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RESEARCH ARTICLE

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Division of ecological species groups and functional groups based on interspecific association – a case study of the tree layer in the tropical lowland rainforest of Jianfenling in Hainan Island, China

Abstract Twenty-three sample plots dominated by *Vatica mangachapoi* at various elevations in the tropical lowland rainforest in the Jianfengling National Nature Reserve of Hainan Island were established. The interspecific association among the 32 dominant species was analyzed and the division of ecological species groups and functional groups are discussed. The results showed that these dominant populations had an overall positive interspecific association. The species pairs with significant, positive association accounted for only about 10% of the total 496 species pairs. Most of the other species pairs showed weak association or non-association, i.e., the dominant populations investigated had relatively independent distributions. The 32 dominant species were divided into four ecological species groups and ten functional groups according to their interspecific association coefficients, based on a cluster analysis of the species. Recognition characteristics of the ten functional groups are proposed.

Keywords tropical lowland rainforest, interspecific association, ecological species group, functional group, Jianfengling in Hainan Island

1 Introduction

On the island of Hainan, the tropical lowland rainforest is also called the tropical evergreen monsoon rainforest (Jiang and Lu, 1991; Hu and Li, 1992). Its dominant species, *Vatica mangachapoi*, belongs to the Dipterocarpaceae family, the representative family in the forests of Southeast Asia. In the past, this species was distributed around the entire island (Guangdong Institute of Botany, 1975), but now it is largely restricted to the Jianfengling, Bawangling, Diaoluoshan, Mihouling and Wanning districts. *V. mangachapoi* is a second-class key protective tree of great economic value. It is not only one of the most favorite building materials in Hainan Island, but also an important industrial material. It has been used as a road or landscape virescent tree because of its dense canopy, evergreen leaves and tolerance to wind and adverse conditions (Zhou, 2001). Some research on the community, forest characteristics (Hu and Wang, 1988; Liang et al., 1994a, 1994b; Fu and Feng, 1995; Fang et al., 2004; Yang et al., 2005; Li et al., 2006), floristic region (Xing et al., 1993) and biological properties (Hu, 1986) of *V. mangachapoi* forests have been reported, but only a few of these dwelled on the interspecific association and the division of its community ecological species group. Most importantly, almost no papers have reported research on plant functional groups. Therefore, it is of great interest to analyze the interspecific association of the tropical lowland rainforest dominated by *V. mangachapoi* in Jianfengling on the island and to discuss the division of ecological species groups and functional groups.

2 Study area

Jianfengling is located in the southwest of Hainan Island, near Ledong and Dongfang cities (18°23′–18°50′N, 108°36′–109°05′E). The typical climate is a tropical island monsoon climate of low latitude, with distinctive dry and wet seasons. The average annual temperature is 24.5°C and the accumulated temperature is (>10°C) 9000°C.

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The lowest average monthly temperature is 19.4°C and the hottest is 27.3°C. The soil forming rock is a porphyaceous granite, with many pink feldspars and phenocrysts. The soil is a lateritic yellow soil. The island has clear climate, soil and vertical vegetation zonation. The zonal vegetation type is a tropical evergreen monsoon rainforest (Huang et al., 1986; Jiang and Lu, 1991; Zeng et al., 1997; Li et al., 2002, 2006).

Our study site was located in Sanfenqu of the Jianfengling National Nature Reserve, which is the core zone of the northwestern reserve at 250–850 m of elevation. The main vegetation type is a moist tropical lowland rainforest dominated by *Vatica mangachapoi* in the middle mountains at 300–700 m of elevation. Because of the increased elevation, rainfall is much higher than that of the tropical semi-deciduous monsoon rainforest at over 300 m of elevation; and the relative air humidity is also considerably increased. Although there is a transient dry season, the duration of this dry season is relatively short. The community is evergreen all year round, almost without any deciduous species (Huang et al., 1986; Hu and Li, 1992).

3 Methods

3.1 Sampling

Twenty-three typical sample plots were set up ranging from the tropical semi-deciduous monsoon rainforest to the tropical mountain rainforest along a 250–850 m elevation gradient, including the tropical evergreen monsoon rainforest in the middle of the range. Twenty-three plots of 20 m × 30 m were spaced at equal intervals in the structured area of good stands. The total area surveyed was 1.38 hm^2. All trees with a diameter at breast height (DBH) $\geqslant$ 12 cm were measured. The records include the name of the species, their DBH and tree height. Detailed information is presented in Table 1 (Li et al., 2006).

3.2 Interspecific association measurements

For the overall association test among the different species we adopted the variance ratio test based on species present vs. species not present (Schluter, 1984), i.e., given the expectation of the variance ratio $(V_R) = 1$ under the assumption of non-association, $V_R > 1$ when species show positive association and $V_R < 1$ when species show negative association. Species pairs are composed of species A and B on the basis of a 2 × 2 contingency table, where n is the total number of plots, a is the number of plots where species A and species B occur together, b is the number of plots where species A and species B do not occur together, c is the number of plots where only species A occurs and d is the number of plots where only species B occurs. The association coefficient (C_A), the percentage of co-occurrence (P_C), the point correlation coefficient (Φ), the Ochiai index (Q_i) and a χ^2 test are used to test the interspecific association (Greig-Smith, 1983; Pielou, 1988; Peng, 1996; Wang et al., 1996; Wang et al., 1997; Huang et al., 2000; Zhou et al., 2000; Luo et al., 2005).

1) The χ^2 test is conducted using the Yates continuity correction formula:

$$\chi^2 = n(|ad - bc| - n/2)^2 \Big/ [(a+b)(c+d)(a+c)(b+d)]$$

where n is the total number of plots. If $\chi^2 < 3.841$, the interspecific association is independent; if $\chi^2 \geqslant 6.635$, the interspecific association is highly significant and if $3.841 \leqslant \chi^2 < 6.635$, the interspecific association is significant. Because χ^2 cannot have a negative value, the following method is used to judge positive and negative association. The interspecific association is positive when $a > (a+b)(a+c)/n$ (or $ad > bc$). The association is negative if $a < (a+b)(a+c)/n$ (or $ad < bc$).

2) The association coefficient (C_A) is used to test the χ^2 result and show the degree of interspecific association. It is calculated as follows:

if $ad \geqslant bc$, then $C_A = (ad - bc)[(a+b)(b+d)]$;

if $bc > ad$ and $d \geqslant a$, then $C_A = (ad - bc)[(a+b)(a+c)]$;

Table 1 Background of 23 sample plots in *Vatica mangachapoi* forest

plot	number of trees	number of species	max. DBH/cm	mean DBH/cm	timber volume/m^3	plot	number of trees	number of species	max. DBH/cm	mean DBH/cm	timber volume/m^3
1	40	25	95.6	26.4	24.2	13	44	27	70.7	25.4	22.3
2	16	14	85.4	30.6	14.2	14	37	20	73.9	28.6	25.0
3	32	24	97.1	34.3	37.0	15	28	9	36.3	17.9	5.8
4	31	27	41.8	23.7	12.7	16	32	22	81.8	31.0	27.2
5	45	29	91.0	28.8	33.2	17	18	15	68.8	27.8	11.5
6	40	28	59.1	26.3	21.5	18	37	24	73.0	33.7	36.6
7	59	35	143.3	36.3	82.8	19	37	21	92.0	40.4	59.4
8	55	30	41.8	20.1	15.2	20	27	15	54.2	26.6	15.4
9	40	25	39.5	22.5	14.5	21	43	25	99.4	31.8	40.8
10	34	22	98.7	34.0	37.9	22	41	28	84.4	33.2	40.1
11	42	27	111.5	33.6	46.3	23	51	24	32.8	20.7	14.6
12	26	18	54.1	23.2	10.3	mean	37	23	75.1	28.6	28.2

if $bc > ad$ and $d < a$, then $C_A = (ad - bc)[(b+d)(c+d)]$.

The range of values of C_A is $[-1, 1]$. The stronger the positive interspecific association, the closer C_A is to 1; the stronger the negative interspecific association, the closer C_A is to -1 and species are fully independent when $C_A = 0$.

3) The percentage of co-occurrence (P_C) is used to measure the degree of positive association. It is calculated as:

$$P_C = a/(a+b+c)$$

The range of value of P_C is [0, 1]. The closer P_C is to 1, the stronger the positive interspecific association.

4) The point correlation coefficient (Φ) is used to show the degree of interspecific association. It is calculated as follows:

$$\Phi = (ad - bc)/\sqrt{(a+b)(a+c)(c+d)(b+d)}$$

The range of value of Φ is $[-1, 1]$.

5) The Ochiai index Q_i is calculated from the following formula:

$$Q_i = a/\left(\sqrt{a+b}\sqrt{a+c}\right)$$

$Q_i = 0$ when there is no association; $Q_i = 1$ when there is strong association.

3.3 Cluster analysis of the dominant populations

To further explore the ecological species groups and the division of functional groups, importance values of the dominant populations are used in a cluster analysis. The three importance values of a population considered in this study are the sum of relative density, its relative dominance and relative frequency (Cox, 1979). The sum of the importance values of all populations is 300. However, we have calculated a relative importance value.

3.4 Ecological species groups and division of functional groups

According to the interspecific association and cluster analysis among the dominant species, different ecological groups are divided and then the division of functional groups is discussed.

3.5 Data processing

All data are analyzed and mapped with Excel 2003 (Microsoft Corporation) and Statistica 6.0 (StatSoft Inc.) separately.

4 Results

4.1 Importance values of the dominant populations

There are abundant species and biodiversity is high in the tropical rainforest. To completely reflect the position and role of the major and dominant species in the community, the importance values of all dominant populations in the plots were calculated. These are then sorted and the 32 populations with importance value above 2.0 (relative importance value $\geqslant 0.6667$) were chosen for the analysis of interspecific association. The results are presented in Table 2.

4.2 Association of dominant populations

4.2.1 Overall interspecific association of dominant populations

According to Table 2, the overall interspecific association of the 32 dominant populations is calculated. The results show that the positive association is supported ($V_R = 1.632 > 1$). The significance statistics (W) is equal

Table 2 Importance values of the dominant populations

No.	species code	species	relative importance	No.	species code	species	relative importance
1	2	Vatica mangachapoi	5.6055	17	16	*Beilschmiedia wangii*	1.2377
2	9	*Litchi chinensis* var. *euspontanea*	2.7233	18	10	*Parapytenaria multisepaia*	1.1387
3	3	*Koilodepas hainanensis*	2.6509	19	23	*Sarcosperma laurinum*	1.0924
4	4	*Canarium album*	2.5430	20	17	*Syzygium buxifolium*	1.0905
5	5	*Amesiodendron chinensis*	2.3455	21	18	*Diospyros eriantha*	0.9564
6	1	*Gironniera subaequalis*	2.2659	22	30	*Dacrydium pierrei*	0.9408
7	13	*Cyclobanalopsis patelliformis*	2.1501	23	21	*Syzygium championii*	0.8677
8	11	*Pterospermum heterophyllum*	2.0424	24	29	*Dalbergia hainanensis*	0.8249
9	7	*Nephelium topengii*	1.8147	25	24	*Pentaphylax euryoides*	0.7928
10	26	*Ficus viries* var. *sublanceolata*	1.5665	26	12	*Cryptocarya chinensis*	0.7864
11	8	*Xanthophyllum hainanense*	1.5376	27	31	*Madhuca hainanensis*	0.7741
12	6	*Mallotus hookerianus*	1.4558	28	19	*Dillenia turbinata*	0.7671
13	14	*Aglaia dasyclada*	1.3639	29	28	*Baccaurea ramiflora*	0.7486
14	20	*Lithocarpus pseudovestitus*	1.3348	30	25	*Schima superba*	0.7334
15	32	*Castanopsis fissa*	1.2995	31	27	*Lithocarpus fenzelianus*	0.7207
16	22	*Alstonia rostrata*	1.2611	32	15	*Michelia balansae*	0.6859

to 37.5455, which is larger than $\chi^2_{0.05\ (23)} = 35.172$ and $\chi^2_{0.95\ (23)} = 13.091$. Therefore, the overall interspecific association of 32 populations is significant and there is a co-existence relationship among these major populations.

4.2.2 Association of major populations

As shown in Fig. 1, 496 species pairs comprise the 32 dominant populations. Forty-eight species pairs show strong positive association ($0.6 < C_A \leqslant 1$), accounting for 9.8% of the total species pairs; 101 pairs show weak positive association ($0.2 < C_A \leqslant 0.6$), accounting for 20.4%; 145 pairs show non-association ($-0.2 < C_A \leqslant 0.2$), accounting for 29.2%; 53 pairs show weak negative association ($-0.6 < C_A \leqslant -0.2$), accounting for 10.7%; and 149 pairs show strong negative association ($-1 < C_A \leqslant -0.6$), accounting for 30.0%. Therefore, the species pairs with positive association are 30.2% of the total.

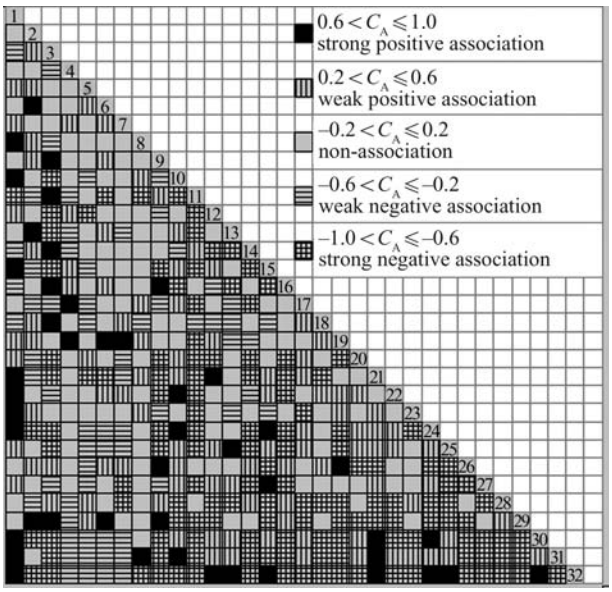

Fig. 1 Half matrix of the association coefficients (C_A) among the dominant populations. The detailed species names of codes 1–32 are listed in Table 2.

Because of the differences between the calculation formulas, the percentage of co-occurrence, P_C, is different from the association coefficient C_A. As shown in Fig. 2, species pairs with $P_C > 80\%$ show strong positive association. However, there is no strong positive association in the 496 species-pairs. Only two species pairs show a fairly strong positive association ($60\% < P_C \leqslant 80\%$), i.e., *Vatica mangachapoi* and *Mallotus hookerianus*, *Litchi chinensis* var. *euspontanea* and *Beilschmiedia wangii*. Thirty species pairs show a fairly weak positive association ($40\% < P_C \leqslant 60\%$), 137 species pairs show weak positive association ($20\% < P_C \leqslant 40\%$) and 327 species pairs show non-association ($0\% < P_C \leqslant 20\%$). Therefore, tropical forest species show weak association and have relatively independent distribution characteristics (Huang et al., 2000).

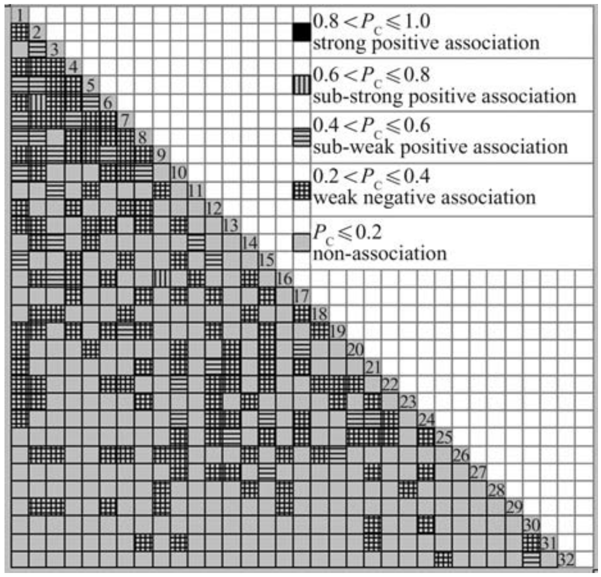

Fig. 2 Half matrix of the percentage co-occurrence (P_C) among the dominant populations. The detailed species names of codes 1–32 are listed in Table 2.

The classification standard of point correlation coefficient Φ is the same as C_A. As shown in Fig. 3, seven pairs show strong positive association ($\Phi > 0.6$), accounting for 1.41% of the total species pairs. One hundred and twenty-one pairs show weak positive association ($0.2 < \Phi \leqslant 0.6$), accounting for 24.4%. Two hundred and forty-two pairs show non-association ($-0.2 < \Phi \leqslant 0.2$), accounting for 48.79%. One hundred and twenty-six pairs show weak negative association ($-0.6 < \Phi \leqslant -0.2$), accounting for 25.4%. There are no strong negative association species pairs ($\Phi \leqslant -0.6$). The following are the species pairs with strong positive association: *Koilodepas hainanensis* and *Pterospermum heterophyllum*, *Koilodepas hainanensis* and *Aglaia dasyclada*, *Nephelium topengii* and *Dillenia turbinata*, *Litchi chinensis* var. *euspontanea* and *Beilschmiedia wangii*, *Cryptocarya chinensis* and *Syzygium championii*, *Michelia balansae* and *Pentaphylax euryoides*, *Dacrydium pierrei* and *Castanopsis fissa*.

The classification standard of the Ochiai index Q_i is the same as for P_C. As shown in Fig. 4, there are no species pairs with strong negative association. Only 31 species pairs show fairly strong association, accounting for 6.25% of the total species pairs. One hundred and twenty-six pairs show fairly weak association, accounting for 21.37%. One hundred and fifty-five pairs show weak association, accounting for 31.25% and 204 pairs show non-association, accounting for 41.13%. Therefore, the tropical forest populations show weak association and are distributed in a relatively independent way (Huang et al., 2000).

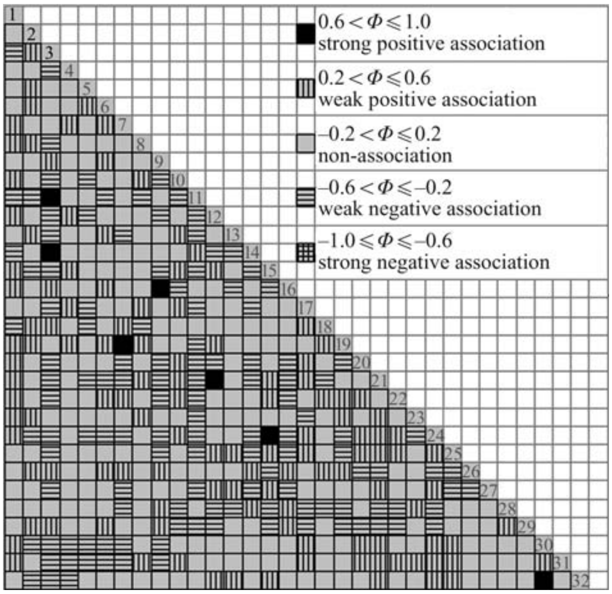

Fig. 3 Half matrix of the point correlation coefficients (Φ) among the dominant populations. The detailed species names of codes 1–32 are listed in Table 2.

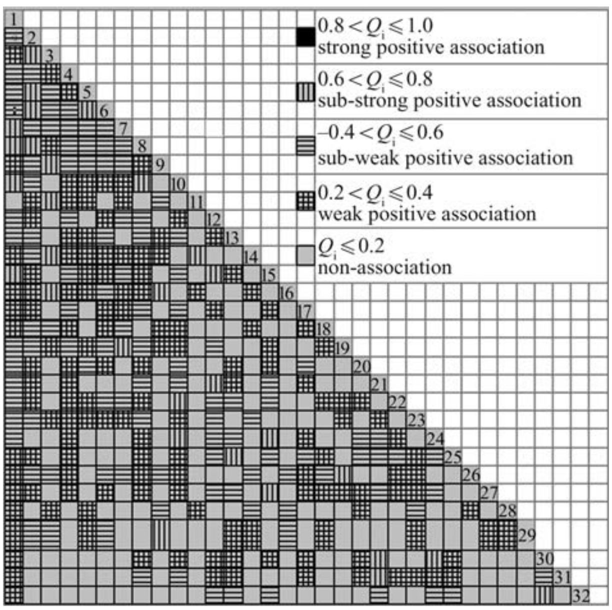

Fig. 4 Half matrix of the Ochai index (Q_i) among the dominant populations. The detailed species names of codes 1–32 are listed in Table 2.

When $p > 0.05$ ($\chi^2 < 3.841$), species pairs have no association and are distributed independently; when $p < 0.01$ ($\chi^2 > 6.635$), species pairs have a highly significant association; when $0.01 \leqslant p \leqslant 0.05$ ($3.841 \leqslant \chi^2 \leqslant 6.635$), species pairs have significant association. Positive and negative association depends on whether species A and species B appears or not (Deng et al., 2003). As shown in Fig. 5, two species pairs show extra significant association ($\chi^2 > 6.635$): *Litchi chinensis* var. *euspontane* and *Beilschmiedia wangii*, *Nephelium topengii* and *Dillenia turbinata*. Thirteen species pairs show significant association: *Gironniera subaequalis* and *Parapytenaria multisepaia*, *Vatica mangachapoi* and *Mallotus hookerianus*, *Koilodepas hainanensis* and *Litchi chinensis* var. *euspontanea*, *Koilodepas hainanensis* and *Pterospermum heterophyllum*, *Koilodepas hainanensis* and *Aglaia dasyclada*, *Koilodepas hainanensis* and *Beilschmiedia wangii*, *Parapytenaria multisepaia* and *Alstonia rostrata*, *Parapytenaria multisepaia* and *Pentaphylax euryoides*, *Pterospermum heterophyllum* and *Aglaia dasyclada*, *Cryptocarya chinensis* and *Michelia balansae*, *Cryptocarya chinensis* and *Syzygium championii*, *Michelia balansae* and *Pentaphylax euryoides*, *Dillenia turbinata* and *Ficus viries* var. *sublanceolata*. Although *Gironniera subaequalis* and *Pterospermum heterophyllum*, *Koilodepas hainanensis* and *Michelia balansae* show significant association, they are negatively associated. Considering the biological properties of these four species, *Gironniera subaequalis* and *Pterospermum heterophyllum* grow at high elevations, while *Koilodepas hainanensis* and *Michelia balansae* are found at low elevations and are quite tolerant to heat.

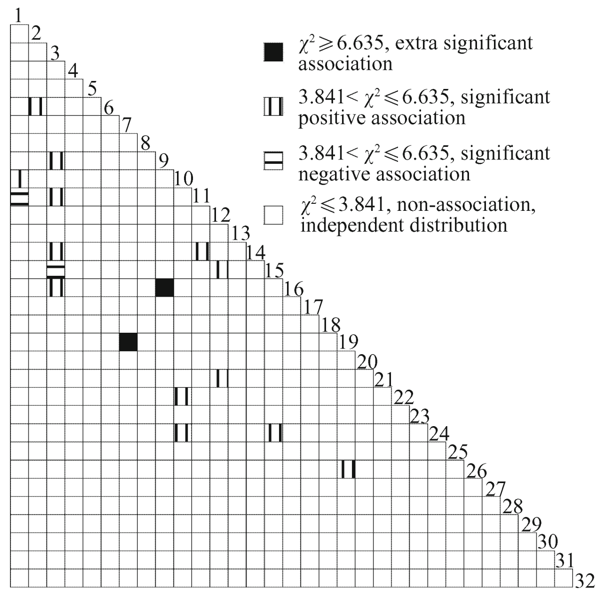

Fig. 5 Half matrix of inter-specific association χ^2 tests among the dominant populations. The detailed species names of codes 1–32 are listed in Table 2.

4.3 Cluster analysis of the dominant populations and the division of ecological species groups

For a better understanding of the environmental adaptability and the degree of similarity of these 32 populations, their population importance values are calculated by cluster analysis.

The cluster analysis results show that the 32 species are divided into four groups (Fig. 6). *Vatica mangachapoi*, the major species in the tropical lowland rainforest, is an independent population and is classified as its own group. It grows at an elevation from 300 to 750 m on western exposed slopes in Jianfengling (Li et al., 2006) (however, on eastern exposed slopes, its lowest elevation is 100 m). It also can grow in different habitats and regenerate better (Guangdong Institute of Botany, 1975). Therefore, it can be called the "ecological key species group" and the "dominant species group" in the tropical lowland rainforest in Jianfengling.

Group I includes nine species: *Litchi chinensis* var. *euspontanea*, *Amesiodendron chinensis*, *Aglaia dasyclada*, *Sarcosperma laurinum*, *Dalbergia hainanensis*, *Baccaurea ramiflora*, *Beilschmiedia wangii*, *Koilodepas hainanensis* and *Pterospermum heterophyllum*. They are thermophilic and secondary species in the tropical lowland rainforest (Huang et al., 1986; Li et al., 2006), but their distribution range is not as wide as that of *Vatica mangachapoi*. They are often present only as single trees when they grow in a suitable habitat and play different roles in different community layers. Therefore, they can be called a "characteristic species group".

Group II also includes nine species: *Canarium album*, *Nephelium topengii*, *Mallotus hookerianus*, *Dillenia turbinata*, *Diospyros eriantha*, *Gironniera subaequalis*, *Xanthophyllum hainanense*, *Cyclobanalopsis patelliformis* and *Ficus viries* var. *sublanceolata*. These species play a major role in the tropical mountain rainforest, because they grow widely and many of them are in the middle or lower layers in the community. Therefore, they can be called a "mutual populations group".

Group III includes 12 species: *Lithocarpus pseudovestitus*, *Alstonia rostrata*, *Parapytenaria multisepaia*, *Castanopsis fissa*, *Syzygium championii*, *Schima superba*, *Pentaphylax euryoides*, *Michelia balansae*, *Lithocarpus fenzelianus*, *Syzygium buxifolium*, *Dacrydium pierrei* and *Madhuca hainanensis*. They are typical associate species in the tropical mountain rainforest (Huang et al., 1986; Li, 1997; Zeng et al., 1997; Li et al., 2002). They grow at high elevation, i.e., above 650 m. For the lowland rainforest, these species can be referred to as a "marginal species group".

The "ecological key species group", the "characteristic species group", the "mutual populations group" and the "marginal species group" division are basically similar to the association analysis presented earlier.

4.4 Division of the species functional groups

Functional groups emphasize the role of species in ecological processes and functions. Based on the analysis and identification of the ecological species groups, the species with similar ecological processes and functions can be classified into one functional group. As shown above, *Vatica mangachapoi* with a high importance value is the dominant species in the tropical lowland rainforest in Jianfengling, which can also be called ecological key species. Other species are divided on the basis of the ecological species groups and then according to the interspecific association, elevation, micro-terrain condition, dominance in the communities and biological properties (such as position in the vertical profile and thermophilic degree). The 32 dominant species are divided into four ecological species groups and ten functional groups (Table 3).

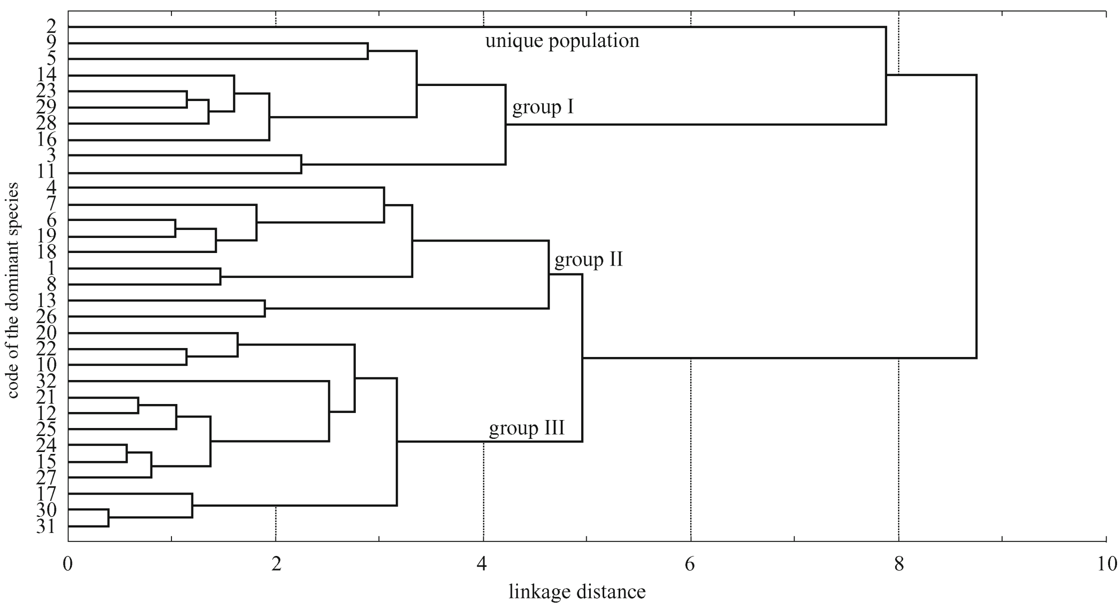

Fig. 6 Dendrogram of cluster analysis for 32 species (using Ward's method and City-block (Manhattan) distance, see Table 2 for detailed species names of codes, 1–32)

The identification of ecological species and functional groups is as follows: 1) the ecological key species group-dominant species, which dominate the distribution area with normal population structure and exist in all canopy layers; 2) the characteristic species group-sub-dominant species, which are upper layer trees and subdominant in the distribution area, although their sub-dominance varies under different terrain conditions; 3) the characteristic species group-associate species, which are not among the largest individuals but for some species their numbers give them dominance; they can be found in all forest layers, especially in the middle and lower layers; 4) the characteristic species group-thermophilic species, which grow in the gaps or edges of the lowland rainforest; 5) the mutual species group-tall species, of which there are only a few individual trees but have large diameters at breast height, protrude from the canopy and have a great impact on the structure and function of the community; 6) the mutual species group-sub-dominant species, with a wide range in elevation, consisting of large single trees, which grow in the middle or upper layers; 7) the mutual species group-associate species, with a wide range in elevation of small trees distributed in the middle and lower layers, with some occurring in large numbers; 8) the edge species group-associate species, small populations of large trees at elevations above 600 m, distributed in the middle and upper layers; 9) the edge species group-special species, distributed on ridges and hilltops at elevations over 700 m; 10) the edge species group-regeneration species, distributed in forest gaps at elevations over 500 m.

5 Discussion

5.1 Interspecific association among dominant populations

The overall positive association of the 32 populations reflects that the community is very stable. Generally speaking, this stability is enhanced with the progressive succession of the community. It not only reflects the stability of the community structure, but also the stability of the species composition. The closer the community to the succession climax, the stronger its stability (Wang et al., 1996; Deng et al., 2003). Therefore, the *Vatica mangachapoi* forest has a strong original nature in its core area of the Jianfengling Nature Reserve. Its composition and structure is rather stable and the community is in the later succession or the dynamic balance stage.

Overall, major species show a positive association in the *Vatica mangachapoi* forest. However, the interspecific association is not necessarily positive, while weak association, non-association or negative association may often occur. Because of the high biodiversity index of tropical forest in Hainan Island (Li, 1995; Li et al., 2002), the probability of a particular species encountering another one in a complex forest community is very small. These conclusions have been verified in the research of interspecific association in tropical forests (Wang et al., 1997; Huang et al., 2000; Dai et al., 2003; Luo et al., 2005). They show that populations in tropical forest have relatively independent distribution characteristics, which is supported by this research. The proportion of the species pairs with positive association (or strong association) is small, which show that the forest we investigated has a mature ecological system, because species pairs show non-association in this progressive succession.

Among the species pairs with positive association encountered in our research, the dominant species *Vatica mangachapoi* has some association with only a few species, such as *Dalbergia hainanensis*, *Koilodepas hainanensis*, *Mallotus hookerianus*, *Amesiodendron chinensis* and *Cyclobanalopsis patelliformis*. A widely distributed species, *Gironniera subaequalis*, has strong association with *Xanthophyllum hainanense*, *Parapytenaria multisepaia*, *Michelia balansae*, *Syzygium championii*, *Alstonia rostrata*, *Sarcosperma laurinum*, *Pentaphylax euryoides*, *Dacrydium pierrei* and *Madhuca hainanensis*. *Koilodepas hainanensis* has close relationships with *Litchi chinensis* var. *euspontanea*, *Pterospermum heterophyllum*, *Aglaia dasyclada*, *Beilschmiedia wangii*, *Ficus viries* var. *sublanceolata* and *Dalbergia hainanensis*. *Amesiodendron chinensis* has a strong association with *Mallotus hookerianus*. It should be pointed out that if species A is strongly

Table 3 Functional groups division and recognition characteristics in tropical lowland rainforests in Jianfengling

ecological species groups	functional groups	representative species code*
ecological key species group	dominant species	1
characteristic species group	sub-dominant species	2, 5
	accompanying species	3, 13, 17, 19
	thermophilic species	8, 24, 29
mutual species group	tall species	7, 10
	sub-dominant species	4, 6, 11, 28
	accompanying species	9, 12, 21
marginal species group	accompanying species	14, 16, 18, 20, 23, 26, 30, 31, 32
	special species	22, 25, 27
	regeneration species	15

Note: * The detailed species names of codes 1–32 are listed in Table 2.

associated with species B, species B is not necessarily associated with species A. This conclusion is similar to that of the ecological niche research by Li (1993).

5.2 Ecological species groups and the division of functional groups

Because the level of the association coefficient reflects the basic requirements of a species for environmental resources and the structure and composition of the ecosystem, interspecific association indices can be regarded as one of the sources of important evidence for the division of ecological species groups. Given the cluster analysis of the 32 species, four ecological species groups were identified: 1) *Vatica mangachapoi*, ecological key species in the tropical lowland rainforest; 2) nine representative species in the lowland rainforests; 3) nine mutual species in the tropical lowland rainforest and mountain rainforest and 4) 12 marginal species only at the ecotone of the lowland rainforest and mountain rainforest.

Based on the characteristics of their composition (i.e., interspecific association and cluster analysis), their distribution, and biological characteristics, ten functional groups have been classified (Guangdong Institute of Botany, 1975; Zhou, 2001). At present, it is obviously difficult to divide the functional groups according to their practical conditions in the tropical rainforest given its high biodiversity and inconspicuous dominant species. Many other quantitative indices (forest microclimate, ecophysiological characteristics) should be introduced. We have divided the functional groups only according to the information from tropical lowland rainforests. The results will be different if tropical mountain rainforest data were used and different species compositions and biological characteristics were considered.

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