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Relationship between space structure characteristics and site environment of *Pinus Yunnanensis* secondary forests on Mopan Mountain in the middle of Yunnan, Southern China

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The influence on forest space structure by the site environment of *Pinus Yunnanensis* secondary forests, which are the main native species at the middle of Yunnan in China is discussed. Based on the analysis of site environment and forest space structure characteristics, the relationships between forest structure and site condition were analyzed using RDA sequencing. Results showed that there are big differences in forest non-space structure at each sample plot, the average diameter and height all displayed significant differences at most sample plots ($P<0.05$) and different distribution ($P<0.05$). Otherwise, in forest space structure, the average uniform angle index and neighborhood comparison at each sample plot were near to 0.5, which indicated that most forests had random distribution in the mean state. The interaction between non-spatial structure and spatial structure of forest stands was not equal, and the spatial structure was more influenced by the line length.

Key words: Site conditions；Neighborhood comparison；Uniform angle index；Box-counting dimension；RDA sequence; *Pinus Yunnanensis* secondary forests

INTRODUCTION

Forest structure is an important manifestation of the stand characteristics, and also is a comprehensive reflection of forest growth developmental process and operation [1], which determines the functions of the forest. Therefore, stand structure is a key aspect of controlling forest function [2-4]. The spatial structure of the stand is the spatial arrangement in the forest, which reflects the spatial relationship of the species in the forest community [5]. Spatial structure determines the competitive potentials of trees and their spatial niche, which largely determines the stability of the stand, the possibility of development and the size of the management space [6].

Studies on forest structure characteristics are some of the main contents of forest ecology research in long terms [7]. But most of them focused on the aspects of the stand structure and its habitat factors while the influence of the site conditions on the stand characteristic factors was relatively small [8]. There are only few reports especially on the study of the relationship between spatial structure and site factors of forest stands [9]. At the same time, the studies on stand structure factors were mostly concentrated on a direct one-to-one relationship, and provided no comprehensive summary of the inherent complexity of the forest ecological system, such as the impact of environment on the growth of the forest nor provided comprehensive information for a systematic study [10,11].

Pinus Yunnanensis is the typical native tree species in Yunnan Province of China, and has a very important role in the forest ecological environment in Yunnan Province, especially the pure forest of the same age [12]. Therefore, this paper chooses the similar age *Pinus Yunnanensis* pure forest as the research object, to explore the effects of different site conditions on stand structure. The relationship between site conditions, stand non-spatial and spatial structure by RDA ordination can provide theoretical basis for the operation and management of *Pinus Yunnanensis*.

STUDY CONDITIONS

The Mopan Mountain National Forest Park is situated in Yunnan Province of China (101°16′06″～101°16′12″, 23°46′～23°54′). The latitude is 1260.0～2614.4 m, which belongs to a subtropical/typical mountain climate region. Annual mean temperature is about 15°C and annual rainfall is about 1050 mm. Extreme maximum temperature is 33°C, extreme minimum temperature is 2.2 °C, the annual sunshine time is 2380 h. The Mopan Mountain soil is upland soil and basalt developed into red soil; the high altitude area is yellow brown soil, soil thickness gives priority to thick soil layer and local thin soil layer with soil thickness of 1 m or so.

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METHODS

Sample setting and investigation

On the basis of comprehensive reconnaissance, small age difference and different site conditions typical *Pinus Yunnanensis* pure natural secondary forest, 8 fixed sampling spots (50 m×50 m) were set away from the road. The basic situations of the plots are shown in Table 1. Combined with the research objective, in order to meet the needs of the fitting model, in the vicinity of each sample a temporary survey was set, a total of 68 (20 m × 20 m) and in each sample four samples (0.04 hm^2，20 m×20 m), that was 32. Hence, 1, 2, 3, 4 samples were in the same location.

The method of mechanical sampling was adopted. In each of the sample plots, the diameter above 3cm and the survival of the *Pinus Yunnanensis* were investigated. Survey indicators including the number of *Pinus Yunnanensis*, diameter, tree height, coordinate and in each sample chose the dominant 2-3 trees, record the number.*Soil sample collection and main physical-chemical indices*

Soil samples were collected at five sampling sites in each fixed plot. Depth was in accordance with the mechanical stratification for 0-20 cm, 20-40 cm and 40-60 cm, using a ring knife (100 cm^3) and aluminum box for each layer of collected soil. In each layer of fresh soil the method of four points was applied over a 0.25 mm, 1 mm and 2 mm copper sieve, respectively and put in the soil bag. The chemical indicators were measured in 0.25 mm or 1 mm sieved soil samples, some physical indicators were measured using 2 mm sieved soil sample.

Soil physical properties included soil moisture content (saturated water holding capacity, capillary moisture capacity, and field water holding capacity), bulk density, porosity, mechanical components, and so on.

Data processing and computing

Site conditions are mainly related to the slope, the slope position, and the physical and chemical factors, in which the slope position and slope direction can be quantified by the method of artificial classification assignment. Stand structure included the stand spatial structure and spatial structure, the latter mainly included stand density, average diameter, tree height; spatial structure mainly included the stand level, tree size differentiation characteristics of distribution and spatial distribution patterns of forest trees; the characteristic indices were: neighborhood comparison (NC), uniform angle index (UAI), box-counting dimension (BCD), etc. [3, 8]. The main factors affecting the stand structure were analyzed according to the order of RDA. In this paper, the correlation analysis, the difference analysis, the multiple comparison and so on used the Spss19.0.

Elevation, terrain and terrain conditions of the sites

According to the law of decreasing temperature with the elevation, the level of the elevation was assessed. For each rise of 100 m, the rank decreased by 1, while the interval from 1600 m to 1700 m was set for grade 4. According to the solar radiation at the different slopes, each unit level was 45ºC, and the north as a clockwise starting point. The division results are shown in Table 3. The greater the number, the bigger was the radiation. Treatment of 0.1 units was performed at different angles of the same grade with different changes of 4.5ºC. According to interflow, the top-down direction was divided into 2 levels, 2 was for downhill, 1 was uphill. In order to evaluate the site quality, the site factors were classified into two types, macroscopic and microscopic. The macro site factors include: elevation, slope direction, slope position and so on. The micro site factors mainly include soil physical and chemical factors.

Table 1. Sample basic condition of the sample area

Sample	1	2	3	4	5	6	7	8
Slope site	Down	Up	Down	Up	Up	Down	Up	Down
Slope	shady	shady	sunny	sunny	sunny	sunny	shady	shady
Latitude(m)	1823	1874	1958	1929	1993	1945	1823	1856
Small number	14	15	12	12	11	12	12	12
Average diameter (cm)	14.77	13.83	16.80	17.67	13.82	16.91	12.90	13.08
Average height (m)	9.05	7.23	8.73	7.90	9.95	11.44	9.42	11.87
Dominant average tree diameter (cm)	23.48	20.63	28.18	30.20	24.73	24.93	20.05	22.83
Dominant average tree diameter (m)	18.75	20.90	24.43	26.88	24.18	22.63	24.50	23.35
Average density (N/ha)	1038	1288	806	519	1550	431	1644	1122
Age(a)	25	26	27	27	26	25	25	25

RESULTS AND DISCUSSION

Site characteristics of Pinus Yunnanensis secondary forest in Mopan Mountain

In the *Pinus yunnanensis* pure forest main distribution area, within the altitude range of 1600 m to 2000 m, 8 samples were set up, covering a series of changes in the south slope to north slope, slope position classification for uphill and downhill. The quantitative results of the topographic elevation are shown in Table 2.

Forest spatial structure angle index features

The smaller the angle index means more uniform trees distribution of the forest structure unit, the opposite means that distribution was assembled. From Figure 2 it is seen that the distribution frequency of the angle index in the first four sample areas of the structure unit was mostly random (W = 0.5), the distribution of plot 3 has an obvious trend to be a more evenly distributed structure unit (W = 0.25), while plot 2 had more assembled distribution of the structural unit (W = 0.75). The characteristics of the last four samples mostly displayed a random distribution of the structural unit; its frequency was around 0.5. The average angle index of each plot was in the order: 0.51, 0.56, 0.48, 0.55, 0.53, 0.52, 0.54, and 0.52. The mean difference was not obvious, so the angle index distribution characteristics of each sample plot difference were tested. The X test was used (Table 3). It can be seen that most of the angle indices of most plots had no significant difference, except for sample plot 1 and plots 2, 7, plots 2 and 3, plots 3 and 4, etc.

Neighborhood comparison characteristics and differences

By the neighborhood comparison, the distribution frequency showed obvious differences in a part of the sample plots. As in the first four sample plots, the plots 1 and 2 had a rather big difference in the neighborhood comparison distribution, there were more reference tree in absolute inferiority in plot 2.

In the last four sample plots, the number of the reference trees in the middle of the sample plot 5 was significantly lower, and the frequency was 0.1. The advantages and disadvantages in the number of reference trees were greater than the mean, and this was similar to the sample plot 8.

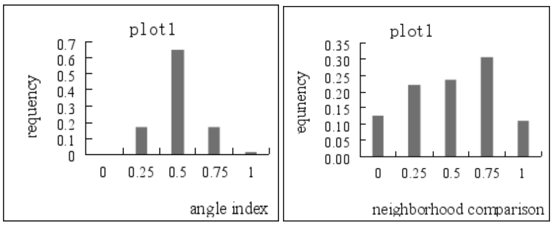

Fig. 1. Angle index and neighborhood comparison for plot 1

In contrast, the distribution of sample plot 6 was more uniform, and the distribution of sample plot 7 was similar to that of 2. Different frequency distribution may be related to forest regeneration, as more young forests favored the neighborhood comparison. In addition, the distribution of the neighborhood comparison was more obvious than that of the angle index. The average number of neighborhood comparison was 0.51, 0.49, 0.53, 0.49, 0.47, 0.48, 0.51, and 0.50, respectively. Because X test distribution can be applied to categorical variables, the distribution of different neighborhoods was also tested. The results are shown in Table 4. It can be seen that the distribution of the neighborhoods in sample plots 1 and 2, 6, 7, 8 showed significant differences, the same was also in plots 5 and 4.

Box-counting dimension characteristics and differences

Level meter box dimension valued generally between 1 to 2, the bigger number pointed to a higher degree of space-occupying, compared with density. This expressed the meaning and the spatial relationship. The inflection point was the demarcation point in different regions of linear of fitting process manifesting the small slope before the inflexion of the linear region. This can be considered as the distribution of individuals in the population state, not having the characteristics of population distribution.

Table 2. Basic situation of sample plots

Sample	Latitude	Latitude number	Slope	Slope number	Slope position	Slope quantization
1	1623m	4	NW20°	1.44	Down	2
2	1674m	4	NW30°	1.66	Up	1
3	1958m	1	SE70°	4.44	Down	2
4	1999m	1	SE45°	7.50	Up	1
5	1993m	1	SW60°	6.67	Up	1
6	1945m	1	S	8.00	Down	2
7	1823m	2	NW45°	3.00	Up	1
8	1756m	3	NW45°	3.00	Down	2

Table 3. Box counting dimensions and turning points for different samples

Plots	Box-counting dimension	Fitted equation	R^2	Turning point
1	1.35	y=1.35x+4.49	0.98	3.22
2	1.44	y=1.44x+4.24	0.94	2.37
3	1.18	y=1.18x+4.12	0.98	4.08
4	1.59	y=1.59x+5.44	0.94	1.67
5	1.22	y=1.22x+4.29	0.89	3.50
6	1.27	y=1.27x+4.73	0.93	2.64
7	1.60	y=1.60x+5.74	0.89	1.99
8	1.56	y=1.56x+5.57	0.92	1.86

So, this paper lists the fitting equation on the scale of the inflection point, considering the characteristics of population distribution above the inflection point, and the distribution characteristics of the individuals below it. From Table 3 it is seen that there exists a certain difference on the inflection point in different sample plots, and the maximum inflection point is in plot 3, which indicates that the individual polyintegrated population scale unit was loose, and with the increase in density, the population distribution scale showed a trend of decrease. The box-counting dimension fitted well on the population scale, the maximum was 1.60, and the minimum was 1.18. To a certain extent, density changes were closely related, but increased not only with the density increasing box-counting dimension, such as sample plots 6 and 2. At the same time, compared with the angle scale, box dimensions denoted the scatter and gather distribution characteristics of trees on the whole, which belonged to the spatial structure index.

Effect of site conditions on forest structure based on RDA ordination

The relationship between species and environment was analyzed by the method of RDA ordination based on a linear model. RDA based on the analysis of the criteria was the species in advance of the DCA analysis, because the length of the first spindle was less than 3, the choice of RDA analysis was considered more appropriate. In the selection of the function and the role of the indicators, the indicators of significance overlapped and the changes were not big. Soil texture and pH in a variety of places were not significantly different. Factors like angle index, neighborhood comparison, box-counting dimension were considered as species (small arrow) 1, 2, 3; the soil physical and chemical factors: saturation moisture content (%), capillary water holding capacity (%), field water holding capacity (%), natural moisture content (%), bulk density (g/cm^3), organic matter (g/kg), total N (g/kg), available nitrogen (mg/kg), total phosphorus (g/kg), total potassium (g/kg) and available potassium (mg/kg) for environmental variables (large arrow) 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11. At the same time, the terrain factors included: slope, slope position, elevation as the environmental factors 12, 13, 14. The angle index, neighborhood comparison, box-counting dimension were regarded as environmental variables 15, 16 and 17.

After variable selection, on the basis of a significant Monte Carlo permutation test ($P<0.05$), the optimal RDA ranking results were obtained (shown in Figure 3). In Table 4 the correlation coefficients between each influence factor and the rank axis are shown. RDA first, two ordination axes of the forest spatial structure and the spatial structure of the forest-impact factor variation of the interpretation of the factors were: 99.4% and 99.6%. Therefore, the sorting results had strong explanatory power. Correlated with the absolute value of the first axis were the average diameter, density, etc. The changes of the forest spatial structure were indicated. The second axis (vertical axis) gradient change reflected the change in water and light. It can be seen that the forest density, the average diameter and the box-counting dimension were positively affected. The water and light had negative effects on the neighborhood comparison showing that good moisture and light intensity can greatly ease the competition among individuals, showing a smaller neighborhood comparison.

To sum up, we can make the following judgments: first of all, forest spatial structure and non-spatial structure influenced each other; secondly, soil nutrient factors were easy to affect the forest non-spatial structure and terrain. To bring the water and light changes in the environment was easier to affect the forest spatial structure, including tree size differentiation. However, just clearing the site condition and forest structure of

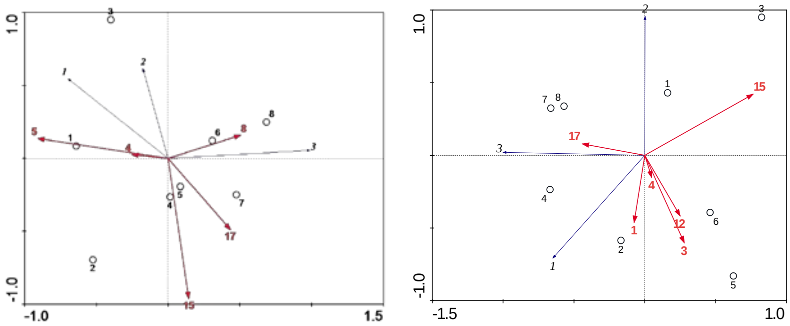

Fig. 2. RDA analysis of non-spatial index, site condition and stand spatial index of stand

Table 4. Correlation coefficients of RDA ordination axis with influencing factors

Variable	4NWC	5BD	8AN	15UAI	17BCD	1SWC	3FWC	4NWC	12Slope	15Average diameter	17Density
First rank axis	-0.250	-0.898	0.499	0.142	0.430	-0.075	0.278	0.049	0.249	0.762	-0.438
Second rank axis	0.025	0.135	0.158	-0.961	-0.489	-0.460	-0.599	-0.151	-0.415	0.419	0.079

Note: SWC-saturation water capacity; FWC- field water capacity; NWC- Natural water content; BD- bulk density; AN- available nitrogen; UAI- Uniform angle index; BCD –Box Counting Dimension

gradient relations cannot point out the relationship within the specific contact, and is unable to determine forest non-spatial structure and spatial structure that are influenced by site conditions. Therefore, it is necessary to work on clarifying and further deepening this relationship.

It should be noted that in the RDA ordination the forest structure factors were not equal, such as angle index as environment variable, which affected the diameter and tree height significantly, and if tree diameter and height were environmental variables, tree height had no effect on angle index (Figure 3).

CONCLUSIONS

This paper studied the relationship between site conditions and forest spatial structure of *Pinus Yunnanensis* on Mopan Mountain in Yunnan Plateau. The following conclusions may be drawn:

Soil moisture was mainly related to forest density, in the middle and low parts, density was high, with more moisture. Some sample plots downhill held more water than the upper slope, soil moisture on sunny slopes was higher than that of shady slopes.

It was found that there was no significant difference in the mean values of the angle index and the neighborhood comparison. But several sample plots in the distribution displayed significant difference. There were significant differences in the angle index distribution, such as plot 1 and 2, 7, plot 2 and 3, plot 3 and 4, and so on. Box counting dimension analysis results showed that the space occupied by forest sample plots was obvious different, box-counting dimension were: 1.35, 1.44, 1.18, 1.59, 1.22, 1.27, 1.60, and 1.56, respectively. The turning point varied, the cluster extent of the sample on the plaque scale was different, and the greater the density, the smaller was the turning point.

There was a mutual influence between the forest spatial structure and the non-spatial structure. The specific performance was: negative influence of the angle index and the box-counting dimension on the average tree height and the diameter. In turn, the density influence on the angle index was positive. For the forest spatial structure, the slope direction and soil physical properties, such saturation capacity, natural moisture content, field capacity, and the neighborhood comparison had negative gradient changes. This showed that good water and light were not significant for the individual size of the forest.

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