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Topography of a Large-Scale Research Plot Established within a Tropical Rain Forest at Lambir, Sarawak

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ABSTRACT A large-scale research plot 52 ha in area was recently established at the Lambir Hills for a long-term ecological research of tropical rain forest in Sarawak, East Malaysia. The work for plot demarcation including a topography survey was initiated in November 1990 and continued till March 1992. Electronic tacheometers with automatic distance meters were adopted to built the plot with reliable accuracy on steep and complex slopes. The plot with an area of 500 m x 1040 m was divided into 1300 quadrats of 20 m x 20 m and further divided into 20,800 subquadrats of 5 m x 5 m, by setting landmarks at all the corners of quadrats and subquadrats. The compass directions and zenith angles to elevation at the base of respective landmarks were carefully surveyed with tacheometers by following conventional land survey methods. The topographical data thus obtained were transformed into altitude values at each landmark. The altitude difference between the lowest and highest points in the plot was ca. 150 m. A topography map was drawn by using these altitude data. Furthermore, a geometrical plane covering each of 1,300 quadrats was numerically determined to calculate the detailed statistics of topographic variables, such as the altitude, direction, angle and convexity of slopes. The statistics of these variables and their distribution maps within the plot suggested the steep, undulating and complex slope-topography of the plot. These topographic features seemed to result in the fragmentation of plant habitats and might be strongly combined with a rich flora of the Lambir rain forest

Key Words: environmental variations / large-scale research / long-term research / mixed dipterocarp forest / plant habitat / Sarawak / topographic heterogeneity / tropical rain forest

A long-term and large-scale research study of a tropical rain forest was recently initiated on a hilly slope of the Lambir National Park (latitude ca. 4° N, longitude ca. 114° E) in Sarawak, East Malaysia, through an international collaboration of foresters, dendrologists, forest ecologists, and botanists from three countries, Malaysia (Sarawak), U.S. A., and Japan. The purposes of the research project declared to the Sarawak State Government by one of us (H.S.L) were: (1) to monitor tree population dynamics in space and time, with reference to the regeneration of keystone species and timber species; (2) to analyze the interaction among species at two contrasting local soil types, sandy and clayish soils, characterizing the Lambir Hills; (3) to provide control observations for silvicultural studies; and (4) to establish a foundation of botanical knowledge indispensable for wildlife biology, socio-economy, and park management (Lee, 1992). The research program involved an establishment of a large-scale research plot in the Lambir National Park. The plot was expected to be a core facility for multi-purpose use in scientific researches, resource conservation, park management, etc. (Yamakura *et al.*, 1995)

In October 1990, the first landmark peg for plot demarcation was established in a forest dominated by various dipterocarp species, which are common in the park. It took about four years to finish all the necessary field and laboratory work for plot establishment. The proposed plot size before initiation of plot demarcation was 50 ha, following similar plots already established at Pasoh in East Malaysia (Manokaran *et al.*, 1989) and Barro Colorado Island (BCI) in Panama (Hubbell & Foster, 1983). However, its size was extended to 52 ha later. The plot was divided into 1,300 quadrats 20 m x 20 m in area. Each quadrat was further divided into 16 subquadrats of 5 m x 5 m, by establishing 21,109 landmark pegs within the whole plot. A total of 358,905 trees with a stem diameter at breast height (dbh) greater than and equal to 1.0 cm were individually labeled, mapped, identified to species, and measured by dbh. The species identification has been continuing since 1991 and its finalization is expected by one of us (P.S.A.) before October 1995. The present study outlines the study site and analyzes topographic features of the plot, since the topography is one of determinant factors of forest architecture, which will be described in a separate paper (Yamakura *et al.*, in preparation) by using the results of this study.

STUDY SITE

Lambir National Park

The Lambir National Park was gazetted for amenity, research, education, and as a reservoir of forest resources and biodiversity in 1975 and was planned to be totally protected since then. The park consists of the central portion of the Lambir Hills with the highest peak of rugged sandstone escarpment of 458 m in altitude. It lies about 30 km south of Miri, the capital of the Fourth Division, Sarawak. The access to the park from Miri is provided by the Sarawak trunk road connecting Miri and Kuching via major cities in Sarawak, such as Bintulu and Sibu (Fig. 1). The park covers a strip of land 6,949 ha in area and is separated into two sections by the road traversing the park at its narrowest part, ca. 1.6 km in width. Thus, about one-third of the park area is isolated from the major park area by the road and is endangered by development activities, such as commercial logging and agriculture. Furthermore, the park boundary was eroded by the pressure of human activities till recently. Therefore, a bird eye appearance of the park looks like a small green island floating in man-made desert, which is derived by a land use syndrome common in the recent history of Sarawak (Watson, 1985).

Climate

The climate around Miri including Lambir Hills is everwet but monsoonal due to distinct shifts in prevailing winds; the north monsoon known as the wet Landas season from November to February and the south monsoon from April to September. These seasonal changes of winds are determined by shifts in the Inter-Tropical Convergence Zone (ITCZ),

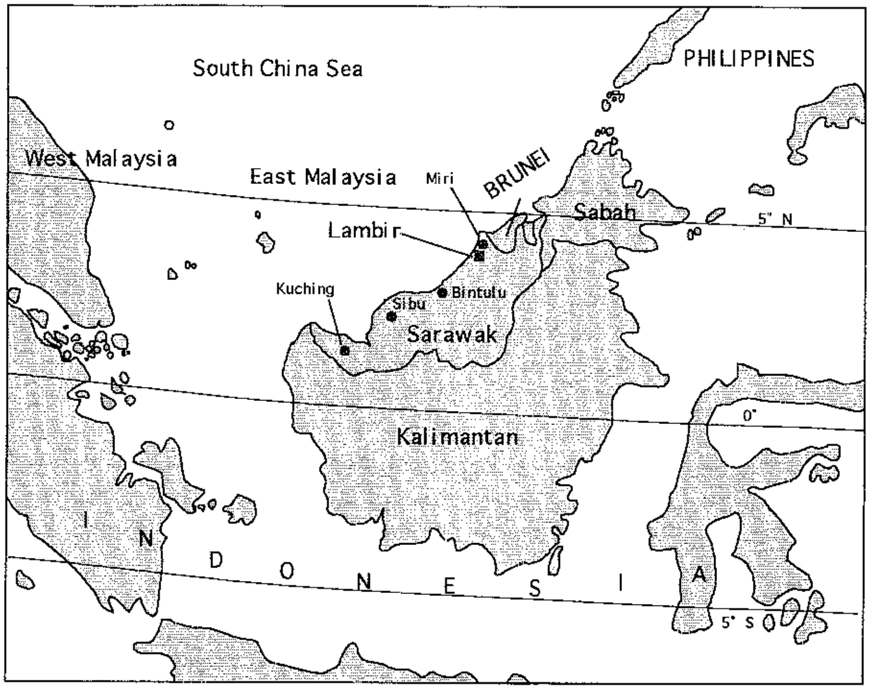


Fig. 1. Location of the study site of Lambir Hills, Sarawak, Malaysia.

i.e. a boundary between northern and southern trade winds. The seasonal shifts of ITCZ is thought to be driven by the changing zenithal position of the sun, since ITCZ is usually situated near the theoretical belt of maximal warming determined by the solar position. When the ITCZ lies to the south of Borneo, the prevailing winds come from northeast (north monsoon). On the other hand, when it lies to the north of Borneo, the winds come from southwest (south monsoon). Although the heavy rainfall and everwet climatic conditions can be explained by an arrival of the north monsoon, anomalous drought also occurs rather more frequently than might be expected (Soepadmo *et al.*, 1984; Watson, 1985). Some severe droughts are associated with anomalies in the movement of ITCZ, such as the El Nino event. Borneo including Sarawak belongs to one of areas susceptible to climatic anomalies resulting from the El Nino (Japan Meteorological Agency, 1994).

The mean annual rainfall during 31 years of observation (1917-1957) at Miri was 3,150 mm, distributed evenly throughout the year. March was the driest month, though it still received 163 mm of rainfall (Department of Civil Aviation & Meteorological Services, British Borneo Territories, 1961). Mean annual temperature during three years (1958-1960) was 26.8 °C with its range between 26.2 °C in February and 27.3 °C in May. The lowest records was 21.5 °C (Kurashima *et al.*, 1964)

Topography

The topography of the park is characterized by a hilly and undulating terrain with steep slopes including scars of landslides, though its details are complex to interpret. About 85 % of the total park area represents slopes. The other 15 % of the area consists of ridges and valleys, both of which dissect the whole park area and seem to result in finely fragmented local habitats for plants. Eight small streams can be seen in the park and are integrated into the tributaries of three major river systems; the Miri, Bakam, and Baram Rivers. These topographic features have high correlation with the geomorphological evolution of the Lambir Hills and are believed to be a joint outcome of three major cycles of peneplanation after land uplift during Pliocene or early Pleistocene period (Liechti, Roe & Haile, 1960; Watson, 1985). According to current understanding of erosion process, the present topography is thought to be at typical immature erosion stage, though erosion is generally rapid in the tropical environment and in a locality with fragile soft rock as in Lambir Hills (Soepadmo, *et al.*, 1984)

Geology

Three geological formations are identified within the park boundary. They are the Setap Shale (or Sibuti), Lambir, and Tukau formations deposited in late Oligocene-early Miocene, mid Miocene, and late Miocene, respectively (Liechti, Roe & Haile, 1960). The Setap Shale is thick and is characterized by fine grained clay and shale, which is bedded well and moderately soft. The Lambir formation occurs above the Setap Shale, widely covers the surface of the park, and is composed of soft fine grained sandstone and shale with calcareous elements, suggesting littoral deposition conditions. At the top of the Lambir formation, coarse grained sandstones with various characters, such as lignitic, gritty, and pebbly properties, are recognized, alternating with shale and clay. Unclear ancient calcareous deposits are rather confined to the Setap Shale and are rare in the Lambir formation. Our research plot was established in an area of the Lambir formation. The youngest Tukau formation outcrops at the eastern corner of the park and is composed of sand and poorly consolidated sandstone alternating with clay The sandstone is soft and medium grained The clay is also soft and poorly bedded (Liechti, Roe & Haile, 1960; Soepadmo, et al., 1984; Watson, 1985). These sandstones and shales of three geological formations offered a variety of parent materials for soils described below.

Soils

Six major soil groups were reported by Wall (1962). They were immature alluvial soils around river banks, red-yellow podsols (ultisols) on slopes and ridges, podsols around the hill summit of Bukit Lambir, and immature regosols on very steep slopes. Among these soils, the red-yellow podsols cover most of the park and further divided into three soil families, Nyalau, Bekenu, and Merit families, characterized by different soil textures or clay contents. The red-yellow podsolic soil is poor in chemical nutrients in general, though it can support huge tropical evergreen rain forest with rich species diversity, as described below

Vegetation

The rain forest in the park consists of two types of indigenous vegetation common in the whole of Borneo, i.e. mixed dipterocarp forest and tropical heath forest. The former with various dipterocarp trees occurs on sites with red-yellow podsols, covers a rather lower area in elevation within the park, and has a territory of 85 % of the total park area The latter with *Casuarina nobile* dominant is recognizable in a limited area with sand podsol soil around the highest peak of the Bukit Lambir and covers 15 % of the total area. The change between these forest types can be explained well by a classic ecological or pedological concept, a forest catena, which relates a series of forest types with a connected series of soils derived from similar parent material, found under similar climatic conditions, but showing different properties due to variations in soil forming factors. Our research plot was established within the mixed dipterocarp forest standing on red-yellow podsolic soils

The mixed dipterocarp forest in Lambir has one of the richest lowland rain forest floras of the Old World. There is exceptional high local endemism at about 35%. Furthermore, it is ca. 75 % in Borneo island (Ashton, 1989). The reason for the exceptionally high biodiversity is unclear. However, several hypothetical explanations are possible in terms of historical and biogeographical patterns, climatic conditions, disturbance regimes, resource competition, symbiotic interactions among organisms of the rain forest community, etc (Ashton, 1989).

METHODS OF PLOT DEMARCATION

Site Selection of the Plot

Before the initiation of plot demarcation in 1990, four small long-term research plots had been already established in the park in 1963 and monitored since then by the Forest Department, Sarawak and several individual colleagues under supervision of one of us (P.S.A.), who was the first forest botanist at the Forest Department (Ashton, 1973; Ashton *et al.* 1986, Ashton & Hall,1992). In addition to these preceding researches, a research group led by Soepadmo at Malaya University carried out an ecological survey of the flora and fauna of the park in April 1981 and listed 684species, 253 genera, and 77 families of plants (Soepadmo *et al.*, 1984). Watson also traversed the park for a resource inventory in 1982-1983 and proposed a park management plan. Wall (1962) had made a study of soil in Bekenu-Niah-Suai area including Lambir and prepared a soil map of the park in 1972, which was reproduced by Soepadmo *et al.* (1984). These preceding studies offered a background and justification for our selection of the research site. The position of the plot was planned so as to cover the aforementioned four small monitoring plots (ca. 2.4 ha in total area) established in 1963.

Topography Survey

The setting of landmarks and the topography survey in plot demarcation were carried out by adopting the methods in a land survey and by using two electronic tacheometers (Total-Station-SDM3, Sokkia, Osaka) with automatic distance meters and reflector mirrors (APS11,Sokkia, Osaka), one electronic digital theodlite (DT2, Sokkia, Osaka) equipped with an electronic distance meter (Red-Mini2, Sokkia, Osaka), and two compasses (Pocket Compass LS25, Ushikata, Tokyo). This major equipment was necessary for establishing the plot with reliable accuracy on steep slopes. Each landmark peg was individually set following the proper angle and horizontal distance determined by the above-mentioned equipment without killing any trees. The general strategy in plot demarcation was to fix at the onset a base line at the center of the plot, though the base line position was shifted later. Along the base line, the new quadrats were built in a step-wise fashion. Survey errors in plot demarcation were minimized by repeated land surveys. This strategy came from a survey procedure tried in Pasoh and BCI. However, this strategy might be inadequate in Lambir with steep and complex topography because the land survey is not free from errors and because the repeated surveys for error corrections exhaust time and man power. The conventional method for plot demarcation, in which the outer boundary lines of the plot are first surveyed, is recommended on steep slopes, where the inevitable cutting of some saplings may prove unavoidable. A total of 21,109 plastic tent-pegs and aluminum poles were used for landmarks. Further details are described in a separate paper written by us (Chai *et al.*, 1994).

RESULTS AND DISCUSSION

Topography Map

The map of Fig. 2 represents the topography of our 52 ha plot. The plot area was a bit greater

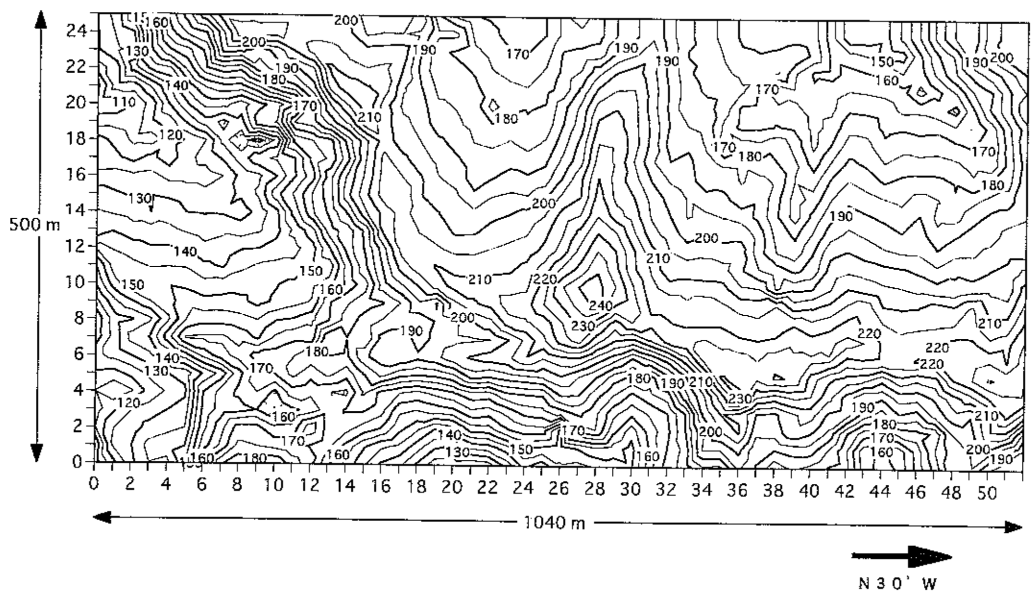


Fig. 2. Topographical map of the 52 hectare research plot at the Lambir National Park. Contour lines are drawn at every 5.0 m interval in altitude. A longer side of the rectangular plot is 1040 m, and a shorter side 500 m.

than the other two similar research plots, 50ha in size, at BCI and Pasoh, though the difference of plot area is not intrinsic in research subjects and data comparisons among the three sites. Numerals along the longer and shorter sides of the plot in Fig 2 stand for the identification number of survey lines demarcated at every 20 m interval for the easy recognition of positions of quadrats in the plot. A position of a given quadrat is expressed by a set of identification numbers of the longer side (*a*) and shorter side (*b*). Furthermore, the whole plot area was divided into 52 sub-areas 20 m x 500 m, each of which was also identified by the combination of identification numbers similar with those of a quadrat (Chai, *et al.*, 1994).

A survey point given by the set of identification numbers (2,10) was used for the standard point at 150 m in tentative hypothetical altitude for measuring the altitude of other survey points, since it lay on an old survey point at which one landmark of the aforementioned monitoring plot (P-2) was established by the Forest Department and Ashton in 1963. By using the relative altitude of survey points, the contour lines were drawn in the map at every 5.0 m interval in altitude. The altitude difference between the lowest point (0,1) and highest point (28,11) was 137 m

A long and steep cliff at the lower side of the map implies that the Lambir hills were worn off by the waves in ancient times. It is inconceivable that a long and complex cliff as seen in our Lambir plot might be created by recent land slides resulting from heavy rain. Traces of landslides are unclear in the map To understand the details of land slide patterns, a map should be drawn by using finer scale and by using altitude data measured at shorter intervals

For precise understanding, the three dimensional expression of the topographical map is given in Fig.3. A national park trail run along a narrow ridge on the upper part of the aforementioned long cliff. The one of the major ridges including the highest peak ca. 250 m in relative altitude runs along a line connecting the two survey points, (25,0) and (31,25), which separated the plot into the two halves. An overall view of the plot topography was characterized by the terms, hilly and complex, owing to steep slopes, ridges and valleys finely bifurcated, and land slides with a variety of scales and times, all of which partition the whole

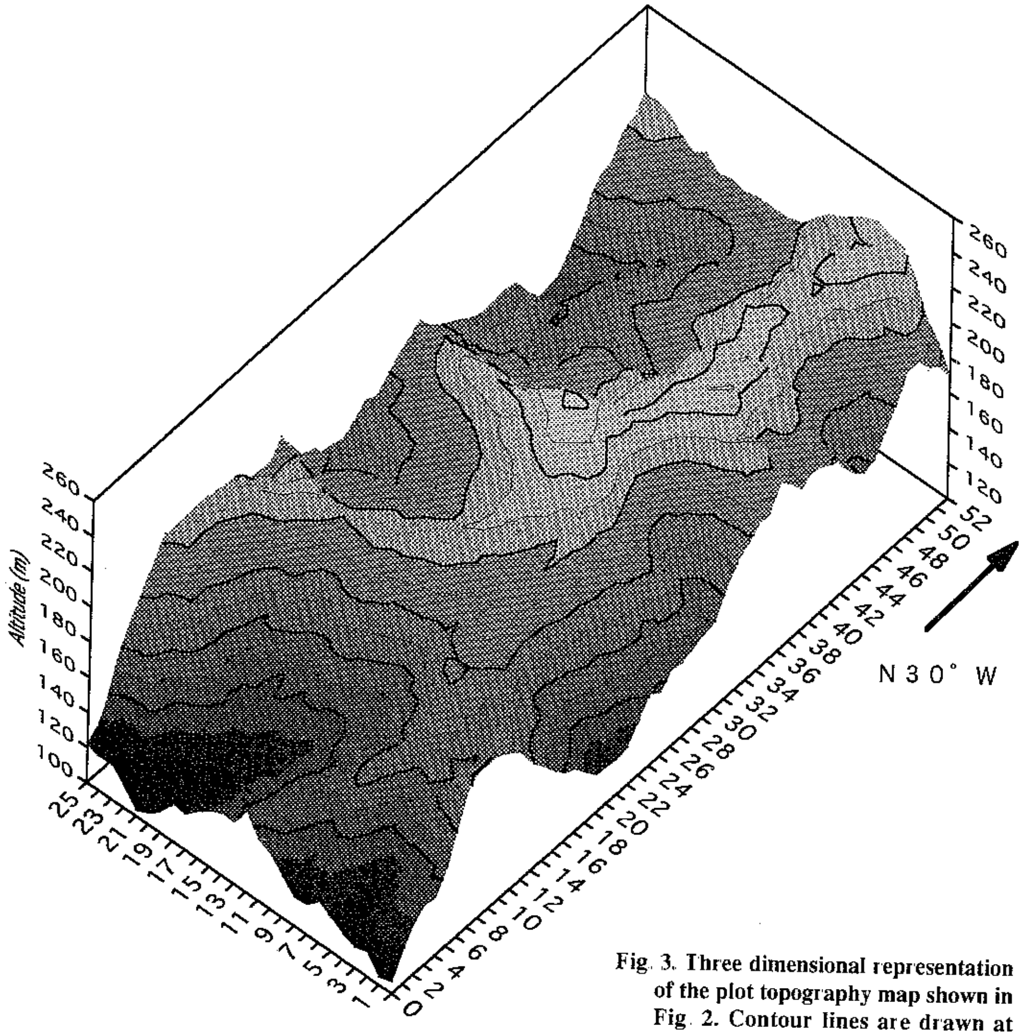


Fig. 3. Three dimensional representation of the plot topography map shown in Fig. 2. Contour lines are drawn at every 10 m interval.

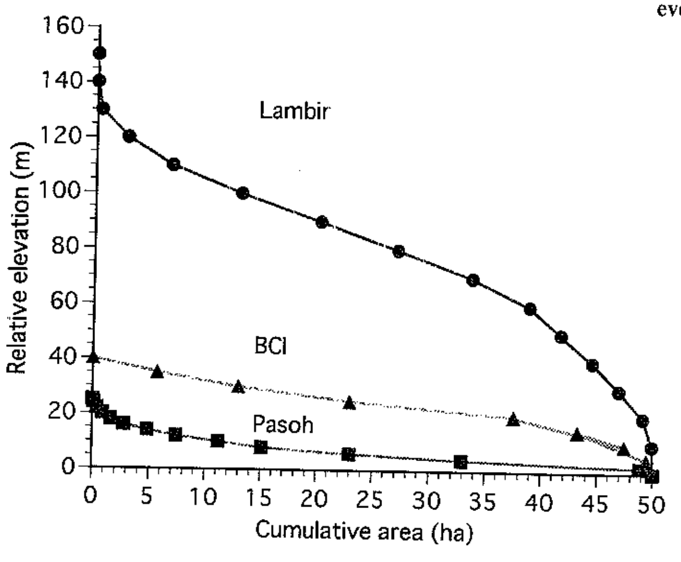


Fig. 4. Hypsographic curves showing the relationship between the altitude and corresponding cumulative area in the plot.

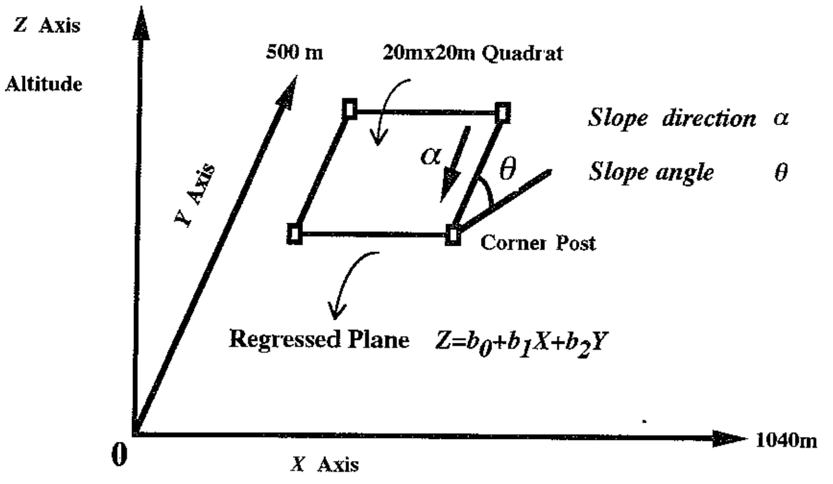


Fig. 5. Schematic representation of a hypothetical geometric plane covering a quadrat.

area of the plot into ecological habitat groups for trees

The hilly and complex topography of the plot could be easily understood by comparing hypsodiagrams in quantitative geography among three sites, BCI, Pasoh, and Lambir (Fig 4). The altitude differences between the lowest and highest places in the three plots were largest at Lambir, and smallest in Pasoh, where a very flat and monotonous topography is suggested. A relative altitudinal difference between the lowest and highest points in BCI was about 40 m and medium among the three sites. It follows that topography in BCI is flatter and simpler than that in Lambir. According to our experience in Lambir, the difficulties of plot establishment seems to be parallel to the slope angle and complexity of topography

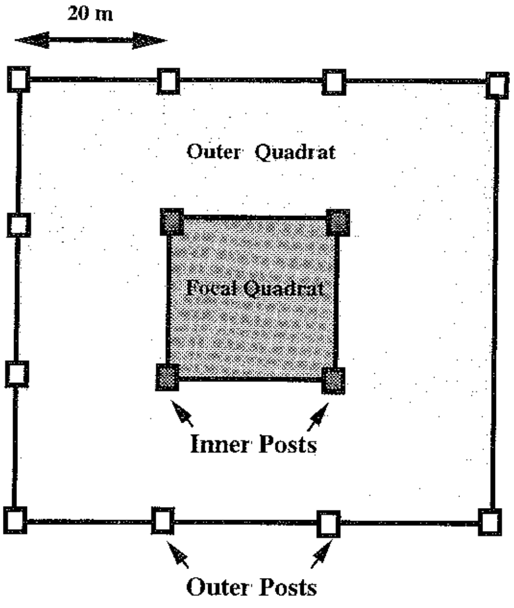
Detailed Statistics of Topographic Variables

Several topographic variables, such as compass directions of slopes etc., were computed for each of 1300 quadrats. In computation, we assumed a three dimensional plane, which covers a quadrat and consists of three orthogonal axes, *X*, *Y*, and *Z*. Among three axes, *X* represents survey points along the longer side (1040 m) of the plot, *Y* is survey points along the shorter side (500 m), and *Z* is relative altitude at survey points (Fig. 5) The three dimensional plane thus defined was tentatively designated a slope and could be expressed by the following three dimensional linear equation, i e.

$$Z = b_0 + b_1X + b_2Y \quad (1)$$

where units of variables, *X*, *Y* and *Z*, are [m],b_0 is a coefficient with a dimension [m], b_1, and b_2 are dimensionless coefficients specific to the quadrat. Eq. (1) were applied to the four observations of variables, *X*, *Y*, and *Z*, which were obtained at four corners of each quadrat. The three coefficients were determined for each quadrat by solving simultaneous equations consisting of four linear equations and by using the least squares method. After estimating the coefficients, topographic variables of quadrats were calculated following the numerical principles in geometry. To calculate a geometrical angle of the plane or slope covering any one quadrat, we introduced a variable f derived from a following numerical transformation of the coefficients, b_1, and b_2, i.e

$$f = \sqrt{b_1^2 + b_2^2 + 1} \quad (2)$$



IC = Mean Altitude of a Focal Quadrat
– Mean Altitude of an Outer Quadrat

Fig. 6. Two geometric planes proposed for a calculation of an index (IC) of the convexity (or concavity) of a focal quadrat.

By using the above variable f, a slope angle of the quadrat, θ, is given by the equation,

$$\theta = \arcsin(1/f). \qquad (3)$$

The compass direction of the slope, α, is also written in the form,

$$\alpha = \arcsin(-b_2/f/\cos\theta). \qquad (4)$$

The mean altitude of a quadrat is an average of relative altitudes observed at four corners of each quadrat

The geometrical form of slopes is an important feature characterizing topography. We can easily recognize a convex slope (or ridge), concave slope (or valley), and straight slope with a fixed slope angle (rectilinear slope). To express these differences in slope form between quadrats, we tentatively introduce another plane or square, which covers any one focal quadrat. The newly introduced plane is tentatively designated the outer quadrat and demarcated by 12 landmark posts surrounding a focal quadrat as shown in Fig.6 The size of this quadrat is 60 m x 60 m including the focal quadrat at its center. Focusing on the outer quadrat thus defined, we calculated the mean of altitudes at 12 landmark posts and designated it as the mean altitude of the outer quadrat Returning to the focal quadrat, its mean altitude

Table 1. Basic statistics of topographic variables

variables	Number of Samples	Minimum	Maximum	Mean	Standard Error	Standard Deviation	Skewness	Kurtosis
Altitude	1300	108.6	240.3	180.2	0.7665	27.64	-0.4232	-0.4782
Inclination	1300	0.3625	54.06	21.27	0.2870	10.35	0.5213	-0.3329
Direction	1300	0.0	360	157.9	2.560	92.31	0.2204	-0.9339
Convexity	1150	-15.25	11.54	0.1120	0.1057	3.584	0.09543	0.3489

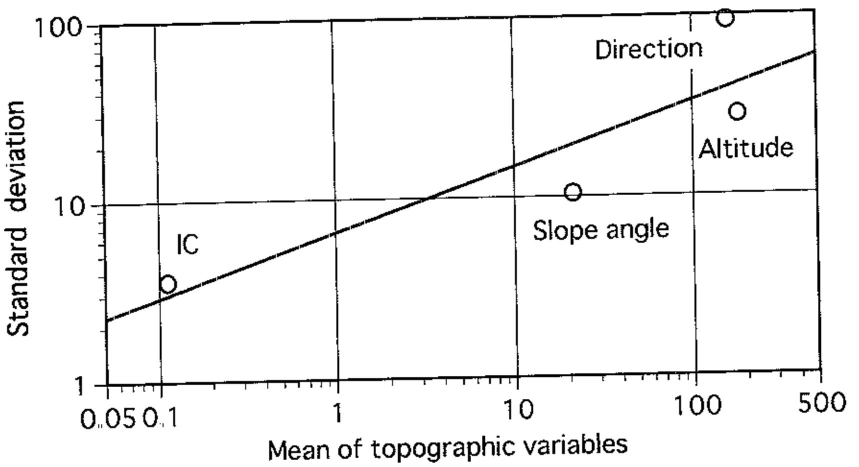


Fig. 7. Relation between the mean and standard deviation of four topographic variables, altitude, inclination, direction, and IC, calculated for a quadrat.

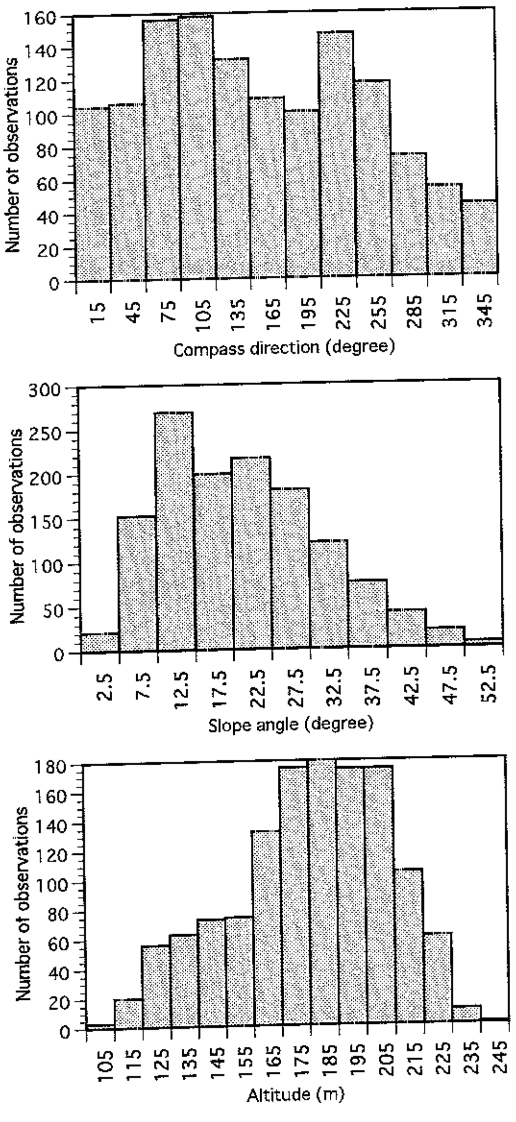


Fig. 8. Frequency distribution of three topographic variables, altitudes (lower), inclinations (middle), and directions (upper), calculated for 1300 quadrats.

was calculated by averaging altitudes at its four corner posts. A difference between the mean altitude of the focal quadrat and that of the outer quadrat was tentatively designated an index of the convexity (or concavity) of the focal quadrat (IC), i.e.

IC = (Mean altitude of a focal quadrat) - (mean altitude of an outer quadrat)

The proposed index IC is positive when a quadrat is in convex micro-topography in its shape. It gives a negative value to a quadrat on a concave slope. The degree of the convexity or concavity of a quadrat is expressed by the absolute value of IC. A slope without unevenness or rectilinear slope has a smaller absolute value of IC.

The basic statistics of the aforementioned topographic variables are given in Table 1. As the altitude shows a relative value, we will transform it into an absolute value in the earliest opportunity. We have no other suitable examples of the statistics of topographic variables comparable with those in Table 1, since these statistics are first calculated in the present study. A relationship between mean and standard deviation values in Table 1 is shown in Fig. 7. An increase of the standard deviation (*SD*) with an increase of the mean (*M*) was not proportional and approximated by the power equation,

$$SD = 6.575\ M^{0.3528}.$$

This *M* vs. *SD* relation denies the constancy of coefficients of variations of samples, when *SD* values are compared between different topographic variables. The skewness was negative for altitudes but positive for the other three variables, suggesting a J-shaped frequency distribution of altitudes. The kurtosis was negative for altitudes, slope inclinations, and compass directions, suggesting a platykurtic frequency distribution of variables. The smallest kurtosis of compass directions implied a rather uniform frequency distribution of the observed values (Fig. 8). The frequency distribution of the IC or convexity was characterized by the smallest absolute value of the skewness and the largest positive kurtosis, suggesting a symmetrical but leptokurtic frequency distribution of observed values (Fig. 9). IC is thought to be important and will be described in detail in a separate paper (Yamakura *et al.*, in preparation) because it seems to reflect soil water conditions in the quadrats.

The distribution maps of the aforementioned four topographic variables within the plot were helpful for understanding the details of the plot topography and are given in Appendix

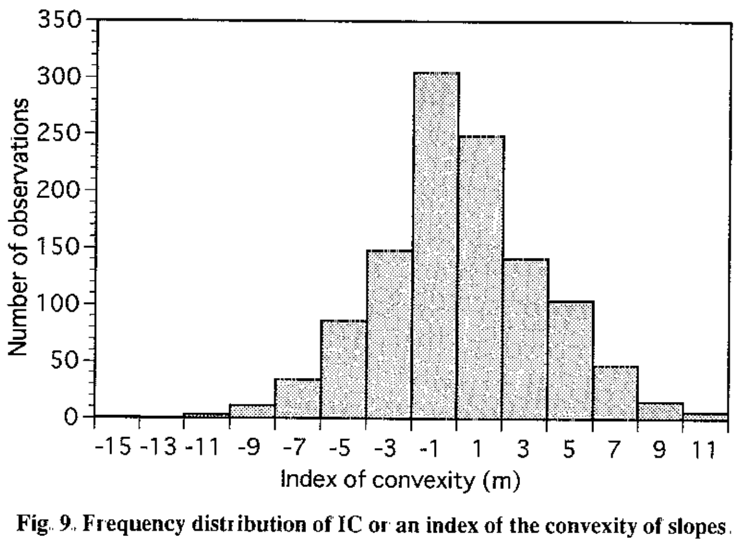


Fig. 9. Frequency distribution of IC or an index of the convexity of slopes.

1, by categorizing respective variables into several classes of variable values The spatial pattern of relative altitudes should be parallel with that of contour lines in Fig. 1. Steep slope inclinations were observed along the aforementioned long cliff and around some ridges along landslides. Compass directions might be biologically meaningless in tropical regions, because solar altitudes are always higher in the tropics than in higher latitudes throughout a year However, if plants could sensitively identify the differences of light quality between morning and evening in their bio-rhythms, compass directions should be an important factor (cf. Appendix 1)

The index IC was categorized into three classes and mapped The number of observations of categorized IC per class was rather similar among three classes. Furthermore, categorized values distributed rather randomly in the plot. The pattern of the IC or convexity index in the map corresponded to that of ridges and rivers, and seemed to be very important in terms of the fragmentation of local plant habitats. (cf. Appendix 1)

CONCLUSION

A large-scale research plot of 52 ha was established within a mixed dipterocarp forest at the Lambir National Park, Sarawak in 1994, after laborious work during five years since 1990. The topography of the plot was studied by analyzing the topographic data. The basic statistics of the topographic variables, such as the altitude, inclination, direction, and quadrat convexity, were calculated for 1300 small quadrats of 20 m x 20 m, by dividing the plot into quadrats. The calculated statistics reflect the steeply sloped, sharply undulating, and complexly bisected topography of the plot. These topographic features are well expressed by the term "broken topography", and thus seemed to fragment the whole entity of the plant habitats into small local fractions, which appear to be a major contribution to exceptional richness of the flora of Lambir rain forest among all the forests of the Old World.

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Appendix 1. Maps of Topographic Variables.

Spatial patterns of topographic variables within the 52 ha plot are mapped and represented in Figs A1-A4 The variables are the altitude, inclination compass direction, and convexity index of slopes, each of which was calculated for respective 20 m x 20 m quadrats consisting the entire plot of 52 ha In map drawing, the calculated values of respective variables are categorized into several classes. The altitude values are classified into four classes with a class interval of 40 m; 100–140, 140–180 180–220, 220–260 m. Altitude values over 240 m are not recorded (Fig A1) Inclinations are represented by categorizing their values into four classes; <15, 15–25, 25–35, and >35 degrees (Fig. A2) Compass directions are classified into four classes north, east, south, and west, with a class interval of 90 degrees (Fig. A3). The index of the convexity (IC) are classified into three categories; <-1 5, -1 5–1 5, >1 5 (Fig. A4)

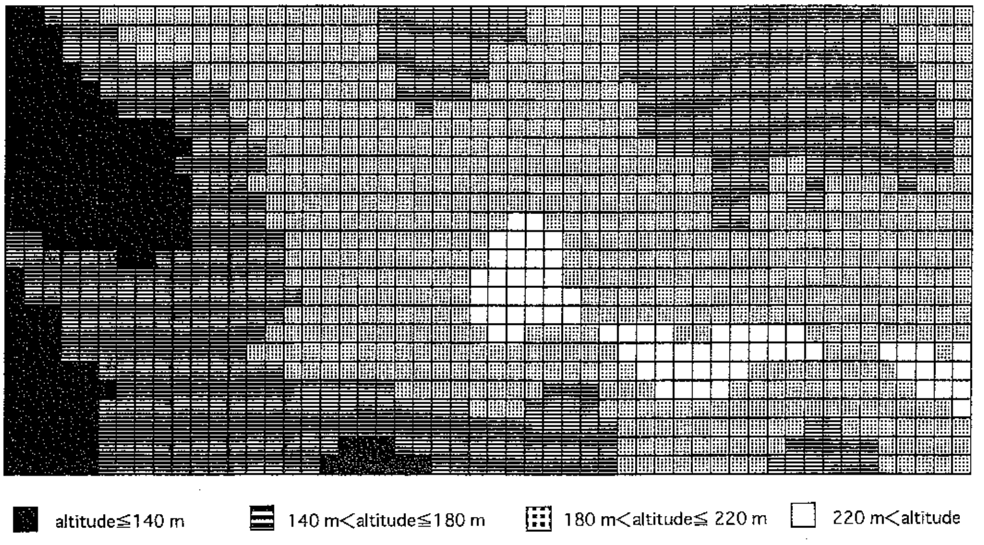

Fig. A1. Spatial pattern of four classes of relative altitude values in the 52 ha plot.

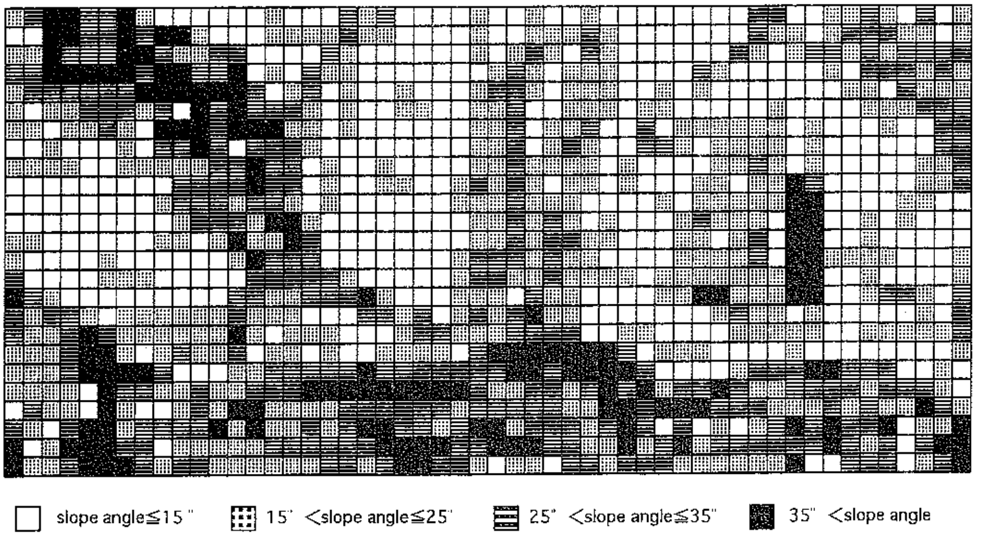

Fig. A2. Spatial distribution of inclinations of quadrats in the plot.

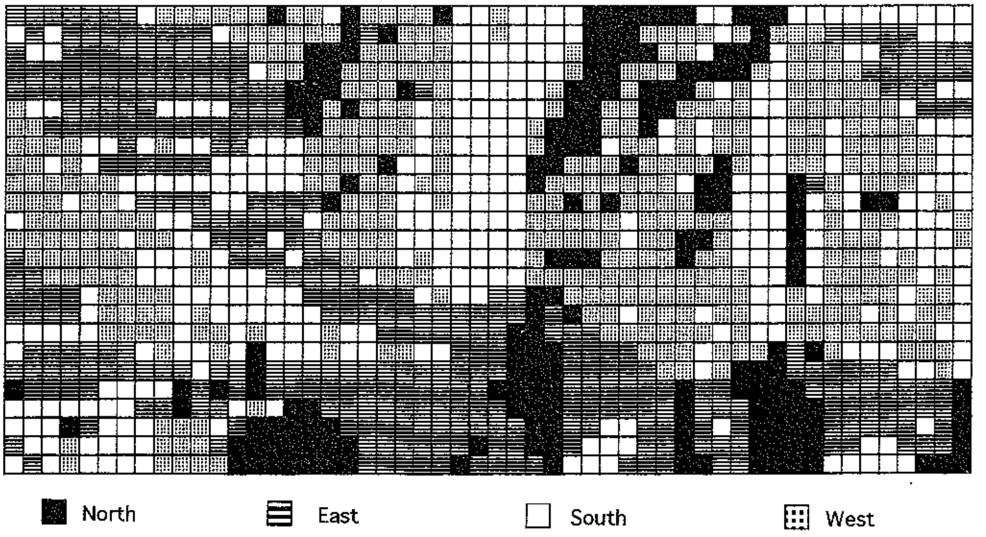

Fig. A3 Spatial distribution of compass directions of quadrats in the plot.

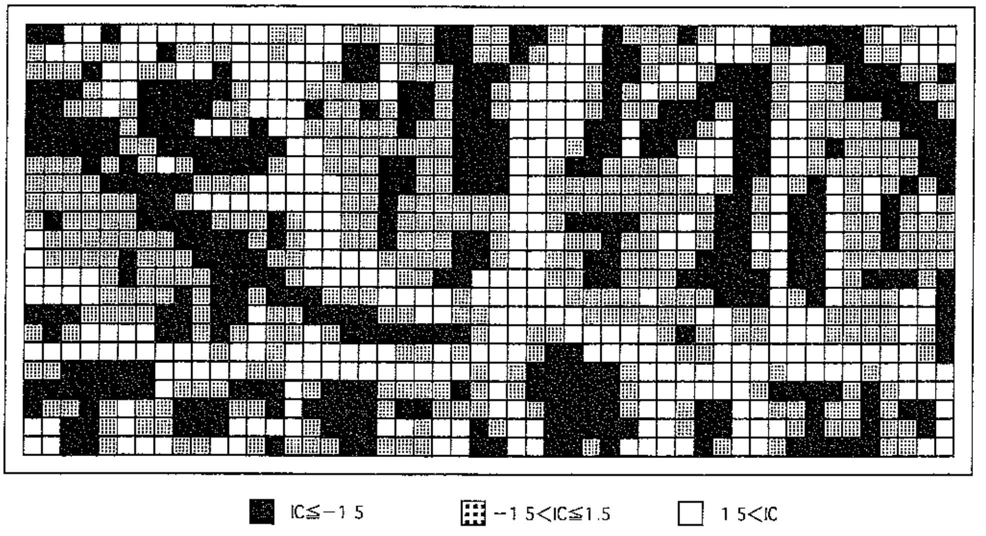

Fig. A4. Spatial distribution of values of the convexity of a quadrat, IC, in the plot.