. 4 on lowland PB (fig. 7a).
DAL on PB and MHP (but not clayey soils) (fig. 8b).

.2 *Dacrydium spp.* leading dominant species at least 10% of G or canopy projection.
Example:
SP. 40 on PB of high-altitude terrace (fig. 7b).

.3 *Shorea albida* and/or *S. pachyphylla* moderately dominant, with *Ploiarium alternifolium, Dacrydium spp., G. nobile, Parastemon urophyllum, Litsea palustris* or *Lophopetalum rigidum* attaining local dominance.

Example: kerapah in Binio basin, top-height 20-25 m max. d 45 cm, on wet PB, grading into open sedge padang with *S. albida, Dactycladus stenostachys* and *Ploiarium alternifolium*, H_T 7 m.

512 Kerangas and kerapah, soil GHP, MHP, PB on sites with deteriorating drainage conditions on almost flat to gently sloping or undulating ground. Frequently marked single-species or group dominance. In transition zones to 511 or 513 emergents often derelict. Common dominant emergent species are:

.1 *Shorea albida* leading dominant species, emergent (locally replaced by or mixed with *S. pachyphylla*, especially on wetter spots).

Example: SP. 21, 28, 30 on MHP, interior terraces (fig. 7b).
SP. 2, 29, 31, 32 on PB, coastal to interior terraces.
SP. 57 on PB on high-altitude plateau (fig. 7c).
SP. 27 on GHP, coastal terrace (fig. 7a).
DAL on PB and MHP (but not on dry sites) (fig. 8b).

.2 *Shorea materialis* leading dominant species, emergent (locally replaced by *Dryobalanops rappa*).

Example.: SP. 45 and 46 on GHP, recent beach terrace (fig. 7a).

.3 *Combretocarpus rotundatus* leading dominant emergent.

Example: SP. 55 on PB on high-altitude plateau (fig. 7c).

513 Kerangas on almost flat to gently sloping (max. 2°) or undulating (variation of relief less than 6m) ground with MHP and medium deep sandy GWP soils. Single-species dominance less pronounced than in 511 and 512:

.1 *Dryobalanops fusca* moderately to weakly dominant species, rarely distinctly emergent.

Example: SP. 1, 3, 7 on MHP on coastal terraces (fig. 7a).

.2 *Agathis borneensis* moderately to weakly dominant species, but rarely distinctly emergent, locally mixed with or replaced by *S. albida* or *Dryobalanops rappa*.

Example: SP. 14, 20, 23, 24, 44, 47 on MHP on lowland terraces (fig. 7a and c).

.9 No distinctly leading dominant species.

Example: SP. 25 on MHP (fig. 7a).

521 Kerangas on undulating to moderately sloping ground along the rims and on the flanks of terraces and on dip-slopes of sandstone plateaux. Soils usually shallow, excessively drained SHP, PG, secondary MHP and PB over sandstone. Frequently marked dominance of single or groups of species:

.1 *Whiteodendron moultonianum* leading dominant species, dominance up to 20% of G. often in mixture with *G. nobile* and *Dacrydium spp.*, mostly in West Sarawak on Plateau sandstone dip-slopes.

Example: SP. 9 on SHP.
SP. 15 on MHP.

.2 *Dacrydium spp.* leading dominant species.

Example: SP. 17, and types 62, 63, 64 in Bako N.P. (BRUNIG, 1967).
SP. 51 on SHP/PB on bouldery undulating plateau, Merurong.
SP. 33 on PG, peneplain remnants, Sagan (fig. 7b).

.3 *Gymnostoma nobile* leading dominant species.

Example: SP. 41, Bumbong Rumah, on sandy PG clay.

.9 No distinctly dominant species.

Example: SP. 52 on SHP (fig. 7c).

522 Kerangas on undulating to moderately sloping ground, species dominance moderate to strong, soils well-drained but with large field water capacity, commonly DHP on terraces or MHP on undulating sandstone:

.1 *Agathis borneensis* leading dominant species, distinctly to moderately emergent, often in small groups, dominance above 10% and occasionally above 50% of G.

Example: SP. 11 on MHP, plateau sandstone.
SP. 22, 26, 43 on DHP, terrace flanks and rims (fig. 7a).
DAL on raised parts and on edge of terrace (fig. 8b).

.2 *Agathis beccarii* leading dominant species, moderately emergent, dominance between 10 and 50% of G.

Example: SP. 56 on MPH (fig. 7c).

523 Kerangas on undulating to moderately sloping ground, drainage moderate, soils medium deep MHP, weak tendency to peat formation:

.1 *Shorea albida* leading dominant species but only weakly to moderately emergent and at most moderately dominant.

Example: SP. 6 on PG.
SP. 48, 49 on MHP on sandstone dip-slope.

Locally, *S. albida* may be replaced by, or admixed with, emergent and dominant *Shorea pachyphylla, D. fusca* and/or *D. rappa* which also have light toned crowns of somewhat similar type as *S. albida.*

524 Sites as in 523, but soils are better drained MHP to RYP, absence of conspicuous single-dominant emergent species, transitional to MDF, number of Dipterocarp species relatively large, but dominance less than 30% G.

Example: SP. 12 on RYP of sandstone dip-slope (fig. 7a).
SP. 13 on SHP of sandstone dip-slope (fig. 7a).
SAB mixed kerangas on MHP, GWP (fig. 12a).
Terrace flanks in Siru F.R. and in the Melinau valley.

531 Kerangas in hilly country with bold topography, sites moderately steeply to very steeply sloping dip and scarp slopes, intersected bold relief or prominent ridge crests. Soils shallow PG, HP and PB. Usually distinct single-species dominance. Occasionally mixed stands:

.1 *Gymnostoma nobile* leading dominant species.

Example: forest type 65 (BRUNIG, 1965) on dissected spurs of the table land in Bako N.P.
SP. 54 on blanket bog on the summit slope of Bukit Skalap, Merurong plateau (fig. 7c).

.2 *Dacrydium spp.* leading dominant species.

Example: Dacrydium — Shorea — Vatica submontane moss forest on Batu Skalap, Merurong plateau (BRUNIG, 1959).

.3 *Dryobalanops rappa* leading dominant species.

Example: The D. rappa — Shorea spp. — Tristania — Diospyros type on SHP, southern dip-slope of the Bukit Metaum — Bukit Sangit cuesta, Merurong plateau (BRUNIG, 1959).

.4 *Tristania obovata* leading dominant species.
Example: SP. 53 on PG.

.5 *Tristania anomala* present to leading species.
Example: Ridge crest of Bungoh range, Batu Patam; kerangas and moss forests on the Merurong plateau.

.9 No distinctly dominant species.
Example: SP. 35, Sagan syncline.

532 Kerangas in hilly country on gentle to moderately steep dip-slopes. Soils shallow to medium HP, GWP and transitions to RYP. Single-species dominance weak to moderate, rarely above 15% G:

.1 *Agathis borneensis* leading, but not emergent, dominant, dominance usually around 10% of G.

Example: SP. 38 on GWP/MHP on sandstone dip-slope.
SP. 50 on GWP on sandstone dip-slope.

.2 *Dryobalanops beccarii* leading, moderately emergent dominant species, dominance rarely above 10% G.

Example: SP. 16 on MHP transition to coastal MDF.
SP. 39 on MHP/RYP, with some *Agathis borneensis.*
SAB on MHP/RYP, transition to MDF.

.3 *Lithocarpus cyclophorus* leading dominant species.
Example: SP. 42 on RYP, transition to mixed submontane oak-forest.

.4 *Shorea rugosa* leading dominant species.
Example: SP. 34 on GWP/RYP, transition to MDF.

.5 *Agathis beccarii* leading dominant species.
Example: Marigan range; Bukit Tudal.

.9 No distinctly leading dominant species.
Example: SP. 50 on medium GWP, sand over clay.

533 Kerangas on gentle to almost flat but very long dip-slopes, soils as in 532, stands show more distinct tendency to single-species dominance and are transitional between 532 and 521.

243. The Ordination of Sample Plots

The fifty-five sample plots were treated as fifty-five stands and ordered by means of the ordination technique described by BRAY and CURTIS (1957) and ASHTON (1964a, 308—314). The thirty-four species which had the highest importance value indices among the seventy leading species (BRUNIG, 1968b, tab. 12b) were used to construct two matrixes. The species represented 45.8% of the total basal area. The similarity between two stands was expressed as the ratio of the mutually shared component in terms of basal area to the combined total basal. This similarity index $c = 2w/(a + b)$ was calculated for all pairs of plots. This produced 1,512 similarity quotients ranging from 0.008 to 0.798.

The use of the basal area introduces a certain bias in favour of large trees. Differences in understorey composition may be ecologically important but will be poorly reflected in the similarity rating. Relatively shallow-rooted understorey species may be expected to respond more sensitively to differences in the moisture regime than more deep-rooted top-canopy species. For example, SP. 20, 22 and 43 are fairly close in the XY- and ZX-planes of the ordination, but SP 43 on the exposed rim of a coastal terrace is ecologically rather dissimilar from the other two plots. The fact that the position of SP 43 is between SP. 20, 22 and the plots with less adequate moisture conditions (SP. 11 and following to the right), however, shows that the general ecological relationship is still meaningfully expressed.

From the 1,512 similarity quotients, the X-, Y- and Z-axes were constructed by using several pairs of reference plots. The following description refers to the ordination which proved to yield the largest amount of information.

Soil types show a distinct trend along the X-axis (fig. 13 b1). On the left are the deep, porous and well- to excessively drained DHP on holocene and late pleistocene terraces. Towards the centre (X = 500), which represents maximum dissimilarity from both reference stands, the kerangas soils are generally shallower. GWP and RYP soils occur especially at lower Y-values. At higher Y-values kerapah soils lead into ANDERSON's peat soils which occupy the right-top corner. Towards the right, altitude increases along the X-axis in a narrow band on both sides of Y = 500 (450 to 570) and PG, SHP and PB soils prevail. The stands in this region are simple-structured and characterized by a relatively high dominance of microphyll and leptophyll species (*Gymnostoma nobile, Dacrydium spp.*) In contrast, dominant microphyll species are more common on the left (fig. 13 b2). The X-axis appears to be related primarily to water regime with a superimposed and possibly independent altitudinal relationship. The trend along the Y-axis appears to relate to nutrient supply from relatively richer and loamy soils at the bottom (recent terrace with some colluvium and podzolic brown loam) to sandy and nutrient deficient soils at the top. At the same time, a trend to increased water-logging exists along the Y-axis (the reference stand is SP. 27 on GHP) which places the lowland PB sites in the top-right quadrant away from good drainage (left), fertility (bottom) and altitude (right on X-axis). With these environmental trends go characteristic changes in the floristic composition of the stands, which permits an ecologically meaningful grouping of stands in the X/Y plane. Altogether five main groups can be distinguished.

From reference plot 22 to right, the first group is lowland kerangas in which *Agathis borneensis* is dominant as large tree on DHP to MHP on almost flat to undulating sites. The second group follows to the right and consists of forests in which *A. borneensis* is present but smaller and rarely more than frequent on SHP to MHP and GWP on undulating to moderately hilly sites. The number of Dipterocarp species increases. The following third group is the centre of the ordination and accordingly rather heterogeneous. One subgroup is characterized by a great number of Dipterocarp species and RYP soils with the exception of SP. 17 which is included but has a secondary MHP. This subgroup represents the transition to MDF. The number of Dipterocarp species but not necessarily of Dipterocarp basal area decreases in the next subgroup to the right, which contains transitional forests to Mixed PSF and kerapah. The number of Dipterocarps decreases also from the centre to the top where the fourth group includes the reference plot 27 with only three species of Dipterocarpaceae, but the highest recorded basal area of *Shorea albida*. This fourth group is the transition to Shorea albida-PSF. Group 5 occupies the right end of the ordination and consists of rather homogeneous submontane kerangas and kerapah forests, in which *Agathis beccarii, Dacrydium spp., Tristania spp., Gymnostoma nobile, Shorea albida* and *Ploiarium alternifolium* are attaining local dominance according to site conditions.

The Z-axis had initially been regarded as representing undirected residual variation. The very dense scatter in the Y-/Z-plane had obscured trends in species composition and in site conditions. Existing trends were only discovered when the rankings of diversity values along the X-axis were examined. *Agathis borneensis, A. beccarii, Dryobalanops fusca* and ecologically related species tend to be gregarious on the left of the X-axis in the Z-/X-plane. The sites are relatively uniform, almost flat quaternary terrace or almost flat to moderately hilly tertiary sandstone dip-slope locations with good to excessive drainage. Closer to the centre of the X-axis follows a less clearly defined complex of stands on mostly SHP to MHP with moderate drainage on terraces and sandstone formations. The species composition varies rather more strongly between these plots and there is lesser tendency to single-species dominance within plots. Beyond the centre to the right of the Z-axis follows a group of stands in which both *Gymnostoma nobile* and *Shorea albida* are present and tend to high dominance. Next in importance in this range are *Melanorrhoea beccarii, Calophyllum spp.* and *Palaquium spp.* The sites are mostly terraces in a rapid succession to peat bog or dip-slopes on sandstone formations with tendency to blanket bog development. Soils are MHP, PG and GP with all stages of bog formation. Edaphic and physiographic variation within and between stands is strong. The fourth group of stands at the right end of the Z-axis is rather heterogeneous and the tendency to species dominance is very weak. Floristic elements of the MDF (SP. 12, 34, 38), the inland-margin Mixed PSF (SP. 37) and of submontane oak-rich forest (SP. 42) occur and may locally achieve some degree of dominance. The sites are peneplain remnants, encased terraces, broad sandstone ridges and, in stands which are floristically transitional to MDF, moderately steep slopes. The soils are loams to clays of the RYP, GWP and PG groups. SHP are confined to dissected but not exposed sandstone slopes. The only MHP soils are on well water-supplied buttresses of terraces and on the margin of encased terraces toward MDF.

The groupings along the three axes correspond well to the previously described classification of forest types at all five levels. The XY-axis exhibits the physiographic, drainage and soil-type related criteria. The XZ-axis chiefly refers to the floristic subdivision by dominance of species.

The trends also conform to the previously described catenas of soil types and vegetation. The catena SP. 46 — 45 — 43 — 44 (sect. 134.3, ex. 1, coastal catena in Similajau F.R.) begins in the centre of the ordination on GHP and close to the positions of wet, clayey terrace sites (SP. 36) from where the PSF series commences with forest type 31 (fig. 13a). The catena proceeds with improving drainage through SP. 45 to SP. 43 (DHP on terrace edge). Then it turns back as drainage worsens towards the centre and higher levels of the terrace (SP. 44).

The Belait-Melinau catena begins in Badas with GHP on a low coastal terrace (SP. 27). Two alternative developments are possible. If the terrace is up-lifted, the GHP changes to poorly drained MHP (SP. 21) and the dominance of *Shorea albida* decreases from 57.7% (SP. 27) to 36.7% (SP. 21). The sequence continues to SP. 23 (DHP), SP. 26 (DHP), SP. 23 (MHP), SP. 24 (MHP) and finally SP. 25 (MHP with poor drainage), which is close to SP. 29 on the Melinau terraces. The Melinau series proceeds from SP. 30 on the lower terrace level (well-drained MHP) to SP. 28 on the higher terrace level with moderate drainage. At the same time the dominance of *Shorea albida* increases from 27.4% (SP. 30) to 33.0% (SP. 28). Drainage becomes poor in SP. 31, peat begins to accumulate and the dominance of *S. albida* increases to 74.6%. Drainage is poorest in the following SP. 29 and stagnant water is above the peat surface most of the time. *S. albida* dominance drops to 36.4% of G and all trees are derelict and moribund. The species declines to 14.9% in SP. 32 in spite of some improvement of drainage as a result of a rise in peat surface level. The stand in SP. 32 is a dense pole crop of species which established themselves in the transition zone between SP. 29 and SP. 32. *S. albida* is beginning to re-invade in SP. 32. A short distance beyond the plot, dense Shorea albida-forest is already established. Consequently, the catena would show a change of direction back to the region between SP. 31 and the PSF type 372, if further plots had been enumerated along the transect.

The sequences in Pueh F.R. seem less clear which is largely due to the wider scatter of the plots in the area. The two plots in peat bog (SP. 2, *Shorea albida* 12.3%, and SP. 4, *Gymnostoma nobile* 14.4%) are on the right of the centre of the X-axis in the zone of poorer drainage. SP. 6 on a GWP heavy clay is surprisingly close to the peat bog plots due to a high dominance of *Shorea albida* (13.8%), in spite of the fact that the associated leading species (*Gymnostoma nobile,* 15.2%; *Whiteodendron moultonianum,* 7.4%; *Diospyros polyalthoides,* 6.1%) are non-PSF species. The Dryobalanops fusca-dominated, well-drained plots 1 and 3 (MHP) are further to the left as would be expected. Somewhat unexpected is the low Y-value of SP. 5 (SHP on a low inland terrace). This may be due to the lack of single-species dominance and the fact that the plot is close to sungai Undan which drains from MDF on the Pueh massif. SP. 7 is ecologically closely related to SP. 46/45 in Similajau F.R. The stand is dominated by *Dryobalanops fusca* (27.2%). *D. rappa* (9.3%) and *Melanorrhoea inappendiculata* (7.5%). The unexpectedly low position on the Y-axis reflects the relatively large proportion of Dipterocarps and the fact that *D. fusca* has not been used in the ordination because of its very restricted range.

The effects of site degradation following destruction of MDF is shown by SP. 17, Bako N.P. Originally, the RYP soil had carried MDF. The original stand would have been located near and probably to the right of SP. 16. The secondary succession has been dominated by *Dacrydium pectinatum, Cotylelobium burckii* and *Whiteodendron moultonianum.* The RYP changed into a secondary MHP soil and the plot position shifted upwards along the gradient of decreasing fertility. It is now near SP. 12 on-RYP soil on a sandstone dip-slope in Sempadi F.R., and SP. 13 on SHP on the summit plateau in Selang F.R., which both carry mixed kerangas transitional to MDF.

The locations of the high-altitude plots on the Sagan ridge (SP. 33-35), Bumbong rumah (SP. 40-42) and Merurong plateau (SP. 51-57) exhibit no patterns related to catena or succession. This is possibly due to the rather irregular hilly topography and the fact, that SP. 56 is the reference plot. This plot is on moderately well-drained MHP which somewhat distorts the gradient of declining drainage from left to right (SP. 41 to 40; SP. 33 to 34; SP. 51 and 56 to 57). SP. 57 might have been a better choice, except for the aberrant presence of *S. albida.*

The short distances between plots belonging to one catena or successional series are certainly in part simply caused by floristic affinity related to geographic distance. On the other hand stand physiognomy varies significantly within catenas in a manner related to site conditions, such as drainage and exposure. This variation is much less between different catena series if corresponding stages or positions are compared and is less than the variation in floristic composition. Some of the oddities of the locations of plots can be explained in this manner. An example is the location of SP. 7 in comparison to the very similarly structured, but floristically different SP. 46.

It had been shown in sect. 223 that the total number of species per plot and the rate of species increase within plots is related to soil group and physiography. The standard deviation about the regression appeared related to site heterogeneity rather than species richness. It could therefore be expected that some relationships should also exist between a diversity index and the position of the sample plots in the ordination. Therefore the existence of a correlation between the ranking of twenty-seven plots (sect. 223.2) on the three ordination axes and the ranking according to the index values was tested by SPEARMAN's rank correlation coefficient. The results indicated no correlation between the diversity index ranking and the position rank on the X- (r_s = 0.015) and on the Y-axis (r_s = − 0.244). The signs of the coefficients conform with the trend to greater site complexity and increased water-supply from left to right on the X-axis, and to increased soil fertility and more favourable soil texture from the top downward on the Y-axis. The corresponding correlation for ranking according to total number of species are r_s = − 0.101 for the X-axis and r_s = − 0.239 for the Y-axis. Again, both coefficients are non-significant. The reversed trend on the X-axis makes sense, because site variability influences total number of species less than the stand diversity. The sites on the left side of the X-axis are relatively uniform, but the species richness is relatively high. On the right side species richness is less but the sites are more varied and complex. Both rankings according to index of diversity and to number of species are significantly ($p = 0.05$) correlated to the ranking of plot positions on the Z-axis (R = 0.437 and 0.443 resp.).

The very poor correlation between either the species richness or the index of diversity and the position of the plots on the X-axis can be explained by the nature of the sample plot distribution in the ordination. We have seen that the centre is occupied by the most heterogeneous group of plots in respect to within-plot and between-plot variation in site, soil and vegetation. Projection of this group on the X-axis creates strong variation about any trend along this axis. The Y-axis exhibits more clearly defined trend from complex vegetation on the richer soils at the bottom to the extremely uniform and species-poor plots on the infertile plots at the top. This trend is much less masqued by projection of the plots at the tails of the X-axis, and the correlation is therefore slightly better, but still non-significant. The trend in stand and site features along the Z-axis is more clearly defined in spite of the very dense scatter about this axis. It is less than along the X- and Y-axes affected by the projection and it seems that the heterogeneity in the centre of the ordination is largely due to variation along the Z-axis. Consequently, the rank correlation along the Z-axis is somewhat improved and significant at the 0.05-level. This is not surprising if it is remembered that the Z-axis primarily represents trends in floristic variation which are directly related to species richness and diversity.

In the case of McINTOSH's diversity index, there is no significant correlation between the index rank and the plot sequence in the ordination along the X-axis (r_s = 0.085 at 38 d.f.), Y-axis (r_s = − 0.258) and Z-axis (r_s = 0.116). The richness and pattern of species content in the stands appear to be little affected by the site gradients, which are apparent in the ordination. The historical factor appears to be more effective than any other, and this factor is poorly represented in the ordination. In contrast, ranking of the stands according to the previous index of diversity is significantly correlated to the ranking along the Z-axis, but not along the X-axis or Y-axis.

25. RELATIONSHIP BETWEEN KERANGAS AND OTHER FORESTS

251. Relationship to other vegetation types in Borneo

The relation of the PSF phasic communities (ANDERSON, 1961) and of the MDF types (ASHTON, 1964c) has been determined from their positions in the X/Y plane of the ordination (fig. 13a). The kerangas forests are clearly intermediate between the other two association groups. The intermediate position of kerangas is confirmed by the species lists of the three association groups (ANDERSON, 1963; ASHTON, 1964b; 1964c, tab. 13 and App. III; BRUNIG, 1966, App. II). The numbers of total and shared species are given in tab. 12. Many species of the MDF also occur in the kerangas forests, but not in the PSF. Relatively more species are shared by PSF and kerangas forests, but only few also occur in MDF. Among the latter is *Neoscortechinia kingii* (Hook. f.) Pax et Hoffm. which is ANDERSON's characteristic species of P.C.1 (ANDERSON, 1961, 68-81). I do not know of any species which occurs in MDF and PSF but not in kerangas forests. It therefore appears that the floristic affinity is closer between kerangas and PSF. The close floristic relationship does not necessarily imply equal environmental similarity. *Shorea albida* offers an example in this respect.

Shorea albida dominates ANDERSON's phasic communities 2 to 4, which correspond to my forest types 36 to 38, where the species forms almost pure dense, uniform, highly reflectant top-canopies. In kerangas forests *S. albida* never forms a dense top-canopy, but occurs as single, widely scattered emergent. It is part of a dense uniform canopy only in association with *Gymnostoma nobile* (Dalam sampling area and SP. 1, 8, 48). Single exposure and phyllodial neighbours both improve ventilation and consequently cooling which is important for a species with relatively large leaves. *S. albida* is never found on periodically dry SHP in spite of its very wide soil tolerance. The distribution of *Shorea albida* in kerangas forests appears primarily related to the soil water regime. In the PSF drought conditions may possibly also occur, but information is lacking. Shorea albida-forests in PSF are characterized by high albedo of single leaves and crowns, dense cauliflower crown shape, dense and smooth canopy surface as a consequence energy absorption and turbulent exchanges are reduced. This may be an adaptation to occasional water deficits or to a high level of toxidity in the oligotrophic peats. Low transpiration rates would then be an advantage for avoiding accumulation of toxins in the plants. This would favour such leaf, crown and canopy features which permit efficient temperature control at low transpiration rates as exist in the Shorea albida-bearing PSF. The close neighbourhood in the ordination of the PSF phasic series (type 31 to 39, fig. 13a) and of the catenas at high altitude from well-drained mineral soils to PB (SP. 52 to 57; SP. 42 and 41 to 40) points at the possibility that soil water regime, nutrient supply and soil toxidity may determine the stand condition in both association groups, but each factor at different degrees. It is of particular interest in this respect that the twenty tree species recorded in ANDERSON's aberrant Dacrydium-Gymnostoma-PSF type in Kayangeran F.R. also occur in kerangas and that the type location in the ordination is between PSF type 39 and SP. 40 in the region of PB in lowland (SP. 2 and 6) and high-altitude (SP. 40, 51, 55, 57) kerapah.

ASHTON (in lit. 1.5.64) describes a peculiar, small-crowned forest on the top of a knoll on Carapa Pila on a basalt outflow in the Mujong-Balui watershed. This forest resembles on the ground and on aerial photographs kerangas structurally, but it is a floristically distinct association dominated by *Trigonobalanus verticillatus* (Fagaceae). The soil is not kerangas but an ultrabasic type with unfavourable water regime and probably unbalanced mineral store. The kerangas-type structure seems also to be characteristic of the stands on the dacite table lands of Usun Apau and ulu Dapoi. The area has been visited by foresters and botanists in 1955-56 (Oxford expedition) and in 1965 (Annual Report of the Forest Research Officer for the year 1965, p. 5) but no information has become available to assess the floristic relationship to kerangas. According to ASHTON (1964c, p. 52) many species of humic podzols at low altitudes seem to be absent on similar montane soils above 1,500 m; the montane ridge forest resembles a floristically poor kerangas, but possesses also several additional species which never seem to be found in the lowlands.

The close relationship between kerangas and the woodlands on exposed rocky ridges and headlands has been hinted as early as 1914 by WINKLER (1914, pp. 204-205). The vegetation on the tops of the large boulders and exposed cliffs of the Klingkang range at 800 m a.s.l. has structurally and floristically much in common with the kerangas forest type 65 and the padang type 72 in Bako N.P. Particularly the commonness of *Baeckea frutescens* in both areas is striking. Similarly, the vegetation on the exposed boulders and cliffs of Bukit and Batu Skalap on the rim of the Merurong plateau, above about 800 m alt., contains on open, mossy Baeckea — Eugenia-facies which closely resembles the corresponding types in Bako N.P. (BRUNIG, 1959 and 1960). The facies changes rapidly through mossy Dacrydium — Shorea-forest into Dacrydium — Gymnostoma-forest (SP. 54) (BRUNIG, 1959/60). The position of the Baeckea — Eugenia-forests in the ordination would be near SP. 54 in the XY-plane. Its position along the Z-axis is uncertain because the reference plots (SP. 25 and 46) are of little relevance to the variation due to exposure and altitude.

Structurally and floristically related to kerangas forests are the pole forests on some lowland limestone hills sites with peat or mor soils resting directly on the rock or with very little mineral soil between surface mor and rock (SP. SER 1-6 fig. 7b). Water supply and extreme oligotrophy are, as in kerangas, probably the primary cause for the simple stand structure and the even and small-leaved canopy (sect. 226.4), low height, high density and relatively small basal area (sect. 225.2). This type of limestone forest vegetation would occupy the area about the coordinates 550 X and 500 Y in the centre of the ordination.

252. Related Forest Types Outside Borneo

According to RICHARDS (1952) Bornean heath forests physiognomically resemble Guiana Wallaba forests so closely that "the two communities are so similar in their general aspect that in the heath forest it is as if every individual plant of the Wallaba forest had been replaced by one of similar habit and general appearance, but with different systematic affinities. . . . Heath forest and Wallaba forest are in different hemispheres and have no species and very few genera in common so that the resemblances must be entirely due to the similarity of climate and soil."

RODRIGUES (1961) describes the caatinga of the Rio Negro as "a thin rachitic vegetation, whose foliage is generally sclerophyllous and persistent, growing on a superhumid, very poor bleached soil." In the high caatinga, *Eperua leucantha* and *E. purpurea* dominate the top-canopy, epiphytes and lianas are very rare. A stand profile of the high caatinga indicates a rather even, dense top-canopy varying in surface height between 25 and 33 m. In the low caatinga, *Aldina discolor* (Leguminosae) dominates the top-canopy in mixture with a number of species of the families Myristicaceae, Lissocarpaceae, Euphorbiaceae, Annonaceae, Guttiferae. He concludes "that what characterizes the caatinga in general, is the similarity of its structure and physiognomy, together with the homogeneity in floristic composition of each one, in spite of the predominating species varying from one caatinga to another." This indicates a semblance between the Amazonian caatinga of the Rio Negro region and the kerangas forests in Sarawak and Brunei. FANSHAWE (1954) reports that the Eperua (wallaba)-association in British Guiana varies in structure as well as in composition. He distinguishes a number of faciations in the range between the subcoastal peneplain and the sandstone areas of the Pokaraima plateau. Some faciations, such as the Dicambe corymbosa-faciation, seem to occur both on the peneplain and on coarse sandy soils on the plateau.

According to TAKEUCHI (1961/62) the soil of the caatinga of the Rio Negro region is bleached sand, which has been described as HP soil by KLINGE (1965). TAKEUCHI distinguishes a low campina forest, H_T 17 m, in the Am climate of the lower Rio Negro, and a high campina forest, H_T 30 m, in the Af climate of the upper Rio Negro. He enumerated a 5 x 40 m sample plot in the high campina, 2 km from the river on high ground with 2 cm surface humus, rooting depth 30 cm, H_T 25 m. Only six species are present in the rather even and dense top-canopy. Five of these are legumes, representing 73% of the number of trees in the A/B layer, and three belonging to the genus *Eperua* (55% of N). The only common non-leguminous top-storey species is *Lucuma sp.* (Sapotaceae). The layer is well-illuminated and 46% of the trees are *Eperua spp.* The density is about the same as in comparable types of kerangas forests (approx. 1.1 tree/m^2 between 1 cm and 10 cm d). A second plot is situated on lower, more humid ground near the river, with 3 — 5 cm surface humus over 1.5 m deep sand. The top-height is about the same as in the first plot, but canopy is more irregular and the A and B layers less distinctly separated. The dominance of legumes (*Eperua sp.* and *Heterostemon mimosoides*) in the A layer is reduced to about 50% of the basal area. The other half is taken up by four species of Bombacaceae, Sapotaceae, Guttiferae and Annonaceae. Seven other top-storey species are rare. The C layer is denser than in the first plot (approx. 1.5 N/m^2). The ground vegetation is also denser in spite of the greater tree density and consequently poorer illumination. The chief difference between the two plots lies in the absence of epiphytes and the poorness of ground vegetation in the plot on high and drier ground, and in the greater density and better integration of the A, B and C layers on the more humid site. The two stands appear structurally very similar to kerangas on poorer sites with less favourable water regime and without strongly dominant emergent single species.

Kerangas sites also occur in the tropical lowlands of the West African coastal rain forest zone but the natural vegetation has been completely destroyed by man and replaced by open woodland or white-sand savannas.

ASHTON (1967) draws attention to the similarity between the gradient from MDF to deciduous savanna forests in South-east Asia and the gradient from MDF to kerangas. The similarity between kerangas and some deciduous forest types is largely structural. (NEAL, 1967). But some of the more evergreen types on lowland and hill podzols and podzolic kerangas-type soils in continental South-east Asia appear also floristically more or less closely related to kerangas forests in Sarawak and Brunei (SETTEN, G.G.K.; ROLLET, B. verbal comm.) According to ASHTON "the widespread quartz sand beach ridges which extend even to Cambodia, with their characteristic humic podzols carry the distinctive but remarkably uniform and probably ancient Heath forest flora. As the species are apparently nearly always found also on sandstone cuestas and plateaux inland, it is not possible to speculate on their origin and dispersal. . . . " (AUSTIN et al. 1972).

BEVERIDGE (1953) and WYATT-SMITH (1963, III-7/17-18) describe a typical kerangas vegetation which occurs on strips of raised former sandy beaches on the east coast of Malaya. Much of this vegetation type has been destroyed by man. Only a few small stands survive which apparently still possess the original species complement in spite of disturbance from timber cutting. These stands show close floristic affinity to kerangas on comparable sites in Sarawak and Brunei. All listed genera in three stands also occur in Sarawak kerangas but stands differ at species level. Of the twenty-three tree and shrub species in a Shorea glauca-community in Tanjong Hantu F.R., only five species have been recorded in Sarawak kerangas. Of the twenty-eight species in a Shorea materialis-forest in Jambu Bongkok F.R., which appears closely related to my SP. 45 and 46, eleven species are also known to occur in Sarawak kerangas. Of twenty-three listed species in a similar stand in Menchali F.R., nine are recorded from kerangas in Sarawak. BEVERIDGE (1953) recognizes five distinct crop types in Menchali F.R. The Hopea nutans-type has an almost pure, dense top-canopy over scanty undergrowth. The Shorea materialis-type is somewhat more complex and has a richer understorey. Both types occupy the drier sandy ridges in the area. Seasonally flooded sites carry a Dipterocarpus gracilis—Calophyllum-type in which the stems may be covered with moss up to 60 cm from the ground. The other types are secondary growth. Common species are *Eugenia spp., Garcinia spp., Vitex pubescens* Vahl., *Rhodomyrtus tomentosa* Wight, *Podocarpus polystachys* R. Br., which are also characteristic of open primary or secondary coastal woodland on kerangas soils in Sarawak. The fifth type is swamp forests. The shallow perimeter swamp has little surface humus on sand and carries stands of an unidentified stilt-rooted *Melanorrhoea sp.* The interior is occupied by pole forests which are dominated by *Vatica wallachii* Dyer. The vegetation changes to stands of stemless palms on deep peat.

The kerangas forests on the east coast of Malaya are obviously quite different from those on the Sarawak coast at species level. The proportion of shared species is apparently not much above 50%. Even if the possibility of continued disturbance by man in Malaya is considered, this difference seems to support the assumption that the kerangas forests in Malaya have evolved in isolation from the Sarawak kerangas for some considerable time. On the other hand, CORNER (1961) points out that the sandy soils on the east coast of Malaya have developed from a mixture of granitic detritus and marine sand. Coastal kerangas in Sarawak is derived from redeposited tertiary p.m. The difference of flora on kerangas sites in Malaya and Sarawak may therefore be caused more by edaphic differences than by geographic factors.

WINKLER (1914, p. 202) reports HALLIER's observation that the kerangas forests near Sambas, Kalimantan, closely resemble Australian forests in their physiognomy. WEBB during the UNESCO symposium field trip to Bako N.P. in 1963 noted the great structural similarity between the tall kerangas forest types 61 to 63 (BRUNIG, 1965), and his simple notophyll vine forest subformation of Australian rain forests on coastal soils of low fertility (WEBB, 1959). There is also some floristic link in the characteristic presence in both areas of species of *Casuarina (Gymnostoma), Agathis, Dacrydium, Podocarpus, Tristania, Baeckea, Eugenia, Leptospermum, Xanthomyrtus, Weinmannia* among others. The Australasian element is according to RICHARDS (1936, p. 354) more important in the mossy forests than in kerangas and least important in MDF. SP. 54 on blanket PB is transitional between kerangas (SP. 51 and 52) and mossy Dacrydium—Shorea—Vatica-forest on the summit of Bukit Skalap. The Australasian element contributes 12% of the species and 50.6% of the basal area of 35.2 m^2/ha in SP. 54. A similarly high proportion of the basal area in kerangas is only reached in the Agathis-bearing forests on sandy HP soils in the lowlands. RICHARDS connects the variation of importance value of Australasian floristic elements in the various Bornean vegetation communities with edaphic and microclimatic conditions (RICHARDS, 1963). The floristic composition of my sample plots indicates that the dominance of the Australasian elements in kerangas is related to conditions of unbalanced moisture regime and nutrient deficiency. This gradient appears comparable to the gradients from more mesic to more xeric forest types in continental South-east Asia and in tropical Australia where the more structured sclerophyllous forest types with greater affinities to kerangas forests occupy the sites with a more unfavourable moisture and nutrient regime.

26. UTILIZATION

261. Growing Stock and Site Potential

261.1 The Exploitable Growing Stock

Man has been exploiting kerangas forests for a great variety of products, such as guttapercha, very hard special purpose timbers, scented incense woods, and several kinds of resins and dyes. Felling of timber in accessible areas intensified since the turn of the century and in many cases severely upset the relatively stable "dynamic balance". Locally, the result was lasting dowrioration of the stand and site productivity. Incense-producing Thymeleaceae have disappeared from many kerangas areas close to villages. The stock of *Agathis borneensis* has been alarmingly exhausted on most lowland terraces in recent years and severely logged stands with negative stand curves of the species have converted to unproductive, dense stands of undesirable species. National goals require more efficient use of the natural resources and maintenance of the site productivity. Decision on policies to achieve these goals requires information on the ultimate limits of production in exploiting natural forest and on productivity potential in regenerated or nearly established stands. Such information is notably meagre for kerangas forests. The following is an attempt to summarize available information by evaluating the few data from the kerangas survey and from departmental inventories.

The cross-sectional or basal area of a tree stem at breast height is easy to measure and gives a convenient indication of a tree's contribution to the plant biomass of the stand. The relationship between g and V or biomass of trees is ideally linear. Deviation occurs, due to differences in height and shape. In kerangas forests, crown shapes of different species vary between narrow-long and broad-spherical. Crown dimensions also change with age usually from narrow and long to broad and flat. Preliminary evaluation of data for *Shorea albida* from PSF at Tanjong Kranji gave evidence that stem taper varies strongly with position on the phasic gradient. We have seen earlier that the distribution of basal area over diameter classes varies between stands of different ecology in kerangas. The same is true for PSF (ANDERSON, 1961; BRUNIG, 1969).

Consequently, the same basal area in two stands may be associated with different bole volumes. The variation is due to differences in tree height/diameter ratio, tree taper and basal area density per diameter class. Tree volume per unit basal area is affected by crown volume. It is smaller in trees with narrow crowns (*Agathis borneensis*) than in trees with big crowns (*Shorea albida*).

The basal areas per hectare of the sample plots are given in fig. 15a in order of plot sequence along the X-axis of the ordination. The weighted mean of all plots (excluding SP. 10) is 36.5 $m^2/ha > 2$ cm d o.b. The basal areas on the well-drained soils with balanced water supply on the left are more uniform than those on the SHP, GWP, PB and RYP soils to the right of SP. 9. The biggest value in kerangas occur in SP. 27 (GHP with *S. albida*) in the transitional SP. 31 (PB margin with overmature *S. albida*).

The basal area of the MDF plot (SP. 10, G 55.5 m^2/ha) on an exceptionally fertile igneous hillside is larger than that of most kerangas plots. It is 30% larger than the mean of the good quality MDF in Sempadi F.R. and probably near the maximum of the association group. The basal areas in the structurally similar phases in PSF lies within the mean range of kerangas forests. A study of variation within stands showed a mean basal area above 9 cm d of 40.8 m^2/ha (± 4.2%) in type 372, 30.6 (± 15.0%) in 381 and 39.0 (± 8.7%) in 382 (BRUNIG, 1958).

The mean top-height of all kerangas plots (excluding SP. 10) is 37.5 m (fig. 15a). The range is from 21 to 51m (1:2.5) compared to 17.5 to 88m^2 (1:5.0) for basal areas. The top-height is only loosely correlated to basal area. The basal area in natural undisturbed forests reflects primarily successional status (e.g., SP. 29 and 31), species presence (e.g., SP. 27, 41) and topographical restrictions to use of space (e.g., rocky slope in SP. 16). The top-height of a stand is more closely related to the micro-climatic site potential. Top-height and canopy morphology together are therefore a more satisfactory indicator of site productivity potential than basal area dominance.

The product of stand basal area above 2 cm d and 1/2 stand top-height assumes a tree volume form factor of 0.5. It is a useful, if conservative, estimator of total above ground wood volume under bark. The relative values of the index are subject to a certain bias, as a result of adopting a constant height instead of actual height per diameter class. The estimator will give too high estimates for plots with a steeply declining stand curve and few emergents (SP. 15, + 43.2%; SP 4, + 28.5%). The estimates will be too low in stands with a bi-modal stand curve (SP. 27, — 17.1%). The deviations of the estimates for plots with moderately steep positive total stand curves and with even basal area distributions are within ± 15% of calculated volumes (SP. 10, + 12.8%; SP. 40, + 16.7%; SP. 1, + 7.3%; SP. 43, + 6.6%; SP. 50, — 11.0%; SP. 54, + 3.4%). The ease of computing makes the estimator useful for quick comparisons of total wood volumes in different forest types. But the possibility of bias in stands with extreme stand curves must be kept in mind.

The estimated total above-ground under-bark wood volume equivalents are shown in fig. 15a. The lowest value is 195 m^3 (SP. 29). The largest values are 1390 m^3 (SP. 27, GHP), 1760 m^3 (SP. 31, MDF to PB) and 1720 m^3 (SP. 10, MDF). The mean of all plots (excl. SP. 10) is 778 m^3/ha. The lowest values occur on the periodically dry SHP on sandstone dip-slopes (SP. 9 and 15), in the transitional zone between kerangas and raised peat (SP. 29) on the PG clay soil of the peneplain relic (SP. 33) and on the blanket bog on the summit slope of the Merurong plateau (SP. 54). Also rather low are the values for floristically very different stands on GWP clay on pleistocene terraces (SP. 6, 36 and 37) and on tertiary sandstone (SP. 51). Moderately large values occur on well water-supplied young GHP (SP. 45). The variation indicates that water regime may be an important factor in determining the limits of growing stock volume on a site.

Detailed and reliable data on stand volumes per species in kerangas and other forests are rare. Some data exist for *Shorea albida* in PSF from a volume table survey in eight blocks of 2.5 ha each in various sub-types of the Shorea albida-consociation at Tanjong Kranji, Saribas, and from a 0.4 ha clear-felled sample plot in sub-type 3.71 of the Shorea albida-consociation near Lingga, Batang Lupar. The latter plot has a basal area > 5 cm d of 38.2 m^2/ha and a top height of 52 m. It contains thirty-eight tree species and 152 trees > 5 cm d, of these sixty-eight *Shorea albida* and forty-four *Gonstylus bancanus*. The other species occur only in the smaller size classes. Measured volumes (in m^3/ha > 5 cm d under bark) are 588 m^3 *Shorea albida* logs (excl. 6 m^3 = 1.02% hollow centre), 54 m^3 *Gonystylus bancanus* logs, 621 m^3 mixed crown wood, and 1263 m^3 total solid timber (BRUNIG, 1958). The corresponding biomass is shown at the right in fig. 15b. In the Kranji project, only trees above 30 cm d are included. The basal areas decrease from 31.6 m^2/ha (N = 150.6) in block 38 near the perimeter of the consociation (type 371) to 29.2 m^2/ha (N = 211.1) in block 68 close to the transition zone to padang (type 3.73/3.81). The top-height decreases from 45 m in type 371 to 42 m in type 374. The growing stock volume of commercial log timber > 25 cm top diameter decreases from 606 m^3/ha in block 38 to 376 m^3/ha in block 68. The agreement between PSF and kerangas estimates seems reasonably close, if the structural differences are taken into account.

The volumes above 5 cm o.b. per 10 cm diameter class were estimated for eight kerangas sample plots and for SP. 10 (MDF) by multiplying basal area o.b. with the mean height of each class. A constant form factor of 0.66 was used for conversion to total above-ground wood volume. Little information exists on form factors. The *Shorea albida* volume surveys indicated a total-wood form factor of 0.66. Measurement of ten sample trees in RP 38, nineteen years old *Gymnostoma nobile*, gave a mean stem-wood form factor of 0.523. The mean branch-wood per cent in the ten trees was 21.4. The adoption of a form factor of 0.66 for total wood volume o.b. appears therefore reasonable. A flat reduction of 15% was applied to allow for bark. The merchantability of trees was assessed by size, visible defects, average frequency and size of hollow heart per species and forest type, referring to conditions in 1962/63. The results of the calculations are reproduced in tab. 14a. The figures show the large disparity between total wood volume and presently commercial volume. The 1962 forest inventory of Pueh F.R. gave the following reliable minimum estimates of the commercial growing stock above 40 cm d: 27 m^3/ha (6.26 Hoppus tons/ac) in mixed kerangas (type 52) on MHP or shallow GWP on undulating plateau sandstone sites, 68 m^3/ha (15.19) in Shorea albida — Dryobalanops fusca—G. nobile-kerapah (type 51) on MHP on low, almost flat sand dunes, and 82 m^3/ha (18.41) in Shorea albida — G. nobile — W. moultonianum-kerangas (type 51) on PB overlying white sand. The means are up to 10% higher. The values agree well with the calculations from the single sample plots in tab. 14a.

An estimate of total plant biomass can be derived from the known average specific timber densities, the species composition of the stand and the above-ground wood volume. The wood volume > 5 cm d is converted to total plant volume by adding 12% for small branches and understorey trees below 5 cm d in SP. 43, 20% in SP. 15 and SP. 54, and 15% in the remaining plots. 15% are added to account for bark volume. The root volume amounts to approximately 15% of the above-ground volume. Volumes are converted to weight in metric tons by average dry weight per stand (0.55 in SP. 43, 0.6 in the Lingga PSF plot and in SP. 10, 40 and 50, and 0.7 in SP. 1, 4, 15, 27 and 54). Leaves may account for up to 8% of the live biomass of forests (OVINGTON, 1962, tab. I) but is most likely considerably less in mature rain forests. The contribution from herbs and epiphytes is small in heath forests on sandy podzols but may be somewhat larger in the Shorea albida-forests and in some kerapah forests. However, it may be ignored in this rough estimate of scale. The results of the calculations are reproduced in fig. 15b and in the last column of tab. 14a. The figures indicate a surprisingly high level of growing stock even on such unfavourable soils as the SHP and PB soils. The relation to site conditions are the same as shown by the volume estimator in fig. 15a. The ratio of presently commercial biomass to total-wood dry-weight demonstrates the tremendous potential for improving yields in all types of stands. It is particularly great in the Shorea albida-forests with a high degree of defectiveness which affects many stems but involves little volume (SP. 27). It is also great in the stands in which the timber is of small size but of rather heavy weight (SP. 15). This indicates that full utilization of the kerangas forests can only be achieved if use is not only extended to a wider range of species but also to smaller tree sizes and to defective timber.

The only stand data available from kerangas-type forests outside Borneo are from Wallaba forest in Guinea (DAVIS and RICHARDS, 1933-34; RICHARDS, 1952). From data given by RICHARDS in tab. 4 the basal area > 10 cm d is calculated as 13.5 m^2/ha and the wood volume as 257 m^3/ha. The wood volume is high in relation to the basal area because *Eperua falcata* has a marked peak of density in the 41-61 cm d class in a stand with a mean top-height of 30 m. This peak raises the volume level of the stand in relation to basal area. It is noteworthy that the basal area in the Wallaba forest is smaller than in any of the kerangas stands measured by sample plots or in forest inventories.

The estimated volumes in the single sample plots as well as the measured volumes in the two Shorea albida-areas are much higher than the figures for whole-tree volumes and stem biomass given by SOERIANEGARA (1965) for several forests in Kalimantan. His Shorea uliginosa-peatswamp forest had 246 m^3/ha tree volume and 170 t/ha stem biomass, and his Agathis borneensis-forest 329 m^3/ha and 216 t/ha respectively. They are also higher than the values which KIRA (1969) calculated for two forest sites in Sabah and a heath forest in Malaya. He uses an empirical formula which derives total and leaf biomass from tree diameter and a height-related constant. His estimates are 493 t/ha (11.4 t/ha leaves) on well-drained sites in east Sabah, and 288 t/ha (6.9) in heath forest at Kuala Rompin. The reason for the relatively large discrepancies between these and my data is obscure. Preliminary evaluation of a recent very careful biomass measurement in a 0.2 ha sample plot in Amazonian terra firma rain forest near Manaus corroborates my assumptions on basal area/height/volume relations (KLINGE, pers. comm. of 21st Jan. 1971). My estimates of biomass in kerangas, MDF and PSF therefore appear realistic.

261.2 The Site Productivity Potential

Productivity is the net matter production of the vegetation per unit time and area. It equals the gross photosynthesis (= primary productivity) minus losses from light and dark respiration minus losses from separated dead parts of the plants. Potential productivity is the amount of net production of a crop per unit time which is the highest possible under the given set of environmental factors acting on this crop. Ultimately, the maximum potential productivity on a site is determined by amount and distribution of light, temperature and water available for plant growth.

The maximum potential net photosynthetic productivity of forests in Sarawak is unknown. Its value may be approximately assessed by means of certain aspects of the energy budget. ROSENZWEIG calculates the net annual above-ground production by a logarithmic relationship to actual evapotranspiration. Evapotranspiration rate is closely related to net radiation rate. Actual evapotranspiration E_o is closely correlated to actual transpiration from vegetation surfaces. According to WIT (1958, p. 59), the correlation between transpiration and total dry matter production of plants is simple, provided the moisture and nutrient regimes, and the stand density are not extreme. The approach of ROSENZWEIG should therefore give a reasonable estimate of the productivity of natural mixed forests on sites where nutrient supply and moisture regime are not too far from optimum. According to the diagram reproduced by ROSENZWEIG, the NAAP is 30.9 t/ha at Yangambi, Kongo, for an E_o of about 1,260 mm. The annual rainfall at Yangambi is 4,300 mm (169.1 in. according to RICHARDS, 1952, tab. 12) and no month with less than 200 mm. According to ROSENZWEIG's formula and using the means of his constants, MDF in Sarawak would have an NAAP of 50.2 t/ha/yr at E_o = 1,700 mm and 63.9 t/ha/yr if E_o were as high as 2,000 mm and no other factors limiting (ROSENZWEIG, 1968). WESTLAKE (1963) estimates the average net primary productivity of tropical rain forests as 50 t/ha.

A different way of assessing potential productivity uses information on locally available energy from incident radiation in the photosynthesic wave-length and on the efficiency of the plant cover to utilize it. The normal range in forests is 3 — 5% efficiency based on measured apparent gross assimilation and incident radiation during the potential growing season. Multiplying the incident radiation in the photosynthetic wave-length by utilization rate and dividing the result by the average calorific value of the produced matter gives the maximum potential apparent gross photosynthesis. Assuming that tropical rain forests have a 5% efficiency, the potential productivity would be 56 t (Amazon) to 89 t (S.E.A.) apparent gross photosynthesis per hectare and year. DAWKINS (1963, p. 59) estimates the apparent gross photosynthesis in tropical high forests as 60 t and WECK (1960) as 82-95 t/ha/yr on the basis of similar calculations.

In concluding, it can be safely assumed that the potential maximum apparent gross photosynthetic rate in Sarawak lowlands is about 90 t/ha/yr on relatively fertile, deep sandy loam to clay-loam soils with adequate water supply. Approximately, 45% of the assimilates would be consumed in dark respiration in the leaves and by respiration in non-leaf tissue, leaving about 50 t/ha/yr net production of plant dry matter. About 8 — 10% will be used for current root-tip and fine-root production below ground. Leaf-fall will consume another 10 to 15 % and other debris (bark, twigs, branches) 3% of the apparent gross photosynthesis. WANNER (1970) calculates a rate of decomposition of organic substance in the soil of the Oncosperma — Salacca — Artocarpus-forest in Bako N.P. as 10.7 t/hr/yr. The soil respiration measurement in the small cylindrical space of the method used reflects mainly the carbon dioxide output from leaf litter decomposition. This amount agrees well with most other records on litter production in tropical rain forests, which average about 10 t/ha/yr. Lower rates would be expected in kerangas as a result of its lower leaf mass and its higher degree of evergreenness.

All this leaves about 1/3 of the apparent gross photosynthesis, or 30 t/ha/yr of which 3 t/ha/yr will be used for bark production, 11 t/ha/yr for branches and roots and about 16 t/ha/yr for the production of stemwood. Higher rates could be obtained only if the tree species had a higher photosynthetic efficiency or if the distribution of assimilates is shifted in favour of stemwood production. Actual rates in the field will usually be lower because of limiting environmental factors and of senility and mortality in overmature stands. In most natural and undisturbed kerangas, MDF and PSF mortality will more or less balance annual net production. Senility of one part of the population is balanced by the youthful vigour of the other. Among the external limiting factors, water and nutrient supply are probably more critical than energy supply and the effect of consumers, decomposers, toxins and abiotic damaging factors. The latter factors may however locally attain critical importance (ANDERSON, 1961b and 1964b; BRUNIG, 1964). WIT (1959) estimates that due to the combined effect of limiting factors on an average only two-thirds of the potential productivity can be realized in Holland.

The effect of mineral nutrients on photosynthetic production is indirectly shown in the results of conventional fertilizer experiments. There are very few records on the direct relationship between nutrient levels and net photosynthesis of tropical tree species. Critical minimum nutrient levels in the plant and in the substrate cannot yet be defined below which net photosynthesis and fertilizer are positively correlated. There are indications that this minimum level is fairly low (WIT, 1958, p. 23). It is possibly lower in plants which habitually grow on such nutrient-poor soils as kerangas. It is known that net photosynthesis rates decline considerably with increasing degrees of water deficiency. This decline is largely independent of any effect of stomata aperture reduction on CO_2 diffusion rates to the place of photosynthesis (WIT, 1958). It is likely that under conditions of water shortage net photosynthesis is controlled by other reactions but almost nothing is known about the nature and effectiveness of these limiting reactions. The rate of productivity decline on kerangas as a result of periodically insufficient water supply and low nutrient level must therefore be assessed by other ways.

The potential productivity of kerangas sites may be approximated by reducing the climate-related maximum potential production rate in proportion of the ratio between the MAI on the best and on the poorest site classes in established forestry yield tables. The yield tables of WIEDEMANN-SCHOBER (1957) for *Fagus silvatica* L. show this ratio as 4 to 1. The corresponding range of soil types is comparable to the range from the best LS and RYP soils to clayey GWP and sandy PG clay soils. The yield ratio in *Pinus silvestris* L. is 7 to 1. The corresponding range in soil types is comparable to the range from sandy RYP and DHP soils to very shallow GWP sands on exposed rock sites. The best beech site produces about 1.5 times the dry weight under beech, than the best pine site under Scots pine.

As a tentative approximate assessment we may assume the potential net annual above-ground production of stem wood on the best kerangas sites as 8 t/ha/yr, or only half of the maximum potential productivity on the well water-supplied sandy RYP, DHP and on sand/clay GWP. The MHP, clayey GWP, GHP and PG soils and well water-supplied SHP most probably lie between 3 and 7 t/ha/yr. The SHP and shallow sandy GWP with high frequencies of periodic drought will accordingly produce between 1 and 3 t/ha/yr (1/7 to 1/5 of the maximum). Productivity of some extreme sites is probably even lower.

Very similar ratios are obtained if the NAAP is calculated according to ROSENZWEIG. The full rate of 50 t/ha/yr is produced at 1,700 mm. 31 t/ha/yr are produced at 1,200 mm E_o, which applies to better kerangas stands, and 10 t/ha/yr at 900 mm E_o in stands on moderately poor SHP. Stemwood production rates are accordingly 16, 10 and 3 t/ha/yr respectively. Even less would be produced on poor PB with dense and uniform pole stands and an E_o of 740 mm. The estimates agree well with the figures given by DAWKINS (1965a) for Malaya. He considers 50 t/ha/yr total above-ground dry-weight production of wood as maximum obtainable from eucalypts on exceptionally good sites. The more normal range obtainable in forestry is 13 to to 40 t/ha/yr, while nothing more than 12 t/ha/yr can be hoped for from indigenes on average sites and good soils in the lowlands. The limiting factor in the latter species is the wide crowns which they need for good growth.

An indication of relative productivity of forests may also be derived from canopy surface morphology and reflectivity. Irregularity of the top forest canopy allows the interception of additional light by individual emergent trees and groups of trees, but will hardly affect interception per unit stand area. High albedo will reduce the amount of absorbed radiation and consequently the energy available for photosynthesis, nutrient absorption and transpiration. *Shorea albida* and other species with high albedo (sect. 226.2), as well as kerangas and PSF types 36 to 38 as a whole, are possibly disadvantaged by their high albedo especially during dull days. The relationships between stand structure and actual evapotranspiration E_o (sect. 117.3) and between canopy surface morphology and aerodynamic roughness (sect. 226.4) have been discussed earlier. NAAP has been calculated for nine stands from E_o and plotted over the corresponding log z_o. The few points suggested the existence of a linear relationship. This would necessarily be so if the same parameters had been used in estimating E_o and z_o, which is not the case (see sect. 117.3 and sect. 226.4). The plot is reproduced in fig. 15c. The few data and the uncertainties underlying the basic estimation demand greatest caution in interpreting, but at least the results suggest that further research into the correlation between canopy roughness and productivity appears promising and is justified in view of its potential usefulness for land use planning.

Fig. 15c shows that in the mixed or more weakly single-dominant stands the NAAP in kerangas rises from about 10 t/ha/yr at z_o = 100 (kerapah on BP, type 51) to about 40 t at z_o = 328 (Agathis-forest on DHP, type 52). Higher productivity occurs in MDF on RYP with about 50 t/ha/yr (type 42) and in PSF, mixed Gonystylus bancanus-forest on shallow peat close to river alluvium with 55 t/ha/yr (type 31) and finally in rich riparian forests with a NAAP of 63.9 t/ha/yr (type 21). The different slopes of the lines for the mixed forests and for the single-dominant Shorea albida-forests (types 381, 371, 362) are possibly related to differences in albedo and in soil conditions.

It would seem reasonable to compare site productivity by using maximum tree sizes as an indicator. HEINSDIJK (1960) states in a report on surveys in the Amazonian rain forests that volume of the average tree is considered the best standard for judging soil fertility. This is certainly true for limited areas and for narrow ranges of site and vegetational gradients. It does not apply to areas in which between-stand and between-region diversities are high. The results of the kerangas study clearly show that present tree size is neither a good indicator of soil type and topographical position, nor of relative soil fertility as indicated by moisture, texture and nutrient status. Tree size can be a good indicator of the relative fertility of soils with respect to defined fertility factors, if the compared stands belong to the same ecological continuum and if the indicator species and their ages are the same. An example is the decline of max.d of *Agathis borneensis*. It is largest on DHP at the terrace margins, where trees are also taller. Diameter and height decline towards the centre of terraces and toward higher terrace levels, if the p.m. is the same and the soil changes to MHP of SHP. Similarly, the max.d of *Agathis borneensis* decreases up-slope along the catena on tertiary p.m. (sect. 134.2, ex.3). Diameters are generally much smaller on any site along the latter catena than on the terrace sites. At the same time, the soils along the catena on the tertiary p.m. are medium deep to deep sandy loams in the top-soils and sandy clay loams in the subsoils. Soils analyses of samples from SP. 48 and 50 show that their nutrient and moisture status is superior to the terrace DHP and MHP soils. The soil data would suggest a pattern of tree sizes which is reverse of what is found in reality.

Increment data from research plots on kerangas soils in Sarawak and Brunei are rare. Mr. C. G. MERTON supplied copies of sample plot records of RP 4 and 5 in Anduki F.R. The plots are an almost pure stand of *Dryobalanops rappa* in a seral forest on coastal GHP with pronounced micro-knoll relief. The age is not known and the stand is probably mature. It has been thinned between 1936 and 1940. After thinning the d-increment increased by 30 to 50%. The MAI is 0.5 to 0.9 cm d/yr, and 1.9 to 2.1 m^3/ha/yr commercial saw-timber. The volume increment of 1.5 t/ha/yr (spec. density 0.75) saw-timber and about 2.5 to 3 t/ha/yr total wood above 5 cm d. From a site in Malaya BEVERIDGE (1953) reported a height growth immediately after a check period in planted *Hopea nutans* and *Shorea materialis* saplings of about 20 to 30 cm/yr on a degraded MHP, and a MAI of 0.4 cm d in twenty years old *Hopea nutans* on coastal MHP in Menchali F.R. Growth in RP 21, Nyabau block, Similajau F.R. (sect. 233) on MHP and DHP shows a MAI of 0.4 cm d in nineteen *Agathis borneensis* trees of 20 to 90 cm d in a mixed stand where competition is probably fairly fierce. Growth data on a number of exotic species in plantations on kerangas were supplied by J. R. PALMER in 1970. The best single-tree performance on record is for one of six surviving trees of originally sixty-four *Eucalyptus deglupta*, New Guinea provenance, planted at 3.7 x 3.7 m on humus podzol (? DHP of MHP) in Nyabau block, Similajau F.R. 2.7 years after planting the tree had reached 13 m height (MAI 4.7 m) and 19.3 cm d (MAI 7.2 cm). The best stand performance at three years after planting at 2.4 x 2.4 m on humus podzol in the same area showed *Pinus caribaea* var. *hondurensis* from British Honduras (MAI 155 cm h), followed by two Bahama provenences (124 and 145 cm), *P. kesiya* from the Philippines (114 cm) and *Agathis macrophylla* from the Solomon Islands (114 cm). The figures must be interpreted with caution because early height growth of exotic conifers on a cleared tropical broad-leaved rain forest site can be deceptive. Also climatic conditions might have been exceptionally favourable, and the trees grown under experimental conditions possibly received more than normal attention. Growth data supplied by J. R. PALMER on *Gymnostoma nobile* in SP. 38, 6th Mile F.R., indicate an early decline of growth rate. The original stand had been MDF. *G. nobile* was planted at 2.4 x 2.4 m in 1937 under a shelter which was removed by 1940. The soil is a gley-type clay-loam with strong bleaching in the more sandy top 30 cm, which there is reason to assume to be largely due to the *G. nobile* crop. In 1956 at nineteen years of age, the mean stand height was 22 m, the mean diameter 16.5 cm and the MAI 11.03 m^3/ha/yr stem volume and 13.42 m^3 tree volume. In 1964, the mean height was 23.8 m and the mean diameter 20.1 which indicates declining growth rates, perhaps partly as a result of excessive density (N = 765 per ha). The increment is unsatisfactory for the site and may reflect a low volume growth potential of the species.

ASHTON (1973) remeasured the growing stock and the girth increment in a number of sample plots in MDF after 5 years. His results support the view that generally girth increment strongly decreases with altitude, but that the volume growth rate and the growth percent are not only determined by the site but also by the structure of the stand, especially by the accumulation of tall and possibly long-lived and less vigorously growing trees. A large biomass is therefore no indication of a large growth rate and growth percent. Also, the biomass and the growth in natural forest cannot be used as indicators of the production potential of the site under a managed forest.

The average dry weight per unit volume of wood tends to be higher in kerangas than in MDF. Within the kerangas forests, stands on well-drained but well water-supplied soils have a lower average stand specific gravity as a result of different species composition than those on excessively drained or very shallow soils. Also, specific density within a species seems to vary in relation to site. Wood samples from seven felled *Shorea albida* trees growing on different soils in SP. 1 (MHP), SP. 3 (GHP), SP. 5 (one tree on PG, one tree on SHP/GWP) and on chain 18, line 3 (1955) on MHP in Pueh F.R. at the same distance from pith were heavier (s.g. 0.964-0.972) on sites with very good to moderately good drainage and lighter (0.834-0.874) on soils with impeded drainage. The weights were consistently higher than those reported by BRAZIER (1956) from peatswamp forests. Consequently, the volume production in the drier types of kerangas may be relatively lower than the dry matter production in comparison to well water-supplied sites. There is practically nothing known about the variation of silica and extractives content between different sites. Higher silica contents and consequently higher weights might be expected in trees on the quartz-rich kerangas podzols. But timber samples of many common kerangas species, such as *Shorea pachyphylla, S. scabrida, S. havilandii, Dipterocarpus borneensis* (MURTHY, 1965) *and Shorea albida* (GOTTWALD and PARAMESVARAN, 1966) do not contain silica, while other species of the same genera in MDF contain silica. For example, all species of the section *Anthoshorea* have silica in the wood except *Shorea albida* which is the only kerangas species in the section.

262. Agricultural Use

The kerangas forests on well water-supplied and well-drained sites are a relatively stable and robust vegetation on very sensitive soils. Rapid seral development along gradients of deteriorating drainage may locally make also the stands very sensitive to disturbance. Throughout the tropics kerangas-type forests in accessible areas have been converted to conventional forms of agriculture by burning. The so-called white-sand savannas in coastal West Africa, Surinam, Honduras and Borneo are examples that usually the final stage of agricultural use of kerangas land is unproductive degraded land. The obvious ecological unsuitability of kerangas soils for permanent agriculture by conventional methods does not protect the sites from continued attempts at farming these soils in coastal areas. Kerangas lands in coastal areas have relatively good external and internal accessibility which continues to attract farmers. The first crop yield may be quite high if the burn has been good and a good supply of nutrients is temporarily available, provided rainfall is adequate during the season after planting. But eventual decline is inevitable when the productivity settles to the low natural potential of kerangas sites for agricultural crops. ANDRIESSE (1962a) found that RYP soils reached their lowest nutrient level already after two crops under the hill rice-bush fallow system. Red- brown LS reached this point after much longer farming. The RYP soils are the relatively most fertile soils in kerangas which is transitional to MDF. It could be expected that sandy HP and GWP soils would lose the store of available nutrients even more rapidly after burning and farming.

The store of unavailable nutrients is very low in sandy HP and GWP soils (sect. 135). The rapid loss of available nutrients during conventional farming and the low level of unavailable nutrients in these soils indicate that they possess low fertility and low agricultural potential. The susceptibility to break-down of structure and erosion precludes the agricultural use of these soils on slopes of greater steepness than 5 — 10°.

Kerangas soils with some amount of clay fraction in the sandy top-soil above clay-pan at medium depth are more favourable for agriculture. There is less surface erosion and leaching of humus and nutrients in more clayey soils. The natural water regime is more balanced, except in shallow PG heavy clay soils. But these soils may be improved by irrigation. DAMES (1962, p. 47) pointed out that the humic PG soils may be suitable for agriculture if irrigation is feasible. Farming of heavy-clay PG and podzolic gley-type soils on slopes is inadvisable because they are easily eroded.

The sandy loam RYP soils under primary kerangas forests are usually moderately to very shallow and restricted to small pockets within areas of HP and GWP soils. They would be suitable for soil-tolerant agricultural tree crops if the soil is sufficiently deep, the slope less than 10 — 15° and the area sufficiently large and of easy access.

In concluding, agricultural use of kerangas for annual crops should be restricted to clay-rich soils on level sites which can be effectively irrigated and fertilized. Agricultural tree crops for oil, latex or fruit production may be grown on sandy loam to sandy clay RYP soils on gentle slopes if the soils are sufficiently deep, of sufficient area extent and of easy access. Yields on these soils will be lower than on MDF, possibly in proportion to the difference in timber yield between MDF and kerangas. The growing of these crops on kerangas will therefore be feasible only on exceptionally favourable sites and if multiple use management can be practised. Annual cropping on all sandy HP and GWP soils and on clay-rich GWP and PG soils on slopes will cause persistent soil deterioration and finally padang formation with permanent loss of productivity and corresponding social costs to the country. Examples of such land misuse are common around Sematan and Kuching, in Bako N.P. and in the Miri-Tutong area. The low-productive PG soils, the kerapah and the blanket bog groups are equally unsuitable for agriculture as for production forestry.

[illegible]. Forestry on Kerangas Soils

Kerangas and kerapah soils appear more suitable for growing perennial crops than annuals. The infrequency and briefness of exposure of the soil surface and of disruption on the mineral cycling in perennial crop-growing are advantageous to soils which are notoriously poorly structured, unstable, poor in nutrients and low in absorption capacity, the latter being largely concentrated in the organic matter of the soil.

The relatively large biomass on the nutrient-deficient tropical podzols is possibly maintained through a closed system of rapid re-cycling of the minerals. The number of dead standing trees (0.2 to 0.7% of standing trees) and of fallen dead timber, which amount to several per cent biomass in some stands, and the dense cover of freshly fallen leaves above a fairly uniform depth of mor and moder are an indication that the turn-over rate may be slow in comparison to MDF, but is relatively high for the infertile sites. The rapid peat accumulation in PSF (ANDERSON, 1964a) is an example of relatively high rates of biomass production on oligotrophic sites in the tropics.

Live and dead mycorrhiza and bacterial root nodules probably play an important part in this system. They are common among kerangas tree species and are likely to improve nutrient supply, especially of nitrogen and phosphorus. Live mycorrhiza also assists in water uptake. The destruction of large portions of the biomass during conversion to annual-crop agriculture disrupts essential processes and upsets the state of dynamic equilibrium beyond its range of tolerance. Persistent soil degradation follows. Extensive areas of sandy podzols have degraded as a result of human activity into white sand savannas in Latin America (HEYLIGERS, 1963; STARK, 1970) and "padang" in Malesia (HENDERSON, 1931). These areas are characterized by the loss of the A_0 and part of the A_e horizons through fire, leaching and erosion. The remaining soil is extremely infertile and carries very poor vegetation of groups of sclerophyllous shrubs and stunted trees separated by bare sand or on open vegetation of sedges, grasses, ferns, fern allies and few other species (BRUNIG, 1965). It would be extremely costly to rehabilitate these areas by planting any timber species. Survival is likely to be low especially in the open sandy areas (WYATT-SMITH, 1963) and judging from occasional invaders, growth will be very slow. A more feasible approach to rehabilitating such areas would be by fire protection and natural succession. In time, soil fertility will be restored to a level that investment into plantation forestry may become feasible.

Forestry is ecologically more adapted to kerangas lands than agriculture with short-lived crops. Forest utilization in kerangas is largely a problem of small sizes and high specific timber densities. Stand conversion by natural regeneration is largely a problem of seedling availability and of controlling aggressive intermediates and ecologically undesirable species. Plantation establishment carries high risk from drought, fire and soil deterioration. The continued management of kerangas for timber production is an ecological problem as much as it is an economic risk. Yields on kerangas lands are lower than on MDF soils and on perimeter peat swamp soils. The productivity of kerangas sites is low (sect. 261.2). The estimated NAAP of 8 t/ha/yr includes at most 2.7 t utilizable timber, of this 1.3 t saw- and pulp-logs (BRUNIG, 1967). On the poorest sites, the NAAP may be as low as 2 t/ha/yr of which about 0.5 t would be utilizable as pulpwood. The dense pole stands on shallow blanket peat and sand on the tops of exposed headlands in Bako N.P. and on the Klingkang range are likely to produce even less than 2 t/ha/yr. The low productivity imposes severe limitations on the level of investments in kerangas management and results in high cost/benefit ratios. An example may illustrate this (tab. 14b). We assume that *Agathis borneensis* is planted at 2.5 by 2.0 m on a well-drained MHP/DHP soil in an area of easy access close to the market. Pulpwood, sawn-timber and peeler logs are produced with a production period of fifty years. The MAI is consequently estimated at 0.5 cm d, 52 cm H_T, and 5.4 m³ pulpwood and timber over 5 cm d under bark corresponding to 8 t/ha/yr NAAP of stemwood. Costs are US$300 for plants and planting, $25 for the weeding during the first five years and $5 for the first thinning by removal of every third row. Opportunity costs for using the land are ignored. The net stumpage return is $160 from the third thinning yielding 40 m³/ha and $1,400 from the final harvest of 200 m³/ha. The compounding rate is 5%. The costs are calculated and adapted from data given by VERSTEEGH (1966), DIXON (1967) and FAO (1968) and include plants, planting, tending and maintenance. The stumpage values were taken from BRUNIG (1970c) and apply to optimum economic and natural conditions. Logging costs given by FAO (1968) were used to check stumpage values. In the plantation case accumulated costs of investment at harvesting time are considerably higher than the stumpage proceeds. Natural regeneration on the same site would reduce initial investment to about $50 per ha for regenerating and establishing the second crop. Greater expenditure is necessary for the first thinning at age ten because more trees have to be removed which cannot be utilized due to their small size. The total compounded costs are less than the revenue, and a small profit is made. This indicates, that production forestry is possible on the best kerangas sites, if access is easy and about 2,000 desirable trees can be established at low cost with little or no additional planting. In the present example, the break-even point would be at $96.79 per hectare for the initial silvicultural work.

The situation is somewhat more encouraging, if the same forest is regarded as a going concern of 50 hectares. Each year 269 m³ are thinned or harvested and return US$1,560 in stumpage. The annual expenditure is US$330 in the plantation and US$90 in the natural regeneration system. Again, the opportunity cost of using the land for forestry are excluded. The model of a going concern is only valid in cases in which natural forest is converted to productive, managed forest and the liquidation of the idle capital in the virgin growing stock produces a stumpage return which is at least as large as the expected stumpage from the first managed crop. An excess of the proceeds from the liquidation over the expected returns from the managed crop is a non-forestry mining bonus which may be freely disposed. If the liquidation returns are less than the expected future returns, application of the going concern model during the conversion period is only justified if the liquidation returns at least balance annual costs of managing the future fully established going concern.

The liquidation of the virgin growing stock may realize less revenue than it costs to establish and grow the succeeding crop. This is very likely to happen in the poorer types of kerangas forests, and generally in stands which had been creamed in the past. In this case, at least the part, which is not covered by the net return, must be viewed as a new investment, and compound interests must be charged as in the example in tab. 14b.

Most kerangas sites appear to be sub-marginal not only to agriculture, but also to production forestry. A profit under a natural regeneration system can only be expected under the most favourable conditions. Plantation forestry is financially feasible only if the costs are considered as plow-back and are written off the net return from the harvest of the virgin-growing stock. Whether such a plow-back is economically attractive or not, will depend on the attractiveness of alternative investment opportunities and on the further benefits which accrue at the conversion and processing stages in the forest-based industry.

A further disadvantage to kerangas forestry is the lack of very fast-growing, short-lived and strongly water- and light-demanding early colonizing ephemeral species which are so characteristic of the MDF vegetation. Such species as *Anthocephalus chinensis* (Lamk.) Rich. ex Walp. have no equivalent in the kerangas flora. A substitute could be exotic pine species which have comparable growth characteristics and are adapted to the nutrient and water regime of kerangas sites. *Pinus caribaea* var. *hondurensis* grew very poorly on degraded white-sand savannas in Surinam (VERSTEEGH, 1966), which seemed to be very similar to the coastal white-sand padang in Sarawak. The poor growth has been attributed to the absence or almost absence of soil organic matter. The species grew well in the same general area and on similar soils if the natural forest was removed without destroying soil organic matter. At five years, the tallest trees were 3.2 m in the white-sand savannas, and 4.6 m to over 10 m on cleared but not severely burnt "savanna forest" sites. Planting on the former sites was discontinued in 1959, because the faster growth on the latter sites was expected to compensate for the cost of removing the forest stand which doubled establishment costs. It is likely that this species would produce a very much higher MAI in pulpwood rotations, than *A. borneensis, S. albida* or other "persistent-seral" (DAWKINS, 1965b) species of the indigenous kerangas flora. It must however be expected that exotic pines will be more expensive than indigenes to protect against damage from fire, fungi and insects. The risk of soil degradation under successive pine crops seem particularly great on the lighter sandy kerangas soils and its reduction may require crop alternation or fertilizing, or both.

Site clearing by burning causes loss of soil humus and nutrients especially on porous sandy soils. The dilemma is that retention of part of the original stand as cover and source of litter, and to avoid severe burning, will involve heavy expenditure to reduce competition with the planted crop. Therefore, burning of the area before planting is usually unavoidable to reduce costs. If burning is unavoidable, it must be as light as the objective of weed elimination admits. Planting of exotics and of kerangas species should be supplemented with heavy and concentrated applications of phosphorus and nitrogen to increase initial growth rates. Both nutrients are generally in limited supply on sandy podzols. Fertilizing on the very acid and poorly buffered kerangas soils is risky and success is uncertain. Soluble phosphate fertilizers may be rapidly fixed and become unavailable to trees. Heavy applications of some forms of N such as ammonium sulphate may cause more mineral leaching than others, such as urea. In some kerangas soils, even P may be leached at substantial rates.

If the humus content of the top-soil is at least 2.5%, fertilizing with urea or ammonium sulphate would be feasible on the best types of RYP, GWP and HP soils. At the same time, superphosphate should be added because the amount of available phosphorus in all kerangas soils is very low. Addition of P is essential because the low phosphorus content in kerangas soils is associated with relatively low rates of biological nitrogen fixation. Fertilizing with phosphorus will therefore also improve nitrogen supply. Additional fertilizing with NH_4-fertilizers is advisable in very inactive soils.

One risk connected with fertilizing is that repeated light applications may reduce the root: shoot ratio and increase the tendency to shallow rooting. As a result, susceptibility to drought would increase, particularly in young plants. This side-effect is particularly undesirable on kerangas sites. Water supply is a severely limiting factor on most kerangas sites. Moisture availability may set the level of productivity so low that the economic justification of fertilizing becomes questionable. It is therefore recommended to fertilize in kerangas only on sites with reasonably satisfactory water supply and to use fertilizing only as an initial booster to overcome weed competion and reduce costs for clearing and weeding. The fertilizer should be concentrated near the plant and applied in holes either loose or in perforated plastic bags to ensure gradual release. The possibility that exchange at the absorptive complexes may, in these soils with low buffering capacity, result in unexpected side-effects must be investigated before fertilizers are applied on kerangas soils. In addition, the possibility that serious deficiencies in trace elements exist must be considered. This is particularly important if tree species are planted which are not native to the site.

Recent observations on the early height growth of exotic pines on humus podzol in Sarawak (see sect. 251.2) indicated that mixed nutrients and trace minerals fertilizing improved foliage colour and height growth in some species, but also palatability to termites (PALMER, letter dd. 24.9.1970).

Pinus caribaea was successfully planted on white sand in the Guianas if 50 g NPK were applied to each plant (VIEIRA, 1967). Growth rates of *Araucaria cunninghamii* on extremely infertile sandy podzols equalled those on its native rain forest soils if adequate amounts of phosphorus and, to a lesser degree, nitrogen were given to the plants (RICHARDS, 1965). In Sarawak, trial plantations of *Shorea albida* and *Dryobalanops fusca* in the 6th Mile F.R. showed rapid early growth on moderately to poorly drained GWP and HP over clayey subsoil, but were still too young to judge in 1963. Fertilizer trials were inconclusive. *Agathis borneensis* disappointed in the same plantations probably due to faults in the nursery and planting technique. Older plantations of *Gymnostoma nobile* in the 6th Mile F.R. showed a moderate to poor increment on degraded RYP soils (sect. 262), but disappointed financially because demand and prices for firewood had drastically dropped when the plantations became harvestable. A further disadvantage of *G. nobile* is the acid, tannin-rich and scleromorphous litter which tends to accumulate as acid raw-humus. The use of this species on sensitive soils is risky and inadvisable, unless humus accumulation is desired on degraded soils.

Reliable information on the long-term effect of tree plantations on the soil is scarce for temperate climates. There is practically none available for the equatorial tropics. In East Africa present soil conditions in a sixteen-year-old plantation of *Cupressus lusitanica* and in an adjacent natural broadleaf forest indicated that changes might have taken place. There was more exchangeable hydrogen, less nitrogen and a lower pH under the conifers. The C/N ratio was 13.2 as compared to 12.3 under the indigenous forest. The nitrogen contents may however be equal if the whole soil-litter complex were compared because there is more litter produced by the conifer forests (ROBINSON et al., 1966). Increased nitrogen contents of whole sites have been commonly found in high-yielding pine plantations replacing natural low-yielding eucalypts in Australia, but decline of nitrogen and growth has been observed in second generation pines and associated with a complex of manifold changes involving biotic and abiotic components of the ecosystem (FLORENCE, 1967; BUNN, 1967). Similar changes in organic matter content and associated changes in soil moisture and nutrients have been observed from time to time under plantations or single trees in savannas, especially in Africa. In India, stronger podzolization as a result of higher soil moisture and lower soil temperature and pH is said to have followed the replacement of dry deciduous forests by more mesic forest types on borderline sites near Chittagong (GAHNI, 1966). The only observation of soil changes under introduced species in Sarawak concerns increased bleaching of the top-soil under *Gymnostoma nobile* and the development of a secondary humus podzol under *Dacrydium pectinatum* in SP. 17. Risk of such changes will always arise if a species is introduced to a new site. In this respect, the difference between mixed and pure plantations is only by degrees and mixing species does not eliminate risks.

Available information is inadequate to assess the ecological consequences of timber plantations on kerangas. More information on plantation ecology and species performance on these and related marginal MDF soils must be supplied by research before an answer can be given to the question whether profitable production forestry on kerangas is ecologically possible. Similarly badly needed is information on private and social costs — benefit ratios in natural and plantation forestry on kerangas sites. Without this information land-use planning and development will remain a gamble with unknown odds. Almost nothing is known about risk levels in different silvicultural systems and on different sites in kerangas. Some species, such as *Shorea albida,* have a significantly higher ratio of heart rot on wet GHP and on heavy GWP clay soils than on well-drained HP soils. Susceptibility to wind-throw seems also to be greater on these soils. It is likely that similar hazards will develop in plantation on these sites. Similarly, the widespread fatal defoliation of *Shorea albida* in natural stands mostly of type 37 is a warning that similar risks may be high in any monoculture in Sarawak. We have discussed earlier (sect. 226) that certain forms of stand structure and stand physiognomy are associated with certain sites. There is strong indication that stand physiognomy and structure affect matter and energy exchanges and are adapted to site conditions. In consequence, the choice of species and of stand structure must consider the energy and matter regime of the site. In kerangas, moisture regime and exposure are of particular importance in this respect. Complex structures, such as a selection forest, with noto-mesophyll physiognomy can only be supported by sites with a well-balanced moisture regime and with adequate supply of water to the stand. Peat bog sites and periodically dry sites limit the choice of species to lepto-nanophylls (e.g., *Gymnostoma, Dacrydium*) and specially adapted noto- or mesophylls (e.g., *Shorea albida*). At the same time simple-structured uniform stands with smooth canopy surface are preferable on these sites which reduce the impact of environmental factors (radiation, wind) on the stand and on single trees.

Site classification and selection of the most productive sites for plantations cannot be based on the volume of the growing stock in the natural forests. Basal area, density, height and size of timber and species composition are only loosely correlated with apparent soil fertility in kerangas and PSF. Decisions on siting of plantations must therefore be based primarily on physiography, soil type and stand structure and stand health. Growing stock volumes in natural forests may be considered in addition, but they are of limited value in forecasting site productivity in managed forests. The commercial volume in the natural growing stock is a more important factor in the pre-investment analysis of the financial feasibility of converting the primary forests into managed production forests. We have been introduced to this problem earlier in this section.

So far we have only considered the role of kerangas forests as timber producers. With continued social and economic development other functions of the forests will attain importance which locally may exceed timber production. Kerangas forests like other forest types protect soils from erosion. They even discharge water from the site. This function is particularly effective on shallow soils. The consequences of indiscriminate removal of the forest cover from such soils can be observed on the rock padang of Bako N.P. where the whole solum has been lost after destruction of the original forests.

Recreational use of forests in scenic areas will rapidly increase, especially in the first division which is becoming more rapidly urbanized. Forests on the light-textured podzols and podzolic soils offer particular attractions in this respect. The predominantly kerangas-type vegetation in Bako N.P. is certainly an additional attraction to visitors. The stand climate in kerangas is drier than in most other lowland forest types. This and the generally good access and easy, well-drained terrain make the sandy podzol sites in the tropical lowlands generally more suitable for recreation and scouting than more mesic forest types. The kerangas as absolute forest site also will be an important factor in landscaping with the aim of optimum overall combinations of production and service functions.

The ecosystem on tropical HP and GWP soils is extreme in its energy and matter regimes. Consequently, physio-ecological reactions of plants and vegetations can be observed *in situ* which would be excessively costly to simulate in experiments. The interaction between plant species and plant individuals and between plant and animals are strongly accentuated on the kerangas sites. The kerangas ecosystem reacts more rapidly and drastically to interference by man, than ecosystems on LS and RYP soils which have a wider latitude for modification, compensation and reserve mobilization. The ecosystems under the marginal conditions of tropical HP, GWP, PG and PB soils offer therefore unique opportunities for research. The tiny amount of research on tropical podzol ecosystems in the Guianas, in Amazonia and in Borneo have already contributed important knowledge to the understanding of forest ecology generally. The protection of natural ecosystem on kerangas is essential if this research is to continue and possibly expand.

ASHTON considers the creation of permanent natural forest reserves an urgent necessity because these reserves offer opportunities: (1) to continue research, (2) to provide refuge for species threatened with extinction, (3) to provide educational facilities, and finally (4) to provide recreation. The preservation of permanent natural forest reserves containing all types of natural forest throughout the tropics has been a subject of concern of the International Biological Programme.

A general model of strategies of land use on kerangas and kerapah sites is out-lined in tab. 15. The suggested strategies are based on the more important site characteristics: (1) natural site productivity, (2) protection value, (3) recreation and scenic value, (4) accessibility, (5) ease of natural regeneration. It does not incorporate alternative political preferences. It is largely forestry orientated and does not fully demonstrate potential alternatives for the use of sites within a scheme of comprehensive land use development. The major concern is to indicate the potential and limitations of land use on kerangas in a manner related to the individual site.

A kerangas site with high productivity is capable of yielding at least 8 t/ha/yr NAAP of wood. This will produce a harvestable wood fibre yield of about 5 t/ha and about 2.5 t/ha (approx. 4.5 m^3/ha) merchantable bole-wood. High protective value means that removal of the vegetation and burning will be followed by heavy erosion of the top-soil. This will certainly happen on sandy HP and GWP soils along terrace edges and on slopes which are steeper than 5°. Heavy clay PG soils are similarly susceptible. Sandy loams to clay loams in kerangas have a somewhat more balanced texture and more stable structure. They will suffer exposure on somewhat steeper slopes to about 10° without destructive erosion.

Recreation and scenic value are difficult to quantify in an objective manner. Appreciation of forests in these respects differs between people and varies with time in relation to general changes in culture and value scales. For the present purpose, recreational and scenic value are considered high if the forest satisfies the majority of people who enjoy recreation within the forest, or its sight from without. A well-illuminated and airy pole forest or a more irreguar Agathis-bearing stand may rate equal to any type of forest which only serves as a background feature in an otherwise open landscape.

Accessibility includes aspects of internal and external accessibility. "Good accessibility" means that the stand contains flat to low hilly ground and is surrounded by country which provides easy access by navigable river or road. "Poor accessibility" means that the area is itself hilly to mountainous and that access to the stand by navigable river or by road does not exist and cannot be provided at presently available means.

Natural regeneration is easy, if a satisfactory second crop can be established at such low cost, that the calculation of the internal rate of return at present cost, prices and yield expectations indicates a satisfactory return in relation to alternative investments. Difficult natural regeneration means that costs of establishment are so high that the internal rate of return is below the rate for alternative investments (BRUNIG, 1970c).

The suggested general strategies indicate broadly possible policies in pursuing the goal of optimum land use. Plantation forestry is restricted to two site classes, both of low protective and scenic value but of good accessibility. The one is a highly productive site, the other is poor. Timber production is suggested only for highly productive and accessible sites. The accessible, but poorly productive sites may be suitable for production forestry, if amelioration is cheap, simple, effective and feasible. All other sites with poor productivity are at most suitable for Protective Forest or National Parks. On some sites, only exploitation forestry

CHAPTER 3

THE FLORA

Altogether 849 tree species have been recorded and collected during the kerangas study. The total number of tree species on kerangas and kerapah sites in Sarawak and Brunei is probably above, but possibly not much more, than 860 (BRUNIG, 1972). The number of species is considerably less in PSF in which ANDERSON (1963) recorded 242 tree species. MDF is much richer in species than the two other groups together. 712 tree species above 10 cm d were recorded by ASHTON (1964c) in the Andulau and Belalong plots alone. The total number of three species in MDF appears to be about 2,000, assuming that the Dipterocarps represent about 10 to 15% of the number of all tree species. ASHTON (1968) records 221 Dipterocarp species in Sarawak.

Tab. 16 shows the distribution of number of individuals and of basal area among the sixty-nine tree families recorded in fifty-five sample plots, excluding twenty tree species of which even the family could not be determined. The Myrtaceae have the largest number of individuals (583.8 per ha, 15.3% of the total number of individuals). Second are the Dipterocarps (501.5, 13.2%) followed by the Sapotaceae (384.3, 10.1%) and Euphorbiaceae (199.5, 5.2%). The Dipterocarps have the largest basal area (9.42 m^2/ha, 25.8%), but they are much less dominant in kerangas than in the MDF. FOX (1967) for example reports that Dipterocarps represented 16.6% of all individuals above 10 cm d in 7 ac. of MDF in Sabah, and 40-100% of the individuals above 50 cm d. Euphorbiaceae were the second most abundant family with 13.6%.

The dominance of Dipterocarps along the X-axis of the ordination is largest near the centre. It declines in the region of the Agathis borneensis-stands at the left and in the Dacrydium-Gymnostoma nobile-stands at the right. On the Y-axis, the basal area dominance is lowest at the centre and increases downwards into the MDF and upwards into the single-dominant Shorea albida-forests. Second most dominant are the Coniferae with four families (4.01 m^2/ha, 11%), followed by the Myrtaceae (3.89, 10.7%), Sapotaceae (3.26, 8.9%), Guttiferae (2.85, 7.8%), Casuarinaceae (1.56, 4.3%), Anacardiaceae (3.7%), Euphorbiaceae (2.6%) and Leguminosae (2.4%). The eight families and Coniferae together account for 77.2% of the basal area in the fifty-five plots.

Family representation differs between the three stand strata A, B and C. The Dipterocarpaceae, Anacardiaceae and the Coniferae have a greater number of species in the A-layer than in B or C. The Guttiferae, Lauraceae, Myristicaceae, Myrtaceae, Thymelaeaceae and Sapotaceae have the largest number of species in the B-layer. The typical understorey families Annonaceae, Euphorbiaceae, Rubiaceae and Theaceae — Ternstroemieae have the greatest number of species in the C-layer. Together with the B-layer species, they also dominate in the regeneration layer of trees with less than 1 cm d.

The number of shrub species is small. Shrubby, terrestrial Ericaceae are an important element of the open padang at high altitude (SP. 57-1), and also are abundant on exposed coastal cliffs (BRUNIG, 1957a and 1959). Palmae are common in the undergrowth on moist sites and are locally good site indicators. (BRUNIG, 1965). Rubiaceous and melastomataceous shrub species occur throughout the kerangas forests. *Podocarpus neriifolius* occurs as shrub in the C-layer of some coastal kerangas, but is an emergent tree at high altitude (SP. 41). Some, especially myrtaceous, tree species grow into a more shrubby life form under extreme environmental conditions on open padang or exposed rocks where they are part of the main canopy of the scrubby vegetation. The most conspicuous shrubby Myrtaceae is *Baeckea frutescens* which is locally common in open lowland padang and on exposed sandstone rocks at high altitude.

Herbs are generally rare and become abundant only locally on wet, riparian sites and in montane open woodlands. Epiphytes are not common. Usually they are rare in kerangas forest. Only locally epiphytes abound on certain tree species in open vegetation and at high altitude. Lianas are rare. *Nepenthes* are locally common on peaty or open sites, especially at high altitude.

An annotated list of all recorded 849 tree species, 133 shrubs, ninety-six herbs, 100 epiphytes and fifty-five lianas in kerangas forests has been published as vol. 2 of "Der Heidewald von Sarawak und Brunei" (BRUNIG, 1968). Revisions since, especially of Coniferae, and a few additional new descriptions made this list obsolete in some parts. A new edition in the English language is planned and will be published in due course.

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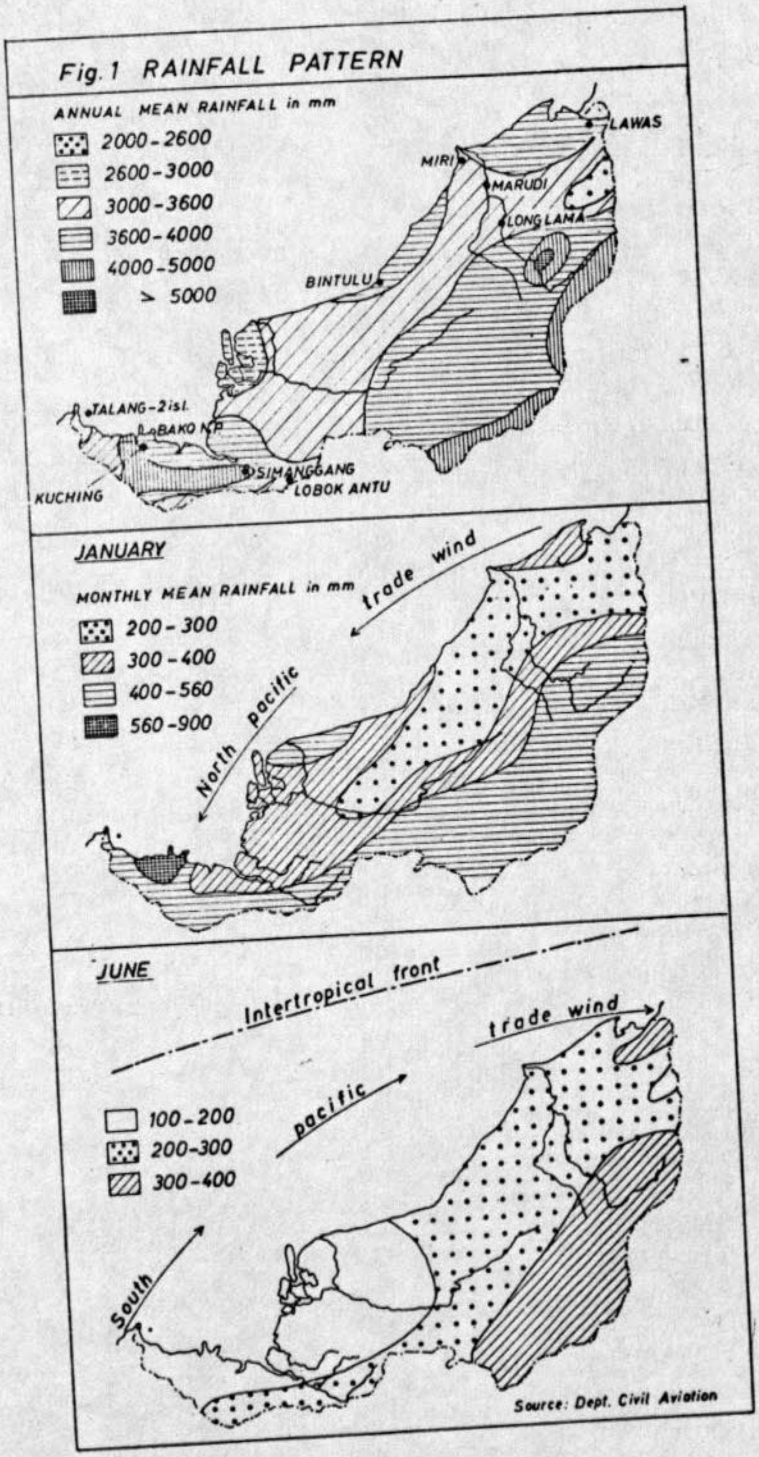


Fig. 1 RAINFALL PATTERN
ANNUAL MEAN RAINFALL in mm
2000-2600
2600-3000
3000-3600
3600-4000
4000-5000
> 5000
LAWAS
MIRI
MARUDI
LONG LAMA
BINTULU
TALANG-2 isl.
BAKO N.P.
SIMANGGANG
LOBOK ANTU
KUCHING
JANUARY
MONTHLY MEAN RAINFALL in mm
200-300
300-400
400-560
560-900
trade wind
North pacific
JUNE
Intertropical front
trade wind
pacific
100-200
200-300
300-400
South
Source: Dept. Civil Aviation

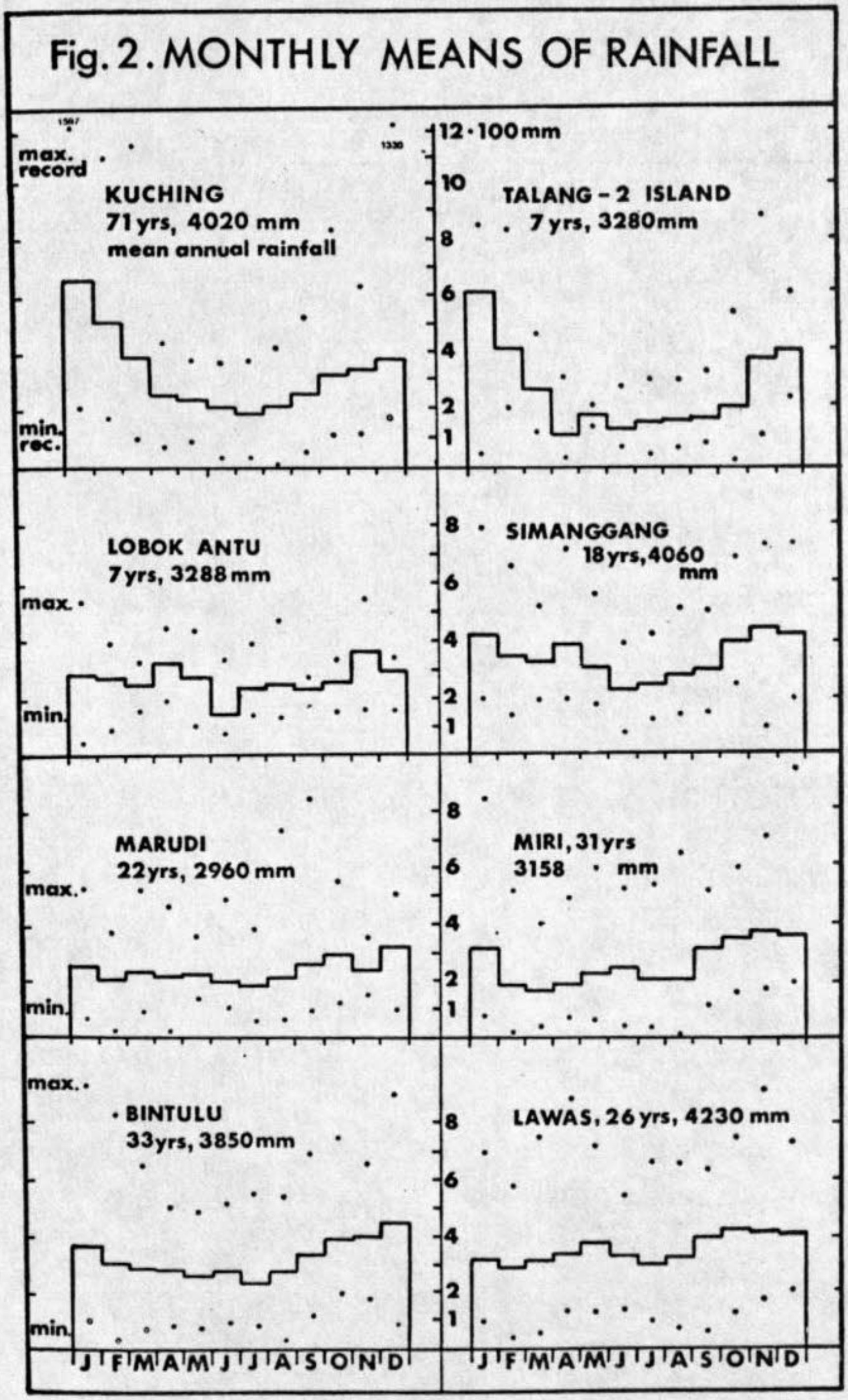
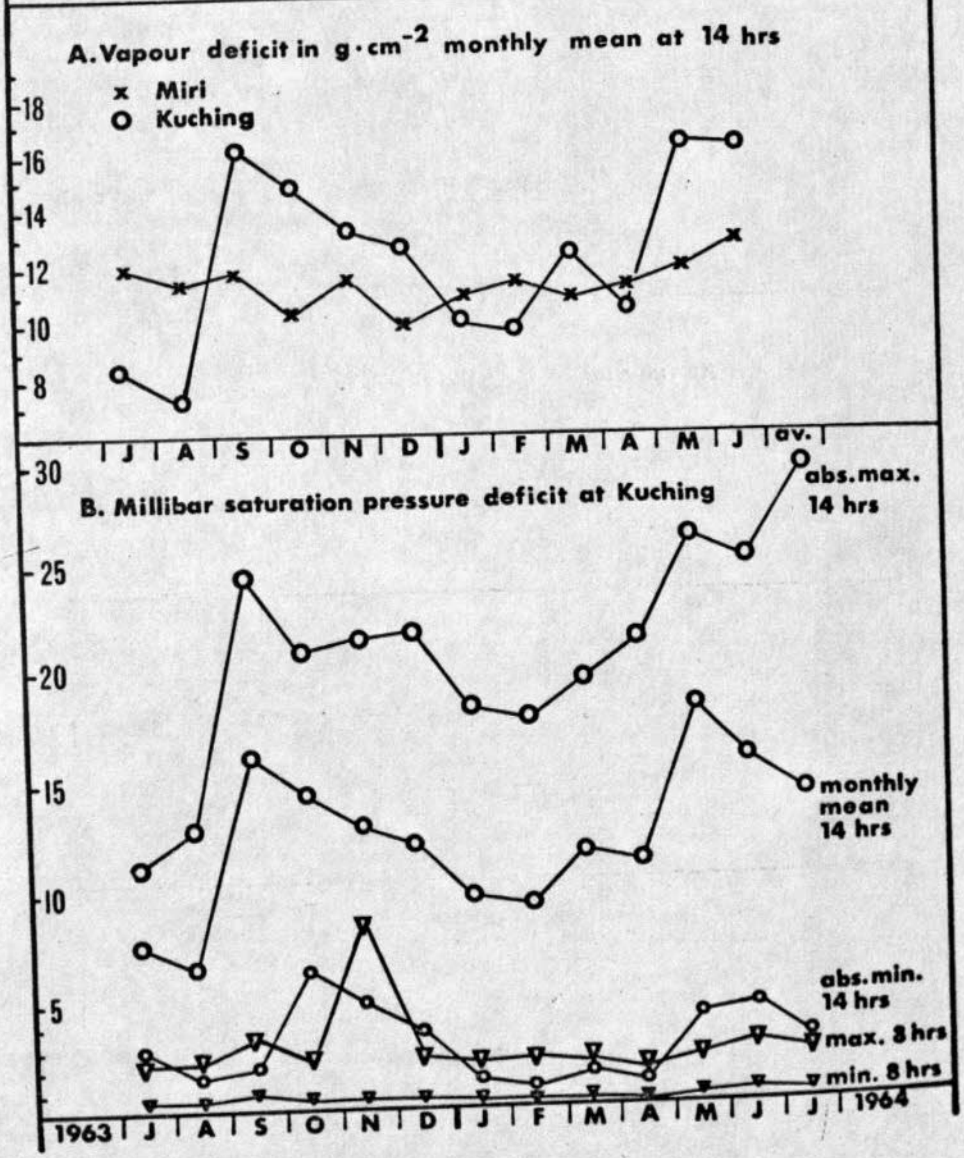


Fig. 2. MONTHLY MEANS OF RAINFALL
12·100mm
10
8
6
4
2
1
max. record
min. rec.
KUCHING
71 yrs, 4020 mm
mean annual rainfall
TALANG - 2 ISLAND
7 yrs, 3280mm
LOBOK ANTU
7 yrs, 3288 mm
SIMANGGANG
18 yrs, 4060 mm
MARUDI
22yrs, 2960 mm
MIRI, 31yrs
3158 mm
BINTULU
33yrs, 3850mm
LAWAS, 26 yrs, 4230 mm
max.
min.
J F M A M J J A S O N D

Fig. 3. SATURATION DEFICIT 1963/64



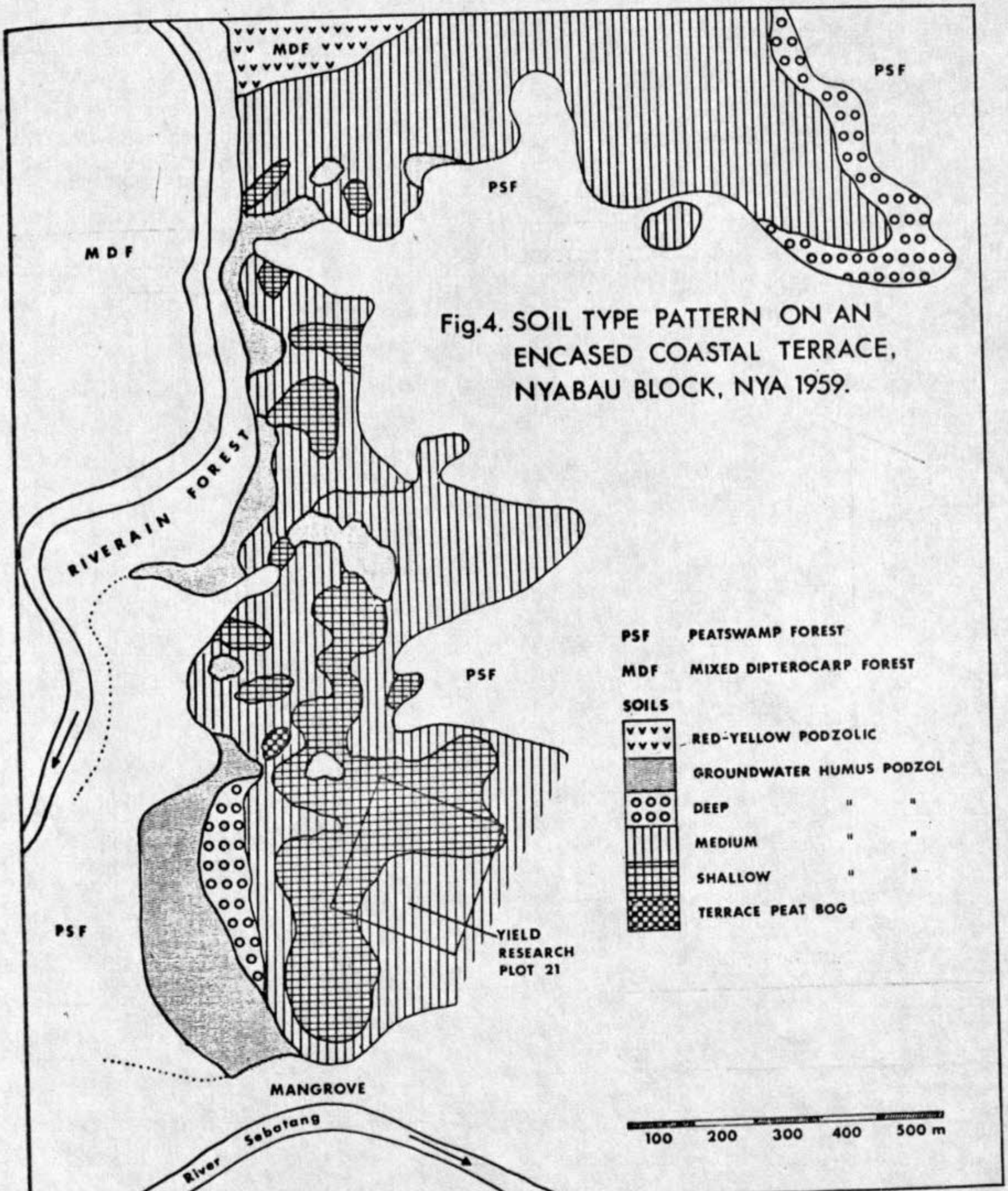
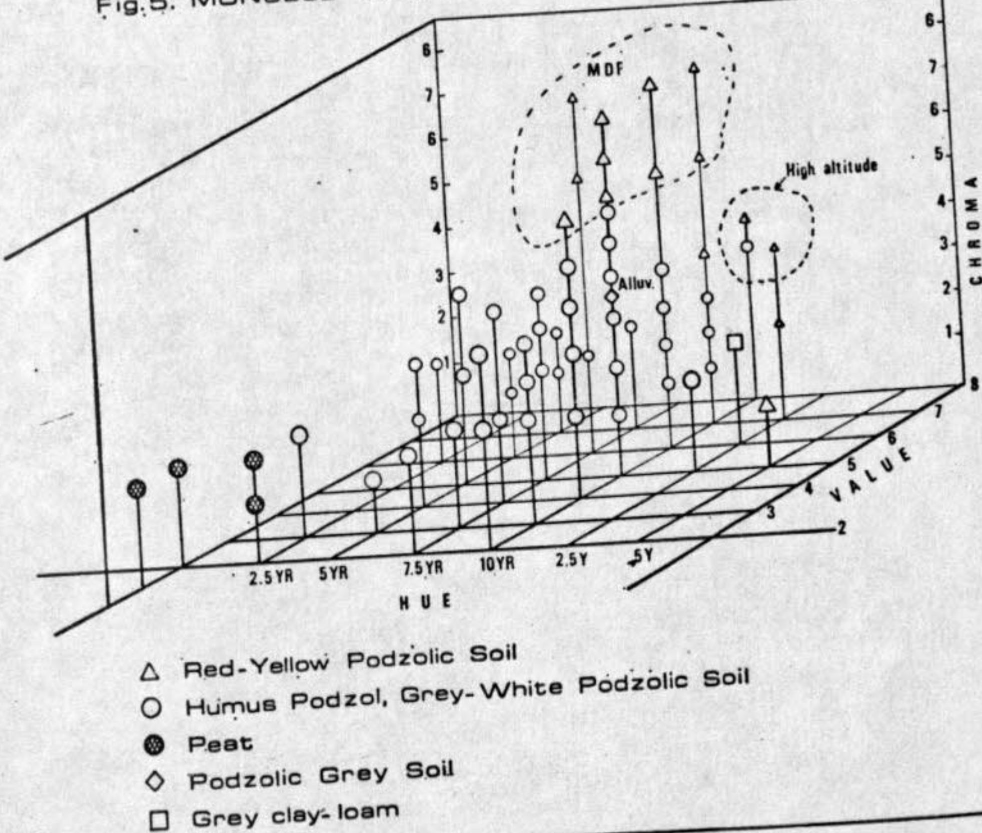


Fig.4. SOIL TYPE PATTERN ON AN ENCASED COASTAL TERRACE, NYABAU BLOCK, NYA 1959.
MDF
MDF
PSF
PSF
PSF
PSF
RIVERAIN FOREST
YIELD RESEARCH PLOT 21
MANGROVE
River Sebatang
PSF PEATSWAMP FOREST
MDF MIXED DIPTEROCARP FOREST
SOILS
RED-YELLOW PODZOLIC
GROUNDWATER HUMUS PODZOL
DEEP " "
MEDIUM " "
SHALLOW " "
TERRACE PEAT BOG
100 200 300 400 500 m

Fig.5. MUNSELL COLOUR NOTATIONS IN 20cm SOIL DEPTH



6: SAND - SILT - CLAY RATIOS AT 20cm SOIL DEPTH

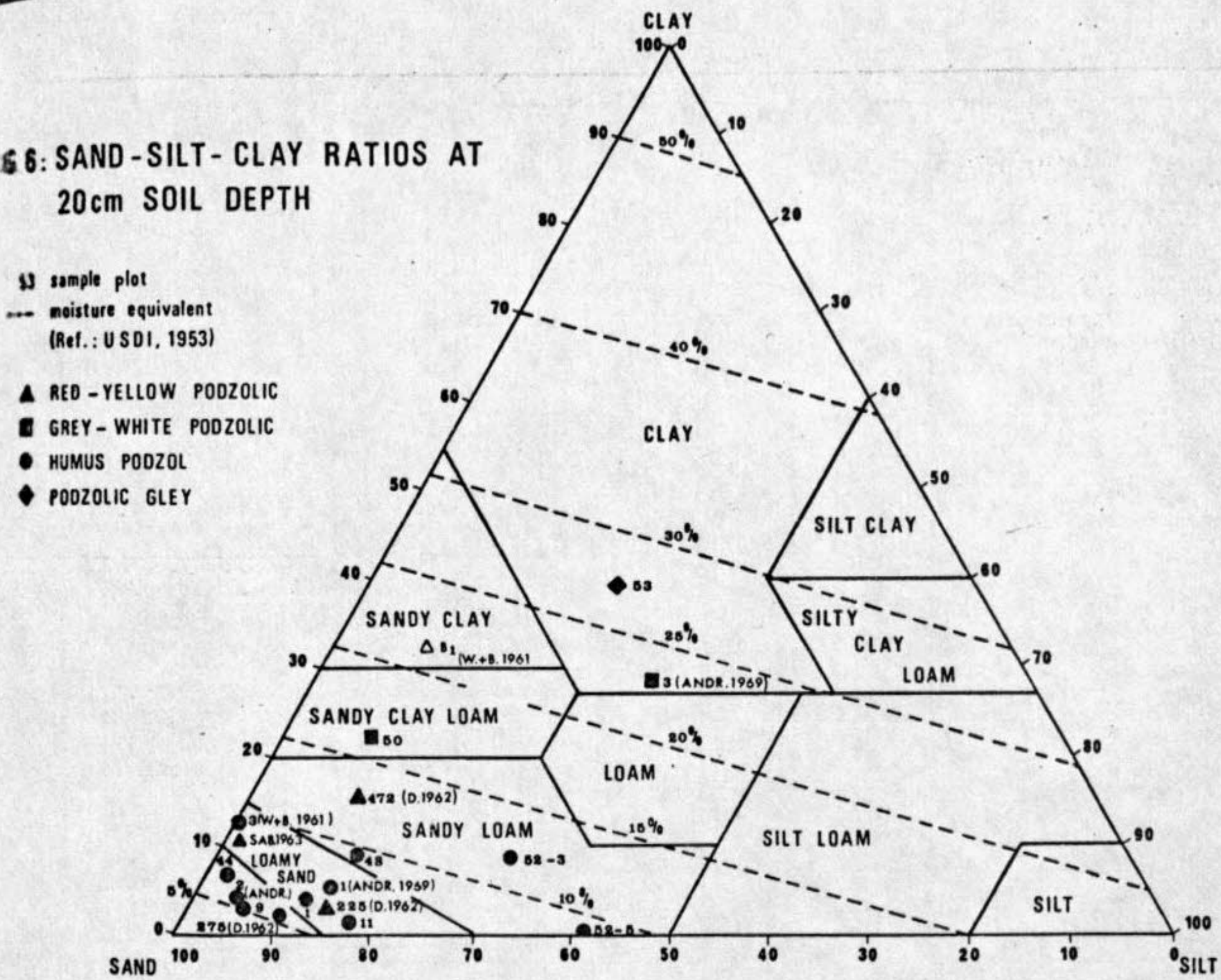
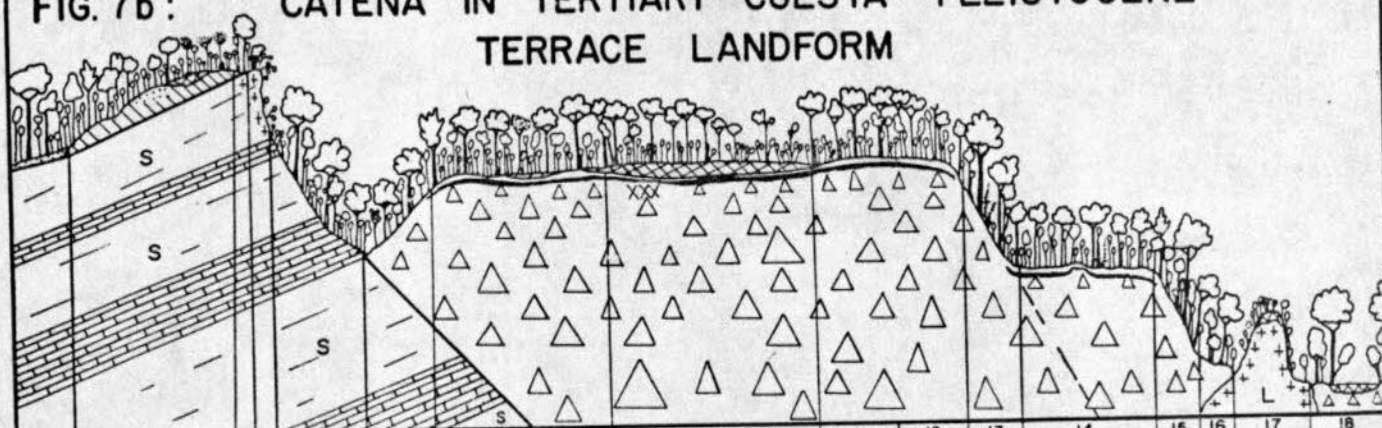


FIG. 7a: CATENA IN COASTAL LANDFORM

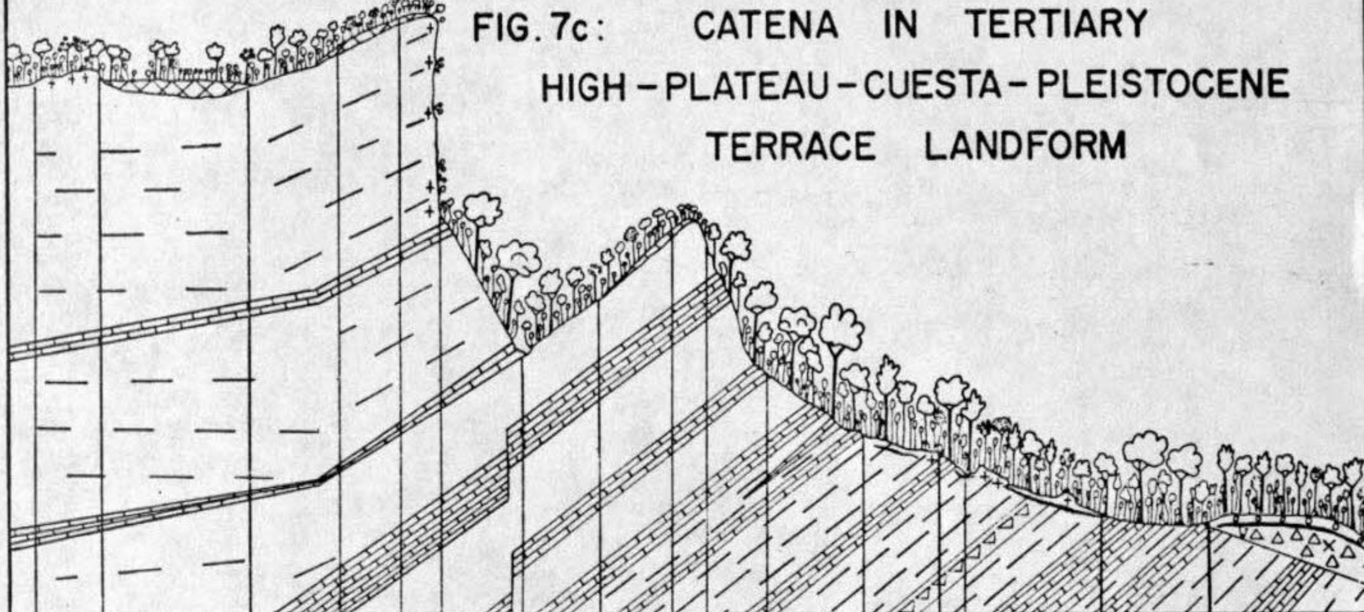
Nr:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
IDI	<20	20 - 30	35.9	33.5 — 40.6				34.7		—	64.5	65.7 — 39.3	30-40	>100	
TYPE	BEACH	KERAN.	KERAPAH	KERANGAS	KS	KS	KS	KS →		KERAPAH	KS	M.D.F. → KS	R.T.	M.D.F.	KS
SOIL	S.	G.H.P.	P.B.	D.H.P.→M.H.P.→D.H.P.	G.W.P.	M.H.P.	G.W.P.	D.H.P.→M.H.P.→P.B.→S.H.P.→M.H.P.				R.Y.P. → S.H.P.	GWP	L.S., R.Y.P.	R.Y.P.
Sample Plot		46	2, 4, 47.	22 - 26, 45. 43	14	7		20.	21.	44	14	-13, 38, 39. 48. 49	50	10, 12,	
Typical species, genera or families	Cas. equis. Cal. inop. Term. cata.	Shorea materi. Dryob. rappa Sapot. Guttif.	S.alb. S.pach Dr.rap Caloph. spp. locally Gymno. nobile	Agathis borneen. Shorea material. S. albida S. retusa S. ovata Hopea ? vaccin. Dipterocarpus borneensis	Dry. rap. Ani-sopt gros	D.born Dryob. fusca S.alb. Gymn. nobile Agath. born. Melan. inapp.	Neesia m.W. moult.	Dryo. becc. Dipt. pach. Anis. gross Sh. spp. Agath born.	A.born. D.born. Shorea havil. S.ovata	S. albida Poiarium alternif. Whiteodendr. moutonian.	Dac.pectin. Gym. nobile Hopea pentaner. Koomp.mal.	Agathis borneen S.ovata S.pallidif. D.borneen. D. pachyph. Cotyl. burckii Vatica spp. Gymnostoma nob. Dacr. pectinat Falcatif. angu-stum	Cot.bur. C.mal.	Dipterocarpacea var.	as in col 10

FIG. 7b : CATENA IN TERTIARY CUESTA – PLEISTOCENE TERRACE LANDFORM



No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
C. or C. SP.	Dipt. var	G. nobile T. obovata S. revoluta S. coriacea S. ovata Cot. malayanum D. crinitus (left) A. borneens (left)	Dryob becc.	Podoc sp. c. mal	Dipt. var. Dr. arom	Dipt. var. S. hypo-chra	S revol. S ovata Upuna b. D. lowii D. crin.	A. borneens. D. borneens. S. multifl. S. ovata G. nobile Cot. burckii Pal. leioc.	S. albida S. ovata Palaquium spp Calophyll. spp. Litsea spp. G. nobile	S. albida Melanorrhoea beccarri Calophyllum spp. Pal. ridleyi Gonystylus spp. Lophopetalum rigida Combretocarpus rot. Mesua spp.	S. albida M. becc. P. ridl S. scabr. G. nobile Dac. pect. Stomon. spp.	S. albida G. nobile Pal. ridl. S. coriac. D. pachyph. Cot. burck.	S. rev. S. ova. D. pach D. crin. Dryo. becc.	S. albida Copaifera pal. Mesua caloph. Engelhardtia serrata. Santiria rubi. Hop. pentan. Cal. fragrans. Ganua curt.	S. rev. D. lowii S. ova.	Alst. sp. D. var.	G. nobile Vatica spp.	S. semin.
I.D	>80	45·2 → 27·2	60	<20	> 100		80–100	70 → 30		25 → 35	40	40 — 70	± 90	34·8	80	100	< 30	± 80
F.T	4	KERANGAS		R	M. D. F.			KERANGAS		KERAPAH	KERANGAS		M.D.F.	KERANGAS	M.D.F.		LIME	RIVER.
SOIL																		
S.T.	RYP	M.H.P. + G.W.P	G.W.P.		LAT.		R.Y.P.	M.H.P. → P.B. →			M.H.P		R.Y.P	M.H.P. + P.B	R.Y.P.	G.	MOR	G.
FO	T.S	PENEPL. C. REMN.	TERT. SANDST.				EARLY PLEISTOCENE TERRACE				JERUDONG CYCLE			MID. P. T.	→ ALL.		CRET.	REC. AL.
EX	SA	S.P. 33; 40	34	SA	-	-	MED	MELINAU — INGEI		S.P. 32; 29; 31	S.P. 28			S.P. 30;20	S.P. 36;37		SER 1-6	—

FIG. 7c: CATENA IN TERTIARY HIGH-PLATEAU-CUESTA-PLEISTOCENE TERRACE LANDFORM



No:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
C. C. SPP.	Dac. Spp. Pal. spp. Trist. obov.	Tristania obovata S. albida Diospyros evena G. nobile Ploiarium altern. Palaquium spp.	A. enderti Cal. mal. G. nobile Dac. spp. S. monticola S. ovata V. brunigi Pal. spp	Dac. spp G. nobile Tristania ellypt Vat. sp nov. S. retusa	Dac. spp. Podoc spp Pal. spp. Vacc. spp.	Dr. beccarii S. spp. D. spp.	Dr. rappa T. obov. S. coriac. S. ovata Pal. spp. Hop pent. Locally A. born	Cal. mal. G. nobile T. ellypt. Pal. rost. Dr. rappa Hop. pent.	Trist anom Cal mal. Dac. spp. Vacc. spp.	Dryob. lanc. Dipt., varia	Dr. beccarii S. scaberrima S. inappend. S. beccarii S. quadrin. S. crassa D. confert. Anis. marg	A. born. S. pallid. S. scabr. S. ovata G. nobile D. born. Cal. burck. Cal. mal.	S. elly. D. pach	D. borneensis A. borneensis G. nobile S spp., Mal spp. Koomp. malacc. Pholidocarpus maj Vat. coriacea Cal. melanox.	S. inappendic D. varia Scorod. borneens.	A. borneensis G. nobile H. pentanerria S. scabrida S. retusa S. havilandii D. borneensis
I.D.	47·8	22·9 – 27·2	37·7–55·2	<20	<20	80–100	65·7–43·8	55 – 25	<20	>100	> 100	39·3-43·8	90	40 — 55	> 100	40 — 65
F.T.	KS	KERAPAH	KS	KH	MF	MDF	KERANGAS		RF	M D F		KS	M.D. F.	KS	MDF	KS
SOIL	S.H.P.	P.B.	G.W.P.	B.B.	P.G.	R.Y.P.	G.W.P.	G.W.P.	G.W.P.	Lat.	R.Y.P.	H.P.	RY.	S+M. H.P.	R.Y.P.	M.H.P.
ALT		600 – 700	700	⟶	1200	⟶ 200 ⟶ 500				500 ⟶ 100		100 ⟶ 50			50 ⟶ 40	50 ⟶ 30 m.
FO	TERTIARY BELAIT, MELIGAN OR PLATEAU SANDSTONE										TERTIARY SILANTEK OR NYALAU FORM					PLEIST. TERR
EX	S.P.51	S.P. 40; 55; 57	41; 42 52; 53; 56	54	SK		38; 39	SANGIT	B.P.		SABAL, 1963; S.P. 39; 48; 49; 50					S.P. 14; 20; 47

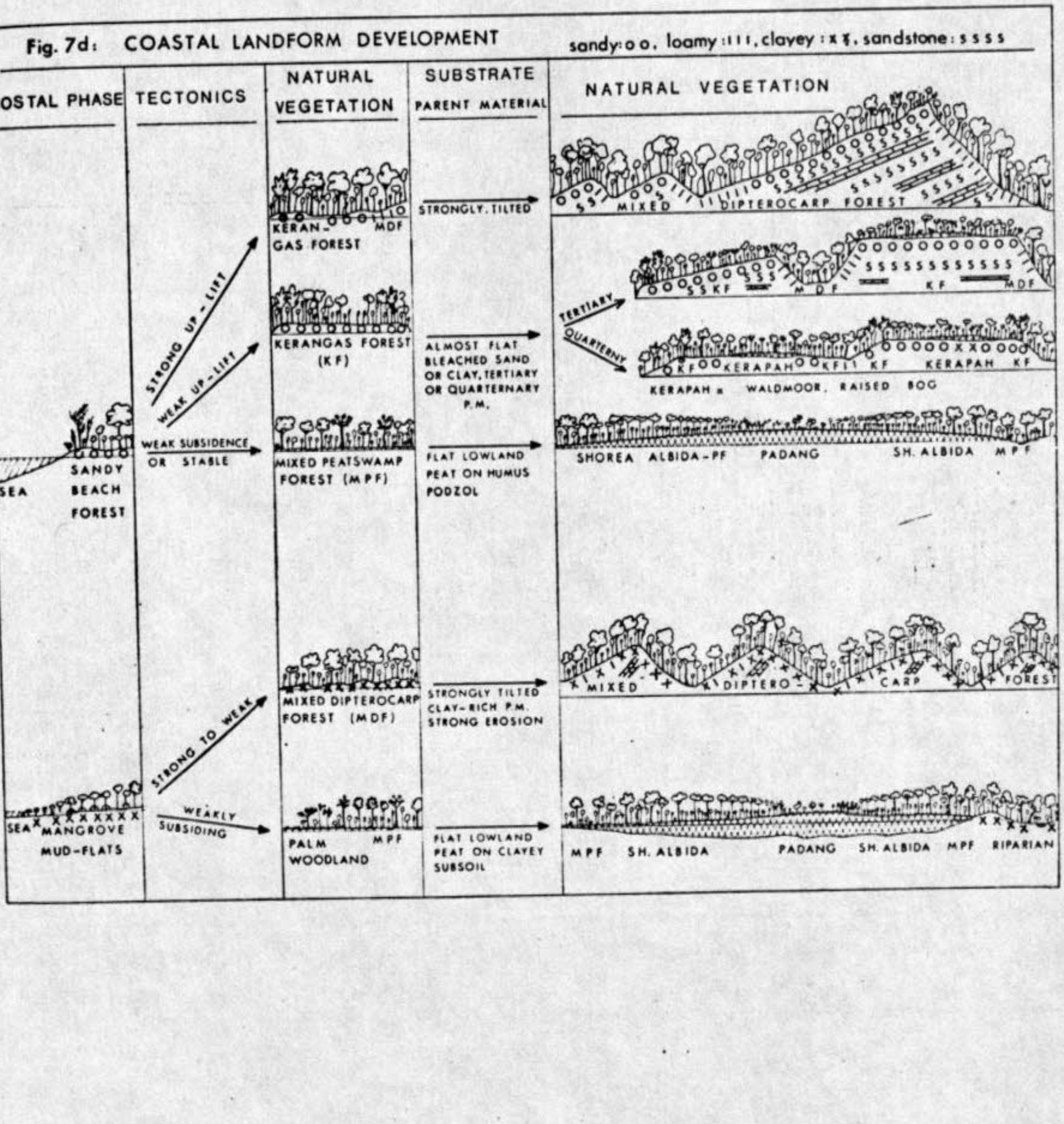


Fig. 7d: COASTAL LANDFORM DEVELOPMENT
sandy: o o, loamy: I I I, clayey: x x, sandstone: s s s s
COSTAL PHASE
TECTONICS
NATURAL VEGETATION
SUBSTRATE PARENT MATERIAL
NATURAL VEGETATION
KERAN-GAS FOREST
MDF
STRONGLY TILTED
MIXED DIPTEROCARP FOREST
KF
MDF
TERTIARY
QUARTERNY
STRONG UP-LIFT
WEAK UP-LIFT
KERANGAS FOREST (KF)
ALMOST FLAT BLEACHED SAND OR CLAY, TERTIARY OR QUARTERNARY P.M.
KF KERAPAH KF KF KERAPAH KF
KERAPAH = WALDMOOR, RAISED BOG
SEA
SANDY BEACH FOREST
WEAK SUBSIDENCE OR STABLE
MIXED PEATSWAMP FOREST (MPF)
FLAT LOWLAND PEAT ON HUMUS PODZOL
SHOREA ALBIDA-PF PADANG SH. ALBIDA MPF
STRONG TO WEAK
MIXED DIPTEROCARP FOREST (MDF)
STRONGLY TILTED CLAY-RICH P.M. STRONG EROSION
MIXED DIPTERO- CARP FOREST
SEA
MANGROVE MUD-FLATS
WEAKLY SUBSIDING
PALM WOODLAND
MPF
FLAT LOWLAND PEAT ON CLAYEY SUBSOIL
MPF SH. ALBIDA PADANG SH. ALBIDA MPF RIPARIAN

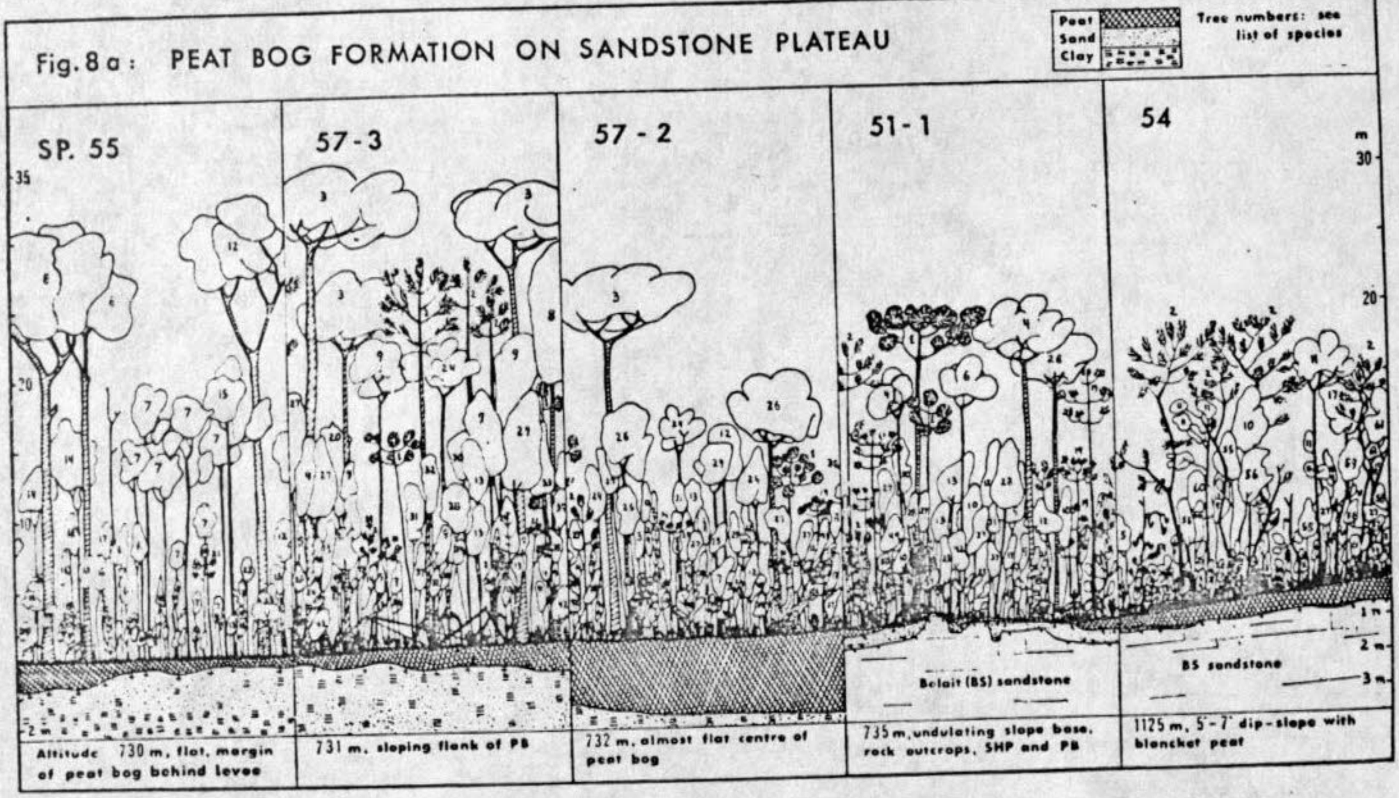


Fig. 8 a : PEAT BOG FORMATION ON SANDSTONE PLATEAU
Peat
Sand
Clay
Tree numbers: see list of species
SP. 55
57-3
57 - 2
51 - 1
54
m
30
20
35
20
Belait (BS) sandstone
BS sandstone
1 m
2 m
3 m
Altitude 730 m, flat, margin of peat bog behind levee
731 m, sloping flank of PB
732 m, almost flat centre of peat bog
735 m, undulating slope base, rock outcrops, SHP and PB
1125 m, 5°-7° dip-slope with blanket peat

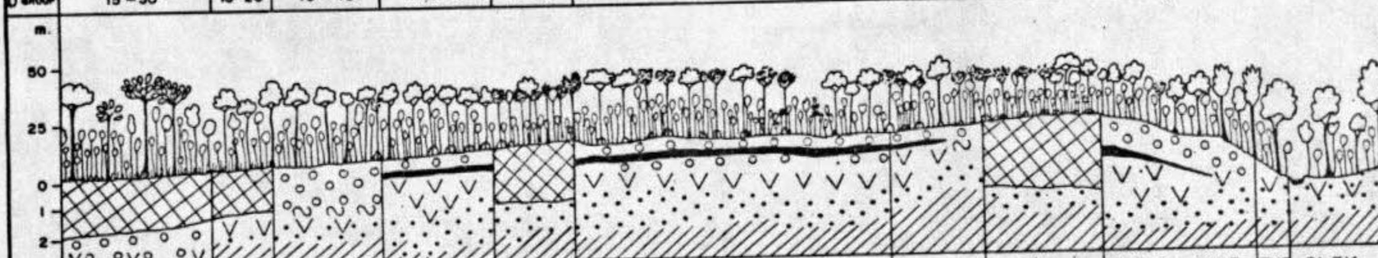
FIG. 8b: DALAM TERRACE CATENA

Length 2·5 Km   Distance from beach approx. 3 Km

Altitude 20 – 30 m   Levels by WOOD, 1965

W   E

FOREST TYPE	3·3	3·1	5·1 w	5·1 d	5·1 p	5·1 d			5·1 m	5·1 p	5·2	4·1	6·1
H. Top	30 – 45	30-35	30–35	25 – 30	23-26(30)	29-31 (em. 35)	15	± 30	30–35	25–27(33)	25–30 (em. 45)	45	25 – 45
Dx	5 – 20; 11 – 15	10–12	7 – 12	5 – 10	5 – 9	5 – 9; 6 (10)	1-3	5–10	5 – 10	3 – 7 (10)	5 – 12	10-16	15 – 20(25)
Dgaps	30 – 50	10–20	10 – 20	10 – 15	< 10	10 – 20	0	10–20	< 10	10 – 20	15 – 25	–	30 — 50
Dgroup	15 – 30	15–20	10 – 15	N. D. G	N.D.G.	NO DISTINCT GROUPS			N. D. G.	15	20	–	30 – 50



S.G.	PEAT-SW.	P.B.	G.W.P.	M.H.P.	P.B.	M. H. P.; Locally G.W.P.			M.H.P/G.W.P.	P. B.	M.H.P – G.W.P.	RYP	GLEY
MOI.	WET	WET	WET	DRY	WET	ALTERN. DRY – WET			MOIST	WET	MOIST	M.	WET
COM. or CHAR SPP.	Alstonia pneum. Campnosp. squam.	Dry. rappa Comb. rot.	Dr. rappa S. pachyph G. nobile	S. albida D. rappa Mel. spp.	G. nobile S. albida Caloph. spp. Nepenthes.	S. albida, S. longifolia G. nobile, Melanorrhoea spp. Dac. pectinatum Sapotaceae, Guttiferae.			S. albida Dac. pect. G. nobile Sw. glauca	G. nobile S. albida Dac. pectinatum. Cal. spp.	A. borneensis S. albida Dac. pectinatum. D. borneesis	D. pach Dipt. vario	Alluvial mixed FLORA

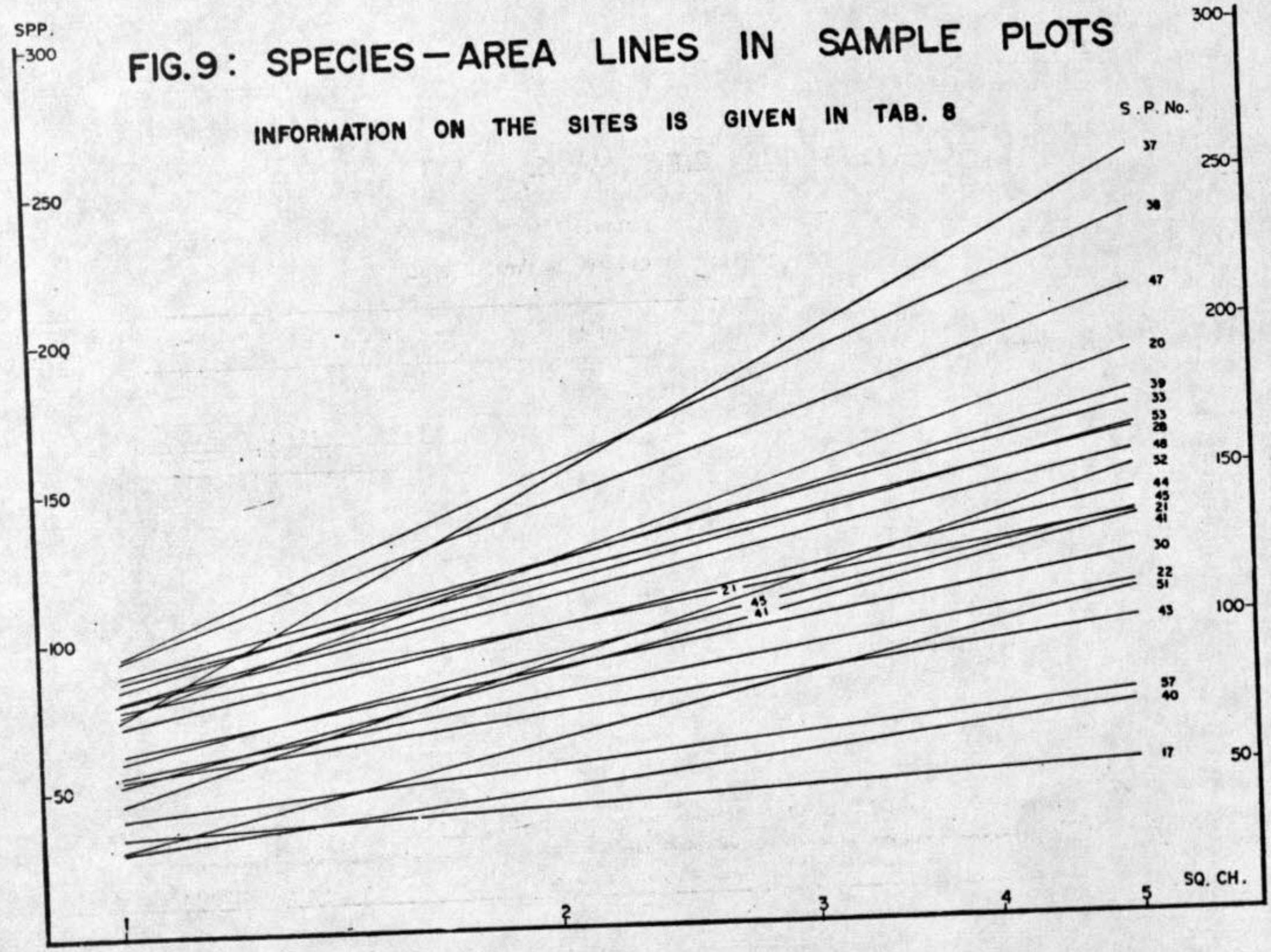


FIG. 9: SPECIES-AREA LINES IN SAMPLE PLOTS

Fig. 10a. DIVERSITY INDEX OF 27 SAMPLE PLOTS (17 – 57)

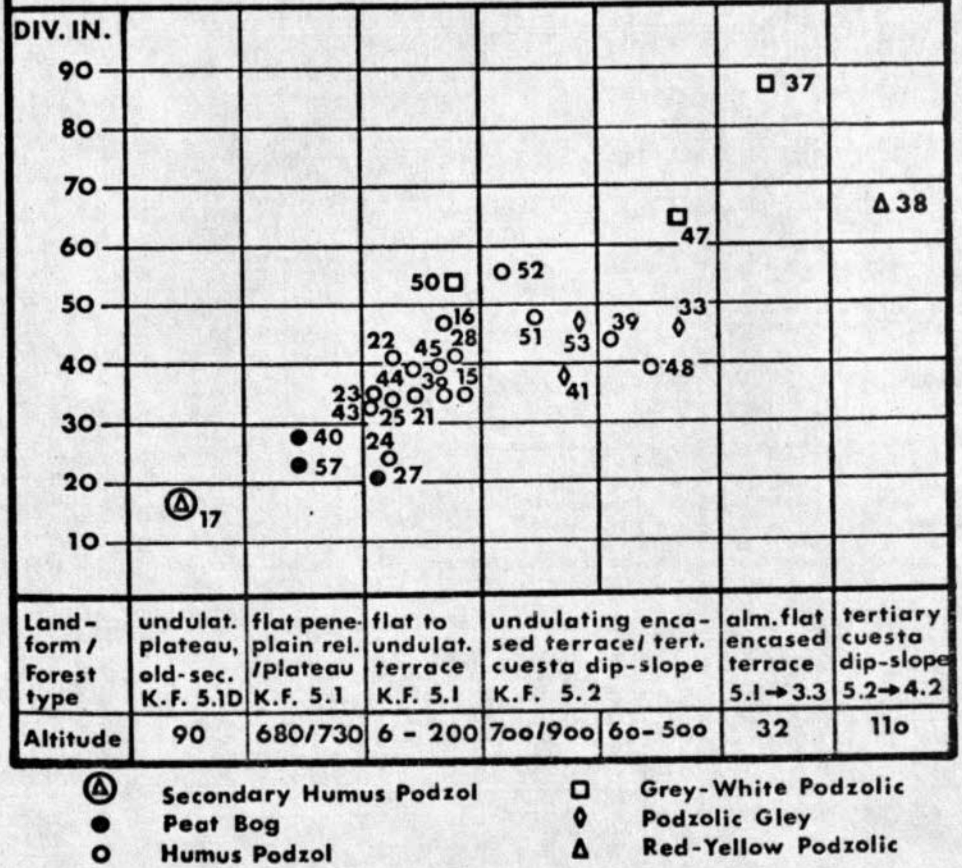
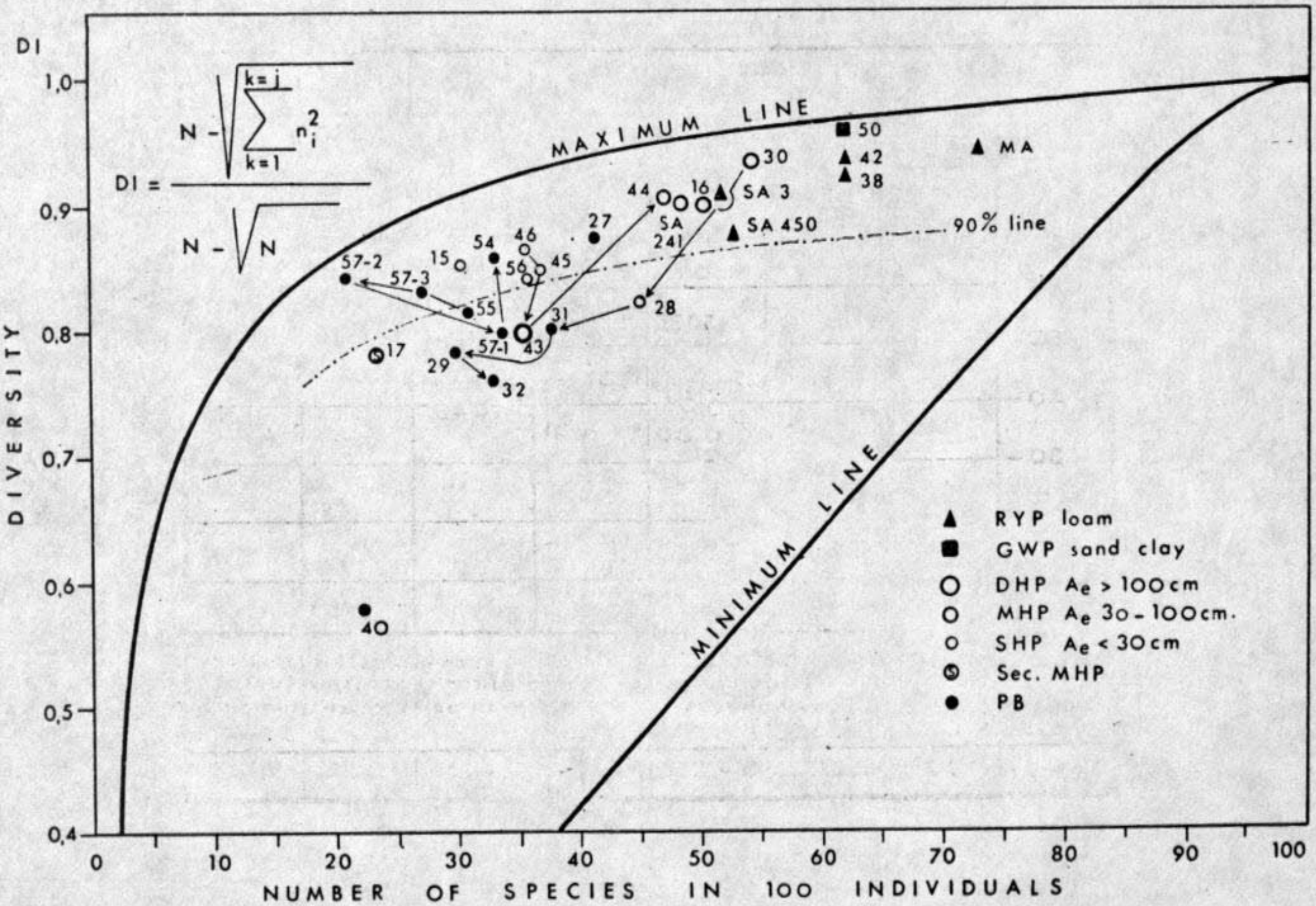


Fig. 10 b : DIVERSITY INDEX IN 40 STANDS FOR N = 100



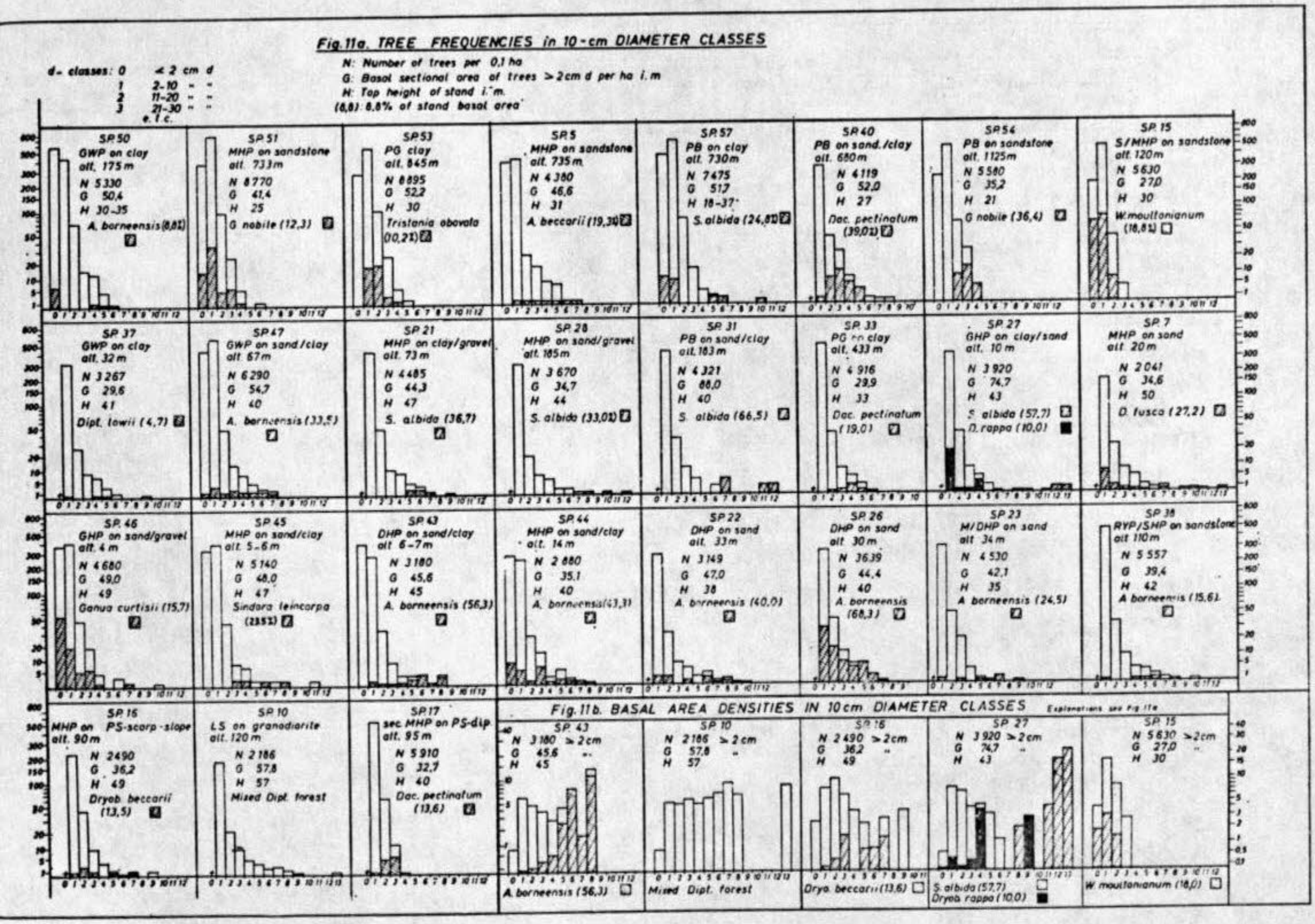
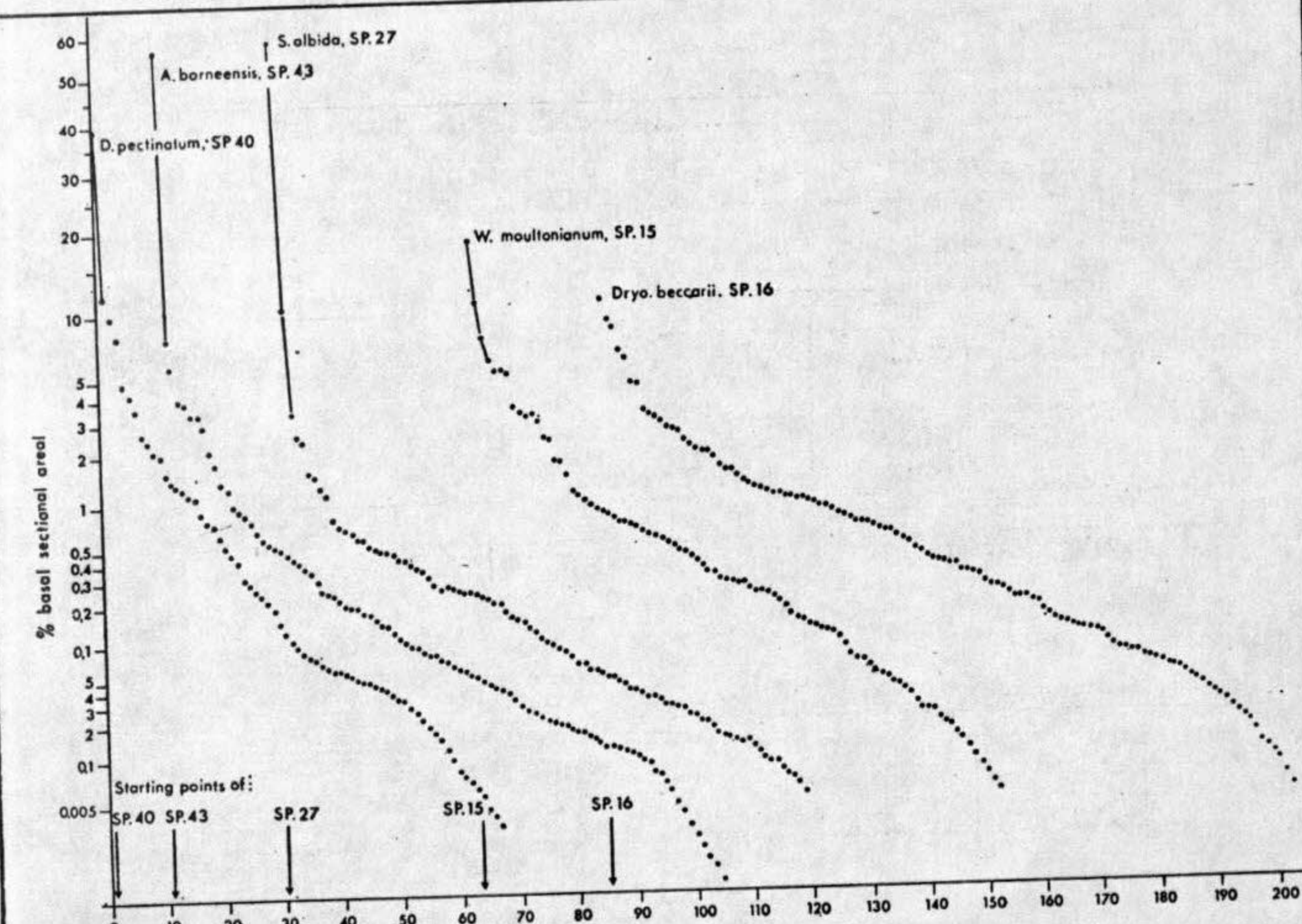


Fig. 11a. TREE FREQUENCIES in 10-cm DIAMETER CLASSES
d- classes: 0 < 2 cm d
1 2-10 " "
2 11-20 " "
3 21-30 " "
e.t.c.
N: Number of trees per 0,1 ha
G: Basal sectional area of trees > 2cm d per ha i. m
H: Top height of stand i. m.
(8,8): 8,8% of stand basal area
SP. 50 GWP on clay alt. 175 m N 5 330 G 50,4 H 30-35 A. borneensis (8,8%)
SP. 51 MHP on sandstone alt. 733 m N 8 770 G 41,4 H 25 G. nobile (12,3)
SP. 53 PG clay alt. 845 m N 8 895 G 52,2 H 30 Tristania obovata (10,2%)
SP. 5 MHP on sandstone alt. 735 m N 4 380 G 46,6 H 31 A. beccarii (19,3%)
SP. 57 PB on clay alt. 730 m N 7 475 G 51,7 H 18-37 S. albida (24,8%)
SP. 40 PB on sand./clay alt. 680 m N 4 119 G 52,0 H 27 Dac. pectinatum (39,0%)
SP. 54 PB on sandstone alt. 1125 m N 5 580 G 35,2 H 21 G. nobile (36,4)
SP. 15 S/MHP on sandstone alt. 120 m N 5 630 G 27,0 H 30 W. moultonianum (18,8%)
SP. 37 GWP on clay alt. 32 m N 3 267 G 29,6 H 41 Dipt. lowii (4,7)
SP. 47 GWP on sand/clay alt. 67 m N 6 290 G 54,7 H 40 A. borneensis (33,5)
SP. 21 MHP on clay/gravel alt. 73 m N 4 485 G 44,3 H 47 S. albida (36,7)
SP. 28 MHP on sand/gravel alt. 185 m N 3 670 G 34,7 H 44 S. albida (33,0%)
SP. 31 PB on sand/clay alt. 183 m N 4 321 G 88,0 H 40 S. albida (66,5)
SP. 33 PG on clay alt. 433 m N 4 916 G 29,9 H 33 Dac. pectinatum (19,0)
SP. 27 GHP on clay/sand alt. 10 m N 3 920 G 74,7 H 43 S. albida (57,7) D. rappa (10,0)
SP. 7 MHP on sand alt. 20 m N 2 041 G 34,6 H 50 D. fusca (27,2)
SP. 46 GHP on sand/gravel alt. 4 m N 4 680 G 49,0 H 49 Ganua curtisii (15,7)
SP. 45 MHP on sand/clay alt. 5-6 m N 5 140 G 48,0 H 47 Sindora leiocarpa (23,5%)
SP. 43 DHP on sand/clay alt. 6-7 m N 3 180 G 45,6 H 45 A. borneensis (56,3)
SP. 44 MHP on sand/clay alt. 14 m N 2 880 G 35,1 H 40 A. borneensis (43,3)
SP. 22 DHP on sand alt. 33 m N 3 149 G 47,0 H 38 A. borneensis (40,0)
SP. 26 DHP on sand alt. 30 m N 3 639 G 44,4 H 40 A. borneensis (68,3)
SP. 23 M/DHP on sand alt. 34 m N 4 530 G 42,1 H 35 A. borneensis (24,5)
SP. 38 RYP/SHP on sandstone alt. 110 m N 5 557 G 39,4 H 42 A. borneensis (15,6)
SP. 16 MHP on PS-scarp-slope alt. 90 m N 2 490 G 36,2 H 49 Dryob. beccarii (13,5)
SP. 10 LS on granodiorite alt. 120 m N 2 186 G 57,8 H 57 Mixed Dipt. forest
SP. 17 sec. MHP on PS-dip alt. 95 m N 5 910 G 32,7 H 40 Dac. pectinatum (13,6)
Fig. 11b. BASAL AREA DENSITIES IN 10 cm DIAMETER CLASSES Explanations see Fig. 11a
SP. 43 N 3 180 > 2cm G 45,6 H 45 A. borneensis (56,3)
SP. 10 N 2 186 > 2 cm G 57,8 H 57 Mixed Dipt. forest
SP. 16 N 2 490 > 2cm G 36,2 H 49 Dryo. beccarii (13,6)
SP. 27 N 3 920 > 2cm G 74,7 H 43 S. albida (57,7) Dryob. rappa (10,0)
SP. 15 N 5 630 > 2cm G 27,0 H 30 W. moultonianum (18,0)

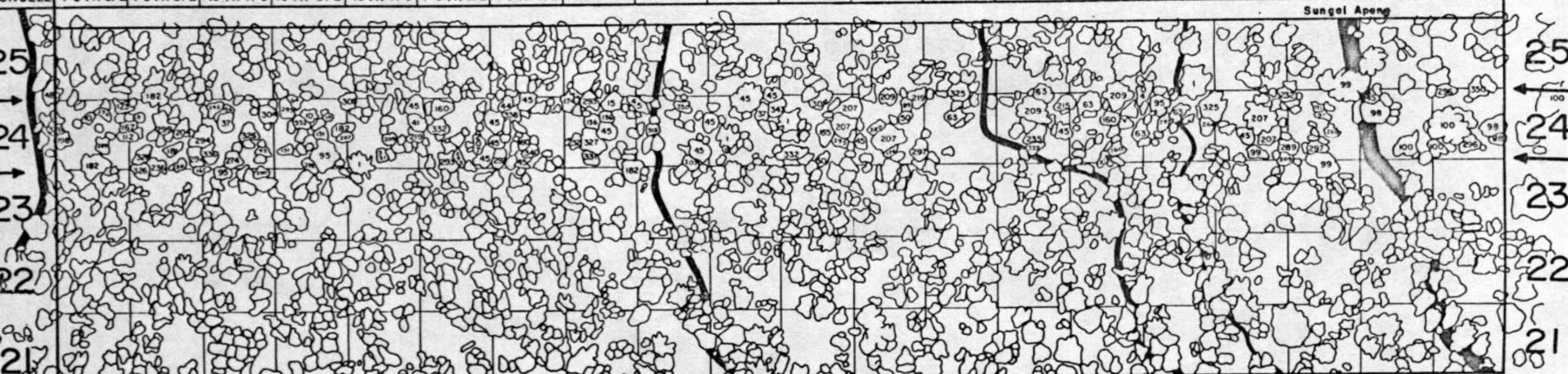
Fig. IIc. DOMINANCE – DIVERSITY CURVES IN 5 SAMPLE PLOTS



E | FIG. 12a: SABAL SAMPLING AREA-TRANSECT EAST-WEST | W

LOT No.	24	49	74	99	124	149	174	199	224	249	274	299	324	349	374	399	424	449	474	499	Serial
ASAL A	35·4	38·2	23·2	32·9	35·0	30·2	38·3	34·7	21·8	43·2	49·8	40·1	24·1	38·5	42·2	44·7	31·2	42·7	19·3	52·1	m2/ha>10
.STEM	94	87	84	77	64	94	97	116	84	94	101	74	86	94	91	84	89	74	47	57	N/ha ≥ 10

L GROUP	M.H.P.	G.W.P.	M.H.P.	M.H.P.	G.W.P.	G.W.P.	M.H.P.	M.H.P.	G.W.P.	G.W.P.	G.W.P.	G.W.P.	G.W.P.	G.W.P.	G.W.P.	G.W.P.	G.W.P.	G.W.P.	R.Y.P.	R.Y.P.	SOIL GROUP
TITUDE	153	152	151	150	150	150	150	150	150	151	152	153	155	152	154	150	150	153	152	149	m
LOPE	5	5	20	4	10	15	15	1	5	5	4	6	5	3	2	1	1	2	7	20 - 35	° NORTH
UNSELL	7·5YR 8/2	7·5YR 8/2	10YR 7/3	10YR 8/2	10YR 7/3	7·5YR8/2	7·5YR 7/2	10YR 6/3	10YR 7/2	10YR 7/6	10YR 5/6	7·5YR 8/2	10YR 5/3	10YR 5/6	10YR 5/3	7·5/10YR7/3	10YR 5/4	10YR 8/1	10YR 7/8	10YR 8/8	MUNSELL



CH:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	CH

Fig.12b: CROWN SHAPES

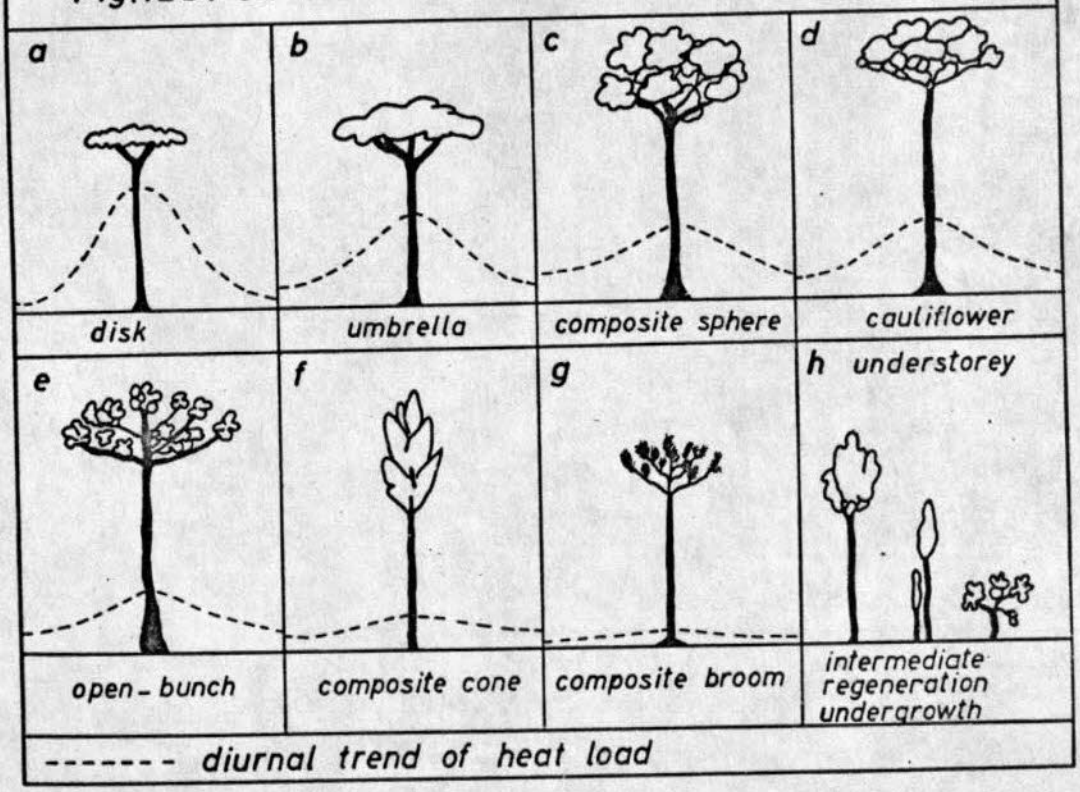
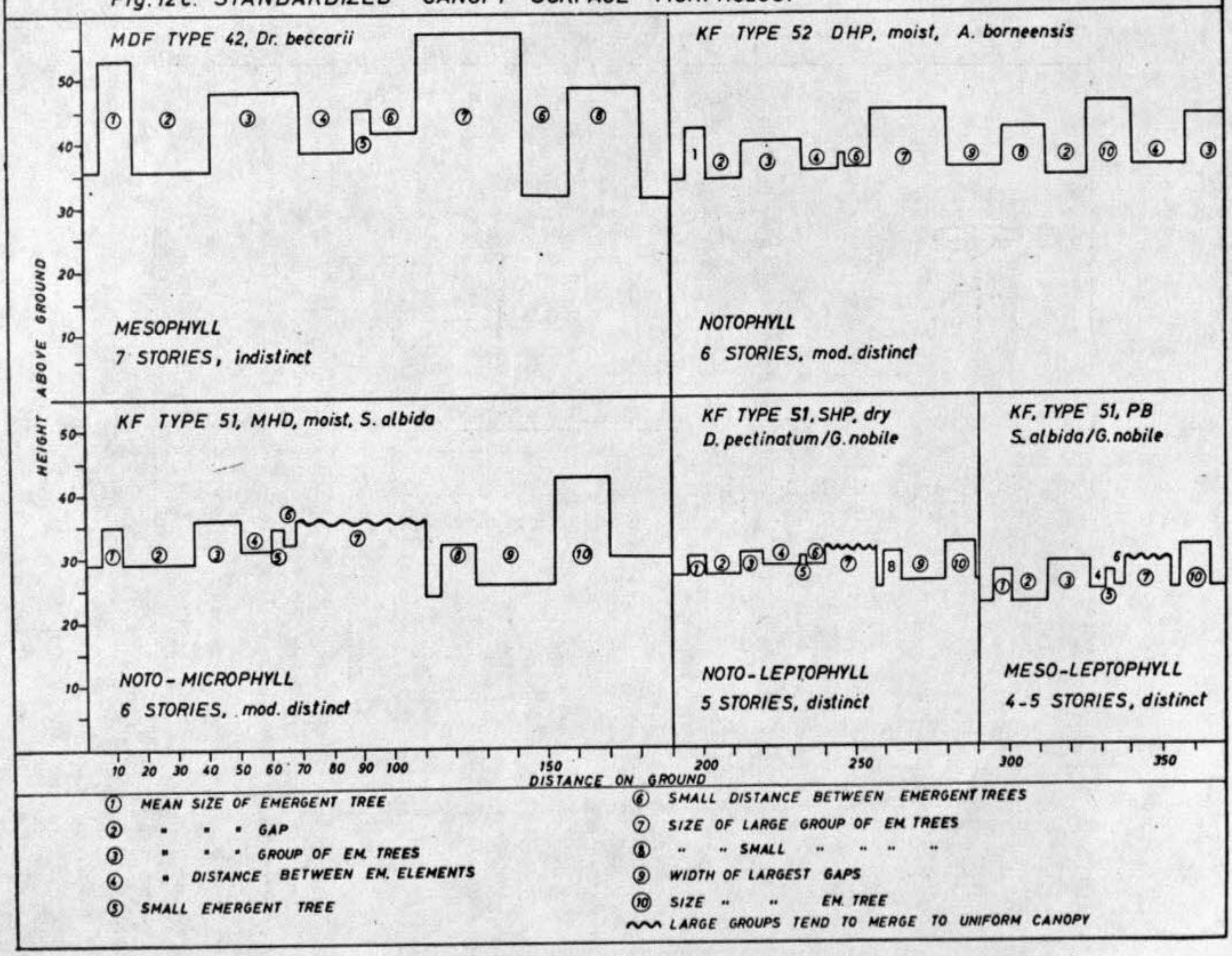


Fig. 12c. STANDARDIZED CANOPY SURFACE MORPHOLOGY



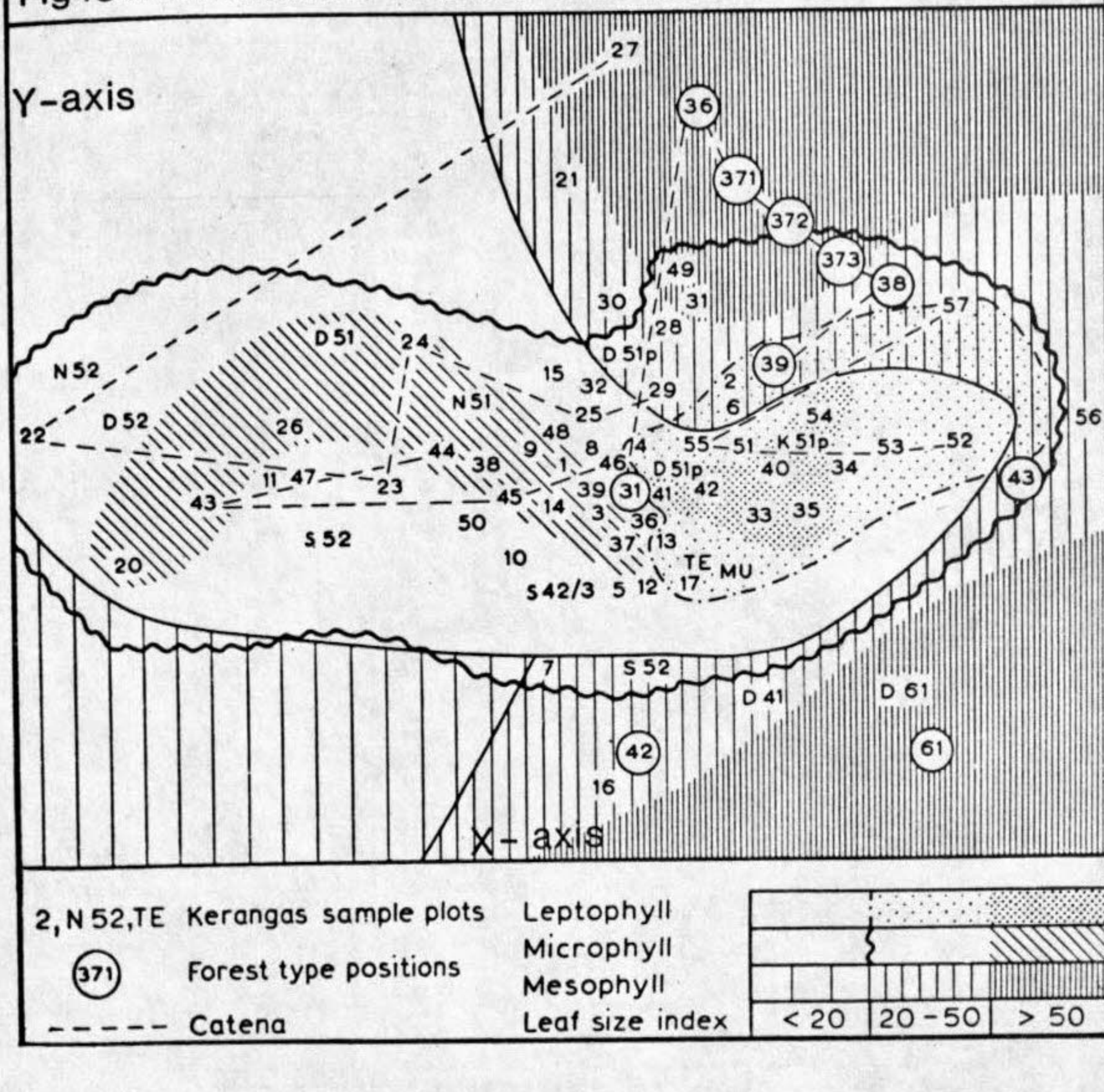
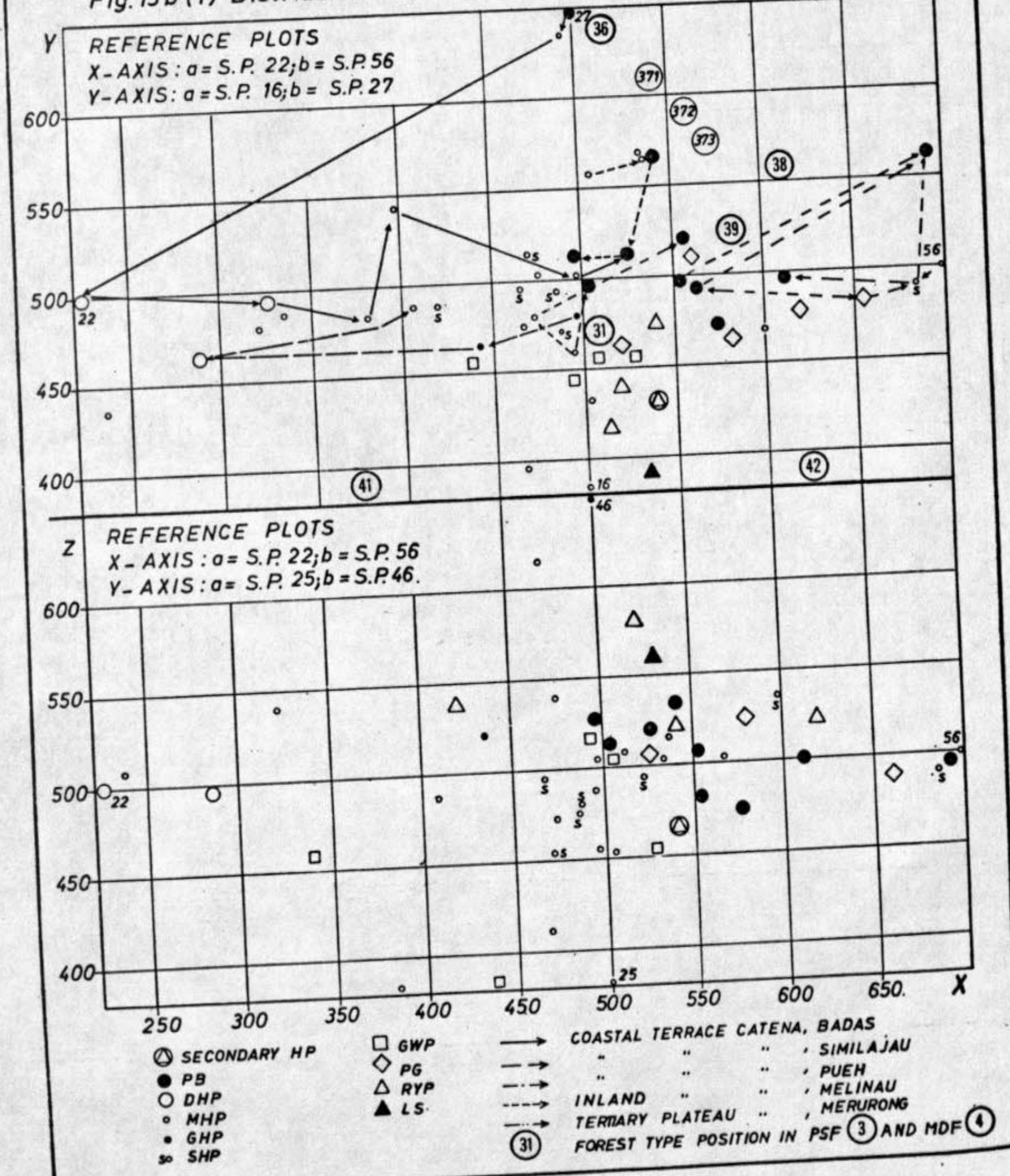


Fig.13a: Distribution of a leaf size index in the ordination

Fig. 13b (1) Distribution of Soils.



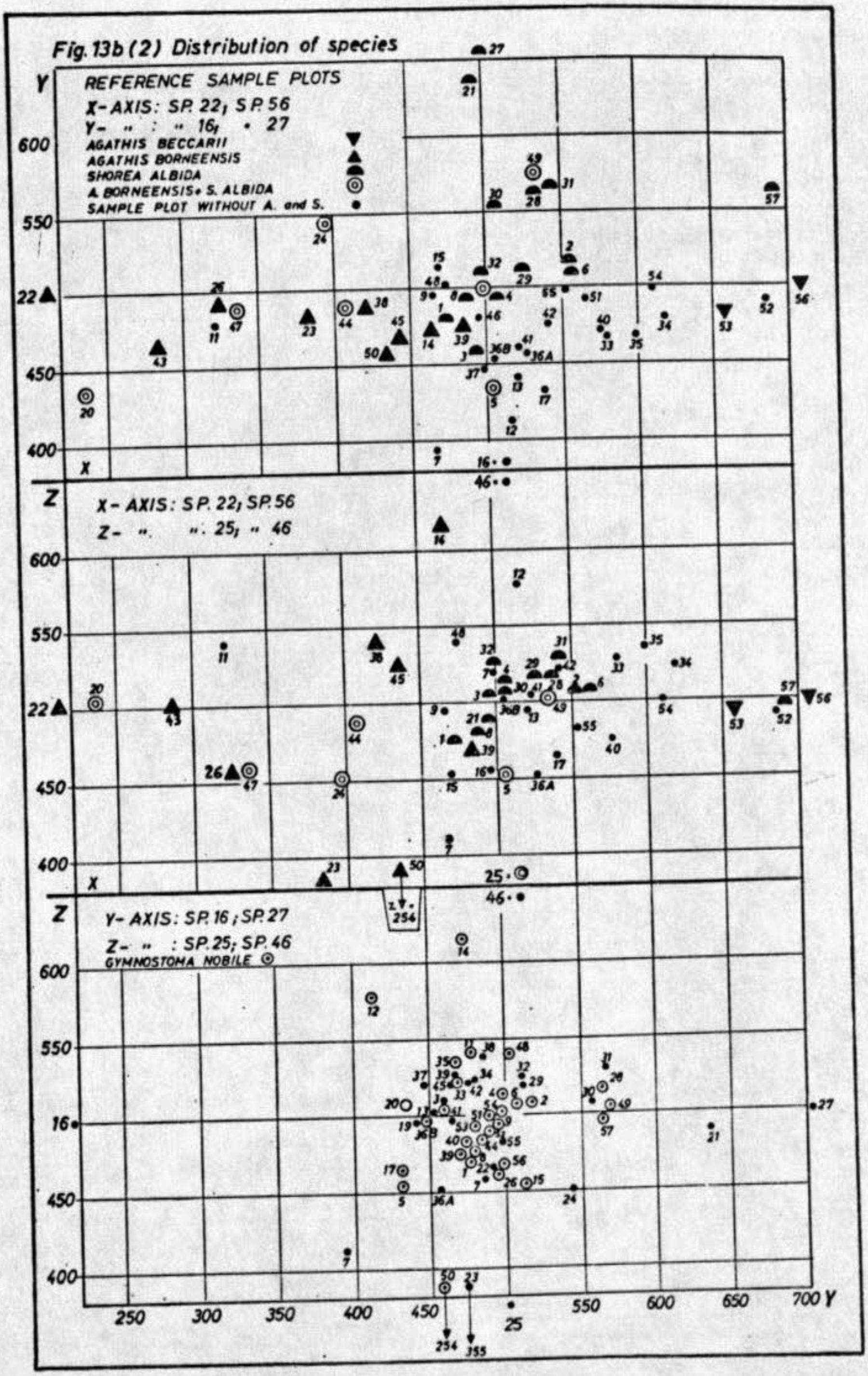


Fig. 13b (2) Distribution of species
REFERENCE SAMPLE PLOTS
X-AXIS: SP. 22; SP. 56
Y- " : " 16; " 27
AGATHIS BECCARII
AGATHIS BORNEENSIS
SHOREA ALBIDA
A. BORNEENSIS + S. ALBIDA
SAMPLE PLOT WITHOUT A. and S.
X-AXIS: SP. 22; SP. 56
Z- " " 25; " 46
Y-AXIS: SP. 16; SP. 27
Z- " : SP. 25; SP. 46
GYMNOSTOMA NOBILE

Fig. 13c. RELATIVE DOMINANCE OF SPECIES ALONG THE X-AXIS

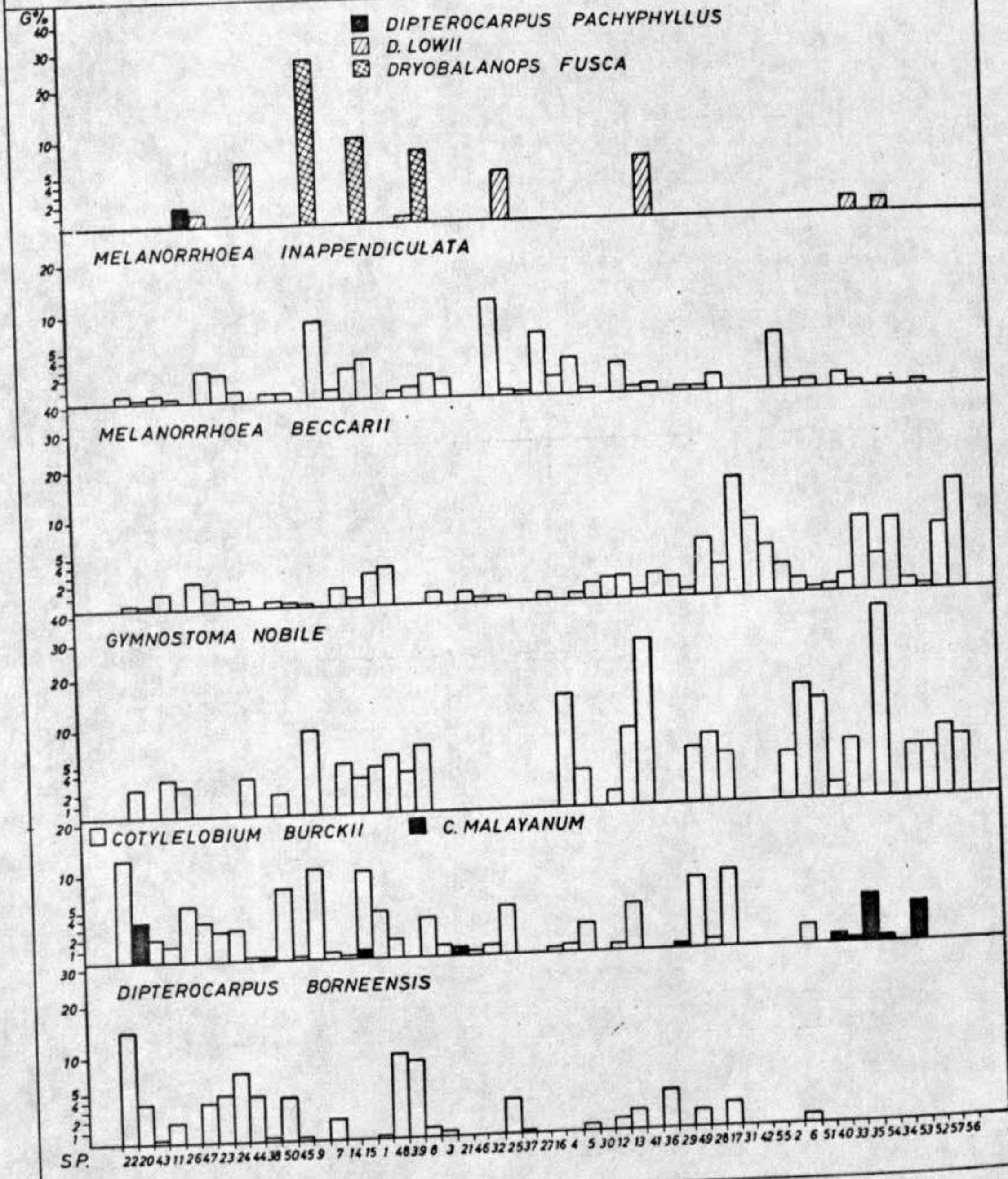
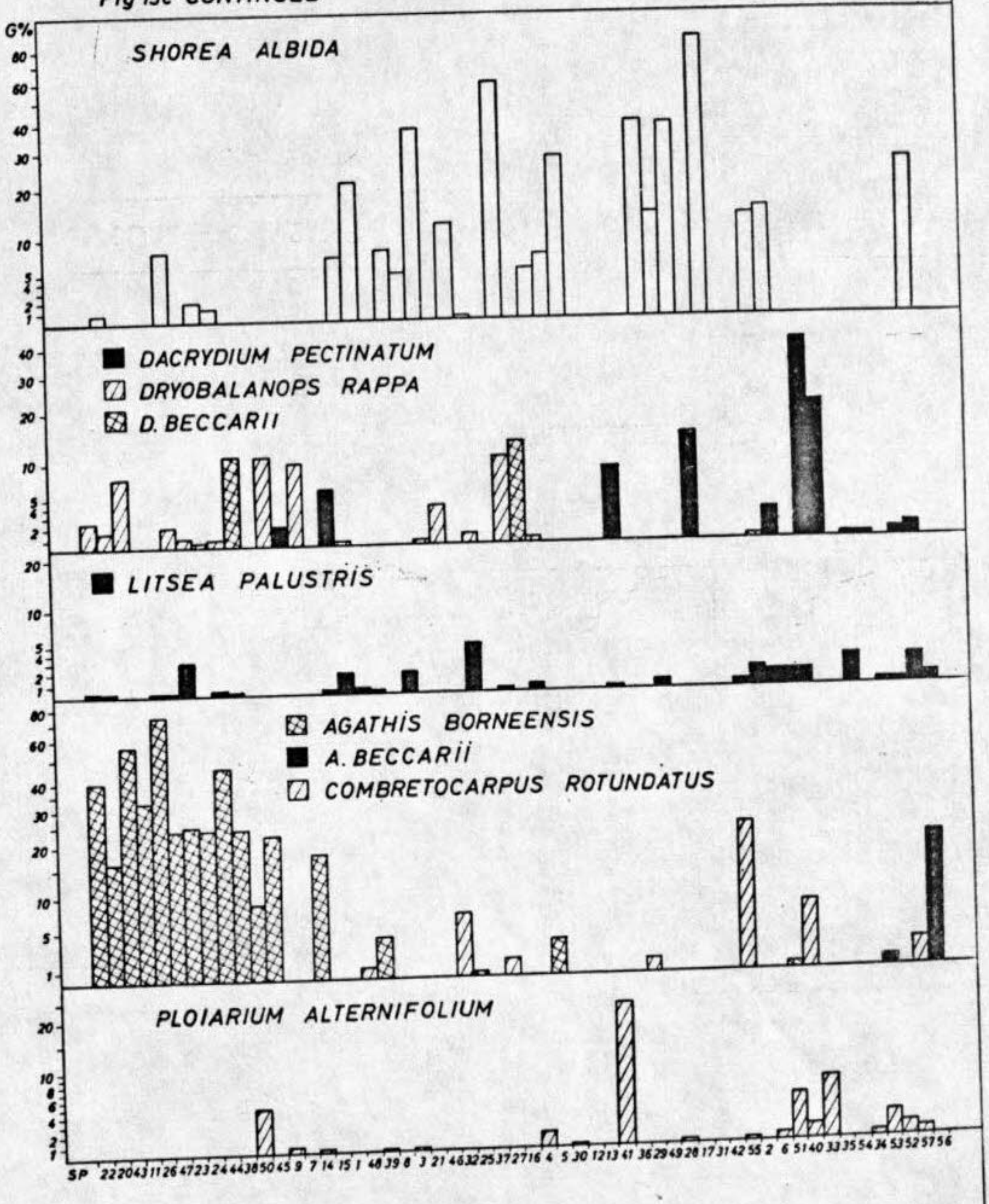


Fig 13c CONTINUED



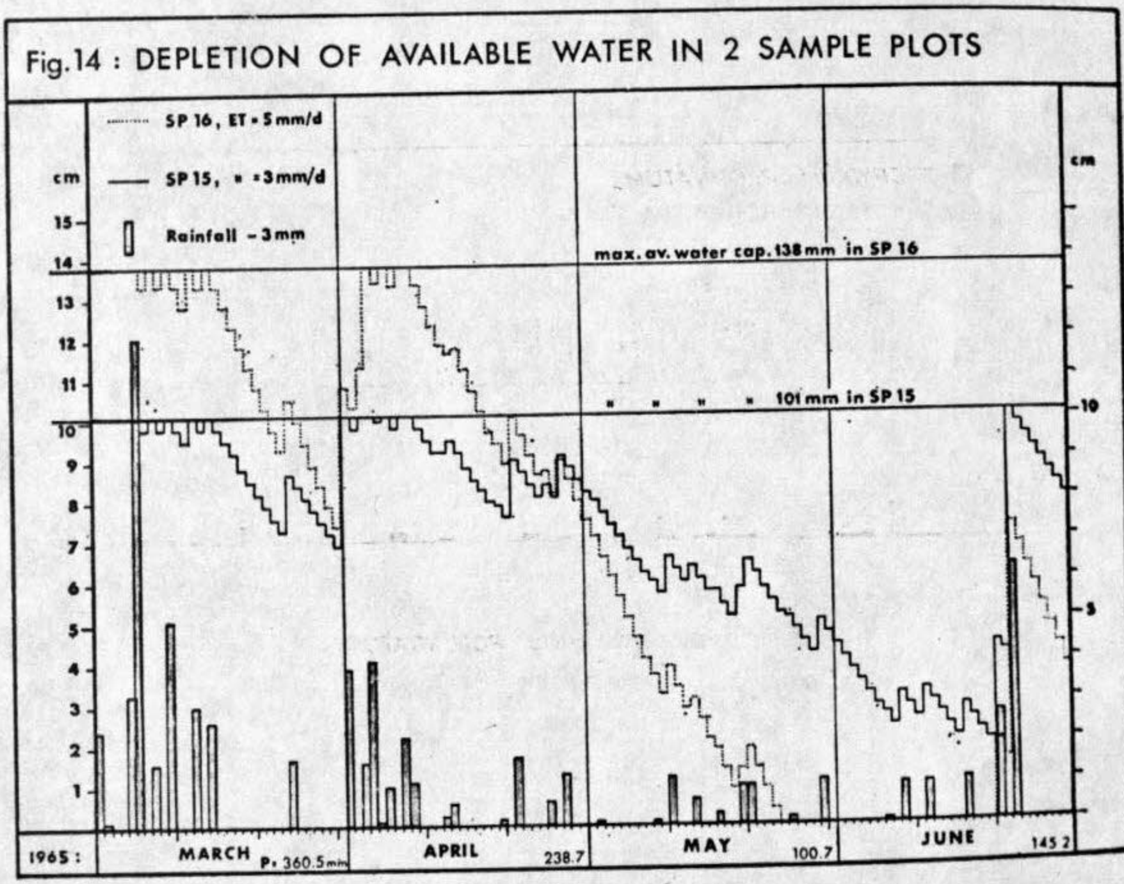


Fig.14 : DEPLETION OF AVAILABLE WATER IN 2 SAMPLE PLOTS
SP 16, ET = 5 mm/d
SP 15, " = 3 mm/d
Rainfall - 3 mm
cm
max. av. water cap. 138 mm in SP 16
" " " " 101 mm in SP 15
1965 :
MARCH P. 360.5 mm
APRIL 238.7
MAY 100.7
JUNE 145.2

Fig. 15a. BASAL AREAS, TOP STAND HEIGHTS AND $G \cdot \frac{1}{2} H_T$

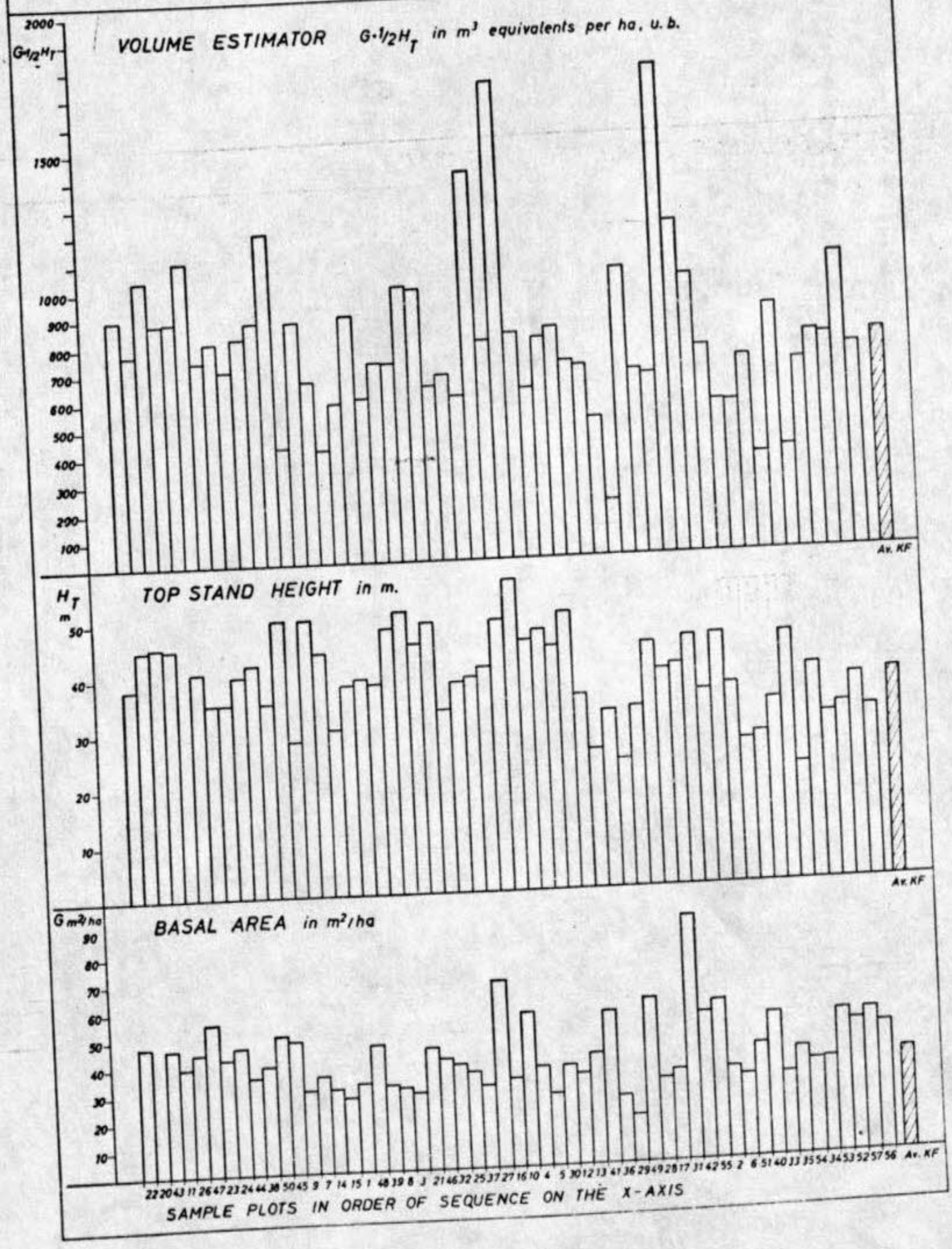


Fig. 15b. GROWING STOCK PER HECTARE

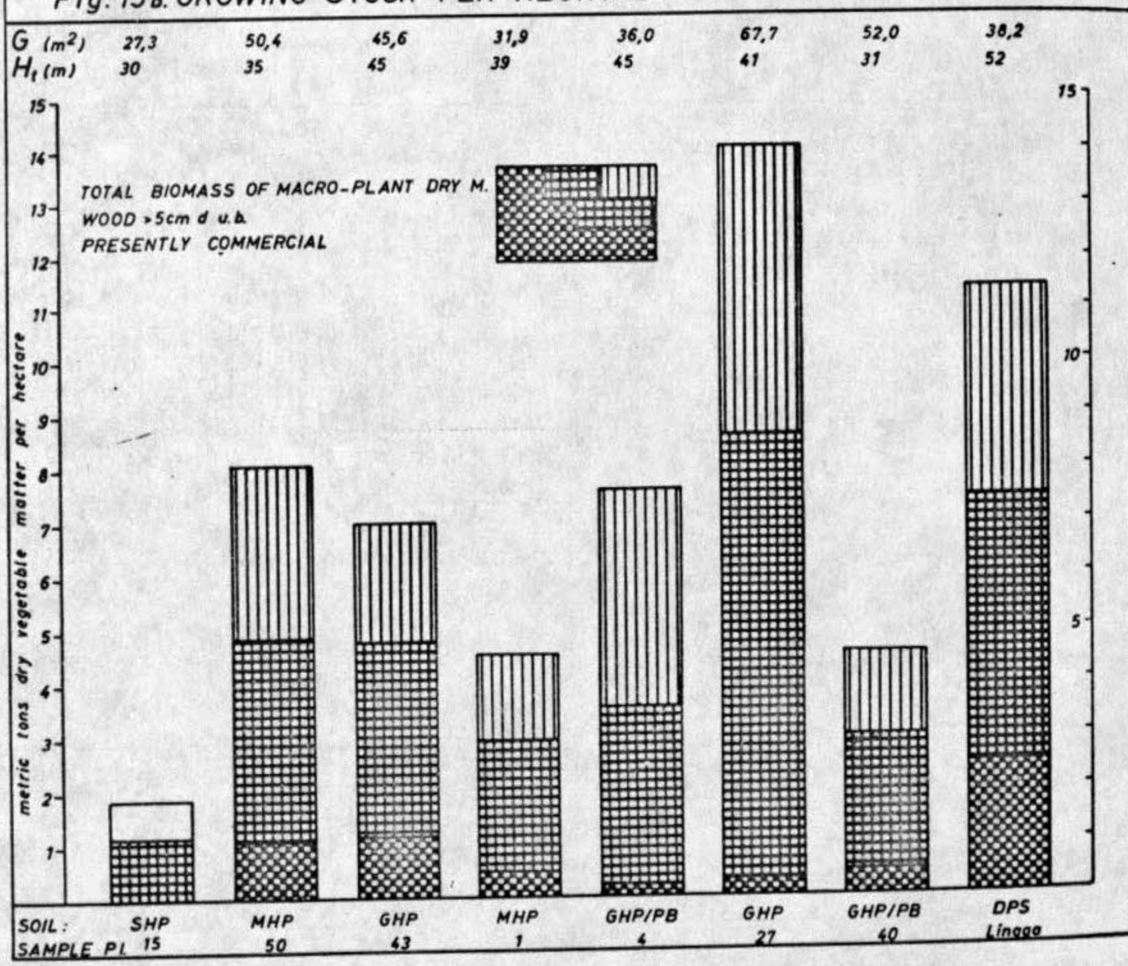


Fig.15c: AERODYNAMIC ROUGHNESS LENGTH 'Z_o' AND NET ANNUAL ABOVE-GROUND PRODUCTIVITY 'NAAP'

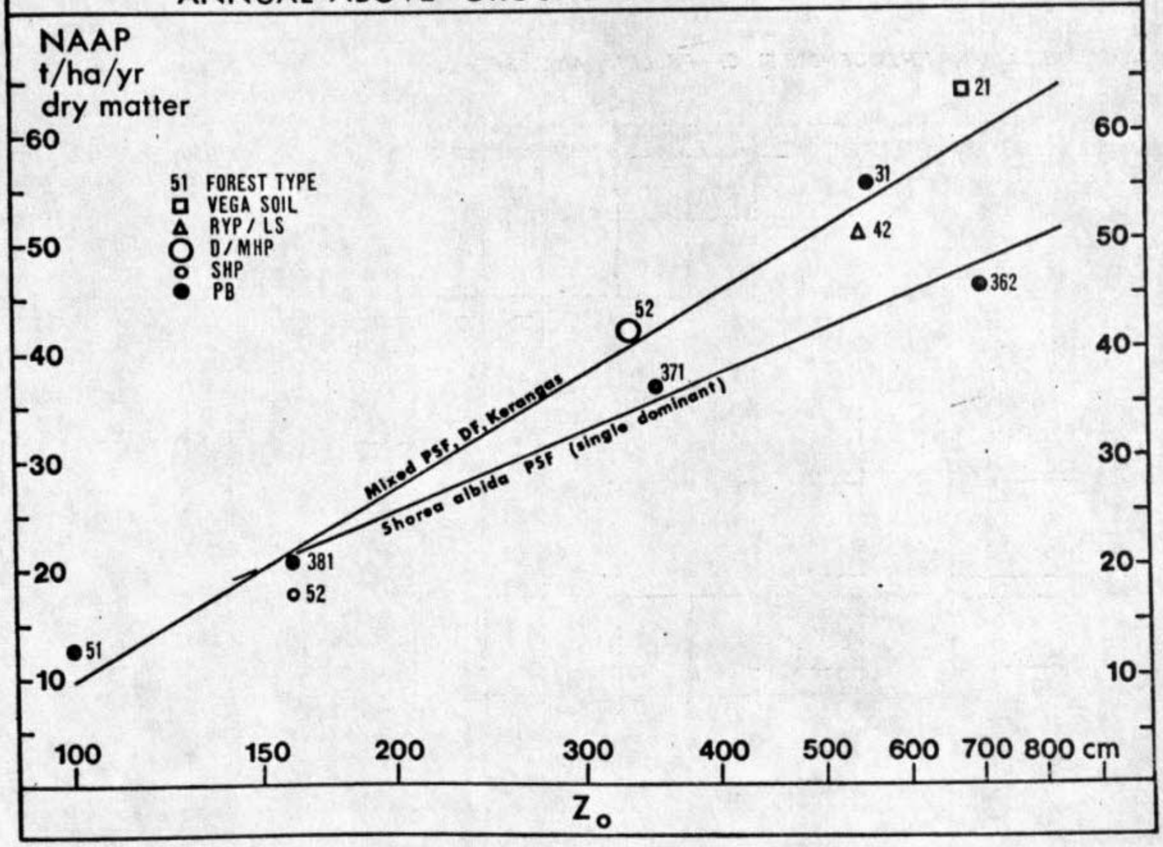


Fig. 16. RELATIVE FREOUENCIES OF POLLEN AND SPORES

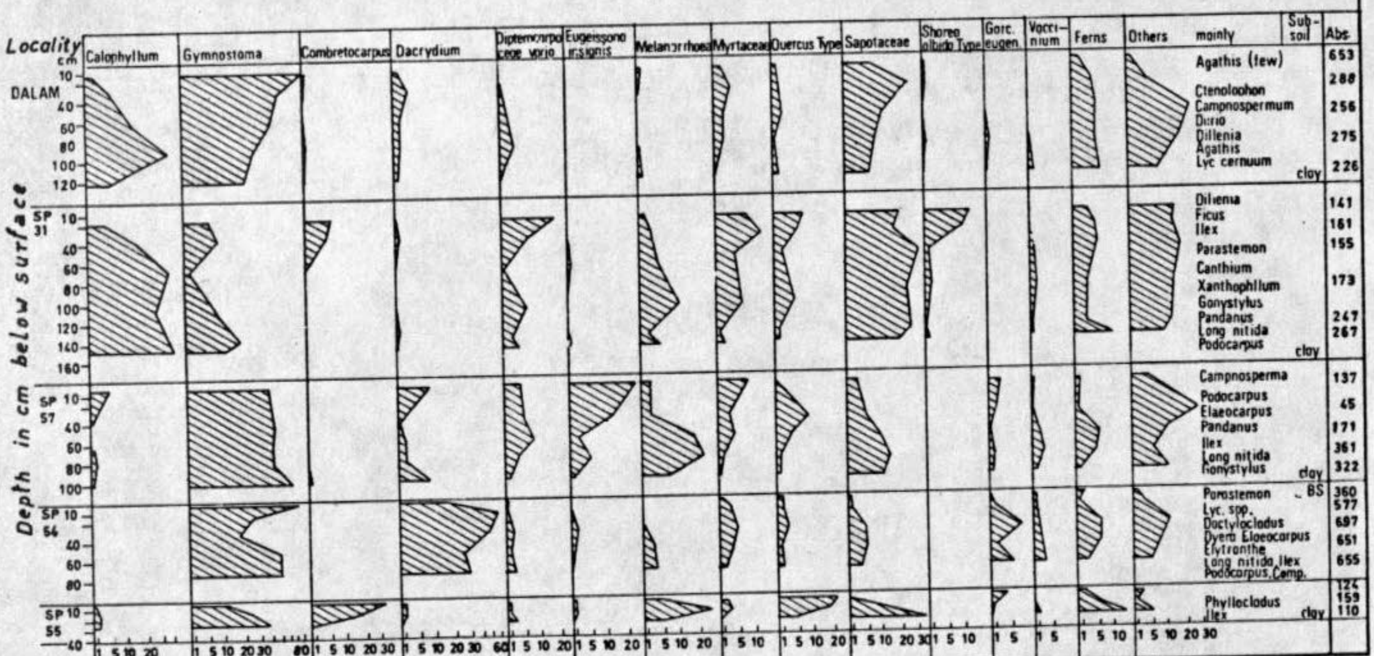


Table I. Frequency distribution of monthly rainfall and monthly and annual values of the MARTONNE Index of aridity

Station	Monthly Rainfall in 2 ins classes, in mm											Martonne Index		
	0-51	-101	-151	-203	-254	-305	-355	-406	-457	-508	508	Pm[5]	Tm[5].	M.I.[2]
	Frequency of Months											mm	C^0	
KUCHING (71 yrs)														
J					1	3	4	4	6	6	47	655	25.4	222
F			1	3	6	7	2	12	5	5	30	505	25.7	170
M		1	6	7	9	8	12	8	6	2	12	385	26.4	127
A		1	7	12	12	18	13	3	5			257	26.9	84
M		2	5	24	10	12	10	7	1			241	27.0	79
J	1	2	15	19	12	10	8	3		1		174	27.6	68
J	1	5	17	24	11	5	6	2				192	27.3	62
A	2	3	10	16	18	15	2	4	1			216	27.0	70
S		3	6	18	13	11	7	8	3	1	1	258	26.9	84
O		1	5	17	13	10	10	9	3	2	1	324	26.5	107
N			1	4	12	12	12	11	8	6	5	344	26.5	113
D				4	4	6	6	8	13	6	24	380	26.7	216
Sum: per yr.	4 0.06	18 0.3	73 1.0	148 2.1	121 1.7	117 1.6	92 1.3	79 1.1	51 0.7	29 0.4	120 1.7	4020	26.6	110
MIRI (31 yrs)														
J		2	3	1	5	5	7	3		2	3	314	26.0	105
F	5	7	5	1	3	2	5			2	1	187	26.3	62
M	1	8	7	6	5		3	1				164	26.9	55
A	1	6	5	5	9	2	1		1	1		189	27.4	61
M		1	7	5	9	4	2	1		1	1	229	27.7	73
J	1	1	4	7	5	6	4	2	1		1	246	27.7	78
J	1	4	4	8	5	4	4				1	204	27.5	65
A	1	4	7	8	2	5	1		1	1	1	207	27.7	68
S			4	1	2		4	3	7	1	1	319	27.3	103
O				1	6	5	7	4	2	1	5	352	27.3	113
N				1	6	4	2	8	2	2	6	378	27.2	122
D				2	5	6	6	2	2	3	4	365	27.6	116
Sum: per yr.	10 0.32	33 1.1	46 1.5	46 1.5	62 2.0	51 1.6	46 1.5	24 0.8	16 0.5	14 0.5	24 0.8	3158	27.2	85
BARAM (22 yrs)														
J		1	6	3	3	3	2			1	3	259	25.8	87
F	2	1	4	4	2	4	4	1				206	26.0	69
M		1	6	4	2	3	4		1		1	237	26.6	78
A	2	2	2	3	5	4	1	1	1	1		220	27.0	72
M			2	9	5	3	2	1				221	27.3	71
J		1	8	4	5	2		1		1		198	27.6	64
J		5	3	5	4	2	1	2				188	27.7	60
A		3	3	8	3	3				1	1	212	27.4	68
S		1	2	8	2	6	1		1		1	261	27.0	85
O			1	2	6	5	5	1	1		1	296	27.0	96
N			1	7	6	4	3	1				240	26.9	78
D			2	1	5	1	4	3	4	2		324	26.5	106
Sum: per yr.	4 0.16	15 0.7	40 1.8	58 2.6	48 2.2	40 1.8	27 1.2	11 0.5	8 0.4	6 0.3	7 0.3	2960	26.9	80

Pm = mean monthly rainfall.
Tm = mean monthly temperature.

Table 2. Frequencies and Length of Periods with a 30-Day Sum of Rainfall below 100 mm for Calendar Months of Certain Rainfall Class, 1963/65.

Monthly rainfall recorded (Rainfall Class)	Number of months recorded (all stations)	STATIONS Kuching Airport	Semengoh F.R.	Bako N.P.	Miri	Long Lama	Total
		Frequencies of 30-days periods with less than 100 mm P					
Below 100	1	0	0	0	1(7)	0	1(7)
101 – 120	4	1(2)	0	4(1,2,2,3)	1(1)	0	6(11)
121 – 150	9	2(2,9)	0	1(20)	3(2,3,10)	0	6(46)
151 – 200	11	0	0	3(2,3,7)	2(1,4)	0	5(17)
201 – 300	36	1(1)	1(2)	1(2)	3(1,2,7)	0	6(15)
above 300	53	0	0	0	0	0	0
Total months	113	23	22	23	23	22	
Frequencies		4	1	9	10	0	24(96)

2(2,9) means 2 events of the 30-days sum of rainfall falling below 100 mm with 2 days duration in the one event and 9 days in the other.

Table 3. Monthly means of daily hours of sunshine and mean monthly frequency of days with thunderstorms.

Station	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	Year (mean)	Year (Total)
1. Sunshine														
Kuching 1955	3.7	3.6	5.3	5.8	7.0	6.2	5.8	4.6	3.6	5.3	5.1	2.8	4.9	1787
1957	2.7	4.3	4.0	5.5	5.8	6.1	6.3	6.4	4.9	4.5	5.4	4.3	5.1	1862
1962	2.6	2.4	4.4	5.0	6.2	6.7	7.1	5.5	4.9	4.9	5.0	4.1	4.9	1789
Bintulu 1955	6.2	4.8	6.5	5.7	7.9	5.3	6.8	6.1	5.6	5.8	5.5	4.5	5.9	2155
1957	5.0	6.0	6.0	7.2	5.4	6.0	6.3	7.0	5.0	6.0	6.0	6.0	6.0	2190
1962	3.4	3.9	5.3	5.8	6.2	7.3	6.8	6.5	5.0	5.8	5.6	5.2	5.6	2044
Miri 1955	6.2	5.3	7.9	6.9	7.4	6.0	6.9	6.2	6.5	7.4	6.3	6.0	6.6	2406
1957	5.6	6.7	6.5	8.4	7.2	6.9	6.7	7.4	5.3	7.1	7.0	6.9	6.8	2482
1962	5.0	5.0	6.8	6.9	7.0	7.9	6.0	7.1	6.2	6.8	6.4	5.9	6.4	2336
2. Thunderstorms (mean for the 3 stations)	2.0	4.0	5.7	6.2	10.2	5.5	5.1	6.6	9.1	6.6	3.8	8.2	6.2	73.0

Table 4. Monthly waterbalance for Kuching after THORNTHWAITE.

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
T	25.1	25.5	26.5	27.0	27.2	27.8	27.4	27.0	26.9	26.7	26.7	26.8	26.7
PE_d	3.9	4.2	4.5	4.6	4.7	4.9	4.8	4.6	4.6	4.6	4.6	4.6	4.6
PE_m	122	118	140	139	148	165	158	144	139	158	139	158	1728
P_m	660	505	390	260	250	225	195	225	270	325	340	375	4020
$P\text{-}PE_m$	538	387	250	121	102	60	37	81	131	167	201	217	2292
ST	80	80	80	80	80	80	80	80	80	80	80	80	80
AE	122	118	140	134	138	165	158	144	139	158	139	158	1728
D	0	0	0	0	0	0	0	0	0	0	0	0	0
S/R.O.	538	387	250	121	102	60	37	81	131	167	201	217	2292

T = mean daily air temperature
PE_d = daily potential evaporation
PE_m = monthly potential evaporation
P_m = monthly precipitation
$P\text{-}PE_m$ = monthly precipitation less potential evaporation
ST = soil moisture storage, average for 80 cm rooting depth in fine sand
AE = actual evaporation
D = any deficit in the water balance
S/R.O. = surplus, resp. run-off

Table 8. Leaf size index representation in sample plots on kerangas (27 – 17) and kerapah (29 – 54)

SP	Alt.	Soil	Lepto-	Nano-	Micro-	Noto-	Meso-	Macro-
27	10	GHP	0	0	18.1	33.3	47.6	1.6
28	185	MHP	3.7	0.5	19.6	38.7	36.1	1.5
52	745	SHP	3.6	1.1	25.6	39.8	28.4	1.3
22	33	DHP	0	1.1	34.3	39.6	25.0	0.5
17	95	MHP	11.7	0.2	31.4	34.6	22.4	0
29	182	MPB	0	1.1	19.4	45.8	33.7	0
32	182	DPB	0	0	14.9	58.5	26.7	0
40	680	DPB	22.0	0.7	19.7	39.0	18.6	0
57	730	MPB	6.5	0.8	31.4	31.0	30.2	0
54	1125	MPB	19.8	3.2	33.9	31.3	12.0	0
27-17	–	–	3.8	0.5	25.8	37.2	31.9	1.0
29-54	–	–	9.7	1.0	23.9	41.1	24.2	0
Bel. 1	70	LAT	0	0	7	20	68	15
And.	20-100	RYP	0	0	20	44	35	1
Bel. 2	700	SLI	0	0	50	36	12	2

Leaf size index: LSI = 1/2 (G % + Spp. %)

Bel. 1: Belalong area, lower hillside, Mixed Dipterocarp forest

And.: Upper hillside of undulating landform, sandy soils, M.D.F.

Bel. 2: Ridge in bold-hilly landform, shallow clay lithosol, species-poor M.D.F.

M.D.F. figures represent leaf size class ratios expressed as percentage basal area (estimated from ASHTON, 1964 c, fig. 37).

Table 8b. Leaf size index representation in storeys A, B and C in 8 selected plots

SP	Storey	Lepto-	Nano-	Micro-	Noto-	Meso-	Macro-	Soil
37	C	0	1.1	16.2	49.6	30.7	2.4	GWP
	B	0	0	19.8	51.1	22.6	6.4	
	A	0	0	53.4	26.5	20.2	0	
44	C	0	3.7	46.0	27.1	23.2	0	MHP
	B	0	0	53.3	32.7	14.0	0	
	A	9.6	0	82.6	0	7.8	0	
22	C	0	3.6	28.5	41.3	25.7	0.9	DPH
	B	0	0	24.5	37.6	37.9	0	
	A	0	0	53.1	33.1	13.8	0	
43	C	0	10.0	42.2	29.0	18.8	0	DHP
	B	0	12.6	57.8	12.3	17.4	0	
	A	0	0	81.1	9.4	9.5	0	
40	C	1.7	0.8	14.5	62.7	20.4	0	DPB
	B	16.8	0	30.1	35.7	17.5	0	
	A	35.7	0	24.1	25.8	14.5	0	
57	C	3.6	0	50.0	36.1	10.4	0	MPB
	B	6.2	0	59.9	29.1	4.9	0	
	A	12.7	0	24.6	23.5	39.3	0	
27	C	0	0	24.4	52.1	20.3	3.2	GHP
	B	0	0	41.5	38.1	20.3	0	
	A	0	0	24.1	0	75.9	0	
17	C	2.0	0	34.6	39.2	24.2	0	sec. MHP
	B	16.2	0	35.7	27.7	20.5	0	
	A	50.3	0	13.5	18.8	17.5	0	

Table 9. Species-area lines on different parent materials in 0.5 acre sample plots in order of total number of species

S.P.	Parent material	Alt.	Soil	Spp.	S.D.	tan	D.I.
37	Encased pleist. terr.	32	G.W.P., clay-loam	256	3.2	0.54	86.9
38	Belait sandstone	110	R.Y.P., sandy loam	240	0.8	0.40	65.7
47	Encased holoc. terr.	67	G.M.P., sandy loam	220	4.0	0.33	64.5
39	Belait sandstone	110	S.H.P., sand	174	0.5	0.25	43.8
33	Pleistocene terrace.	430	Gley, clas-loam	168	1.5	0.24	45.2
28	Pleistocene terrace	185	M.H.P., sand on clay	163	0.9	0.22	41.0
50	Belait sandstone	175	G.W.P., sand on clay	162	3.7	0.27	54.7
53	Belait sandstone	845	Gley, sand on clay	161	1.7	0.25	46.4
48	Belait sandstone	107	M.H.P., sand on clay	157	0.5	0.22	39.3
52	Belait sandstone	745	S.H.P. on rock	155	2.7	0.31	55.2
44	Pleistocene terrace	14	M.H.P., sandy loam	140	1.3	0.20	38.6
16	Plateau sandstone	90	M.H.P. on rock	136	2.8	0.23	47.0
21	Pleistocene terrace	73	S.H.P., sand	135	1.9	0.16	34.7
45	Pleistocene terrace	6	M.H.P., sand	135	1.0	0.22	39.2
41	Meligan sandstone	740	Gley, clay	133	0.5	0.23	37.7
30	Pleistocene terrace	165	M.H.P., loamy sand	120	1.4	0.17	34.8
51	Belait sandstone	733	M.H.P., on rock	119	3.1	0.23	47.8
22	Pleistocene terrace	33	D.H.P., sand	106	1.7	0.22	40.6
24	Pleistocene terrace	34	M.H.P., sand	100	0.7	0.10	23.7
15	Plateau sandstone	200	M./S.H.P. on rock	98	2.8	0.11	34.8
43	Pleistocene terrace	6	D.H.P., sand	95	1.3	0.17	33.3
25	Pleistocene terrace	33	M.H.P., sand	93	1.0	0.06	34.8
23	Pleistocene terrace	34	M./D.H.P., sand	90	0.9	0.21	35.2
27	Holocene terrace	10	G.M.P., sand/clay	89	0.7	0.07	19.9
40	Pleistocene terrace	680	Peat bog on sand	73	1.5	0.08	27.2
57	Belait sandstone	730	Peat bog on clay	65	0.7	0.11	
17	Plateau sandstone	95	Secondary M.H.P.	54	0.8	0.04	16.8

Spp. Total number of tree species. over 1 cm d. recorded in 0.5 acres (5 sq. ch.).
S.D. Standard deviation of species numbers about the regression
tan tangent of the species/area line between square 1 and 5 on fig. 9
D.I. Index of diversity (spp.% of total number of tree species in the formation type) + (S.D. as percent of number of species/5) + (tan times 100)

Table 11. Structural characteristics of forest types

Type	SP.	Soil	H_T	$\triangle$ H_T/H_L	Mean diameter (range) of Crowns	Mean diameter (range) of Groups	Mean diameter (range) of Gaps	Distance betw. em. elements	Zo	Leaf size	St.	d max.	G	Grouping
			m	m	m	m	m	m	cm	class		cm	m^2/ha	1-3
33	D –	Peat	45	15	13 (5-20)	20 (15-30)	37 (30-50)	21 (17-35)	527	me	7	100	30	1
31D	B –	"	39	19	15 (10-26)	30	40 (30-55)	23 (20-31)	607	me	7	120	28	2
362	B –	"	49	14	20 (12-33)	45	35 (20-60)	33 (30-50)	712	me/n	5	120	50-60	1
371	B 38	"	48	7	15 (10-22)	22	25 (14-60)	15 (12-20)	353	me/n	5	96	60-70	2
371	B 40	"	45	5	12 (7-17)	28	10 (7-35)	9 (8-11)	251	me/n	4	90	60-70	2
372	B 61	"	43	3	11 (4-14)	18	7 (5-30)	9 (8-12)	230	me/n	4	82	60	2
373	B 63	"	42	2	9 (3-11)	17	6 (5-10)	8 (7-12)	178	n	4	60	50-60	2
381	B 68	"	38	2	8 (2-10)	12	7 (6-12)	7 (5-10)	157	n/m	4	66	40-50	2
382	B 70	"	36	2	6 (2- 8)	11	7 (5-13)	7 (4-11)	–	n/m	4	60	25-40	2
42	S 500	RYP	53	17 (15-20)	12 (5-25)	35	25 (15-40)	17 (15-25)	565	me	7	120	52.1	1
51	D 67	GWP	45	8 (5-12)	7 (5-12)	13 (10-20)	25 (10-25)	12 (7-20)	329	n/1	6	74	44	1
51	D 16	MHP	35	6	6 (5- 9)	11 (10-13)	13 (10 20)	7 (5-10)	293	n/1	5	45	42	2
52	S 274	GWP	42	8 (6-10)	5 (2-10)	20	13 (10-15)	11 (8-15)	283	n	6	58	49.8	1
52	S 149	MHP	40	6 (5- 8)	5 (2- 8)	15	13 (10-15)	8 (6-12)	219	n	6	48	38.7	1
52	S 49	SHP	28	2 (2- 3)	4 (2- 8)	11	11 (8-15)	7 (6- 9)	157	n/m	5	47	23.2	1
51	D 47	DPB	33	6 (4- 8)	5 (3-10)	15 (10-25)	12 (7-20)	5 (4- 9)	188	m/1	4	51	37	3

SP: Numbers of sampling units in Dalam (D) and Sabal (S), and of Blocks (B) in Tanjong Kranji

$\triangle$ H_T/H_L: the difference between the top-height and the height of the intermediate top-canopy trees

Leaf sizes: predominant sizes classes in the type, me = mesophyll, n = notophyll, m = microphyll, 1 = leptophyll

St.: number of more or less distinct storeys. Ground vegetation counts as one storey.

Grouping: the tendency of trees to associate in groups, 1 = weak, 2 = moderate, 3 = strong.

Table 12. Species shared by Kerangas, Mixed Dipterocarp and Peatswamp forests

in dm^2/ha)

a. Mixed Dipterocarp forest and Kerangas forest

Site (ASHTON, 1964c)	1	2	3	4	5	6
Dipterocarp species	24	30	15	14	34	0
Common in KF and MDF	15	20	10	10	7	0
" %	67	67	67	71	21	0
Non Dipterocarp species	137	126	196	68	83	0
Common in KF and MDF	54	57	75	38	19	0
" %	40	45	39	56	23	0
Total species	161	156	211	82	117	0
Common in KF and MDF	69	77	84	48	26	0
" %	43	49	40	59	22	0
of 25 leading species of the site in the MDF are common	16	0	13	15	13	6
of these are also leading species in the KF	5	0	1	1	0	0

Site 1 = Andulau F.R. , broad ridge, RYP
2 = " " , slope of broad ridge
3 = " " , flat valley bottom, gley soil
4 = Belalong " , exposed shale ridge, high altitude
5 = " " , broad ridge, low hilly, clay latosol
6 = " " , clay alluvial soil
All plots are 2.1 ha.

b. Peatswamp forest and Kerangas forest

Phasic community	1	2	3	4	5	6	La. 1	La. 2
Plot size in ha	1.4	2.5	1.6	2.4	0.2	0.8	0.8	0.8
A-layer								
Total species	16	16	7	9	6	3	8	8
Common in PSF and KF	15	15	6	8	6	3	5	8
B-layer								
Total species	27	31	12	10	5	–	11	5
Common in PSF and KF	24	28	11	10	5	–	5	5
C-layer								
Total species	24	37	19	18	8	–	13	7
Common in PSF and KF	18	20	16	17	8	–	11	7
Total species	67	84	38	37	19	3	32	20
Common in PSF and KF	57	63	33	35	19	3	27	20
Common %	85	75	87	95	100	100	85	100

Phasic Com. 1 = Gonystylus-Dactylocladus-Neoscortechinia Assoc. (P.C.1)
" " 2 = Shorea albida-Gonystylus-Stemonurus Assoc. (P.C.2)
" " 3 = Shorea albida Consociation (P.C.3)
" " 4 = Shorea albida-Litsea-Parastemon Association (P.C.4)
" " 5 = Tristania-Parastemon-Palaquium Association (P.C.5)
" " 6 = Combretocarpus-Dactylocladus Association (P.C.6)
La.1 = Lawas Peat Swamp Forest P.C.1 (S.P. ANDERSON 43/44)
La.2 = Lawas Peat Swamp Forest, Dacrydium-Gymnostoma-type (S.P. ANDERSON 49/50)

Soil unit:	I	II	III	IV	V
Agathis borneensis	72	268	272	72	248
Melanorrhoea beccarii	63	199	331	465	77
Gymnostoma nobile	30	36	114	165	201
Cotylelobium burckii	15	30	80	76	150
C. melanoxylon	7	15	23	2	75
Dipterocarpus borneensis	102	88	116	74	66
D. crinitus	13	–	3	–	–
D. pachyphyllus	17	32	21	–	–
D. sarawakensis	14	13	29	–	8
Dryobalanops beccarii	205	3	1	+	–
Hopea vaccinifolia	75	67	92	20	95
Shorea elliptica	146	36	12	2	–
S. multiflora	10	8	5	17	+
S. ovata	40	56	94	50	114
S. pallidifolia	30	48	78	54	36
S. rugosa	30	20	25	58	63
S. scabrida	32	147	232	120	30
S. venulosa	45	10	5	4	40
Vatica cuspidata	166	87	169	27	150
Calophyllum ferrugineum	98	48	50	30	5
C. sclerophyllum	194	432	462	529	363
Tristania obovata	33	36	53	63	122
Whiteodendron moultonianum	80	100	183	152	68
Ganua curtisii	80	165	162	435	177
Palaquium multiflorum	25	62	27	20	135

I = red-yellow, brown-yellow, light yellow RYP; modal MUNSELL notation 10 YR 8/6 at 20 cm depth
II = very pale brown, light brown, clayey GWP; modal notation 10 YR 7/3
III = white, light grey, light brown-grey MHP; modal notation 10 YR – 7.5 YR 7.5/1-2
IV = dark yellow-brown or grey-brown, brown GWP and PB; modal notation 10 YR 4/3-4
V = pink-white, pink-pale grey SHP; modal notation 5 YR 7.8/1-2.

Table 14. Yield:

a. Growing stock volume and biomass

SP. No.	Geol. form.	Soil type	Leading species (G %)	Basal area m^2/ha	Top height m	Above-ground wood volume > 5 cm d m^3/ha	Commercial volume m^3/ha	Total plant dry matter t/ha	Locality
27	HT	GHP	S. albida (64.5)	67.7	41	1 381	280	1 415	Badas
10	TIG	LS	(MDF)	55.5	62	1 279	156	1 160	Sempadi F.R.
—	AL	Peat	S. albida (86.3)	38.2	52	1 269	421	1 158	Lingga
4	HT	GHP/PB	G. nobile (14.4)	36.0	45	504	23	765	Pueh F.R.
50	BS	MHP	A. borneensis (8.5)	50.4	35	819	174	747	Jelalong P.F.
43	PT	DHP	A. borneensis (56.3)	45.6	45	867	204	709	Similajau F.R.
40	BS	PB/HP	D. pectinatum (39.0)	52.0	31	500	61	457	Bumbong rumah
1	HT	MHP	D. fusca (9.8)	31.9	39	425	57	452	Pueh F.R.
9	BS	PB	G. nobile (36.4)	30.1	22	246	nil	264	Merurong
15	PS	SHP	W. moultonianum (16.4)	27.3	30	215	nil	246	Bako N.P.

b. Yield estimate for *Agathis borneensis* on a moist Medium to Deep Humus Podzol

Cost nat. reg. $/ha	Cost plant. $/ha	Year	N ha^{-1}	D cm	H_T m	d_K m	G m^2/ha	v m^3	V m^3/ha	F m^3/ha	V_r m^3/ha	Net Revenue $/ha
50	300	1	2000	0.5	0.3	0.2	0.2	—	—	—	—	0
12	12	2										
8	8	3										
5	5	5	1800	4	4	—	—	—	—	—	—	0
15	5	10	1800	7	7	2.5	7.7	0.01	15	5	10	0
0	0	20	1200	12	13	2.9	22	0.04	71	24	47	0
0	0	30	800	17.5	18	4.0	21	0.14	110	40	70	160
0	0	50	400	25.0	26	5.5	20	0.50	200	200	0	1,400
1,360	4,050									269		1,825

All costs and returns are compounded at 5%.

N = number of trees of *A. borneensis*
D = mean diameter of stand under bark
H_T = stand top height
d_K = mean crown diameter
G = basal area under bark
v = volume of mean diameter tree under bark
V = stand volume under bark
F = removals
V_r = residuals

Table 15. General strategy for land use on kerangas sites

Natural site productivity	Protection value	Recreation and scenic value	Accessibility	Natural Regeneration	General strategy
High	High	High	Good	Easy	FR, SS; NP
				Difficult	FR, SS asst. nat. reg.; NP
			Poor	Easy	FR, GLS with pg
				Difficult	FR, GLS
		Low	Good	Easy	FR, MUS
				Difficult	FR, MUS with improvement and residual pg
			Poor	Easy	GLS, low limit
				Difficult	GLS, medium limit
	Low	High	Good	Easy	FR, SS or MUS; NP
				Difficult	FR, MUS asst. nat. reg.; NP
			Poor	Easy	GLS, low limit
				Difficult	GLS, high limit
		Low	Good	Easy	FR, MUS; intensive agriculture
				Difficult	FR, SS or MUS asst. nat. reg.; PL; int. agric.
			Poor	Easy	GLS, very low limit
				Difficult	GLS, med. low limit
Low	High	High	Good	Easy	NP; FR if MUS feasible
				Difficult	NP
			Poor	Easy	PF for future conversion to FR
				Difficult	PF
		Low	Good	Easy	PF, admission of GLS with medium limit
				Difficult	PF
			Poor	Easy	PF
				Difficult	PF
	Low	High	Good	Easy	NP, admission of SS if feasible
				Difficult	NP
			Poor	Easy	PF for future use as NP
				Difficult	PF
		Low	Good	Easy	FR, MUS if site amelioration feasible
				Difficult	FR, PL if site amelioration feasible
			Poor	Easy	Protection against alienation
				Difficult	No action

FR — Productive permanent forest reserve
PF — Protective permanent forest
NP — National park for recreation and research
PL — Plantation forestry
SS — Selection system of silvicultural management
GLS — Girth limit system of exploitation
MUS — Malayan Uniform System of silvicultural management
asst. nat. reg. — Natural regeneration assited by planting of blanks or along lines
pg — Silvicultural treatment by poison-girdling

Table 17 List of Single Sample Plots with Soil Features, Leading Dominant Tree Species and Basal Areas

SP	Locality	Geol.	Alt.	Av. slope	Parent material	Depth from A surface of A_0 (in cm)	A_1	A_2	A_3	B_1	B_h	B_3	C/D	Max. rooting depth in cm.	Soil type	Drainage class	Name	G %	Name	G %	Name	G %	G % 18–20	G/ha	SP.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		19		20		21	22	23
1	Pueh	PT	15	1–5	Sand on gravel	8	0	18	26	30	40	—	—	35	MHP	2	D. fusca	9.8	S. albida	6.7	G. curtisii	5.0	21.5	31.9	1
2	"	HT	5	0–1	Clay	90	0	20	—	—	—	—	—	?	PB	5	S. albida	12.3	G. curtisii	5.8	M. inappendiculata	5.2	23.3	32.9	2
3	"	PT	12	0–1	Sand and gravel	7	0	10	—	—	33	—	52	45	MHP	3	D. fusca	12.3	W. moultonianum	6.8	P. ridleyi	5.6	24.7	28.0	3
4	"	PT	10	0–1	" and clay	150	–	—	—	—	—	—	0	?	PB	5	G. nobile	14.4	C. sclerophyllum	12.6	C. rhizophorum	12.1	39.1	36.0	4
5	"	PT	13	2–3	" " "	20	0	15	—	–	20	25	50	60	SHP/PG	3	G. rheedii	7.0	E. multibracteolata	4.5	W. moultonianum	3.8	15.3	25.7	5
6	"	PT	10	3–7	Clay	3	0	—	—	17	—	—	50	55	PG	3.5	G. nobile	15.2	S. albida	13.8	W. moultonianum	7.4	27.3	30.1	6
7	"	PT	20	1–3	Sand	5	0	20	—	—	45	—	60	60	MHP	2	D. fusca	27.2	D. rappa	9.3	M. inappendiculata	8.6	45.1	34.6	7
8	"	PS	50	0–10	Sandstone	3	0	10	—	—	18	25	70	75	SHP	2 w	V. borneensis	10.7	P. ridleyi	7.8	S. albida	7.5	26.0	29.9	8
9	Sempadi	PS	33	2–10	Sandstone	15	0	15	23	—	25	35	60	80	SHP	2 w	W. moultonianum	19.3	C. burckii	10.5	G. nobile	10.0	39.8	29.7	9
10	"	GD	120	20–30	Granodiorit	0	0	—	—	—	—	—	—	40	LS	3	Dipterocarpaceae	37.8	—	—	—	—	—	54.8	10
11	"	PS	35	2–8	Sand and clay	8	0	25	—	40	55	—	90	80	MHP	2.5	A. borneensis	32.3	G. curtisii	7.0	W. moultonianum	5.1	44.4	38.6	11
12	"	PS	37	5–10	Loam on PS	3	0	—	—	12	—	25	70	60	RYP	2	V. borneensis	7.5	G. curtisii	6.0	E. kuchingensis	3.7	17.2	32.9	12
13	Selang	PS	450	1–8	Sand on PS	5	0	21	—	—	22	—	30	70	SHP	2 w	S. ovata	11.1	P. ridleyi	11.0	G. nobile	8.6	30.7	40.0	13
14	"	PT	27	0–1	" " gravel	20	0	20	—	—	60	85	100	50	MHP	2	A. borneensis	17.1	G. curtisii	7.9	S. retusa	5.3	30.3	37.7	14
15	Bako	PS	200	5–7	Sandstone	20	0	25	—	—	40	—	40	40	MHP	1 w	W. moultonianum	18.0	C. burckii	10.6	S. ovata	7.3	33.7	27.0	15
16	"	PS	90	10–45	"	3	0	10	—	—	35	47	80	70	MHP	1	D. beccarii	12.1	S. flava	10.3	D. borneensis	8.6	31.0	28.7	16
17	"	PS	95	5–7	"	3	0	30	—	—	75	—	80	75	MHP	1.5	Dac. pectinatum	13.6	C. burckii	7.6	W. moultonianum	6.8	28.0	32.7	17
20	Ingei	PT	66	0–5	Sand and clay on gravel	8	0	20	—	—	55	—	110 D	80	MHP	3	A. borneensis	15.9	S. multiflora	9.0	D. borneensis	4.1	29.0	34.1	20
21	"	PT	73	0–5	–"–	5	0	20	42	—	45	60	62 D	120	MHP	4	S. albida	36.7	Ison. lanceolata	6.1	T. grandifolia	5.0	35.9	44.3	21
22	Badas	PT	33	0–3	Sand	10	0	30	—	—	290	—	360	290	DHP	1	A. borneensis	40.0	D. borneensis	14.8	C. burckii	12.7	67.5	46.5	22
23	"	PT	34	0–1	"	10	0	40	—	—	80	100	?	80	MHP	3	A. borneensis	24.5	H. pentanervia	10.3	P. leiocarpum	6.7	41.5	41.6	23
24	"	PT	34	0–2	"	10	0	27	70	—	75	—	?	75	MHP	3	A. borneensis	23.7	S. albida	20.4	D. borneensis	7.3	51.4	46.1	24
25	"	PT	33	0–1	"	13	0	30	60	—	82	—	?	80	MHP	3.5	M. inappendiculata	11.1	H. pentanervia	10.5	St. umbellatus	10.2	31.8	34.8	25
26	"	PT	30	0–5	"	25	0	90	—	—	140	—	?	140	DHP	1	A. borneensis	68.3	C. burckii	5.5	P. leiocarpum	4.5	78.3	44.4	26
27	"	HT	10	0	" and clay	10	0	50	80	—	100	—	?	55	GHP	5	S. albida	57.7	D. rappa	10.0	Dyera lowii	3.1	78.9	74.5	27
28	Melinau	PT	185	0–2	Sand on gravel	15	0	12	27	—	31	—	60 D	70	MHP	2.5	S. albida	37.3	G. nobile	7.3	P. ridleyi	5.8	50.4	29.9	28
29	"	PT	182	0	" " "	90	0	(humic sand and clay)						?	PB	5	S. albida	36.4	M. calophylloides	9.7	P. ridleyi	8.3	54.4	16.9	29
30	"	PT	165	0–2	" " "	20	0	15	—	45	50	55	60 D	50	MHP	2	S. albida	27.4	C. palustris	12.6	M. calophylloides	8.2	48.2	35.7	30
31	"	PT	183	0	" " "	120	0	(humic sand and clay)						?	PB	5	S. albida	74.6	M. beccarii	11.9	P. ridleyi	4.1	90.6	88.0	31
32	"	PT	182	0	" " "	180	0	(" " " ")						?	PB	4	C. flavoramulum	17.5	S. albida	14.9	M. calophylloides	10.4	42.8	38.1	32
33	Sagan	PT	433	0–5	Clay	10	0	—	—	—	—	20	25	60	PG	4	Dac. beccarii	19.0	S. revoluta	9.1	T. obovata	4.2	32.3	29.9	33
34	"	BS	425	10	"	2	0	—	—	—	—	7	30	80	RYP	3	S. rugosa	17.8	C. scriblitifolium	8.1	M. inappendiculata	7.7	33.6	35.1	34
35	"	BS	420	15	Sandstone	12	0	—	—	—	—	24	25	60	SHP	2	M. beccarii	8.1	C. scriblitifolium	7.4	C. malayanum	4.7	20.2	38.6	35
36	Temburong	PT	35	0	Clay on gravel	25	–	0	—	—	—	—	15	45	GWP	5	V. vinosa	4.2	D. lowii	3.7	Dill. pulchella	2.7	10.6	24.0	36
37	"	PT	32	1–3	" " "	7	0	5	—	—	—	—	20	25	GWP	5	D. lowii	4.7	M. beccarii	3.0	S. parvifolia	2.7	10.4	29.6	37
38	Kpg. Bako	BS	110	5–10	Sandstone	5	0	3	13	—	—	20	35	40	RYP/GWP	2	A. borneensis	15.6	P. spicatum	10.8	D. beccarii	10.7	37.1	39.3	38
39	" "	BS	110	3–7	"	3	0	—	—	—	—	—	25	25	GWP	1	P. spicatum	15.9	D. borneensis	8.6	T. obovata	7.8	32.3	31.4	39
40	B. rumah	PT	680	0	Sand and clay	300	0	20	—	—	45	—	—	?	PB	5	Dac. beccarii	39.0	P. rostratum	11.4	T. obovata	9.3	59.7	52.0	40
41	" "	MS	740	5–20	" on	20	–	0	—	—	—	7	50	25	PG	3	G. nobile	28.8	P. alternifolium	22.4	D. beccarii	8.3	59.5	55.0	41
42	" "	MS	790	10–20	Sandstone	7	0	—	—	—	25	—	70	70	RYP	2	Lith. cyclophorus	12.7	M. havilandii	11.4	M. beccarii	8.1	32.2	52.7	42
43	Similajau	PT	6	1–5	Sand and clay	4	0	43	150	160	170	—	290	170	DHP	1	A. borneensis	56.3	D. rappa	7.4	E. spicata	3.7	67.4	45.6	43
44	"	PT	14	0–2	" " "	8	0	27	60	—	65	—	120	85	MHP	3	A. borneensis	43.3	S. ovata	11.3	K. malaccensis	7.0	61.6	35.1	44
45	"	PT	6	15	" " "	6	0	60	70	—	72	—	130	110	MHP	2	S. leiocarpa	23.5	A. borneensis	21.9	D. rappa	10.3	55.7	48.0	45
46	"	HT	4	0	" on gravel	5	0	40	60	—	—	—	60	80	GHP	3.5	G. curtisii	15.7	S. scabrida	15.4	E. cf. chrysantha	7.1	38.2	40.2	46
47	Jelalong	HT	67	0–5	Sand and clay	10	0	26	—	130	—	190	210	40	GWP	3	A. borneensis	33.5	S. albida	7.6	S. rugosa	6.6	47.7	54.8	47
48	"	BS	107	2–3	Clay and sand	5	0	22	45	—	48	80	100	25	MHP	3	S. albida	20.1	D. borneensis	10.0	P. urophyllum	9.1	39.2	45.8	48
49	"	BS	155	3–5	Sandstone	2	0	30	37	—	40	75	80	40	MHP	2.5	S. albida	35.4	S. pachyphylla	14.6	C. burckii	7.3	57.3	59.3	49
50	"	BS	175	12	Sand a. claystone	2	0	—	—	—	—	13	28	50	GWP	3	A. borneensis	8.8	C. burckii	7.8	Garc. Sp. Ny 134	4.3	20.9	50.4	50
51	Merurong	BS	733	0–10	Sandstone	7	0	50	—	—	60	—	62	60	MHP	4	G. nobile	12.3	Dac. beccarii	8.9	P. rostratum	6.2	27.4	41.4	51
52	"	BS	745	5–7	"	15	0	(variable)			25	—	10/60	60	SHP	2	D. ferruginescens	11.5	P. leiocarpum	9.7	S. scabrida	7.3	28.5	47.5	52
53	"	BS	845	3–15	Claystone	10	0	—	—	—	20	—	60	100	PG	4	T. obovata	10.2	P. leiocarpum	8.4	G. nobile	5.1	23.7	52.2	53
54	"	BS	1125	5–7	Sandstone	70	–	—	—	—	—	—	70	70	PB	2 w	G. nobile	36.4	T. elliptica	8.6	P. rostratum	6.4	51.4	35.2	54
55	"	BS	730	0–2	Clay	30	–	—	—	0	—	—	10	10	PB/PG	5	C. rotundatus	26.1	D. evena	15.2	T. obovata	12.6	53.9	56.6	55
56	"	BS	735	0–7	Sandstone	10	0	20	50	—	60	—	63	60	MHP	2.5	A. beccarii	19.3	P. leiocarpum	17.2	M. beccarii	13.5	50.0	46.6	56
57	"	BS	730	0–1	Sand and clay	70	0	—	—	20	—	—	30	30	PB/PG	5	S. albida	24.8	D. evena	9.8	G. nobile	7.8	42.4	51.7	57

*) Drainage class: 1 = very easy; 2 = easy; 3 = moderate; 4 = slow; 5 = very slow; w = moisture extremely variable.

Table 5 a. Range of some chemical characteristics of 3 profiles in sandy Red Yellow Podzolic Soil.

	A_{e1}	A_{e2}	C
Org. matter %	1.3 – 2.5	0.5 – 2.0	0.4 – 0.8
N%	0.1 – 0.3	0.06 – 0.1	0.03 – 0.2
C/N	8 – 20	10 – 35	6 – 20
C.E.C. m.e.%	4 – 15	2 – 10	3.5 – 7
Ca	0.1 – 0.6	0.06 – 0.5	0.03 – 0.4
Mg	0.4 – 0.7	0.08 – 0.3	0.04 – 0.1
K	0.02 – 0.4	0.01	0.01 – 0.3
Na	0.01	0.002	0.01
C sat.%	8 – 10	3 – 10	5 – 16
pH	3 – 4	4 – 5	3 – 5
P_2O_5 p.p.m. (available)	2 – 5	1 – 2	1 – 3

Table 5 b. Range of some chemical characteristics of 3 profiles in sandy Grey-White Podzolic Soils over clay subsoil.

	A_{e1}	A_{e2}	B	C
Org. matter %	1 – 2	0.2 – 0.7	0.2 – 1.4	0.3 – 0.7
N%	0.03 – 0.1	0.01 – 0.03	0.02 – 0.03	0.01 – 0.04
C/N	15 – 35	8 – 22	9 – 30	11 – 17
C.E.C. m.e.%	3 – 4	2 – 10	4 – 10	10 – 20
Ca	0.13	0.06 – 0.15	0.03 – 0.3	0.05 – 0.2
Mg	tr	tr – 0.01	tr – 0.1	tr – 0.06
K	0.19	0.01 – 0.06	0.02 – 0.12	0.01 – 0.19
Na	0.02 – 0.3	0.03 – 0.1	0.1 – 0.3	0.02 – 0.18
Base sat.%	10 – 20	2 – 3	3 – 9	1 – 2
pH	4 – 5	4.5 – 5.5	4 – 5	5 – 6
P_2O_5 p.p.m. (available)	1 – 4	2 – 4	1 – 2	1 – 2

Table 5 c. Range of some chemical characteristics of 5 profiles in Medium Humus Podzol over sandy loam subsoil.

	A_{e11}	A_{e12}	A_{e2}	B	C
Org. matter %	75 – 90	1.5 – 3.0	0.3 – 1.2	2.0 – 8.2	0.3 – 1.9
N%	0.8	0.04 – 0.1	tr. – 0.01	0.03 – 0.1	0.004 – 0.02
C/N	33 – 100	20 – 40	20 – 32	40 – 122	80
C.E.C. m.e.%	3 – 20	3.5 – 20	0.5 – 31	4 – 45	5 – 10
Ca	0.3 – 0.7	0.3 – 0.7	0.3	0.3 – 0.4	0.1 – 0.3
Mg	0.3 – 0.8	0.3 – 0.6	tr.	tr. – 0.3	tr. – 0.2
K	0.01 – 0.1	0.1 – 0.6	0.05 – 0.15	0.05 – 0.3	0.01 – 0.1
Na	0.01 – 0.3	0.2 – 1.1	0.1 – 0.3	0.02 – 0.8	0.03 – 0.2
Base sat.%	30 – 40	10 – 40	17 – 100	4 – 8	6 – 13
pH	3 – 4	3.8 – 5.6	4.5 – 6.7	2.9 – 4.9	4.5 – 51
P_2O_5 p.p.m. (available)	n.d.	3 – 4	tr. – 1	2 – 5	1 – 2

Table 5 d. Some chemical characteristics of Kerapah peat bog soils and peatswamp soils.

	SP. 52 – 5	SP. 53 – 3	PSF 19*	PSF.5*
Loss in ign.,%	75.5	86.7	89.0	98
N%	0.80	1.12	1.90	1.41
Ca in % ash	0.70	0.75	n.d.	n.d.
Mg in % ash	0.78	0.60	n.d.	n.d.
K in % ash	0.16	0.43	n.d.	n.d.
Na in % ash	0.32	0.18	n.d.	n.d.
P p.p.m.	0.5	0.7	0.6	0.6
pH (KCl)	3.4	3.2	3.7	3.5

* Both PSF – samples are from RICHARDS (1965). PSF 19 is Alan peatswamp forest close to SP.27 and PSF.5 is Alan bunga peatswamp forest between SP.27 and SP 22 – 26 (Badas quarternary terrace). Both samples are top-layer peat above the water table at the time of collecting.

Bruing 1974.