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石塚悟史，田中伸一，櫻井克年，平井英明，廣谷博史，荻野和彦，**Hua Seng LEE, Joseph Jawa KENDAWANG**　土壌硬度と土性からみたマレーシア・サラワク州ランビル国立公園の土壌の分布と特徴

熱帯諸国において，土壌荒廃地を修復するためには，残された自然林の状況を様々な角度から明らかにしておく必要がある．この報告は，マレーシア・サラワク州ランビル国立公園内に設けられた8 ha プロットにおいて実施され，野外においてプロット内の地形と土壌硬度及び野外土性の分布を調べ，植物の根の阻害が予想される土壌のマクロな分布を把握しようとするものである．さらに，8 haプロット内の尾根部と谷部において，土壌水分と土壌温度のモニタリングをおこなった．同時に，より詳しく土壌の特徴を把握するために，尾根部と谷部で採取した土壌の理化学性を調べた．

尾根部では，土層が厚く，表層でのみ有機物含量が高かった．土壌水分は著しく変動しており，土壌は期間を通じて乾いていた．谷部では，土壌水分は降雨の後でさえ比較的安定していた．谷部では，周囲から多くの水の供給を受けるため，細粒質画分と養分の流亡が進んでいた．

地形調査の結果から，プロット内の地形は大きく3つのエリアに分けられた．

1）急傾斜エリア：土壌と植生は，土壌侵食や地滑りによってしばしば変化している可能性がある．土性は sandy loam，loamy sand，loam であった．レキ質が深さ 20～40 cm 付近の次層で見つかり，根の下層への伸長が困難であると考えられた．

2）緩傾斜エリア：土壌と植生は長期間安定である．土性は light clay，heavy clay であった．粘土物質が，有機物によって土壌が細分化され，また20 cm以深に集積していた．

3）尾根エリア：土壌と植生は地形的には安定であるが，水分状況が他の地点とは異なっている．土性は clay loam，sandy clay loam であり，急傾斜エリアと緩傾斜エリアの中間的なレンジであった．土壌硬度の観点からの物理的な阻害は確認されなかった．しかし，降雨の少ない期間には，土壌水分が不足するため，根の伸長を含め生育が遅くなる可能性があると推測された．

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Topographic Analysis of a Large-scale Research Plot in Seasonal Dry Evergreen Forest at Huai Kha Khaeng Wildlife Sanctuary, Thailand

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ABSTRACT The demarcation of a 50-ha (500 m × 1,000 m) research plot was initiated in seasonal dry evergreen forest at Huai Kha Khaeng Wildlife Sanctuary, western Thailand, in December 1990 and its field work was completed at the end of 1991. The land survey of the plot was carried out by using a theodlite and by measuring unit horizontal distance of 20 m with a steel measure tape paralleled to the ground. A survey angle measured by the theodolite was corrected by repeating measurements. The plot was divided into 1,250 quadrats of 20 m × 20 m and subdivided into 20,000 sub-quadrats of 5 m × 5 m. The land survey data from theodolite measurements were compiled into a data matrix from which a contour map was drawn. A three-dimensional regression plane was designed to cover each of 1,250, 20 m × 20 m quadrats and was used for the numerical determination of the statistics of topographic variables; altitude, aspect, inclination, and convexity (or concavity). The statistics successfully exhibited topographic patterns within the plot. The plot was shown to be consist mainly gentle slopes, including small areas of steep slopes, streams, and drainage. A semivariogram, a useful tool in the geography information system (GIS), was drawn for each of the topographic variables and was investigated. Semivariograms for four topographic variables indicated clearly a spatial distance by which a focal topographic variable could be considered homogeneous. The semivariogram further suggested the appropriate quadrat size or sampling area, which is available for the sampling design for research into ecological topics, such as the species dependence on topography in the 50 ha plot.

Key words: large-scale / long-term / environmental variations / topography / seasonal dry evergreen forest / Thailand

Demarcation of a long-term and large-scale research plot was initiated in Huai Kha Khaeng Wildlife Sanctuary, western Thailand in December 1990. Although the plot will be available for multi-purpose research use in the future, a major aim of plot establishment was to aid the Royal Forest Department,

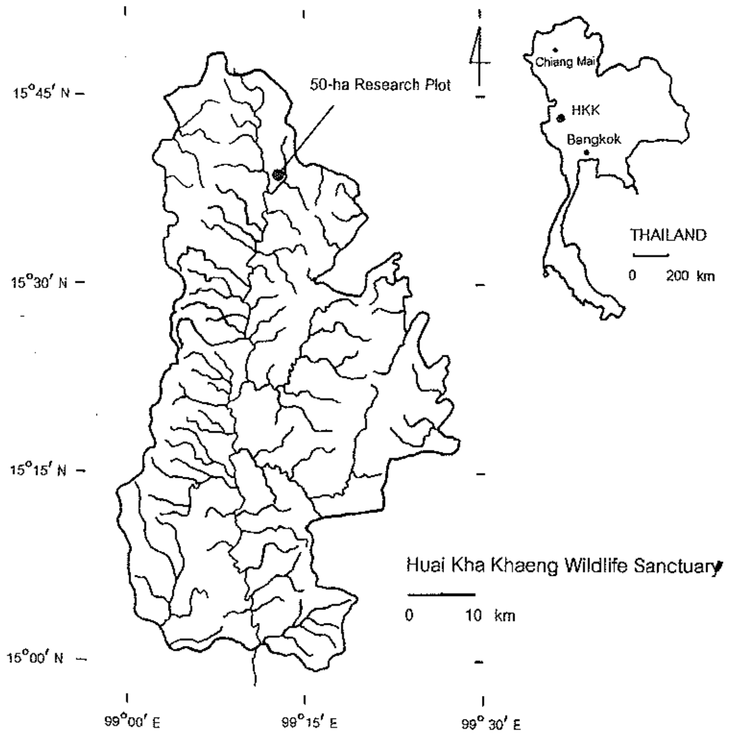

Fig. 1. Location of the study site.

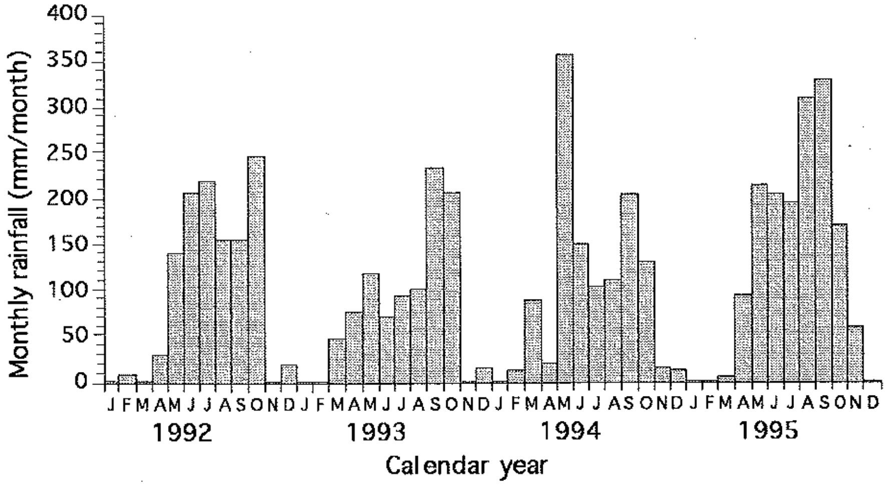

Fig. 2. Rainfall in the study site.

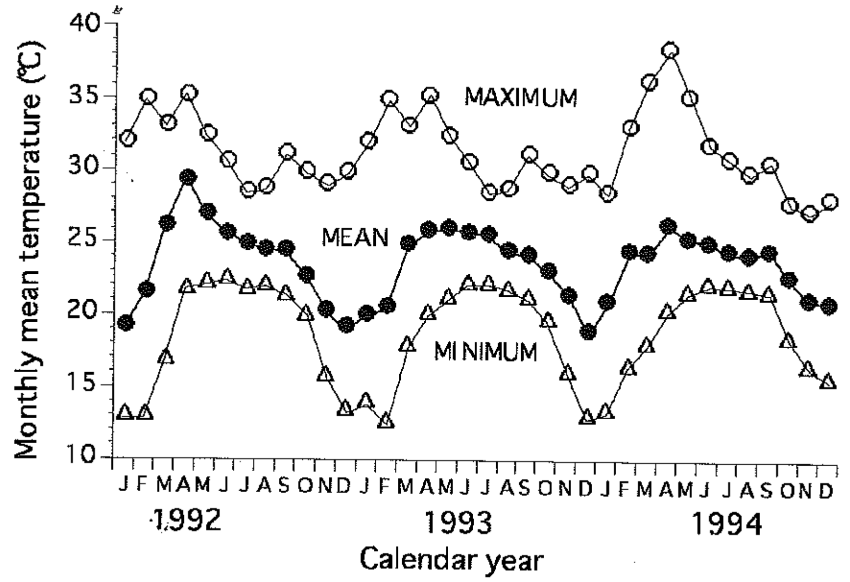

Fig. 3. Temperature in the study site.

Thailand, which is devoting a great effort to forest conservation and rehabilitation in the face of the pressure of forest degradation, by documenting the ecology and demography of individual species making up the forest. The plot establishment can also be seen in the context of a regional program to formulate the means for sustainably managing seasonal dry evergreen forest, an endangered forest type in Asia, for optimizing the utilization of its goods and services, and for conserving its biodiversity. From these overall aims, the following specific objectives are derived: (1) to understand the dynamic interrelationships between seasonal dry evergreen and dry mixed deciduous forest in Thailand in order to naturally regenerate these forests in the absence of fire, and (2) to determine how the species richness and patterns of commonness and rarity within the forest relate to overall patterns of forest composition and environmental factors, especially soil moisture (Bunyavejchewin *et al.*, 1997).

Topography is one of the factors affecting the complexity of a given area, and is highly correlated with variation in local forest architecture (Yamakura *et al.*, 1996) and spatial patterns of species (Rogstad, 1990; Yamada *et al.*, 1997). In general, topographic features are difficult to quantify in a small sampling area and require a large-scale study plot to get meaningful results (Yamakura *et al.*, 1996). The present study analyzes details of the topographic features of the 50-hectare plot in Huai Kha Khaeng Wildlife Sanctuary. The results of these analyses will provide basic information for further studies of local patterns in species diversity, forest structure etc. in the study forest.

STUDY SITE

Huai Kha Khaeng Wildlife Sanctuary and Its Climate

Huai Kha Khaeng Wildlife Sanctuary (HKK), UNESCO World Heritage Site, covers an area of about 2,780 km^2. It lies about 90 km west of U-Thai Thani City in the western part of Thailand. Its geographical extent ranges between 15°00' and 15°47' N latitude, and 99°00' and 99°27' E longitude, respectively (Fig. 1). Altitude ranges from 250 m up to 1,689 m. The general climate is monsoonal (Meteorological Department, Thailand, 1987). Average annual rainfall in four years from 1992 to1995 was 1,242 mm with a 4-6 months-dry period, normally from November to April. Mean annual temperature for the three years 1992 to 1994 was 23.5°C. The maximum and minimum temperature were recorded daily during the aforementioned three years and their calculated overall mean values were 31.2°C for the maximum and 18.6°C for the minimum, respectively. Details of monthly patterns of rainfall and temperature are given in Figs 2 and 3. The general patterns in rainfall and temperature are characterized by clear seasonal rhythms driven by the Asian monsoon. The largest monthly rainfall of 331.1 mm was recorded in September 1995. The highest record in the monthly mean of the daily maximum temperature was 38.5°C, which was observed in April 1992. The lowest record in the monthly mean of the daily minimum temperature was 12.4°C observed in February 1993. Thus the annual climatic range and between year climatic variability at HKK is large.

Topography, Geology and Soil

The topography of the sanctuary is hilly or undulating. A high mountain range lies from the northern to the western boundary and also in the eastern part of the sanctuary. The mountain range results in rain shadow effects on the western edge of the area and makes the weather dry there. A major stream flows down from north to south through the sanctuary and separates the area into two halves, the east and west.

The geological surveys available for this region are very general. According to a geological map (Javanaphet, 1969), the sanctuary consists of three parent material types: (1) Carboniferous granite occurring in the northern and eastern parts of the sanctuary, and covering about half of the area; (2) the Carboniferous and Permian Ratburi Formation of massive light-gray limestone interbedded with shale, sandstone, mud-stone, conglomerate, and volcanic tuff, covering about one-quarter mainly in the south portion of the sanctuary; and (3) the Carboniferous, Devonian, and Silurian Kanchanaburi Formation of a group of shale, sandstone, and sandy shale metamorphosed to phyllite, argillite, quartzite, and slate, occurring in the western part and other areas along the south of the sanctuary. There exists no detailed soil survey of the sanctuary, although it is believed that the soil is predominantly clayey-oxisol.

Vegetation

Vegetation in HKK consists of four major forest formations, among which two are deciduous and the other two are evergreen. Deciduous dipterocarp forest and dry mixed deciduous forest form a mosaic pattern and occupy about three-quarter of the area, mainly in the middle and southern parts of the sanctuary. Lower montane forest occupies hilly slopes at high altitude, along the north and western edge and on the mountain area in an eastern part of the sanctuary, whilst seasonal dry evergreen forest occurs in lower altitude areas adjacent to the lower montane forest. Small areas of bamboo thickets and abandoned cultivated areas are found in the southern part of the sanctuary (Faculty of Forestry, 1989).

METHODS OF PLOT DEMARCATION

Site Selection

The study area was chosen in 1990 after inspection of several proposed sites. The study site is in a large area of old growth of both evergreen and deciduous forests, which form a mosaic structure. No recorded data on logging and forest management activities have been found, suggesting that the site is primary and safe for long-term studies. All these characteristics justified us to select this area for the study site.

Plot Survey

The 50 ha (500 m × 1,000 m) plot is located at 15°40' N latitude and 99°10'E longitude, about 4 km west of Kapook Kapieng Ranger Station in the northern part of HKK. The plot is oriented with its long 1,000 m axis aligned north-south direction.

The land survey of the plot was begun by using a theodolite in mid December 1990 and completed by the end of 1991. A theodolite set on a tripod was used to establish survey posts at 20 m intervals along a survey line with a right angle. Parallel lines were then surveyed at 20 m distance, so that posts became corner posts of 20 m × 20 m subplots. The 20 m horizontal distance between posts was measured by steel tape paralleled to the ground, and corrected for the vertical angle as measured by the theodolite. The exact survey procedures follow those fully described by Manokaran *et al.* (1990). The survey posts are made of short concrete blocks, 10 cm in diameter and 30 cm in length. On the top of each post, an aluminum band bearing the plot coordinates was placed. In HKK, concrete blocks were recommended instead of aluminum poles or PVC pipes to avoid of fire damage and disturbance by big wild animals, such as elephant and wild cattle. The 5 m corner points were marked with short iron rods about 25 cm long, bent at the upper end, and painted red. A total of 1,326 short concrete blocks and 18,975 short iron rods were used for landmarks.

From theodolite measurements, the 50 ha plot was divided into 1,250 quadrats of 20 m × 20 m. A position of a given quadrat was recognized by a set of identification numbers referring to the longer (X) and shorter (Y) sides of the plot. The identification numbers follow the number of survey lines demarcated at 20 m intervals. The first quadrat was identified as (0,0) and for the last quadrat (49,24).

To estimate the base altitude of the plot, a military contour map was consulted. A confluent point of two streams in the map was chosen for a tentative landmark situated about 1 km southwest from the plot. After reading the altitude of the selected landmark point in the map, we connected the landmark and one of the corner posts of our plot by careful land survey. Thus, all 20 m survey points in the 50 ha plot were calculated for their altitude.

RESULTS AND DISCUSSION

Topography Map

A topographic contour map of the 50 ha plot is shown in Fig. 4. The lowest altitude is 549 m at the point (48, 23) and 638 m at the point (17, 3) is the highest altitude in the plot. Two small hills occur just below the middle of the plot and seem to separate the plot into two halves, the north and southwest facing slopes. There exists one stream in the north end and one drainage in the south end of

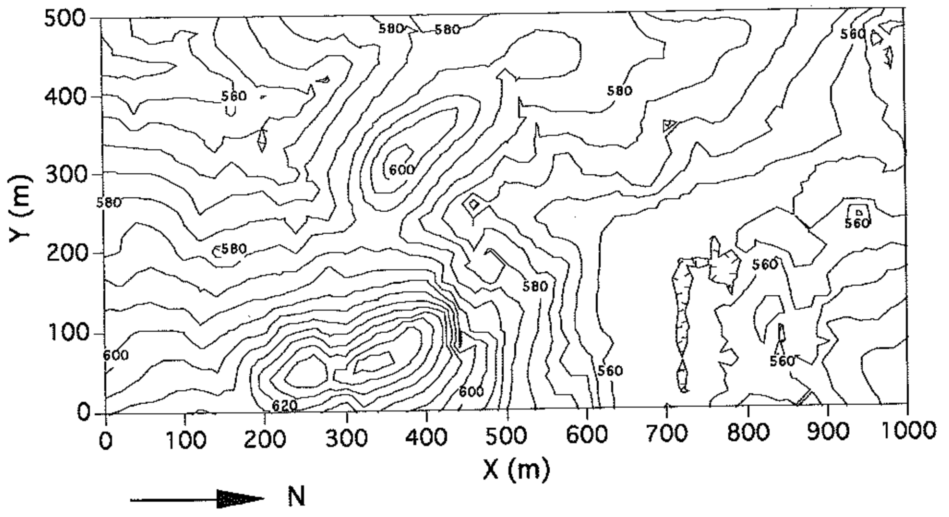

Fig. 4. Topographic contour map of the 50 ha research plot at Huai Kha Khaeng Wildlife Sanctuary. Contour lines are drawn in 5 m interval in altitude.

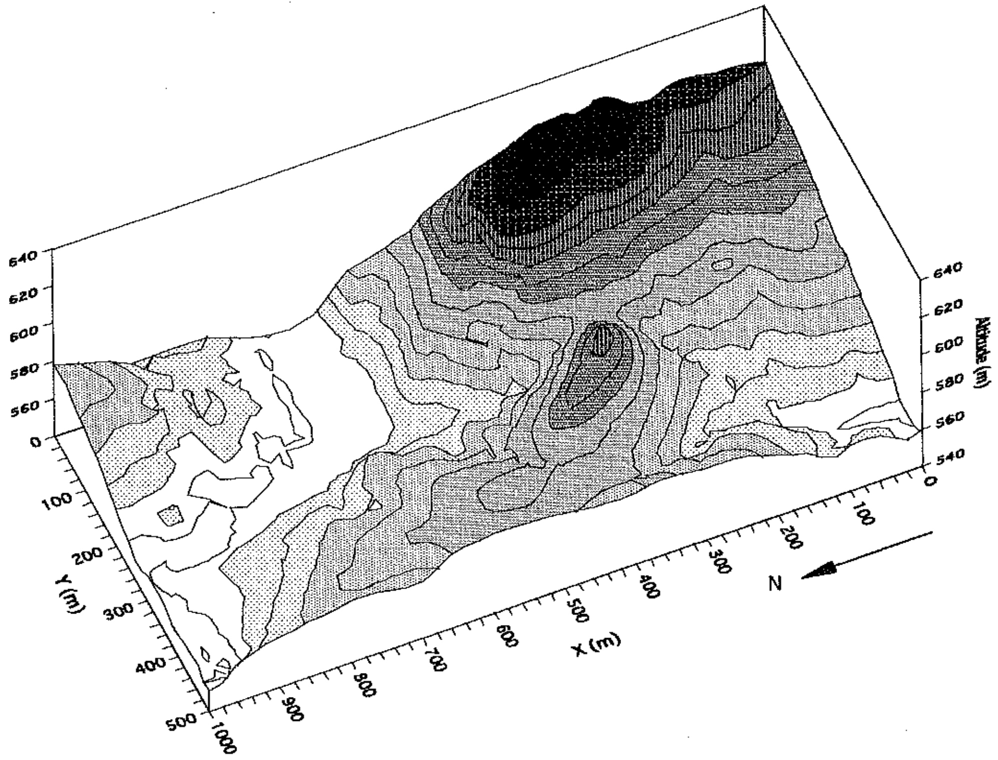

Fig. 5. Three dimensional map of the 50 ha research plot. Contour lines are drawn in 5 m interval in altitude.

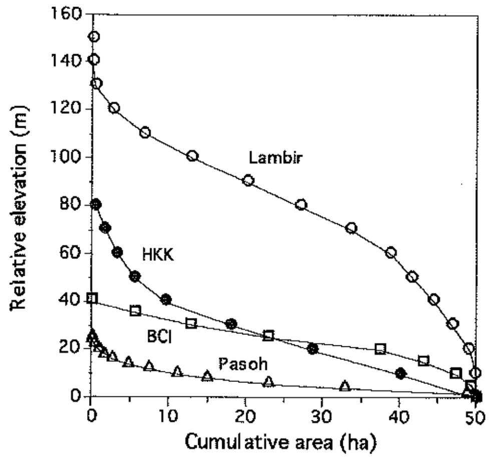

Fig. 6. Hypsographic curves showing relationships between altitude and corresponding cumulative area for the four large-scale research plots.

the plot. The plot is mainly characterized by gentle slopes, although small areas of rather steep slopes are included. A three-dimensional map gives a clearer view of the topography of the plot (Fig. 5).

Fig. 6 represents hypsographic curves of four large-scale research plots in the network of the Center for Tropical Forest Science (CTFS) of Smithsonian Tropical Research Institute, at Barro Colorado Island (BCI; Hubbell & Foster, 1983), Pasoh (Manokaran *et al.*, 1990), Lambir (Yamakura *et al.*, 1995), and HKK (this study), respectively. The range of altitude was the largest in Lambir, medium in HKK and BCI, and the smallest in Pasoh. We tentatively defined the relative altitude as a difference between the highest and lowest altitudes and calculated the highest relative altitude for each site. The highest relative altitude values for four plots were arranged in descending order, Lambir > HKK > BCI > Pasoh. In the sequence of the four relative altitude values, the difference between Lambir and HKK is ca. 80 m, while it is ca. 40 m between HKK and BCI and ca. 20 m between BCI and Pasoh, respectively (cf. Fig.6). Thus the sequence of four values follows a geometric progression.

A gradient of a hypsographic curve for HKK in Fig.6 is rather constant within a range of relative altitudes between 0.0 m and 40 m, at which cumulative area is greater than 10 ha. When relative altitude is higher than 40 m, the gradient of the curve gradually increases and is steepest around the peak of relative altitude. The curve of HKK is close to that of BCI, if we compare the curves among the four sites. However, about half of the HKK plot consists of the areas lower than BCI in relative altitude, while the other half of the plot area is higher than those in BCI. This suggests more complex topographic conditions in HKK than in BCI. There is no doubt that topography in Lambir is more complex than in the other three plots. Topography in Pasoh and BCI is flat with small areas of steep slopes. In terms of topographic complexity, the plot in HKK represents the middle of the four sites.

Calculation of Topographic Variables

Topographic variables of each 20 m × 20 m quadrat were analyzed by numerical methods. The total number of sample quadrats is 1,250 in the 50 ha plot. Each quadrat was assumed to be covered by a three-dimensional regression plane. This plane is expressed by X, Y, and Z coordinates, which stand for topography data of each corner post of a given 20 m × 20 m quadrat, and can be determined by

Table 1. Statistics of topographic variables. IC is an index of convexity

Variables	Number of Samples	Min.	Max.	Mean	Standard Error	Standard Deviation	Skewness	Kurtosis
Altitude	1250	549.818	634.418	576.58	0.5088	17.987	0.9754	0.5664
Inclination	1250	0.079	45.872	10.33	0.1722	6.087	1.3836	3.1302
Aspect	1250	0.773	359.694	186.27	3.0548	108.005	0.2332	1.3318
IC	1104	- 6.072	10.729	0.04	0.0516	1.713	1.0009	4.4452

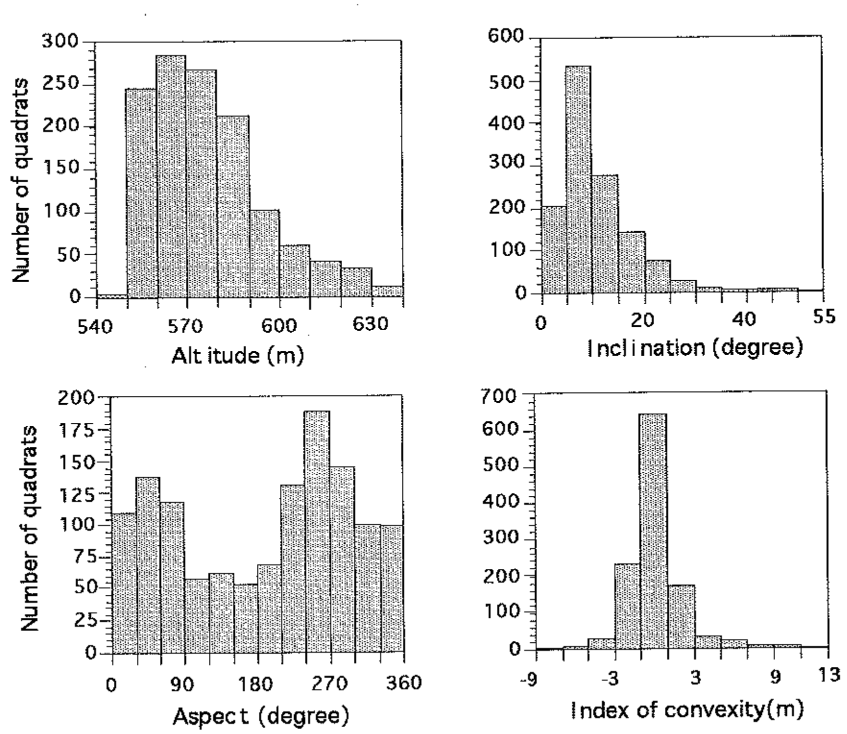

Fig. 7. Frequency distribution of altitude, aspect, inclination, and convexity (or concavity) in the 50 ha research plot.

using the least square method (Yamakura *et al.*, 1996). In computation, the origin of the coordinates is tentatively established at one of four corners of the 50 ha plot. The coordinate axis X represents a position of a survey post along the longer (1,000 m) sides of the plot, Y is the distance of the survey post along a shorter (500 m) side of the plot, and Z is the relative altitude at a survey post. Inclination and aspect in a quadrat, respectively, were defined as those of the regression plane. An average of altitude values from the four corner posts was defined as the altitude of the quadrat, which is hereafter designated a focal quadrat.

An index of convexity or concavity of a slope, IC (Yamakura *et al.*, 1996), was adopted to characterize the geometrical form of a focal quadrat. The index IC is empirical and is defined by the difference between the mean altitude of the focal quadrat and mean altitude of the twelve surrounding corner posts on the four sides of a 60 m × 60 m quadrat (3 × 3 of 20 × 20 m quadrats) which contains the 20 m × 20 m focal quadrat at its center. By using IC, shapes of focal quadrats were classified into three categories; convex (ridge), concave (valley), and rectilinear (level) quadrats. Positive and negative IC values correspond to the convex and concave quadrats, respectively. When IC is small and close to zero, the quadrat shape is rectilinear. The details of computation were fully explained in our preceding study (Yamakura *et al.*, 1995).

Statistics of Topographic Variables

Topographic variables of the 1,250 quadrats in the 50 ha plot were calculated by using the aforementioned numerical methods, and their statistics are given in Table 1. In calculation, altitude above sea level was transformed into the aforementioned relative altitude.The frequency distribution of the topographic variables can clearly describe the details of topographic features appearing in the map (cf. Fig.4). The positive skewness in altitude and inclination suggest a reverse J-shape distribution. Kurtosis of both variables were positive, suggesting leptokurtic frequency distribution. However inclination data have higher frequency distributions around the mean than in altitude data, and have a larger kurtosis value than that of altitude data. An extreme platykurtic frequency distribution of aspect implies a bimodal distribution of the samples (Fig. 7; Sokal & Rohlf, 1969). The skewness of IC is close to 1.0 and suggests a bell shaped frequency distribution. The positive kurtosis of IC represents the leptokurtic frequency distribution of samples, which concentrate around the mean (Fig. 7).

A comparison of the statistics of the topographic variables between the large-scale research plots can allow us to better further understand the influence of topography on vegetation characteristics. Besides HKK, Lambir was the only site having detailed statistics of topographic variables for comparison (Yamakura *et al.* 1995). The larger values of standard deviation with negative kurtosis for altitude and inclination in Lambir suggested wider ranges of altitude and inclination than in HKK. The two variables also showed platykurtic distribution, in which the frequency of observed samples did not concentrate around the mean but scattered rather widely around the intermediate region of their ranges.

Although the frequency distribution of IC was symmetric with respect to the mean in HKK and Lambir, respectively; Lambir data exhibited twice the standard deviation and much smaller kurtosis than those of HKK. This clearly defined the narrower topographic changes in slope convexity in HKK.

The spatial distribution maps of inclination and IC in the 50 ha plot are given in Appendix 1. The variables are categorized into several classes in the maps, which let us understand the details of topographic mosaic patterns in the plot. Steep slopes occur around the hills in the southeast of the plot. The spatial pattern of IC represented well the local positions of ridge, stream, and drainage, respectively in the plot. These maps are more informative than the contour maps, such as Figs. 1 and 2, for interpreting topographic details. Furthermore, the IC pattern may play an important role for identifying soil-water conditions of the plot.

Spatial Structure of Topography

The spatial structure of topographic features in the plot was quantitatively analyzed by using a geostatistical tool designated the semivariance, which is introduced for the quantification of spatial variability in geostatistical space and applied in geology (e.g. Journel & Huijbregts, 1978), soil science (e.g. Burrough, 1983), ecology (Phillips, 1985; Palmer, 1988; Rossi *et al.* 1992). The semivariance $\gamma(h)$ is written in the form (eg. Rossi *et al.* 1992),

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2$$

where the subscript i is an identification number of a sampling location, the variable x_i is the sampling location within a whole sampling space, h is a separation vector or lag in a pair of sampling locations, $z(x_i)$ is a sample variable at the sampling location x_i, and $z(x_i + h)$ is the sample variable at another sampling location $x_i + h$. The variable $N(h)$ represents the total number of samples, depends on the sampling lag h, and is determined by all the possible pairings of data. The symbol Σ stands for the summation of variables. As is understood from the definitions of the component variables, the semivariance is analogous to the variance in conventional statistics.

In applying the semivariance analysis to our topography data, the sampling space was the 50 ha plot. The sampling lag h was expressed by the distance between any pair of 20 m x 20 m quadrats. Furthermore, the direction of h was first fixed to the longer side (i.e. X axis) of the plot and was changed later to the shorter side of the plot (Y axis) because the paring of data depends on both the magnitude and direction of h. By changing the sampling lags along one of the selected directions, X and Y, we calculated the semivariance values for altitude, inclination, convexity (IC), respectively. The slope direction was ignored in semivariance computation, since its values are circular, have the same geometrical meaning at the two ends, zero and 2π, and difficult to explain their exact differences around the ends. The results of calculation were expressed by the semivariograms as described below.

A graphical representation of the h vs. $\gamma(h)$ relationship is designated a semivariogram and is given in Fig. 8, which stands for three topographic variables observed at two research plots, HKK and Lambir. The maximum lag distance is 150 m for all the semivariograms because a large lag distance brings a bias resulting from the shortage of sample pairings. The clear circles for HKK and clear triangles for Lambir represent the h vs. $\gamma(h)$ trajectories, where the direction of h follows the X axis. On the other hand, closed circles for HKK and closed triangles for Lambir represent the trajectories along the Y axis. The clear circles overlap well on closed circles in semivariograms, suggesting an extraordinary similarity of semivariance values between two lag directions in HKK. The similarity in semivariance between the two lag directions is also true in Lambir. Because of the lower complexity of topographic features in HKK than that in Lambir as already described, semivariograms exhibit smaller semivariance values in all lag distance scales in HKK (cf. Fig. 8).

The observed $\gamma(h)$ increases as h increases and appears to arrive at a saturation point of $\gamma(h)$ when h is infinity (Fig. 8). For random data, all semivariance values are essentially the same, and thus the semivariogram appears nearly horizontal. The patterned data, on the other hand, produce a semivariogram that has small values for short lags, then increases with increasing distance, but levels off at $h >> 0$. These features reflect the degree of spatial variability or, conversely, continuity in the data because the degree of variability or continuity is expressed by the magnitude of the semivariance, and because the constancy of semivariance values with respect to lag distance suggests the spatial independency of variables (Rossi *et al.*, 1992). The changes of semivariance with respect to lag distance is approximated by the following mathematical equation designated an exponential model (Burrough, 1986)

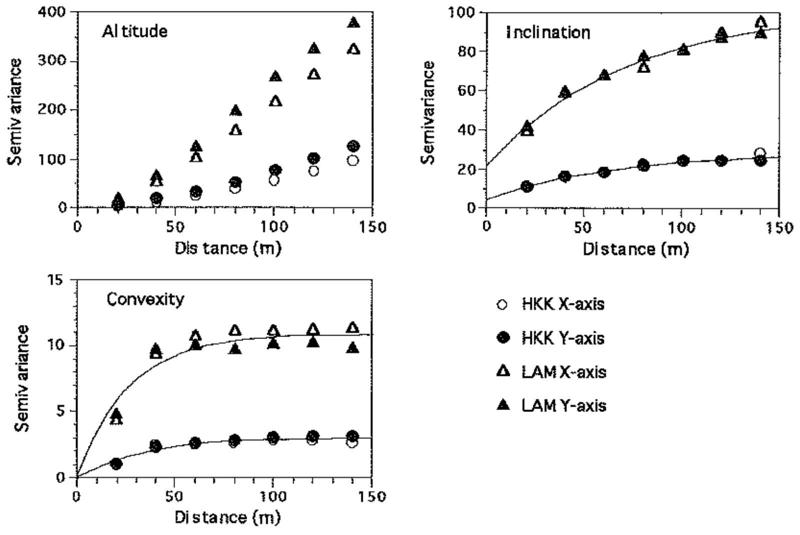

Fig. 8. Directional semivariograms of altitude, inclination, and IC for research plots in HKK and Lambir.

$$\gamma(h) = a + b[1 - \exp(-h/c)]$$

where a is a coefficient corresponding to a variance component due to a nugget effect, b is a coefficient representing the degree of variability due to the patterned structure, and a coefficient c stands for the range of lag distance. The sum of two coefficients, $a + b$, gives an asymptote of semivariance at $h >> 0$. This asymptote $(a + b)$ is designated a sill in geostatistics and is considered to be approximately equal to the variance of the variables. A practical range of lag distance is defined by $3c$, at which the semivariance is equal to ca. 95% of b (Bellehumeur *et al.*, 1997).

In applying the model to observed semivariance values, the semivariance values along the X and Y axis were lumped together by ignoring the difference of lag directions. The semivariance of altitude in HKK increased monotonously with an increase of lag distance without exhibiting a clear sill in semivariograms (Fig.8). It follows that the sample variables are more dissimilar as the sampling lag distance increases. The lack of the clear sill was true in the semivariogram of altitude in Lambir. Therefore the aforementioned exponential model could not be applied to the observed semivariance data. Inclination and IC values showed well defined sills in both HKK and Lambir. However the curve fitting to the IC semivariograms gave negative y-intercept in both plots (Table 2). To avoid the

Table 2. Model parameters of semivariograms in Fig.6. IC is an index of convexity. The coefficient of determination stands for the correlation between observed values and calculated values.

Site	Topographic Variables	Models	Nugget Variance a	Structural Variance b	Range c	Coefficient of Determination r^2
Huai Kha Khaeng, Thailand	Inclination	Exponential	4.881	24.079	64.269	0.954
	IC	Exponential	- 2.532	5.384	18.013	0.953
	IC	Exponential without a	0	2.990	32.954	0.912
Lambir, Sarawak, Malaysia	Inclination	Exponential	22.046	80.650	72.954	0.981
	IC	Exponential	- 24.746	35.245	11.347	0.943
	IC	Exponential without a	0	10.906	26.902	0.864

negative nugget variance, the exponential model without the nugget effect was used for the IC semivariograms. The equation for IC is written in the form,

$$\gamma(h) = b[1 - \exp(-h/c)]$$

The negative y-intercept in semivariograms might imply extraordinary uniformity, similarity, or correlation structure of topographic variables in small lag distance scales around the possible minimum lag distance, which is practically determined by the unit quadrat size.

The estimated coefficients of the exponential model are listed in Table 2. The estimates of the nugget effect a, structural variance b , and lag distance range c for inclination are smaller in HKK than in Lambir, suggesting the higher continuity of slope inclination in HKK than in Lambir. The nugget variance includes the residual errors in curve fitting and small scale correlation structure which can not be explained by lag distance nor be separated into further components. The nugget effect is about 20% of the structural variance in HKK and 27% in Lambir, suggesting a large contribution of unknown small scale structure in Lambir.

The coefficient c for IC in HKK is greater than that in Lambir, although the other coefficients a and b for IC in HKK are smaller than those in Lambir. The larger estimate of the coefficient c explains a slow increase of spatial variability with an increase of lag distance. The major increase of semivariance with respect to lag distance h is attained in a domain between $h = 0$ and $h = a$, since the nugget variance a is generally smaller than the structural variance b. The semivariance is given by $a + 0.632b$ at $h = c$, after which it becomes rather constant in semivariograms. Hence the range c of lag distance can express a scale of spatial dependency. Thus the scale of spatial dependency in HKK is larger than in Lambir. Although the two plots were composed of heterogeneous topographic patches, Lambir contained a much higher degree of small scale correlation structure than in HKK, as suggested by the nugget variance. To clarify the fine structure of the nugget variance, the semvariance should be further analyzed by using a smaller unit quadrat, such as 5 m x 5 m.

The aforementioned results will offer a clue for planning the random sampling of ecological variables in the plot in further studies. For example, if an ecological variable is highly correlated with IC, the sampling area should be greater in HKK than in Lambir because the range of lags in IC semvariance is greater in HKK. The spatial patterns of tree habitats are different from species to species and are expected to be highly correlated with topographic variables (Yamakura *et al.*, 1996). To understand the spatial dependency or independency of tree species in their habitat patterns, the information of topographic spatial variability will be helpful.

CONCLUSION

Topographic data of the 50 ha plot in Huay Kha Khaeng (HKK), U-Thai Thani Province in Thailand were analyzed. The statistics of four topographic variables, altitude, inclination, aspect, and IC, were calculated for each of 1,250, 20 m x 20 m quadrats comprising the 50 ha (500 m x 1,000 m) plot. Detailed statistics of four topographic variables were listed in a Table and mapped for easy understanding of their spatial patterns. According to the statistics, the topographic features of the plot seemed to be not so complex and were mainly characterized by gentle slopes, although small area of steep slopes were included in addition to streams and drainage.

The semivariance and its graphical representation, designated a semivariogram, were used for analyzing the spatial variability of the topographic variables. The semivariance is defined by a function of sampling lag distance in terms of geostatistics and can express the spatial dependency or independency of sample variables within a whole geographical sampling space. The analysis clarified rather small spatial variability in topographic variables in HKK, compared with Lambir, Sarawak, Malaysia. Furthermore, the results of the analysis suggested a suitable quadrat size and sampling area, which would be appropriate for further studies on the sampling scheme and spatial dependency of tree habitats limited by topography.

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タイ国フェイ・カ・ケン野生生物保護区の季節常緑林に設置した大面積調査区における地形解析

1990年12月から1991年12月にかけて，タイのフェイ・カ・ケン野生生物保護区の季節常緑林に50 ha（500 m × 1,000 m）の調査区を設置した。調査区の設定にはセオドライトを使用し，水平距離20 m間隔の格子点を測量により設置した。測量に際して方位角，傾斜角の測定は反復して行い正確を期した。この測量により，調査区は1,250個の20 m × 20 mのコドラートに分割され，さらに各コドラートは16個の5 m × 5 mのサブコドラートに細分割されている。測量データから各20 m × 20 m格子点の標高データマトリックスを作成し，等高線図を作成した。さらに1,250個の20 m × 20 mコドラートのそれぞれについて，4すみの格子点の標高データを使って回帰平面を決定し，それをもとに標高，斜面方位，傾斜，地形凹凸度の4つの地形変量を求めた。これらの地形変量の数値によって，調査区内の地形パターンを適切に表現することができた。調査区のほとんどは緩斜面に覆われ，一部が急斜面や流路に覆われていた。地理情報システム（GIS）で用いられるセミバリオグラムを各地形変量について作成し，地形の均質性が保たれる距離を地形変量ごとに決定した。このようなセミバリオグラムを利用した解析結果は，種の分布の地形依存性などを研究するときのサンプリングデザインを決め，適切な調査区面積を決定する際に利用できる。

Appendix: Maps of Topographic Variables

Spatial patterns of the inclination and index of convexity (or concavity) of slopes, IC, within a 50 ha plot are mapped. Inclination is calculated for 1,250, 20 m × 20 m quadrats and for 1,104, 20 m × 20 m quadrats for IC. The calculated topographic values are categorized into classes for map illustrations. Inclinations are classified into 4 classes; <5, 5-10, 10-20, and >20 degrees (Fig. A1). IC values are classified into 5 classes; <-1.0, -1.0 - -0.5, -0.5 - <0.5, 0.5 - <1.0, and > 1.0 (Fig. A2).

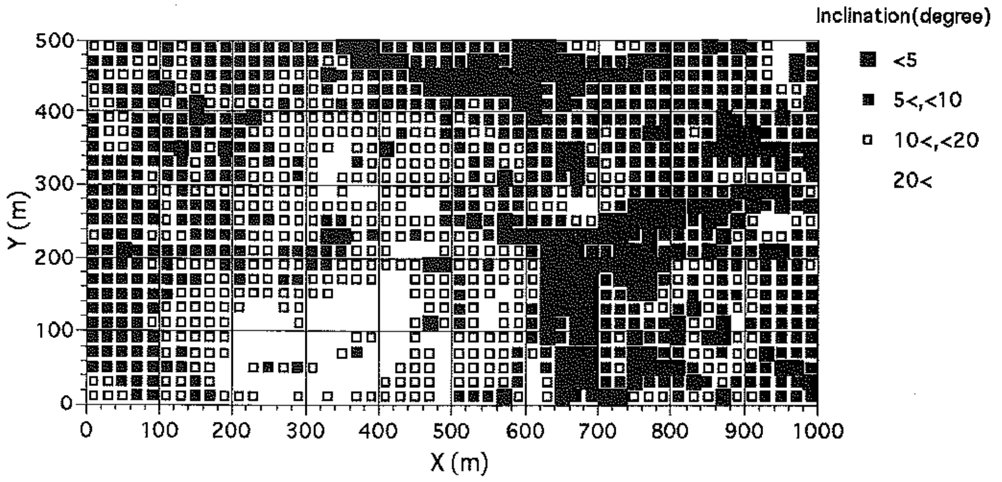

Fig. A1. Spatial pattern of inclinations of each 20 m × 20 m quadrat in the plot.

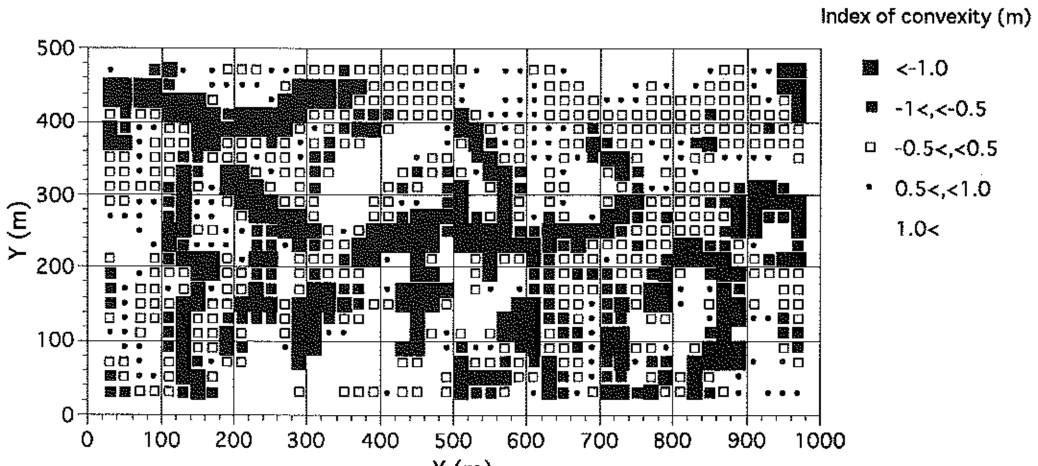

Fig. A2. Spatial pattern of IC of each quadrat in the plot.

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Differences in Soil Properties of Dry Evergreen and Dry Deciduous Forests in the Sakaerat Environmental Research Station

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ABSTRACT To clarify the soil-plant relationship in the Sakaerat Environmental Research Station (SERS), northeast Thailand, soil survey was conducted in the two major types of forest, *i.e.*, dry evergreen forest (DEF) and dry dipterocarp forest (DDF). In addition, DDF with fire protection treatment since 1967 (FPDDF) was also selected as a study plot to know the effect of protection of land cover during dry season on both soil and vegetation. As a result of the soil analysis, such as soil hardness, soil morphological, physical, chemical, and mineralogical properties, the current vegetation in the SERS seemed to be affected greatly by the strength of the impacts (fire) given to the forest. If no fire protection is attempted in the DDF, soil erosion due to loss of organic matter on the surface soil is easily brought about. Soil properties such as clay content and associated properties (water holding capacity, cation exchange capacity, water permeability, and moisture content) become worse easily and shortly, after soil erosion.

The various soil properties of the FPDDF can be considered in the intermediate condition between those of DDF and DEF. The stronger the impact of fire is, the more the soil erosion occurs. On the basis of soil properties, the following mechanism can be suggested to explain the current vegetation; once the original vegetation was destroyed, DEF type forest could not regenerate easily in such a dry and infertile soil condition, and therefore, the other type of vegetation, *i.e.*, DDF, is found elsewhere in northeast Thailand at present. The extremely dry soil condition currently found in the DDF is not intrinsic property of a forest soil. It is created by the removal of the vegetation which used to be there. The fire protected DDF suggests it.

Key words: soil-plant relationship / soil fertility / soil hardness / soil environment / dry dipterocarp forest / dry evergreen forest / fire protection / forest structure

Soil-plant relationship is a quite important aspect persistently occurring in the natural environment. However, both vegetational distribution and soil material distribution are quite complex under the actual condition, it is still very difficult to understand them clearly. If we focus on some specific plant species, we can evaluate the difference in soil properties and geomorphology as a site quality (*e.g.*, Hirai *et al.*, 1997). They showed that the segregated distributions of two dipterocarps were mostly