Journal of Tropical Forest Science 9 (4): 477 - 498 (1997)

THE DIPTEROCARP FOREST OF HAINAN ISLAND, CHINA

Hu Yujia

Department of Biology, Zhongshan University, Guangzhou, 510275 China

Received November 1994

HU, Y.J. 1997. The dipterocarp forest of Hainan Island, China. Hainan Island, China, has a total area of 34 104 km^2 and a dipterocarp forest which covers mainly the mountainous area below 1000m a.s.l. over a total area of about 6500 km^2. The forest consists of mixtures of species and single-dominance of species such as *Vatica hainanensis, Hopea exalata, Heritiera parvifolia, Amesiodendron chinense* and *Litchi chinensis* var. *euspontanea.* The forest possesses all features of the physiognomy and structure of a tropical rain forest, but not so typical as those of the equatorial forests. It can be divided into five types: hygrophilous mixed *Vatica* forest, hemihygrophilous mixed *Vatica* forest, mesophilous mixed *Vatica* forest, single-dominant *Hopea* forest, and single-dominant *Vatica* forest. Floristic and structural characteristics of the forest can clearly be correlated with the five forest types.

Key words: Dipterocarp forest - Hainan Island - China

HU, Y. J. 1997. Hutan dipterokarpa di Pulau Hainan, China. Pulau Hainan, China mempunyai kawasan seluas 34 104 km^2 dan hutan dipterokarpa di kawasan pergunungan kurang daripada 1000 m dari aras laut. Hutan ini mengandungi spesies campuran dan spesies dominan tunggal seperti *Vatica hainanensis, Hopea exalata, Heritiera parvifolia, Amesiodendron chinense* dan *Litchi chinensis* var. *euspontanea.* Hutan tersebut. mempunyai semua ciri fisiognami dan struktur hutan hujan tropika, tetapi tidak begitu tipikal seperti di hutan khatulistiwa. la boleh dibahagikan kepada lima jenis: hutan *Vatica* higrofilus campur, hutan *Vatica* hemihigrofilus campur, hutan *Vatica* mesofilus campur, hutan Hopea dominan tunggal dan hutan *Vatica* dominan tunggal. Ciri flora dan ciri struktur hutan tersebut dapat dikaitkan dengan lima jenis hutan tersebut dengan jelas.

Introduction

Hainan Island, China (1810[1]- 20° 10' N , 108° 37'-111° 03' E) has a total area of 34 104 km^2 and a 1528 km long coastline. In landform, the highlands (more than 500m altitude) amount to 9. 8% of the island's total area, hills and table land amount to 90. 2% (Dong & Zeng 1985). The highest mountain, Wuzhishan, 1867 m high, is located in the centre of the island. Diaoluoshan, located in the southeast of the island, is 1498 m high. Bawangling and Jianfengling, located in the southwest of the island, are 1512 m and 1412 m high respectively (Figure 1).

Dipterocarp forest covers mainly the mountainous area below 1000 m above sea level in the southeast, the center, the southwest and the southeast coast of the island, over a total area of about 6500 km^2 (Zhang 1963, Hu 1982, Xu l990, Hu & Li 1992). As tropical forest area is limited in China, the dipterocarp forest of Hainan Island is an important part of China's tropical forest producing valuable wood, medicinal herbs and other economic plants. Since the forest has been disturbed by economic development, an intensive study of the forest is urgently needed to provide a sound basis for its protection, sustainable development and management.

The objectives of the study were (1) to analyse the floristics, physiognomy and structure of the forest; (2) to determine the productivity and mineral nutrient elements of the forest; and (3) to determine the forest types.

Study sites:

This study was sited in Diaoluoshan, Jianling, Bawangling, Ganjialing and Wanning County coastal area of the island (Figure 1).

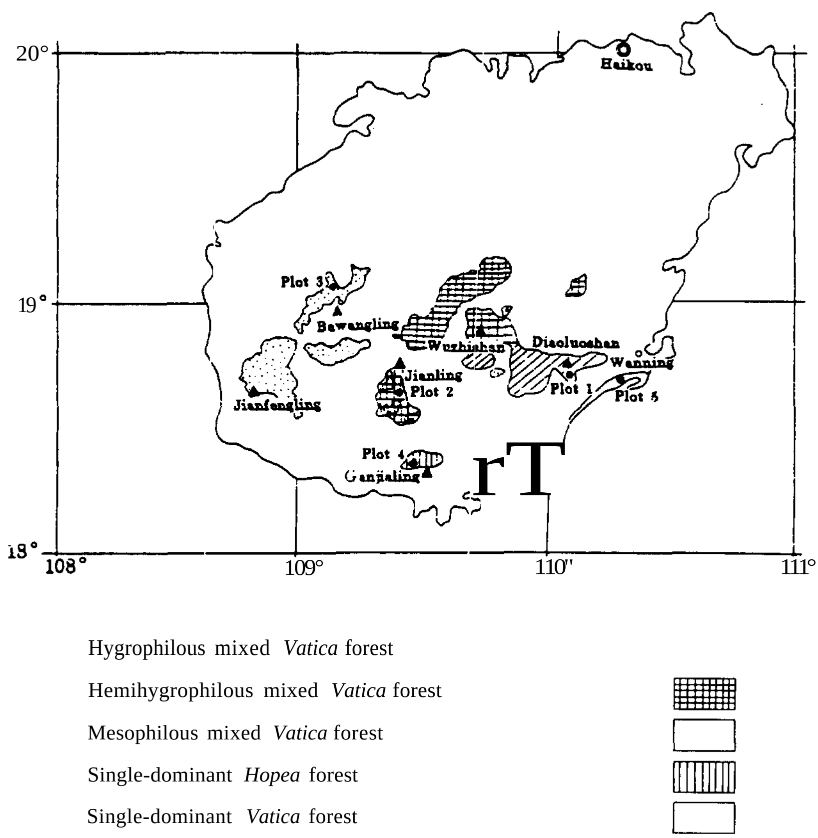


Figure 1. Distribution of dipterocarp forest in Hainan Island

Diaoluoshan is located at the southeast of the island, about 18° 45' N and 110° 02' E and the highest peak is 1498 m high. The soil is kransnozem developed from granite or igneous rock. The horizon of the soil is clear and more than 2 m in depth. The soil pH is 5.1, the humus content 2.10%, N content 0.11%, P content 0.005% and K content 0. 01% in the A horizon of the soil (Hu & Li 1992). The climate of the site is governed by monsoon. The average annual temperature is 24. 3 °C; the annual temperature varies from 9. 8 °C to 18. 5 °C in January, and 28. 3 °C injuly, the average annual rainfall is 2151.0 mm with a maximum of 417.8 mm in October and a minimum of 35.4 mm in January (He 1980) (Figure 2).

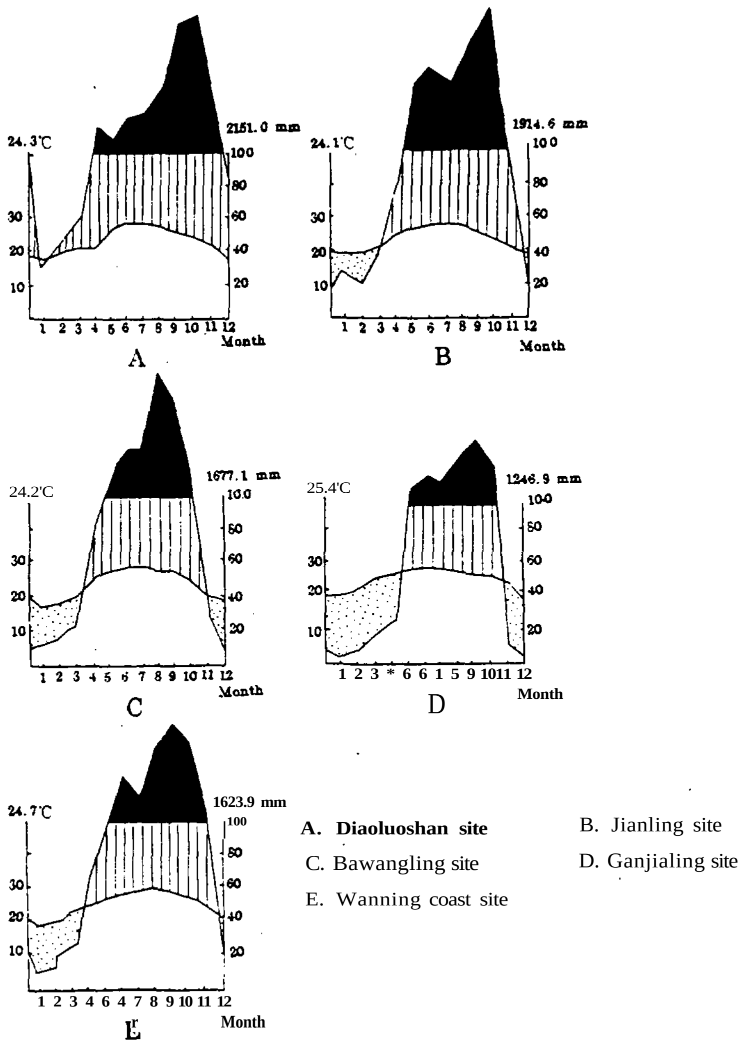


Figure 2. Climate diagrams of the main areas of dipterocarp forest in Hainan Island

Jianling is at the centre of the island, about 18°40' N and 109° 30' E, and the highest peak is about 800 m high. The soil is krasnozem developed from granite. The horizon of the soil is clear and more than 2 m in depth . The soil pH is 5.3, the humus of the soil content 1.64%, N content 0.10%, P content 0.009% and K content 0.01 % in the A horizon of the soil (Hu & Li 1992). The climate of the site is also governed by monsoons. The average annual temperature is 24.1 °C; the annual temperature varies from 8.5°C to 19. 6°C in January, and 28.1 °C in June. The average annual rainfall is 1914.6 mm with a maximum of 433.7 mm in September and a minimum of 20.4mm in December (He 1980) (Figure 2).

Bawangling is located at the southwest of the island, about 18°50'N and 109°05'E, and the highest peak is 1512 m high. The rock there is mainly granite with some sandstones below. The soil is krasnozem. The horizon of the soil is clear but thinner, about 1.5m in depth. The soil pH is 5.5, the humus content 2.76%, N content 0.20%, P content 0.008% and K content 0.026% in the A horizon (Hu & Li 1992). The climate of the site is governed by monsoons, the average annual temperature is 24.2 °C, the annual temperature varies from 9.9 °C to 18.5 °C in January and to 28.4 °C in July. The average annual rainfall is 1677.1 mm, with a maximum of 383.7 mm in August and a minimum of 8.8 mm in January (He 1980) (Figure 2).

Ganjialing is located at the south of the island, about 18°21 N and l09°34'E, and the highest peak is about 500 m high. The soil is krasnozem developed from granite. The horizon of the soil is thinner, about 1 m in depth. The soil pH is 5.8, the humus content 2.50%, N content 0.13%, P content 0.018% and K content 0.019% in the A horizon (Hu & Li 1992). At this site, the annual temperature variation as not so distinct, but annual rainfall is less. The average annual temperature is 25.4 °C, ranging from 20.8 °C in January to 28.5 °C in July; the average annual rainfall is 1246.9 mm, with a maximum of 270.5mm in September and a minimum of 7.8 mm in January (He 1980) (Figure 2).

Wanning County coastal site (18° 32'N, 110°02'E) is located on the south-east coast of the island, about 500 m from the South China Sea, and the highest altitude is about 10m. The average annual temperature is 24.7 °C and the annual temperature varies from 19.6 °C in January to 27.4°C in June. The average annual rainfall is 1623.9 mm, with a maximum of 326.8 mm in September, and a minimum of 10.3mm in January (He 1980) (Figure 2). However, the soil of the site is totally different from those of the above four sites. At this site, the soil, being coastal sand, has no structure and profile development. The soil has a pH of 5.2, humus content 0.29%, N content 0.091%, P content 0.006% and K content 0.003 % in the horizon of 5-20 cm depth (Hu & Li 1992).

Methods

Field sampling

Five sample plots were selected at the five different sites of the island (Figure 1). Plot 1 in Diaoluoshan area was located on the southern lower slope of the area at an altitude of 600 m and measured 20 X 100 m. Plot 2 in Jianling area was located on the northeastern lower slope of the area at an altitude of 580 m and measured 20 X 100 m. Plot 3 in Bawangling area was located on the southeastern lower slopes of the area at an altitude of 400 m and measured 20 X 100 m. Plot 4 in Ganjialing area, located on the northeastern lower scopes of the area at an altitude of 200 m, measured 20 X 100 m. Plot 5 in Wanning County coastal area, located on Shimei which is 7km away from Wanning Town and about 500 m from the South China Sea, measured 20 X 100 m.

All stems on the plots with a height of 1.5 m and over were recorded. Height, diameter at breast height or above buttress, crown features and number of buttresses were measured or estimated on the standing trees. A profile diagram was then drawn of a wellstocked part of the plot. Specimens of tree leaves were collected and leaf characters of the trees were measured.

Forests of Plots 1, 2 and 3 are generally undisturbed, and those of Plots 4 and 5 have been more or less disturbed.

Data analysis

Species similarity analysis: Two species similarity coefficients were used (SOrensen 1948)

Kulezyski coefficient *(Kc)* $= \frac{(n_1 + n_2) \cdot n_c}{2 n_1 \cdot n_2} \times 100$

SOrensen coefficient (Sc) $= \frac{2n_c}{n_1 + n_2} \times 100$

where

n_1 = no. of species in plot A

n_2 = no. of species in plot B

n_c = no. of same species in plots A and B

Species diversity analysis

Three diversity indices were used (Peet 1974):

Shannon-Wiener index *(H)* = -Z(n./JV) log *(n/N)*

where

n. = individual number of *i* species
N = total individual number

Simpson index *(D)* = 1-Z(n./7V)^2
Equitability index (£) = H/log 5 *(S* = number of species)

Pattern analysis

Three methods of pattern analysis were used:

Variance/Mean ratio (Greig-Smith 1983):

$V = \sum_{i=1}^{N} (X_i - m)/'(AM)$ $\quad\quad m = \sum_{i=1}^{N} X_i/N$

t = (V/w-l)/V2/(AM)
V = variance, *m* = mean, 7V = sample number
X_i = individual number of sample

Morisita index (Morisita 1959):
I_i = [S/(N-1)] . [m + (V/m - 1)]

Index of mean crowding (Lloyd 1967):
M_i = *m* + *(V/m-l)*. [1 + *V/(S.* m^2)]

Biomass and net production analysis

Biomass and net production were determined by the following two formulas (Tong & Zeng l985):

$$B_n = 0.00003396 D'^2 \cdot H$$
$$P^n_n = 0.000010246 (D'^2 \cdot H)^{MW}$$

where

B_m = biomass (t, dry weight)
P = net production (t, dry weight/year)
D = tree diameter at breast height (cm)
H = tree height (m)

Results

Floristics

Floristics elements

The dipterocarp forest has a varied species composition. A total of 249 species of trees with height of 1.5 m and over belonging to 58 families and 147 genera were found in the five plots totalling 1 ha of sample area. In terms of major growth forms, there are 212 tree species and 37 shrub species. These constitute 14.3% of the total species and 24.6% of the total genera of Hainan's xylophyta. Among them 107 genera and 165 species are tropical elements amounting to 72. 8% of the total genera and 67.0% of the total species in this floristic group. The main families of the dipterocarp forest are Dipterocarpaceae, Euphorbiaceae, Sapindaceae, Rubiaceae, Sterculiaceae, Moraceae, Annonaceae and Lauraceae, and the main dominant species are *Vatica hainanensis, Hopea exalata, Heritiera parvifolia, Litchi chinensis* var. *euspontanea, Amesiodendron chinense, Diospyros hainanensis* and *Coelodepas hainanensis.* Their relative density and dominance are more than 3.5 % and 17.0% respectively.

In addition, there are 2 single-species genera, 1 endemic genus and 33 endemic species. The single-species genera are *Tarrietia* and *Aquilaria,* the endemic genus is *Parapyrenatia.* The endemic species are *Machilus pomifera, Phoebe hungmoensis, Neolitsea oblongifolia, Beilschmiedia longipetiolata, Goniothalamus gardneri, Syzygium tephrodes, Pyrenocarpa hainanense, Eurya ovatifolia, Hopea exalata, H. hainanensis, Microcos chungii, Elaeocarpus howii, Firmiana hainanensis, Heritiera parvifolia, Antidesma maclure, Actephila merriliana, Drypetes hainanensis, Coelodepas hainanensis, Dalbergia hainanensis, Aphania digophylla, Ellipanthus glabrifolius, Diospyros maclurei, D. hainanensis, D. howii, Styrax hainanensis, Strychnos confertiflora, Olea neriifolia, Linociera parvilinba, L. caudatifolia, Randia merrilii, Lasianthus hainanensis, Saproma hainanensis* and *Radermachera hainanensis.* However, an overwhelming majority of these species are of low importance in the forest.

Species and area

Altogether 249 species of trees with height of 1. 5 m and over were identified on the five plots, i.e. 142,105, 98, 88 and 47 for plots 1 to 5 respectively. Additive species area curves for trees of 1.5 m and over are presented in Figure 3. There seems to be a correlation between the number of species and area. Plot 1 has the highest number of species and Plot 5 the lowest. The number of species continues to rise and the curves show little sign of flattening out from Plots 1 to 3 (especially Plot 1), but the curves of Plots 4 and 5 show a tendency to level out. The numbers of species in the latter two plots are low and their levelling out is related to their forest ecology and structure.

Species similarity

Species similarity means similarity of forest communities. This similarity is compared by the Kulezyski and SOrensen coefficients given in Table 1 for the five plots. The results show that the Kulezyski species similarity coefficients vary within a range of 25.4, from 36.2 to 10.8, and the SOrensen species similarity coefficients vary within a range of 25.8, from 35.0 to 9.2. The species similarity is therefore low, i.e. species composition varies among the five plots.

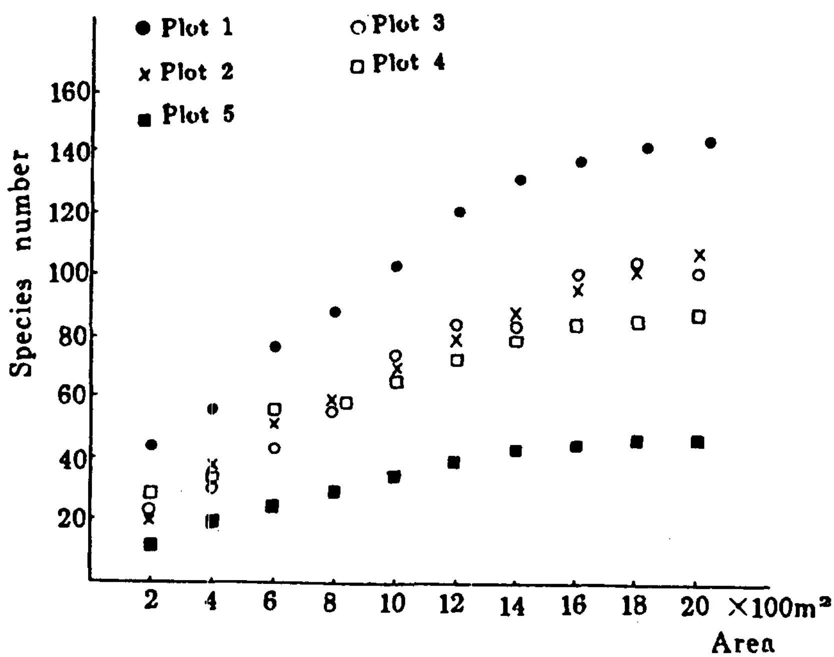


Figure 3. Species-area relationship for the five plots

Table 1. Comparison of species similarity in the five plots

Plot A: Plot B	No. of species of Plot A : No. of species of Plot B	No. of similar species in Plot A and Plot B	Species similarity	
			Kulezyski coefficient	SOrensen coefficient
Plot 1: Plot 2	142:105	41	34.0	34.0
Plot 1: Plot 3	142:98	42	36.2	35.0
Plot 1: Plot 4	142:88	39	35.9	33.9
Plot 1: Plot 5	142:47	11	15.6	11.6
Plot 2: Plot 3	105:98	33	32.6	32.5
Plot 2: Plot 4	105:88	24	25.1	24.9
Plot 2: Plot 5	105:47	7	10.8	9.2
Plot 3: Plot 4	98:88	24	25.9	25.8
Plot 3: Plot 5	98:47	8	14.1	11.0
Plot 4: Plot 5	88:47	10	16.3	14.8

Species diversity

All species with height of 1.5 m and over, the stem numbers and the Shannon-Wiener, Simpson and Equitability indices are given in Table 2. Generally , Plot 1 has the highest species diversity index and Plot 5 the lowest. The indices of Plots 1,2 and 3 are similar to each other and those of Plots 4 and 5 also similar to each other. The results show that the forests of Plots 4 and 5 also have alow number of species and an unsteady state at the present time.

Table 2. Comparison of species diversity in the five plots

Plot no.	Species no.	Stems	*H*	*D*	*E*
1	142	566	6.06	0.97	0.85
2	105	388	5.86	0.97	0.87
3	98	457	5.35	0.93	0.80
4	88	1977	3.22	0.67	0.50
5	47	849	2.95	0.67	0.54
Average	96	847	4.69	0.84	0.71

Physiognomy

Life form

Life form is also called "biological spectrum" (Richards 1952). We use the well-known "epharmonic" life form classification of Raunkiaer (1934) to make a life form spectrum of the forest (Figure 4). The spectrum shows an enormous preponderance of woody phanerophytes. Therophytes and geophytes are entirely absent. Species number of vascular epiphytes is very low and the epiphytes generally grow on tree branches or underground rocks.

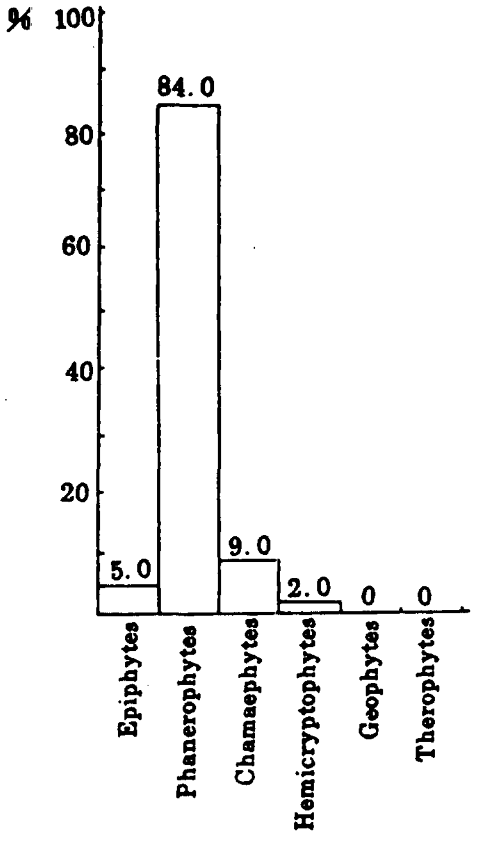


Figure 4. Life form spectrum of the dipterocarp forest in Hainan Island

Leaf characters

Leaf size was measured in the laboratory on three to six leaves of each tree species and recorded as leptophyll, nanophyll, microphyll, mesophyll, macrophyll and megaphyll (Raunkiaer 1934). Leaf shape was recorded as simple or compound, acumen or without acumen. Leaf margin was recorded as entire or non-entire. Percentages for each character per plot based on the number of species are given in Table 3. The results show that differences between plots are rather small, all plots have a high percentage of mesophyll leaves, a high percentage of leaves with acumen shape, and enormous preponderances of simple leaves and entire margin leaves. However, the mesophyll percentages of all plots are lower than those of a typical rain forest in Southeast Asia. This differences is due to the differences in climate., mainly rainfall, and floristics.

Table 3. Leaf characters in percentages of number of species

Plot no.	Leaf size						Leaf shape					Leaf margin	
	le	na	mi	mes	ma	meg	si	co	ac	length of ac (mm)	non-ac	entire	non-entire
1	0	1	40	57	2	1	92	8	50	8.5	50	98	2
2	0	1	32	59	6	2	85	15	38	10.0	62	94	6
3	0	0	39	53	7	1	94	6	45	10.0	55	94	6
4	0	0	53	46	1	0	89	11	44	7.2	56	96	4
5	0	0	43	54	3	0	92	8	43	8.3	57	95	5

le = leptophyll; na = nanophyll; mi = microphyll; mes = mesophyll; ma = macrophyll; meg = megaphyll; si = simple; co = compound; ac = acumen.

Buttress

Buttressed species were classified, the number of buttresses was counted for each tree and the height measured in meter. Only buttresses with a height of 1 m or more were recorded and branched buttresses were counted as one.

Data on buttresses are presented in Table 4. Buttressed species and stems are few in all plots and are mainly of dominant species and trees. The trees are all of stratum A or B.

Table 4. Quantitative data on buttresses

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Buttressed species (% of total number of species)	12.0	12.3	20.2	13.6	6.7
Buttressed trees number (% of total number of trees)	17.0	17.0	21.0	7.0	17.0
Height of buttresses (% of number of buttressed trees)					
Height (m)					
0.3 - 0.8	33.3		45.0		
0.9 - 1.4	30.3		35.0		
1.5 - 2.0	9.2	No data	5.0		No data
2.1 - 2.6	24.2		5.0		
> 2.6	3.0		5.0		
Number of buttresses (% of number of buttressed trees)					
Number					
1-2	10.0		0		
3-4	52.0		50.0		
5-6	35.0	No data	15.0		No data
7-8	3.0		25.0		
>8	0.0		10.0		

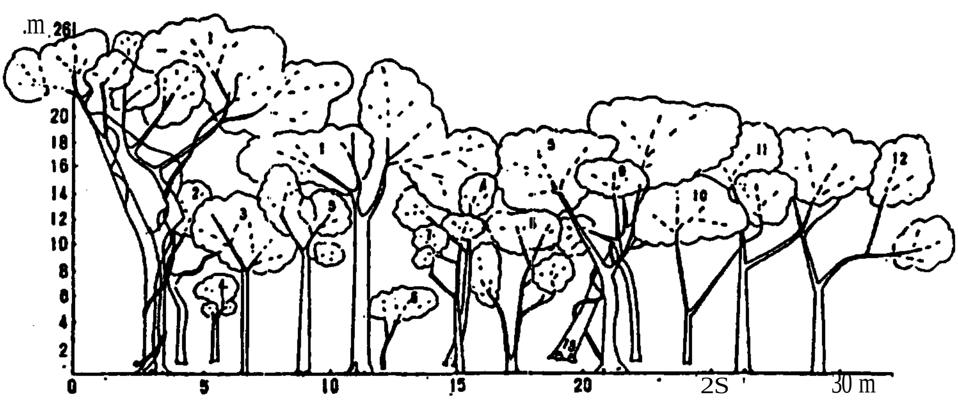
Forest structure

Tree density

Tree density in the forest varies (Table 5). From the data, the tree density in Plot 4 is much higher than those in Plots 1,2,3 and 5, particularly in the lowest diameter class. The densities in Plots 1,2,3 and 5 are similar, whether in the low diameter class or high diameter class. The results show that the forest of Plot 4 has been disturbed by man and the forest is now regenerating; the forests of other plots are relatively stable.

Table 5. Tree density (number of trees/2000 m^2)

Plot no.	2. 5(cm)£ diameter<7. 5(cm) (a)	7. 5(cm)^ diameter (b)	Ratio (a:b)
1	233	226	1.03
2	160	158	1.01
3	194	219	0.89
4	818	329	2.48
5	203	282	0.72
Average	322	243	1.30



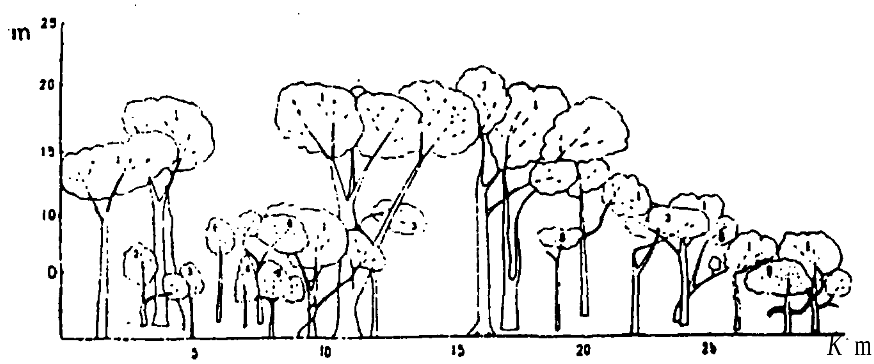
1. *Valica hainanensis* 2.*Dalbergia hainanensis* 3.*Dellnia turbinata* 4. *Heritiera angustata* 5. *Heritiera parvifolia* 6. hainanensis 7,*Radermachera hainanensis* 8. *Diospyros strigosa* 9. *Amesiodendron chinese* 10. *Memecylon ligustrifolium* 11. *Neolitsea obtusfolia* 12. *Aguilaria sinensis*

Figure 5. Profile diagram of hygrophilous mixed *Vatica* forest in Plot 1. (The diagram represents a strip of forest 30 m long and 5 m wide; only trees over 5 m high are shown).

Profile diagrams

Profile diagrams were drawn of an area 30 X 5 m in each of the five plots at a scale of 1: 100 (1 cm =lm) or 1: 200(1 cm = 2 m). All trees on the profile area with a height of 5 m and over were recorded. Tree diameter was measured and tree height and crown shape and size were estimated.

Profile diagrams adjusted according to measurements and estimates on the pofile area are presented in Figures 5 to 9. A common feature is that the crowns are dense, but the layer of small trees between about 6 and 8 m heights is sparse. The diagrams of Plots 1,2 and 3 show distinct layering, their canopy heights being about 27, 22 and 26 m respectively. The diagrams of Plots 4 and 5 show indistinct layering, their canopy heights being about 12-16m and 10-13m respectively.

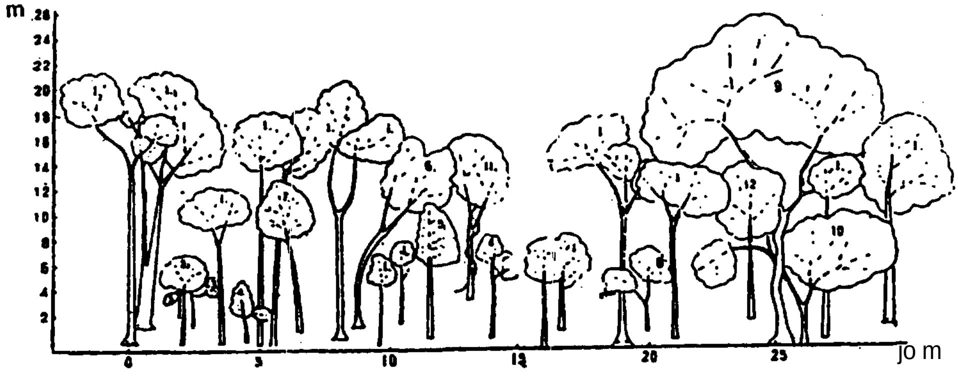


1. *Vatica hainanensis* 2. *Pseudostreblus indica* 3. *Xanthophyllum hainanense*
4. *Rapanea neriifolia* 5. *Scleropyrum wallichianum* 6. *Canthium dicoccum*
7. *Heritiera parvifolia* 8. *Neolitsen oblusifolia* 9. *Garcinia oblongifolia*

Figure 6. Profile diagram of hemihygrophilous mixed *Vatica* forest in Plot 2. (The diagram represents a strip of forest 30 m long and 5 m wide; only trees over 5 m high are shown).

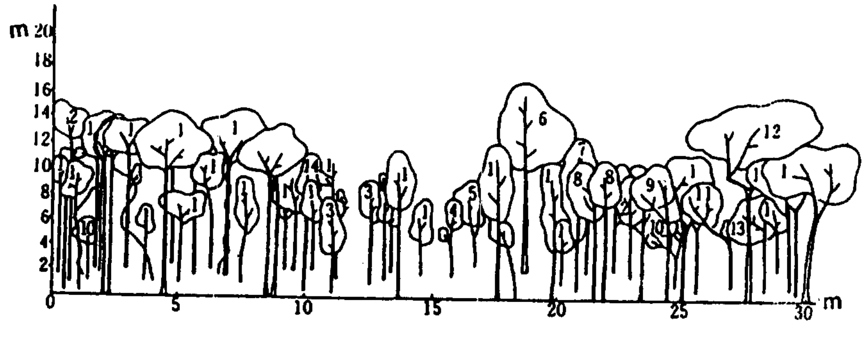
Frequency and pattern

Species frequency indicates horizonal distribution of species in the community. Frequency class of species is divided into five percentage classes by Raunkiaer (1934): A class 1-20%, B class 21-40%, C class 41-60%, D class 61-80 %, E class 81-100%. Frequency percentage classification of the five plots is given in Table 6. From the data, the frequency percentage class sequence is A>B>C>D>E. It does not tally with Raunkiaer's frequency law: A>B>C|D<E. This indicates that the species elements of the dipterocarp forest are complex and dominant species indistinct. Thus there is little uniform distribution of species, the E class frequency percentage being the lowest. Whether the law is applicable to tropical vegetation remains to be further studied.



I. *Vatica hainanensis* 2. *Diospyros eriantha* 3. *Neolitsea obtusifolia* 4. *Coelodepas hainanensis* 5. *Garcinia oblangifolia* 6. *Syzygium araiocladum* 7. *Polyalthia laui* 8. *Homanoia riparia* 9. *Litchi chinensisvar. euspontanea* 10. *Dillenia pentagyna* 11. *Diospyros hainanensis* 12. *Xanthophyllum hainanense*

Figure 7. Profile diagram of mesophilous mixed *Vatica* forest in Plot 3. (The diagram represents a strip of forest 30 m long and 5 m wide; only trees over 5 m high are shown).



1. *Hopea exalata* 2. *Machilus chinensis* 3. *Glorhidion sp.* 4. *Symplocos caudata* 5. *Syzygium buxifolium* 6. *MacHilus thunbergii* 7. *Cryptocarya chingii* 8. *Vatica hainanensis* 9. *Heritiera angustata* 10. *Coelodepas hainanensis* 11. *Beilschmiedia percoriacea* 12. *Heritieraparvifolia* 13. *Alphonsea monogyna* 14. *Styrax marrilli*

Figure 8. Profile diagram of single-dominant *Hopea* forest in Plot 4. (The diagram represents a strip of forest 30 m long and 5 m wide; only trees over 5m high are shown).

1. *Valica hainanensis* 2. *Cleistanthus saichikii*
3. *Olea dioica* 4. *Scleropyrum wallichianum*

Figure 9. Profile diagram of single-dominant *Vatica* forest in Plot 5. (The diagram represents a strip of forest 30 m long and 5 m wide; only trees over 5 m high are shown).

Table 6. Frequency percentage

Class	Plot 1	Plot 2	Plot3	Plot 4	Plot 5
A	85.5	88.1	86.5	69.0	77.8
B	6.7	9.9	11.7	17.2	8.9
C	3.0	2.0	0.9	6.9	6.7
D	3.0	0	0.9	5.6	4.4
E	1.5	0	0	1.3	2.2

Species pattern indicates time and spatial state of the species in the community, the pattern being influenced by the biological characteristics of the species and their ecology (Peng &Wang 1984, Lu 1986). The pattern of some main dominant species of Plots 1, 2, 3 and 5 was determined by the variance/mean ratio method, Morisita index and index of mean crowding. The results are presented in Table 7. The three main dominant species of Plot 1 show a random distribution and some main dominant species of Plots 2 and 3 show a colonial distribution. The reason is that the soil and climatic conditions of Plot 1 are superior to those of Plots 2, 3 and 5.

Table 7. Pattern of some main dominant tree species

Plot no.	Species	Variance/Mean ratio					Morisita index		Index of mean crowding
		m (a)	V(b)	b/a	t	Result	Index	Result	
1	V	2.15	0.87	0.41	1.83	Random	0.73	Random	1.55
	H	1.75	1.88	1.08	0.23	Random	1.04	Random	1.83
	A	1.05	1.00	0.95	0.15	Random	0.45	Random	1.00
2	V	1.65	9.40	5.70	4.47	Colonial	3.79	Colonial	7.16
	H	1.55	10.36	6.69	17.53	Colonial	4.60	Colonial	8.46
	A	0.65	0.66	1.02	0.05	Random	1.02	Random	0.66
3	V	5.00	47.37	9.47	26.12	Colonial	2.63	Colonial	14.28
	L	0.75	0.83	1.11	0.32	Random	1.14	Random	0.86
5	**V**	23.50	63.52	2.70	5.23	Colonial	11.07	Colonial	22.26

V = *Valica hainanensis* H - *Heritiera parvifolia* A - *Ameiodendrom chinese*
L = *Litchi chinensis euspontane.*

Productivity and mineral nutrient elements of the forest

Biomass and net production

The biomass and net production of the forest are given in Table 8. The forest of Plot 1 has the highest biomass and net production and that of Plot 5 the lowest. The forests of high biomass and net production such as those of Plots 1,2 and 3 are generally primary mixed forest, the species are complex and trees big, and the ecological environment is healthy. However, the forests of lower biomass and net production such as those of Plots 4 and 5 are single-dominant forest, the species are simple, the trees young, and the soil and moisture conditions of the forests are adverse.

Table 8. Biomass and net production in the five plots

Plot no.	Biomass ($t\ ha^{-1}$)	Net production ($t\ ha^{-1}\ y^{-1}$)
1	372.36	5.15
2	218.42	3.40
3	318.62	4.40
4	157.00	2.65
5	90.95	2.45
Average	231.47	3.61

Mineral nutrient elements of the forest

Fresh leaves of two dipterocarps and three main dominant species were collected at Plots 1, 2, 3 and 5 in September. Their nutrient contents were analysed by standard analytical methods and compared with the contents of some main dominant tree species in other forest types of China. The data are presented in Table 9.

The data show that the contents of nitrogen, phosphorus and potassium in leaves of the dominant species, especially the dipterocarps, are generally higher than those of other forest types in China. This is probably due to the roots of the most dominant species in the forest having rhizobia and mycorrhiza (Ashton 1981, Hu & Li 1992) such that the autotrophic ability or self-fertility ability of the species is greater (Zeng 1990). Moreover, because the dominant species of the forest grow in the tropics, their period of nutritive growth is longer, the number of their leaves is greater and the lifespan of the leaves is longer. Hence the photosynthesis of the leaves is more efficient and nutrients are relatively better stored.

Table 9. Comparison of nutrient compositions (%)

Forest type	N	P	K	Ca	Mg
Dipterocarp forest of Hainan Island, China (4 species, total 8 trees)	1.60 - 2.55	0.12-0.26	0.48-1.11	0.34-1.15	0.18-0.26
Montane rain forest of Hainan Island, China (9 species, total 15 trees) *	0.87-1.90	0.06-0.22	0.27-0.92	0.12-0.92	0.10-0.41
Subtropical evergreen broad-leaved forest of China (14 species, total 25 trees) * *	0.96 -1.69	0.02-0.14	0.34-1.04	0.22-1.49	No data
Temperate evergreen Coniferous forest (6 species, total 10 trees) * *	0.86 - 1.25	0.07-0.12	0.43-0.59	0.33-0.76	No data

*Data from Hu & Li (1992),
"Data from Hou (1982).

Forest types

According to the forest floristics, the physiognomy and structure of the five plots, the dipterocarp forest of Hainan Island may be classified into at least five types: hygrophilous mixed *Vatica* forest, hemihygrophilous mixed *Vatica* forest, mesophilous mixed *Vatica* forest, single-dominant *Hopea* forest, and single-dominant *Vatica* forest.

Hygrophilous mixed *Vatica* forest

The forest covers naturally the southeast of the island, mainly in Diaoluoshan, Sanjiaoshan, Xinglongshan and Liulinling area, below 1000 m above sea level (Figurel). The climate, soil and ecology of this type are the best of the five types. The type has the highest number of species, species diversity (Table 2), biomass and net production (Table 8). The main species are *Vatica hainanensis, Heritiera parvifolia, Mallotus hookeriensis,* etc. (Table 10). Undergrowth is dominated by *Licuala fodiana* and *L spinosa;* and herbs are few. Wood climbers are many, main species being *Gnetum montanum, G. pavifolium, Milletia dielsiana, Ancistrocladus tectorius* and *Sabia limoniacea.* Buttressing and tillering are common; cauliflory and strangling are present. This type is exemplified by Plot 1, situated on the southern lower slopes of Diaoluoshan at an altitude of 600 m.

Table 10. Species elements of hygrophilous mixed Vatica forest (Importance value > 5.0, sample area 2000 m^2)

No.	Species	Tree stems	Basal area (m^2)	Importance value (%)
1	*Vatica hainanensis*	42	3.60	33.7
2	*Heritiera parvifolia*	32	3.38	29.6
3	*Mallotus hookerianus*	45	0.11	12.7
4	*Amesiodendron chinense*	20	0.95	12.5
5	*Coelodepas hainanensis*	29	0.06	9.4
6	*Diospyros hainanensis*	19	0.44	8.8
7	*Polyalthia laui*	20	0.21	8.7
8	*Schima superba*	7	0.86	7.9
9	*Ormwsia balansae.*	25	0.05	7.3
10	*Neolitsea obtusifolia*	4	0.77	5.7
11	*Dillenia turbinata*	11	0.20	5.4
12	*Beilschmiedia intermedia*	4	0.62	5.1
	....			
	Sum	571	17.10	300.0

Hemihygrophilous mixed *Vatica* forest

This forest covers naturally the south centre of the island, mainly in Wuzhishan, Jianling, Kafaling and Limushan area, below 800 m above sea level (Figure 1). The forest type is considered a transition type between hygrophilous forest and mesophilous forest. The transition is mainly shown in the species elements. The main species are *Vatica hainanensis, Amesiodendron chinense, Ficus gibbosa,* etc. (Table 11). This type is shown in Plot 2 situated on the southern lower slopes of Jianling at an altitude of 580 m.

Table 11. Species elements of hemihygrophilous mixed *Vatica* forest (Importance value > 5.0, sample area 2000 m^2)

No.	Species	Tree stems	Basal area (m^2)	Importance value (%)
1	*Vatica hainanensis*	33	1.96	31.3
2	*Amesiodendron chinense*	14	1.71	24.7
3	*Ficus gibbosa*	2	1.96	20.6
4	*Heritiera parvifolia*	32	0.25	13.9
5	*Litchi chinese* var. *euspontanea*	5	0.81	11.6
6	*Wrightia laevia*	15	0.24	9.8
7	*Polyalthia laui*	11	0.34	9.3
8	*Chieniodendron hainanensis*	10	0.31	7.9
9	*Litsea boviensis*	14	0.31	7.9
10	*Canthium dicoccum*	15	0.08	6.0
11	*Xanthnphyllum hainanense*	10	0.11	5.8
12	*Garcinia oblongifolia*	8	0.12	5.4
	......			
	Sum	388	11.30	300.0

Mesophilous mixed *Vatica* forest

The forest covers naturally the southwest of the island, mainly in Bawangling and Jianfengling, below 800 m above sea level (Figure 1). The species elements differ distinctly from those of the hygrophilous mixed *Vatica forest* because of the relative dry climate in the forest type. The characteristic dominant tree species are *Vatica hainanensis, Litchi chinensis* var. *euspontanea, Coelodepas hainanensis,* etc. (Table 12). The characteristic species of the above two types, *Heritiera parvifolia,* is not present. *Amesiodendron chinense* is also unusual in the forest type. Undergrowth is dominated by *Calamus,* a physiognomical characteristic in the type. Grass and herbs are sparse and wood climbers are few. Buttressing is common but cauliflory and strangling are not distinct. A sample of the forest type is given by Plot 3, situated on the northern lower slope of Bawangling at an altitude of 400 m.

Single-dominant *Hopea* forest

The forest covers only the south of the island, in Ganjialing, over an area of about 3400 ha (Figure 1). The climate and soil of the forest are similar to those of the forest types 1,2 and 3, but with different dominant and characteristic species. *Hopea exalata* is exceptionally predominant and its importance value is 112.0 in the forest. Other main characteristic species are *Vatica hainanensis, Coelodepas hainanensis, Aporvsa yunnanensis,* etc. (Table 13). Undergrowth is dominated by young trees and seedlings of crown species. Tree stratification is not clear (Figure 8). Buttressing, cauliflory and strangling are absent. This forest type is shown in Plot 4, situated in the northwest lower slope of Ganjialing at an altitude of 200 m.

Table 12. Species elements of mesophilous mixed *Vatica* forest (Importance value > 5.0, sample plot area 2000 m^2)

No.	Species	Tree stems	Basal area (m^2)	Importance value (%)
1	*Vatica hainanensis*	100	4.52	57.3
2	*Litchi chinensis* var. *eusponlanea*	16	4.36	35.5
3	*Coelodepas hainanensis*	54	0.11	14.5
4	*Ficus altissima*	1	1.76	11.9
5	*Syzygium araiocladum*	9	0.51	7.7
6	*Xanthophyllum hainanense*	10	0.41	6.6
7	*Phyllochamys taxoides*	14	0.08	5.5
8	*Polyalthia laui*	9	0.11	5.5
	.....			
	Sum	457	15.60	300.0

Table 13. Species elements of single-dominant *Hopea* forest (Importance value > 5.0, sample plot area 2000 m^2)

No.	Species	Tree stems	Basal area (m^2)	Importance value (%)
1	*Hopea exalata*	1113	3.91	112.0
2	*Vatica hainanensis*	110	1.00	22.8
3	*Coelodepas hainanensis*	101	0.21	12.5
4	*Aporosa yunnanensis*	74	0.12	9.0
5	*Quercus patelformis*	1	0.55	7.3
6	*Glochidion poberum*	28	0.14	7.0
7	*Garcinia oblongifolia*	24	0.13	6.1
8	*Heritiera parvifolia*	31	0.05	5.5
9	*Mallotus hookeriansis*	29	0.04	5.6
10	*Diospyros eriantha*	23	0.10	5.4
11	*Prismatomeris tetrandra*	38	0.01	5.3
12	*Amesiodendron chinense*	21	0.04	5.2
	....			
	Sum	1977	7.87	300.0

Single-dominant *Vatica* forest

The forest, appearing only along Wanning County coast to Lingshi County coast, is composed of a natural strip of coastal forest 25 km long and 400 m wide, with a total area of about 10 km^2 (Figure 1). The species elements, physiognomy and structure of the forest distinctly differ from those of the mixed *Vatica* forest. *Vatica hainanensis* is highly predominant and its importance value is 156.6 in the forest. Other characteristic species are *Mischocarpus sundaicus, Psychotria rubra, Cleistanthus saichikii,* etc. (Table 14). Wood climbers, buttressing and cauliflory are absent, but vascular epiphytes occur on the tree branches. Tree stratification is not clear (Figure 9). The forest has a climate and geography similar to those of the hygrophilous mixed *Vatica* forest, but the soil is different. The soil of the forest is developed from sea sand. The soil is a limiting factor to the growth and development of the forest. Based on Richards' (1952) definition, this single-dominant *Vatica* forest should be experiencing an "edaphic climax".

Table 14. Species elements of single - dominant *Vatica* forest (Importance value >5, sample area 200 m^2)

No.	Species	Tree stems	Basal area (m^2)	Importance value (%)
1	*Vatica hainanensis*	471	7.64	156.6
2	*Mischocarpus sundaicus*	60	0.01	14.2
3	*Psychotria rubra*	46	0.04	13.6
4	*Cleistanthus saichikii*	59	0.04	11.3
5	*Sceropyrum wallichianum*	14	0.19	8.9
6	*Randia spinosa*	26	0.01	8.1
7	*Olea dioica*	18	0.01	7.1
8	*Parcinia oblongifolia*	12	0.01	6.4
9	*Microdesmis casearifolia*	12	0.10	5.4
	....			
	Sum	849	8.37	300.0

Discussion

The dipterocarp forest of Hainan Island covers extensively the southeast, the centre, the southwest and the south mountainous regions below 1000m above sea level. In those regions, the soils are mainly krasnozem, the average annual temperature is between 23 °C and 25 °C, the average temperature in January is more than 18 °C and the average annual rainfall is more than 1500 mm. Thus the climate matches the general climatic characteristics of a tropical rain forest. The floristics and structure of the forest also show distinct characteristics as those of a tropical rain forest, but differ prominently from the Asian silva. Because of these features, we consider the dipterocarp forest of Hainan Island to be a tropical rain forest rather than a monsoon or other tropical forest type. It should be a part of the Asian tropical rain forest.

The tree species diversity indices of Diaoluoshan (Plot 1),Jianling (Plot 2) and Bawangling (Plot 3) forests are greater than those of Ganjialing (Plot 4) and Wanning coast (Plot 5) forests. These results indicate that the forests of Plots 1 , 2 and 3 are relatively stable mixed forests, whereas those of Plots 4 and 5 are relatively unsteady single-dominant forests.

Species frequency distribution of the dipterocarp forest of Hainan Island show a frequency class sequence of A>B>C>D>E. This sequence is different from that given by Raunkiaer's frequency law, as is the sequence of the montane rain forest in Hainan (Yu 1983). On these grounds we believe the law could not be used for tropical vegetation. The lowest percentage in the E class frequency may be one of the important characteristics of tropical rain forest.

There are many different classification systems for the dipterocarp forest of Hainan Island (Zhang 1963, Guangdong Institute of Botany 1976, Wu 1980, Xu 1990). According to the floristics, physiognomy and structure of the five plots, combined with the conditions of the plots, especially humidity, the dipterocarp forest of Hainan Island is composed of five types: (I) hygrophilous mixed *Vatica* forest, (2) hemihygrophilous mixed *Vatica* forest, (3) mesophilous mixed *Vatica* forest, (4) single-dominant *Hopea* forest, and (5) single-dominant *Vatica* forest.

In the dipterocarp forest of Hainan Island, rich tropical plant resources are found. They include such species as *Dalbergia odorifera, Homalium hainanensis, Hopea hainanensis, H. exalata, Vatica hainanensis, Litchi chinensis* var. *euspontanea, Terminalia hainanensis,* etc., valuable wood species such as *Cephalotaxus hainanensis, Aguilaria sinensis,* etc., valuable medicinal plants and many other economic plants. The resources have been disturbed by man for economic gains; hence the protection and sustainable utilisation of the forest remain a problem which demands an urgent solution.

References

ASHTON, P.S. 1981. Future directions in dipterocarp research. *Malaysian Forester* 44(2-3) : 193-196.

DONG, HANFEI & ZENG, SHUIQIAN. 1985. *Quality Analysis Synthetical Appraisal of the Ecological Environment in Hainan Island.* Zhongshan University Press : 1, 5.

GUANGDONG INSTITUTE OF BOTANY. 1976. *Vegetation of Guangdong.* Science Press, Beijing : 41,46, 57, 77.

GREIG-SMITH, P. 1980. *Quantitative Plant Ecology.* 3rd edition. Blackwell Science Publishers : 59 - 79.

HE, DAZHANG, 1980. Study on tropical climate of Hainan Island. *Journal of South China Normal College* 2:8-18.

HOU.XUEYU. 1982. *Vegetational Geography and Dominant Plant Chemical Elements of China.* Science Press, Beijing: 48, 101 -103.

Hu.YujiA. 1982. *Hopea exalata* forest of Hainan Island. *Tropical Subtropical Forest Ecosystems* 1: 251-271.

Hu, YUJIA & LI, YUXING. 1992. *The Tropical Rain Forest of Hainan Island.* Guangdong Higher Education Press, Guangzhou : 3 - 5, 18 -19, 51,124.

LLOYD, M. 1967. Mean crowding. *Journal of Animal Ecology* 36 : 1 - 30.

Lu, YANG, 1986. The application of the sampling method to the plant population pattern in the lower subtropical forest. *Acta Phytoecologica et Geobotanica Sinica* 10(4): 272-282.

MORISITA, M. 1962. Index, a measure of dispersal of individuals. *Research Population Ecology* 4:1-7.

PEET, R.K. 1974. The measurement of species diversity. *Annual Review of Ecological Systems* 5: 282 - 307.

PENG, SHAOLIN & WANG, BOSUN. 1984. Forest communities analysis of Dinghushan, Guangdong Province. III. Population pattern. *Tropical Subtropical Forest Ecosystems* 2 : 24 - 37.

RAUNKIAER, C. 1934. *The Lifeforms of Plants and Statistical Plant Geography.* Oxford : 368 - 378.

RICHARDS, P.W. 1952: *The Tropical Rain Forest.* Cambridge : 7.

SORENSON.E. H., 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. *Biol Skr.* 5 (4) : 1 - 34.

Wu, ZHENGYI. 1980. *Vegetation of China.* Science Press, Beijing : 366, 383.

XU,YIANQIAN. 1990. *Forests of Guangdong.* Guangdong Science & Technology Press, Guangzhou: 120, 131-141.

Yu, TONGQUAN. 1983. The montane rain forest of Hainan Island. *Ecological Science 2 :* 1-9.

ZENG, SHUIQIN. 1990. *The Geochemistry of Soil and Vegetational System in Hainan Island.* Guangdong Science & Technology Press, Guangzhou : 47 - 48.

ZHANG HONGDA. 1963. The vegetation classification plan of Hainan Island. *Acta Phytoecologica et Geobotanica Sinica* 1(1-2) : 141.