

# Species composition and correlation of understory woody plants in Chinese fir plantation in the lower subtropical area

KANG Bing<sup>1,2</sup>, LIU Shirong (✉)<sup>2</sup>, CAI Daoxiong<sup>3</sup>, WEN Yuanguang<sup>4</sup>

1. College of Life Sciences, Northwest Sci-Tech University of Agriculture and Forestry, Yangling 712100, China

2. Institute of Forest Ecology, Environment and Protection, the Chinese Academy of Forestry, Beijing 100091, China

3. Experiment Center of Tropical Forestry, the Chinese Academy of Forestry, Pingxiang 532600, China

4. Forestry College, Guangxi University, Nanning 530001, China

© Higher Education Press and Springer-Verlag 2006

**Abstract** There are 71 species in the shrub layer of the *Cunninghamia lanceolata* plantation after natural succession. The species richness and diversity have increased with slight anthropogenic disturbance. The status and function of understory woody species were judged by the analysis of the important value (*IV*).  $\chi^2$  statistics and *r* test were used for testing the significance of interspecific association and correlation among 25 main understory woody plants selected from the woody population. The results clearly showed their interspecific relationships and their differences in resource utilization. Species-pairs of positive association were in the majority. Most species were accommodated in the shady habitat. There was a positive correlation between the *IV* of the species and the interspecific association. The higher the *IV* of the species, the closer and more significant was the interspecific association. Based on analytical results of interspecific association and correlation, 25 woody plants in the shrub layer could be divided into four ecological species groups: I. *Ficus hispida* + *Antidesma bunius* + *Mallotus barbatus* + *Ficus cunia* + *Saurauia tristyla* + *Mallotus philippinensis* + *Maesa japonica* + *Ficus hirta* + *Alchornea rugosa* + *Ficus fulva* + *Mallotus apelta*; II. *Cudrania tricuspidata* + *Schefflera octophylla*; III. *Cunninghamia lanceolata* + *Clerodendron cytophyllum* + *Milletia semicastrata* + *Randia spinosa* + *Litsea cubeba* + *Litsea pungens*; IV. *Ardisia japonica* + *Psychotria rubra* + *Vitex quinata* + *Cephalanthus occidentalis* + *Pithecellobium lucidum* + *Mycetia sinensis*. If species group III or II is the advantaged species in the shrub layer, the community would change from a coniferous forest to a sparse evergreen broad-leaved forest. For group IV, the community would be relatively stable. For group I, the

coniferous forest would be mixed with coniferous-broad leaved forest. The classification of ecological species groups would provide a theoretical basis on judging its ecological function, adjusting the stand structure of the plantation and directing the suitable natural vegetation type through the close-natural restoration process.

**Keywords** the lower subtropical area, *Cunninghamia lanceolata*, man-made forest, close-natural state, understory shrub composition, interspecific association and correlation, ecological species groups

## 1 Introduction

*Cunninghamia lanceolata* is the main timber tree in the low subtropical area in China. The forest structure is very simple for the aim of traditional management of the pure forest. With disadvantaging factors, such as over-cutting and replanting over several generations, the negative effects (decreased ecological qualities, worse stabilities, degraded soil fertilities, and shorted productivities etc.) dictate that the recovery of the single forest must be put in practice as soon as possible. The understory shrub that can make the forest stand multiplex with the natural succession plays an important role in keeping up the micro-environmental factors, such as land nutrient and water, and community stabilities (Liu et al., 1995, 1998; Yu et al., 1999). The main woody vegetation has intensive adaptabilities, and some of them have better timber quality. Interspecific association and correlation are important quantitative and structural characteristics in a community. They can significantly serve as a guide in knowing community structure, function, and classification as one scale of comparability between two species; furthermore, they can give information for forest management, natural restoration, and biodiversity conservation

Translated from *Acta Ecologica Sinica*, 2005, 25(9): 2173–2179 [译自: 生态学报, 2005, 25(9): 2173–2179]

E-mail: liusr@forestry.ac.cn

(Wang, 1987; Guo et al., 1997; Liu et al., 1998; Ludwig and Reynolds, 1991; Zhang, 1998; Sun and Zhao, 1996; Li, 1999). This work, using the interspecific association and correlation measurements in 13-year-old Chinese fir forests, is to supply academic proof on the collocation vegetation and adjustment relationship among species during the close-natural vegetation restoration.

## 2 Study area and methods

### 2.1 Study area

The study area (106°39'–106°59'E, 21°57'–22°19'N) is located on the south-eastern border in the Guangxi Zhuang Autonomous Region, China. This region belongs to the south-eastern edge of the sub-tropical monsoon climate area. It is adjacent to the north tropical zone in the humid and semi-humid area. Resources such as sunlight, heat, and water are abundant. The annual air temperature mean is 20.5°C–21.7°C, extreme high temperature is 40.3°C, extreme low temperature is –1.5°C. The active accumulated temperature ( $\geq 10^\circ\text{C}$ ) is 6 000–7 600. The average annual rainfall is 1 200–1 500 mm, annual evapotranspiration 1 261–1 388 mm. The relative humidity is 80%–84%. The main geomorphic types are lower mountains and hills. The zonal soil type is latosol.

We selected the Chinese fir plantation in 1993 with slight human disturbance. The mean height was 10.9 m, 12.9 cm in mean diameter at breast height (DBH), and the forest density was 2 867 plant individuals / hm<sup>2</sup>.

### 2.2 Methods

#### 2.2.1 Plot establishment and data investigation

We selected three plot areas according to the slope position (upside, middle part, and underside) in the 13-year-old *Cunninghamia lanceolata* forest; furthermore, four permanent quadrants with a size of 20 m × 30 m were established in every plot area. Five contiguous shrub subplots with a size of 5 m × 5 m in one quadrant were located along the middle of the two diagonals. The shrub species and their number, height, coverage, etc. were surveyed.

#### 2.2.2 Calculation of the important value (IV)

The value of IV is equal to the sum of the relative frequency (%), relative density (%), and relative coverage (%); the range of IV is 0–300.

### 2.2.3 Interspecific association and correlation measurement

#### 2.2.3.1 Interspecific association

Firstly, we translated the original matrix as  $S \times N$  ( $S$ : species number;  $N$ : plots number) into duality matrix as  $0, 1$  type. Afterwards, we established a  $2 \times 2$  interspecific couplet list respectively and carried out the statistic values of  $a, b, c, d$ .  $a$  was the plots number wherein species A and B exist,  $b$  the plots number wherein only species B exists,  $c$  only species A exists,  $d$  neither the A nor B exist, and  $n$  is the total plots number. Because of the discontinuous sampling, discrete data  $x^2$  were estimated according to the following continuous revised equation (Ludwig and Reynolds, 1991; Zhang, 1997; Zhang et al., 2003)

$$x^2 = \frac{[(ad - bc) - 0.5n]^2 \times n}{[(a+b)(b+d)(c+d)(a+c)]}$$

If  $ad - bc > 0$ , the interspecific association was positive; If  $ad - bc < 0$ , the association was negative. We could compare the value of  $P_{0.05}$  and  $P_{0.01}$  in the  $x^2$  table as  $n = 1$ , according to the association degree to get the result of the significance test for the association.

#### 2.2.3.2 Interspecific correlation

We calculated the interspecific correlation relying on the following formula and checked the significant degree using the correlation coefficient table.

$$r = \frac{\sum (x_i - x)(y_i - y)}{\sqrt{\sum (x_i - x)^2 \sum (y_i - y)^2}}$$

Where  $x_i, y_i$  were two species quantity, respectively,  $x, y$  their mean values,  $n$  the plots number. Here, we used IV as a fixed quantity (Zhang et al., 2003).

## 3 Results

### 3.1 Shrub species composition and structure analysis

The IV of natural regenerative shrub species was recorded and analyzed (Table 1). Total species were 71 in the shrub layer (Table 1). IV of *Ficus hispida* was the highest. In the next place, the important values of *Cudrania tricuspidata*, *Mallotus apelta*, and *Millettia semicastrata* were 72.43, 64.09, and 62.47, respectively, indicating that understory plants were dominated by these species in the local area. The species (important values  $> 40$ ) were *Mussaenda pubescens*, *Periploca forrestii*, *Alangium Chinese*, and *Broussonetia Kazinoki*, which distributed evenness. Species with IV ranging from 30 to 40 were *Pueraria thunbergiana*, *Mallotus barbatus*, *Ficus cunia*, *Saurauia tristyl*, *Ficus hirta*, *Lygodium japonicum*, etc. Species with IV from 20 to 30 were *Tetrasigma planicaule*, *Tetrasigma planicaule*, *Dioscorea batatas*, *Cunninghamia lanceolata*, *Evodia leptia*, *Alchornea trewioides*, etc. The natural regenerating Chinese

fir could not be the dominant understory species. Species with an important value less than 10 were *Viburnum dilatatum*, *Cayratia japonica*, *Rubus palmat*, etc. and they were the rare species (Table 1).

**Table1** The shrubbery composition and important value in *Cunninghamia lanceolata*

Code	Species	Relative frequency /%	Relative density /%	Relative Coverage /%	Important value
1	<i>Ficus hispida</i>	1.23	83.24	15.96	100.43
2	<i>Cudrania tricuspidata</i>	0.49	19.44	52.50	72.43
3	<i>Mallotus apelta</i>	0.25	38.84	25.00	64.09
4	<i>Millettia semicastrata</i>	0.25	40	22.22	62.47
5	<i>Mussaenda pubescens</i>	9.87	25.78	13.84	49.49
6	<i>Antidesma bunius</i>	3.95	16.81	27.55	48.31
7	<i>Periploca forrestii</i>	0.25	6.25	40.00	46.50
8	<i>Alangium chinese</i>	0.74	15.55	30.00	46.29
9	<i>Pueraria thunbergiana</i>	1.48	16.79	21.49	39.76
10	<i>Mallotus barbatus</i>	0.25	18.18	20.00	38.43
11	<i>Ficus cunia</i>	1.73	26.04	9.38	37.15
12	<i>Saurauia tristyla</i>	0.25	11.71	22.72	34.68
13	<i>Ficus hirta</i>	0.08	21.35	12.00	33.43
14	<i>Lygodium japonicum</i>	1.97	10.5	18.08	30.55
15	<i>Musa balbisiana</i>	0.99	5.97	23.23	30.19
16	<i>Tetrasigma planicaule</i>	0.49	9.62	18.81	28.92
17	<i>Ipomoea hederaceae</i>	0.49	10.84	16.77	28.10
18	<i>Dioscorea batatas</i>	4.93	11.79	10.23	26.95
19	<i>Cunninghamia lanceolata</i>	4.19	8.43	9.47	22.09
20	<i>Evodia leptota</i>	2.47	8.58	9.76	20.81
21	<i>Alchornea rugosa</i>	0.25	20	0.20	20.45
22	<i>Schefflera octophylla</i>	0.25	3.03	16.13	19.41
23	<i>Clerodendron cytophyllum</i>	2.96	9.38	6.52	18.86
24	<i>Lonicera japonica</i>	0.49	16.72	1.47	18.69
25	<i>Cephalanthus occidentalis</i>	0.25	10	8.30	18.55
26	<i>Maesa japonica</i>	3.70	6.02	7.28	17.00
27	<i>Dioscorea bulbifera</i>	2.22	14.24	0.20	16.66
28	<i>Ardisia japonica</i>	0.25	15.79	0.20	16.24
29	<i>Ficus fulva</i>	1.48	5.22	9.03	15.73
30	<i>Randia spinosa</i>	0.25	5.26	10.00	15.51
31	<i>Desmodium szechuenense</i>	0.25	14.28	0.20	14.73
32	<i>Calystegia sepium</i>	0.25	14.28	0.20	14.73
33	<i>Psychotria rubra</i>	1.23	7.57	5.76	14.56
34	<i>Zanthoxylum avicennae</i>	1.97	6.16	4.89	13.02
35	<i>Litsea cubeba</i>	0.25	12.5	0.20	12.95
36	<i>Secamone sinica</i>	0.25	12.5	0.20	12.95
37	<i>Maoutia puya</i>	0.74	7.31	4.34	12.39
38	<i>Stauntonia chinensis</i>	0.49	11.47	0.20	12.16
39	<i>Mallotus philippinensis</i>	0.25	9.82	1.54	11.61
40	<i>Litsea pungens</i>	0.74	5.97	4.87	11.58
41	<i>Pithecellobium lucidum</i>	1.48	4.56	5.44	11.48
42	<i>Mycetia sinensis</i>	0.99	9.29	1.15	11.42
43	<i>Vitex quinata</i>	0.49	2.47	7.36	10.32
44	<i>Eurya nitida korthuls</i>	0.49	4.69	5.09	10.27
45	<i>Viburnum dilatatum</i>	0.25	3.24	6.00	9.49
46	<i>Cayratia japonica</i>	5.67	3.33	0.20	9.20

(continued)

Code	Species	Relative frequency /%	Relative density /%	Relative Coverage /%	Important value
47	<i>Melastoma candidum</i>	0.25	4.35	4.00	8.60
48	<i>Itea chinensis</i>	0.25	4.35	3.70	8.30
49	<i>Glochidion eriocarpum</i>	1.23	3.49	3.50	8.22
50	<i>Piper mutabile</i>	0.49	3.49	4.22	8.20
51	<i>Rubus palmatus</i>	1.97	3.72	2.45	8.14
52	<i>Hosiea sinensis</i>	0.25	6.25	1.41	7.91
53	<i>Osmanthus marginatus</i>	0.49	1.96	5.39	7.84
54	<i>Bischofia trifoliata</i>	0.25	2.56	4.72	7.53
55	<i>Breynia fruticosa</i>	0.25	6.67	0.20	7.12
56	<i>Hypoestes purpurea</i>	0.25	6.67	0.20	7.12
57	<i>Cocculus sarmentosus</i>	0.25	3.13	3.13	6.51
58	<i>Pericampylus glaucus</i>	0.99	5.26	0.20	6.45
59	<i>Oldenlandia auricularia</i>	1.48	3.6	0.42	5.50
60	<i>Melastoma candidum</i>	0.25	1.47	3.45	5.17
61	<i>Callicarpa rubella</i>	0.25	1.47	3.45	5.17
62	<i>Machilus velutina</i>	0.49	3.13	1.54	5.17
63	<i>Gynostemma pentaphyllum</i>	0.25	3.13	1.54	4.92
64	<i>Aralia chinensis</i>	0.25	3.13	1.54	4.92
65	<i>Ardisia japonica</i>	0.25	4.35	0.20	4.80
66	<i>Melothria heterophylla</i>	0.25	4.34	0.20	4.79
67	<i>Delonix regia</i>	0.25	4.16	0.20	4.61
68	<i>Millettia reticulata</i>	0.25	1.47	1.47	3.19
69	<i>Tylophora renchangii</i>	0.25	2.56	0.20	3.01
70	<i>Aporosa chinensis</i>	0.25	1.00	0.20	1.45
71	<i>Elaeocarpus sylvestris</i>	0.25	0.65	0.20	1.10

### 3.2 Interspecific association and correlation analysis of main woody shrub species

#### 3.2.1 Total interspecific association and correlation

We considered the important value of the main species in the shrub layer and were referenced according to their growth and economical features. On the other hand, because of the evergreen broad-leaved trees being the zonal climax species (Li et al., 2002), these species played a prominent role in the vegetation close-natural restoration. Hence, we selected 25 tree plants after taking out some vine and small actors for interspecific association and correlation analysis. Results are shown in the  $\chi^2$  and  $r$  half-matrix-diagram (Fig. 1). Statistics results of  $\chi^2$  association and  $r$  correlation are indicated in Table 1 and Table 2.

Species-pairs having positive association and correlation were more than the negative or no association. Despite the results between  $\chi^2$  and  $r$  statistics being various in quantities, the collective rules were in agreement. The significance of  $r$  statistics decreased evidently as compared with that of  $\chi^2$  statistics because the  $r$  test is according to the quantity index of the practice and had higher precision, while  $\chi^2$  mainly referred to the frequency of two species between species-pairs and depended on species existent or inexistent

duality data.  $r$  test made up the  $\chi^2$  statistics efficiently.

$\chi^2$  statistic indicated that the positive, negative, no association occupied 87.0%, 6.3%, and 6.7% of 300 species-pairs, respectively. The positive association was the majority and had much significance, while negative association did not show significance. It could show that most woody understory species were in the shady and humid environments, indicating that these species tended to utilize environmental resources homogenously. Species with high important value, such as *Ficus hispida*, *Millettia semicastrata*, *Cudrania tricuspidata*, *Mallotus apelta*, *Antidesma bunius*, *Mallotus barbatus*, etc., showed that these species utilized the resources sufficiently and became the advantaged populations. Species with middle important value as *Schefflera octophylla*, *Litsea cubeba*, *Ardisia japonica*, *Ficus fulva*, *Randia spinosa*, etc., had no significant association with other species. These species were not suitable to the shady habitat and were distributed widely under the forest, some of which were xerophil and heliophytes, such as *Randia spinosa*, *Litsea cubeba*, etc. Species with lower important value, as *Mycetia sinensis*, *Pithecellobium lucidum*, adapted to the humid habitat. They had positive association with each other (Table 2). Chinese fir in the under forest having positive association with the other species (except *Antidesma bunius*) validated that most understory populations had adaptabilities in the environment of

the Chinese fir community.

*r* statistics showed that species-pairs being positive, negative, and no association took up 73.7%, 12.3%, and 14.0% of 300 species-pairs, respectively (Table 3). In contrast with  $\chi^2$  statistical analytical results, species-pairs having positive correlation decreased slightly, while increasing a little in significance for positive, negative, and no correlation. *r* statistics approached the real state on account of the amount of test. *Cephalanthus occidentalis*-*Randia spinosa* and *Clerodendron cytophyllum*-*Mallotus barbatus* had no association in the  $\chi^2$ , yet being negative correlation in the *r* test. *Cephalanthus occidentalis* was in the shady habitat, and *Randia spinosa* was in the weald. Various living conditions showed significant positive correlation between the two species. Despite *Clerodendron cytophyllum* and *Mallotus barbatus* having photosynthetic characteristics, there were no different significant positive associations for the various degrees of photosynthetic characteristics. Species-pairs, such as *Cudrania tricuspidata*-*Mallotus barbatus*, *Psychotria rubra*-*Litsea pungens*, *Clerodendron cytophyllum*-*Cephalanthus occidentalis*, *Mycetia sinensis*-*Mallotus philippinensis*,

*Ardisia japonica*-*Clerodendron cytophyllum*, *Clerodendron cytophyllum*-*Schefflera octophylla*, etc., had a positive association in the  $\chi^2$  statistic, while having a negative correlation in the *r* test. One of species-pairs was different in distribution at the actual environment. Really, it should be negative association for *Mallotus barbatus* and *Cudrania tricuspidata*, *Mallotus barbatus* acclimated the humid habitats, *Cudrania tricuspidata* adapted to dry environment, the chance of having a negative association between the two species became more intensive (Table 3).

3.2.2 Ecological species groups

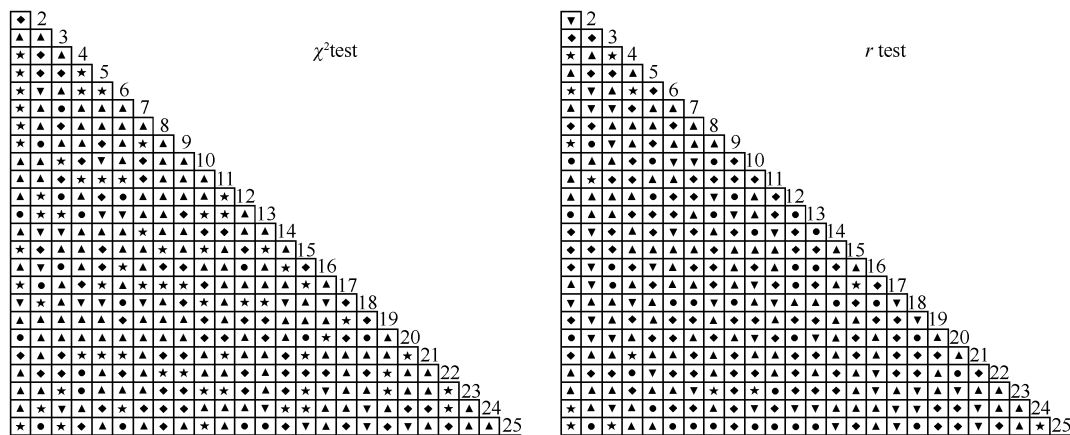
Species having similar ecology habits could associate with one ecology species group (Muller and Ellenberg, 1986). Understory shrub in subtropical Chinese fir could not go all the way in ecological habits. Interspecific association and correlation could show various species mutuality of spatial distribution embodying the effects of the microenvironment (Yang and Li, 1994).

**Table 2** The statistics of  $\chi^2$  association analysis of 25 main woody plants in shrub layer

Species-pairs being significant association		Species-pairs being no significant association		Species-pairs being no association
Positive	Negative	Positive	Negative	
198	0	63	19	20

**Table 3** The statistics of *r* correlation analysis of 25 main woody plants in shrub layer

Species-pairs being significant correlation		Species-pairs being no significant correlation		Species-pairs being no correlation
Positive	Negative	Positive	Negative	
120	0	101	37	42



Positive association ★:  $P \leq 0.01$  (most significant); ▲:  $0.01 < P \leq 0.05$  (significant); ◆:  $0.05 < P$  (no significant);  
 Negative association ●:  $0.05 < P$  (no significant) ; ▼ no association (Zhang and Jiao, 2003; Sun and Zhao, 1996; Li, 1999);  
 Code 1: *Ficus hispida*; 2: *Cudrania tricuspidata*; 3: *Millettia semicastrata*; 4: *Mallotus apelta*; 5: *Antidesma bunius*; 6: *Mallotus barbatus*; 7: *Ficus cunia*; 8: *Saurauia tristyla*; 9: *Ficus hirta*; 10: *Cunninghamia lanceolata*; 11: *Alchornea rugosa*; 12: *Schefflera octophylla*; 13: *Clerodendron cytophyllum*; 14: *Cephalanthus occidentalis*; 15: *Maesa japonica*; 16: *Ardisia japonica*; 17: *Ficus fulva*; 18: *Randia spinosa*; 19: *Litsea cubeba*; 20: *Psychotria rubra*; 21: *Mallotus philippinensis*; 22: *Litsea pungens*; 23: *Pithecellobium lucidum*; 24: *Mycetia sinensis*; 25: *Vitex quinata*. Species in Fig. 1 was the same as in Table 1.

**Fig. 1** Half-matrix-diagram of interspecific association test of 25 main woody plants in shrub layer

According to the interspecific relations and appetency, understory main woody populations using the results of interspecific association and correlation, 25 woody plants in shrub layer could be divided into four ecological species groups: I. *Ficus hispida* + *Antidesma bunius* + *Mallotus barbatus* + *Ficus cunia* + *Saurauia tristyla* + *Mallotus philippinensis* + *Maesa japonica* + *Ficus hirta* + *Alchornea rugosa* + *Ficus fulva* + *Mallotus apelta*. These species were the constructive species in the community. They had high  $\chi^2$ ,  $r$  values, and had positive association with most species. They had extended ecological range, and needed sufficient quantity of heat and a lot of quantity of light. II. *Cudrania tricuspidata* + *Schefflera octophylla*. They endure aridity and barren land, they are suitable to varied habitats and had positive association with some species, except that it was negative for the species with shady humid habits, such as *Ardisia japonica*, *Mycetia sinensis*, *Cephalanthus occidentalis*, *Vitex quinata*. III. *Cunninghamia lanceolata* + *Clerodendron cytophyllum* + *Millettia semicastrata* + *Randia spinosa* + *Litsea cubeba* + *Litsea pungens*. These species were mainly distributed at the relatively sparse microenvironment and had positive association with each other, while they had negative association with most understory plants with shady humid habits. IV. *Ardisia japonica* + *Psychotria rubra* + *Vitex quinata* + *Cephalanthus occidentalis* + *Pithecellobium lucidum* + *Mycetia sinensis*. They are suitable to humid habitats in the extreme and were only distributed at the shady areas.

Based on the characteristics of ecological species groups and community features, we could judge the Chinese fir community status in the successional sequences. If species group III or II were the advantaged species in the shrub layer, the community would change from coniferous forest to sparse evergreen broad-leaved forest. For group IV, the community would be relatively stable in the local climatic condition. For group I, the coniferous forest would be mixed coniferous–broad leaved forest, and the results matched the facts, for there was a quantity of evergreen broad-leaved trees by natural succession.

#### 4 Discussion

There are 71 species in the shrub layer of the *Cunninghamia lanceolata* plantation after natural succession. The species richness and diversity have increased with slight anthropogenic disturbance. The status and function of understory woody species are judged by the analysis of IV. *Ficus hispida*, *Cudrania tricuspidata*, *Mallotus apelta*, and *Millettia semicastrata* are the constructive species. *Periploca forrest*, *Alangium chinese*, *Pueraria thunbergiana*, and *Mallotus barbatus* are the subdominant species. *Clerodendron cytophyllum*, *Maesa japonica*, *Randia spinosa*, and *Litsea cubeba* are the companion species. *Viburnum dilatatum*, *Cayratia japonica*, and *Rubus palmatus* are the rare species.

$\chi^2$  statistics and  $r$  test were used for testing the significance of interspecific association and correlation among 25 main understory woody plants selected from the woody population. The results clearly show their interspecific relationships and their differences in resource utilization. Species-pairs of positive association are in the majority. Most species were in the shady habitat.

There is a positive correlation between the IV of the species and the interspecific association. The higher the IV of the species is, the closer and more significant interspecific association is. Species with high important value, such as *Ficus hispida*, *Millettia semicastrata*, *Cudrania tricuspidata*, *Mallotus apelta*, *Antidesma bunius*, and *Mallotus barbatus*, showed that these species utilized the resources sufficiently and became the advantaged populations. Species with middle IV such as *Schefflera octophylla*, *Litsea cubeba*, *Ardisia japonica*, *Ficus fulva*, and *Randia spinosa* show no significance association with other species. These species are not suitable to the shady habits and are widely distributed in the under forest, some of which are xerophil and heliophytes, such as *Randia spinosa* and *Litsea cubeba*. Species with lower important value as *Mycetia sinensis*, *Pithecellobium lucidum*, etc. adapt to the humid habitat and have a positive association with each other. Chinese fir in the under forest having a positive association with the other species (except *Antidesma bunius*) validates that most understory populations have adaptabilities in the environment of the Chinese fir community.

Based on analytical results of interspecific association and correlation, 25 woody plants in the shrub layer could be divided into four ecological species groups: I. *Ficus hispida* + *Antidesma bunius* + *Mallotus barbatus* + *Ficus cunia* + *Saurauia tristyla* + *Mallotus philippinensis* + *Maesa japonica* + *Ficus hirta* + *Alchornea rugosa* + *Ficus fulva* + *Mallotus apelta*. II. *Cudrania tricuspidata* + *Schefflera octophylla*. III. *Cunninghamia lanceolata* + *Clerodendron cytophyllum* + *Millettia semicastrata* + *Randia spinosa* + *Litsea cubeba* + *Litsea pungens*. IV. *Ardisia japonica* + *Psychotria rubra* + *Vitex quinata* + *Cephalanthus occidentalis* + *Pithecellobium lucidum* + *Mycetia sinensis*. If species group III or II is the advantaged species in the shrub layer, the community would change from coniferous forest to sparse evergreen broad-leaved forest. For group IV, the community would be relatively stable. For group I, the coniferous forest would be mixed coniferous–broad leaved forest. The classification of ecological species groups would provide a theoretical basis on judging its ecological function, adjusting the stand structure of the plantation, and directing the suitable natural vegetation type through the close-natural restoration process.

**Acknowledgements** This study was partially supported by the Forestry College, Guangxi University, Experiment Center of Tropical Forestry, Chinese Academy of Forestry. We thank Liang Hongwen, Zhu Hongguang, Lu Lihua, Guo Wenfu, Luo Yinghua for help in the field investigations.

## References

- Guo Z. H., Zhuo Z. D., Chen J., Interspecific association of trees in mixed evergreen and deciduous broadleaved forest in lushan mountain. *Acta Phytocologica Sinica*, 1997, 21(5): 424-432 [郭志华, 卓正大, 陈洁. 庐山常绿阔叶、落叶阔叶混交林乔木种群种间联结性研究. *植物生态学报*, 1997, 21(5): 424-432]
- Li C. H., Yu S. Q., Zhou G. M., Review of researches in restoration of subtropical evergreen broad-leaved forests. *Journal of Zhejiang Forestry College*, 2002, 19(3): 325-329 [李翠环, 余树全, 周国模. 亚热带常绿阔叶林恢复研究进展. *浙江林学院学报*, 2002, 19(3): 325-329]
- Li X. R., Interspecific association and correlation of shrub layer in the coniferous broad-leaved mixed geobotanical zone of Russia plain. *Acta Ecologica Sinica*, 1999, 19(1): 55-60 [李新荣. 俄罗斯平原针阔混交林群落的灌木层植物种间相关研究. *生态学报*, 1999, 19(1): 55-60]
- Liu S. R., Jiang Y. X., Shi Z. M., A study on the biological diversity in warm temperate forest in China. Beijing: China Science and Technology Press, 1998 [刘世荣, 蒋有绪, 史作民. 中国暖温带森林生物多样性研究. 北京: 中国科学技术出版社, 1998]
- Liu S. R., Li X. M., Niu L. M., The degradation of soil fertility in pure larch plantation in the northeastern part of China. *Ecological Engineering*, 1998, 10: 75-86
- Liu S. R., Nitrogen cycling and dynamic analysis of man-made larch forest ecosystem. *Journal of Plant and Soil*, 1995, 169: 391-397
- Ludwig J. and Reynolds J., *Statistical Ecology*. New York: Academic Press, 1991.
- Muller D. and Ellenberg H., (Bao X. C., et al translation), *The objective and method of vegetation ecology*. Beijing: Science Press, 1986 [Muller D. and Ellenberg H., (鲍显诚等译), *植被生态学的目的和方法*. 北京: 科学出版社, 1986]
- Sun Z. W., Zhao S. D., Interspecific association and correlation of lime-broad leaved Korean pine on the northern slope of Changbai Mountain. *Chinese Journal of Applied Ecology*, 1996, 7(1): 1-5 [孙中伟, 赵士洞, 长白山北坡椴树阔叶红松林群落木本植物间联结性与相关性研究. *应用生态学报*, 1996, 7(1): 1-5]
- Wang B. S., *Plant community ecology*. Beijing: High Education Press, 1987 [王伯荪, *植物群落学*. 北京: 高等教育出版社, 1987]
- Yang Y. C., Zhuang P., Li X. R., Ecological studies on the forest community of *Castanopsis platy, acantha-schima sinensis*. *Acta Phytocologica Sinica*, 1994, 18(2): 105-120 [杨一川, 庄平, 黎系荣, 峨嵋山峨嵋栲、华木荷群落研究. *植物生态学报*, 1994, 18(2): 105-120]
- Yu X. B., Zhong L. S., Yang W. D., Structure of understorey vegetation in eucalyptus plantation. *Chinese Journal of Tropical Crops*, 1999, 2(1): 66-72 [余雪标, 钟罗生, 杨为东等. 桉树人工林林下植被结构的研究. *热带作物学报*, 1999, 2(1): 66-72]
- Zhang J. T. and Jiao R., Interspecific association between woody plants in Shen Weigou of Guandi mountains. *Bulletin of Botanical Research*, 2003, 23(4): 458-463 [张金屯, 焦蓉, 关帝山神尾沟森林群落木本植物种间联结性与相关性研究. *植物研究*, 2003, 23(4): 458-463]
- Zhang J. T., Review in communities. *Rural Eco-Environment*, 1997, 13(4): 48-53 [张金屯. 群落中物种多度格局的研究综述. *农村生态环境*, 1997, 13(4): 48-54]