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RESEARCH ARTICLE

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Spatial distribution pattern and dynamics of the primary population in a natural *Populus euphratica* forest in Tarim Basin, Xinjiang, China

Abstract One 50 m × 50 m standard plot was sampled in a natural forest of *Populus euphratica* in Awati County, situated at the edge of the Tarim Basin, Xinjiang Uygur Autonomous Region, China. The field investigation was conducted with a contiguous grid quadrate method. By means of a test of variance/mean value ratio, aggregation intensity index and theoretical distribution models, the spatial distribution pattern and the dynamics of primary populations in *P. euphratica* forest were studied. The results showed that the spatial distribution pattern of two dominant arbor populations conformed to clumped distribution. The aggregation intensity of the *P. euphratica* population was higher than that of *P. pruinosa* population. The spatial distribution pattern of two companion plant populations in the shrub layer also conformed to clump type, though the aggregation intensity of *Tamarix chinensis* was higher. In the herb layer, the distribution patterns of *Glycyrrhiza uralensis* and *Asparagus persicus* conformed respectively to a clumped pattern and a random pattern. The results of a Taylor power method test and Iwao's m^*-$\overline{x}$ regression model also verified that both *P. euphratica* and *P. pruinosa* populations belong to a clumped pattern. Although the distribution pattern of *P. pruinosa* population at different development stages all belonged to a clumped distribution pattern, the aggregation intensity dropped gradually along with age development. The distribution patterns of the *P. euphratica* population at different development stages changed from random type to clumped type, and further to random type. The differences in spatial distribution patterns of different populations at different development stages were related not only to ecological and biological characteristics of each species in the communities in the light of competitive exclusion principle among the populations, but were also closely related to the habitats in which the species lived in.

Keywords *Populus euphratica* community, population, spatial distribution pattern, aggregation intensity, dynamic pattern

1 Introduction

Spatial distribution patterns and dynamic trends are the main factors affecting the development of populations (Shang and Zhang, 1988), the result of adaptation of population biological characteristics, and preferences for certain environments over a long time period (Gittins, 1985). These are also the fundamental quantitative characteristics of populations (Zhou et al., 1992) and one of most active domains in population ecology research (Pielou, 1985). The purposes of population pattern research are not only to understand the spatial structure of plant communities and to describe it at a quantitative level, but more importantly, to reveal some biological and ecological characteristics of populations (Lan and Lei, 2003), the interaction among populations (Greig-Smith, 1983) and the impacts of certain environmental factors on population behavior or existence (Zheng et al., 1992). Such research also leads us to evaluate the productivity of the community and to predict the development trends of communities and populations (Wang et al., 2003). Analyses of spatial distribution patterns can be divided into two categories: one based on distance and another based on quadrates (Lamont and Fox, 1981; Eccles et al., 1999; Dale, 1999; Wang et al., 2003). The scale of pattern analysis has drawn the attention of many ecologists who have proposed various methods to measure different patterns (Greig-Smith, 1983; Zhang, 1995), yet every method has its own advantages and weaknesses (Forman and Hahn, 1980; Lu, 1986; Xu et al., 1994). To date, many

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methods have been advanced to study spatial distribution patterns, among which, the aggregation intensity index is a simple method with wide application and effectiveness. It can determine the type of spatial distribution pattern and can also provide certain messages about the activities of individual plants and population spread (Su et al., 2000). Extensive studies have been carried out on spatial distribution patterns by means of this aggregation intensity index (Zheng et al., 1992; Su et al., 2000; Wu et al., 2000; Cao et al., 2002; Cheng et al., 2003; Wang et al., 2003; Song et al., 2005), yet studies on natural *Populus euphratica* forests in the Tarim Basin are few and far between. *P. euphratica* is the most primitive xylophyte in the evolution of the family Salicaceae. It is also a constructive tree species in arid deserts, and a precious species, resistant to adverse environments, in Xinjiang in western China. *P. euphratica* is highly adaptive to extreme climates and arid desert habitats and has thus become the subject of interest in the desert ecosystem of the Tarim Basin. The species has an important ecological function in improving ecological environments, biodiversity and artificial oases, and can even protect agricultural production. We have used traditional methods to study the main spatial distribution pattern of *P. euphratica* populations in the Tarim Basin and we trust that it will help people to understand the quantitative characteristics, spatial distribution, and conditions of the main *P. euphratica* population. We also tried to elaborate on the rules of formation of population distribution patterns and predict the trend of development of dominant tree populations. As well, we offer a theoretical basis for the cultivation of natural *P. euphratica* forests, rational management, establishment of mixed plantations, population restoration and effective protection.

2 Study area and methods

2.1 Study area

A standard plot was set in a natural forest of *P. euphratica* in an oasis in Awati County, Xinjiang. This forest is located at 39°40′N and 80°25′E, at an elevation of 992 m. It belongs to an arid desert climate in the warm temperate zone, with four distinctive seasons, rich in heat and light resources. The annual average sunshine time is 2729.0 h, annual total solar radiation energy 144.4 kcal/cm^2, annual average temperature 10.4°C, accumulated temperature of $\geqslant$10°C is 4340°C; the maximum temperature recorded so far is 39.4°C and the lowest temperature –25.0°C. Because the oasis exists in an extreme continental climate, it has the characteristic of large daily temperature changes. The annual average precipitation is 50.4 mm, annual average evaporation capacity 1880.0 mm, relative humidity 56% and aridity 12–19. Sandstorms occur frequently and gales characterize spring and summer. The soil texture is sandy soil, total salt content is 0.14%, pH 7.77, and organic content is 0.88%.

The natural *P. euphratica* forest is located on a smooth terrain, and great differences exist among individual trees, with an average height of 7.2 m and an average diameter at breast height (DBH) of 19.3 cm. In contrast, the average height of a *P. pruinosa* forests is 7.5 m and the average DBH is 20.4 cm. Tree composition under the main canopy in six *P. euphratica* and four *P. pruinosa* forests with a canopy closure of 0.5 consists of the main shrubs *Tamarix chinensis*, *Lycium barbarum* and *L. chinese*, with an average height of 1.0 m. Shrubs are relatively large and the growth potential is strong, with a coverage of 9.12%. Companion herbs are mainly *Glycyrrhiza uralensis* and a few *Asparagus persicus*.

2.2 Research methods

After a thorough investigation, we chose a representative, yet undestroyed, natural *P. euphratica* forest. One standard plot was set up at a 50 m × 50 m square area, where all living standing trees with DBH >2.5 cm were investigated using a contiguous grid quadrate method, measuring indices such as DBH, tree height, crown width etc (Cheng et al., 2003) and determining the coordinates of each tree. We investigated all seedlings of shrubs and trees in a 2 m × 2 m standard plot and investigated herb species, quantity, height and coverage in a 1 m × 1 m standard plot with a diagonal method (Cao et al., 2002). We calculated abundance, density, dominance and frequency of every species in this *P. euphratica* community based on the smallest plot.

2.3 Data analysis

In this study, we used a contiguous quadrat method for pattern analysis, which has already been widely accepted and applied. The scale in the pattern analysis has always been an important aspect, because people can reach different results when using different sizes of standard plots (Lai et al., 2006). Presently, there is still a lack of accurate information on pattern analysis of natural *P. euphratica* populations in the Tarim Basin. In this study, we used the commonly used standard plot area of 5 m × 5 m for trees (Lamont and Fox, 1981; Wang et al., 2003), 2 m × 2 m for shrubs and 1 m × 1 m for herbs (Su et al., 2002). A two-tailed t-test was used for testing the variance/mean value ratio of quadrat sampling (Li et al., 2000). We measured the population aggregation intensity with aggregation intensity (k), Green's index (GI), diffusion index (I_δ), Cassie index (Ca), clumping index (I) and mean crowding (m^*), patchiness index ($m^*/\bar{x}$), Taylor's power law and Iwao's m^*-$\bar{x}$ regression (Zheng et al., 1992; Li et al., 2000; Wu et al., 2000; Cao et al., 2002; Su et al., 2002; Cheng et al., 2003; Wang et al., 2003; Song et al., 2005; Lai et al., 2006). We used a Poisson distribution, negative binomial distribution and Neyman A model for fitting of population distribution patterns (Wang et al., 2003; Zhang et al., 2005). The pattern dynamics of dominant tree species was studied using Qu's method (Qu, 1982), which divided the tree distribution into four levels: the saplings ($33\ \mathrm{cm} < H$, $\mathrm{DBH} \leqslant 2.5\ \mathrm{cm}$), young trees ($2.5\ \mathrm{cm} \leqslant \mathrm{DBH} \leqslant 7.5\ \mathrm{cm}$), median trees ($7.5\ \mathrm{cm} \leqslant \mathrm{DBH} \leqslant 22.5\ \mathrm{cm}$) and large trees ($\mathrm{DBH} > 22.5\ \mathrm{cm}$), referred to as A, B, C and D respectively.

3 Results

3.1 Analysis of spatial distribution patterns of main populations in a *P. euphratica* community

We took the relevant data of the *P. euphratica* community into the models mentioned earlier, to test the spatial distribution pattern of the main stand and analyze the different kinds of models described, testing the space distribution pattern of every layer of the main populations in this *P. euphratica* community. Because the number of species in the three layers, i.e., the tree, shrub and herbage layer in *P. euphratica* community are rather small, we have listed all species on our study site in Table 1.

What is meant by spatial population distribution patterns is the interrelation among and between individual plants distributed within a horizontal space (Li et al., 2000). The aggregation index is used to evaluate the intensity of concentration of the spatial population pattern and is intended to overcome the often confused and contradictory explanations that populations belong to the same genera even if they have various frequency distributions when comparisons are made (Wu et al., 2000). Given the measurements made on our standard plot, we calculated the variance/mean ratio and aggregation indices of the main species in the tree layer (Table 1). We can see from Table 1 that the variance/mean ratio >1 for the *P. euphratica* population and that the calculated $t > t_{0.05}$. $K < 8$; $I_\delta > 1$; Through significance testing of random deviation degree, $F_0 > F_{0.05}$; $I > 0$, $Ca > 0$, $m^* > \overline{x}$; $m^*/\overline{x} > 1$; $GI \approx 0$; fitting with a distribution model, it conforms to a negative binomial distribution. Therefore, it shows that the spatial distribution pattern of the *P. euphratica* population is an aggregate type. Similarly, every index shows that the spatial distribution pattern of the *P. pruinosa* population conforms to a clumped distribution, but the aggregation intensity of the *P. euphratica* population was higher than that of the *P. pruinosa* population. Analysis of the cause of spatial distribution patterns of the two dominant populations must lead us perhaps to look at the over-cultivation of the land and to constant changes in the river course in this oasis in the Tarim Basin, and may point to the reason why natural *P. euphratica* seeds could not germinate and why the underground water level constantly changed.

There are only two kinds of vegetation in the shrub layer of the *P. euphratica* community (Table 1). The variance/mean value ratio of *Tamarix chinensis* is >1, tested against a $t > t_{0.05}$. Eight aggregation indices show that its aggregation intensity is relatively large, which conforms to the Neyman model, fitted with the data of our frequency distribution. The Neyman model could be applied to produce reliable results, inferring that the *T. chinensis* population has a clumped distribution. The variance/mean value ratio of *Lycium barbarum* >1, again tested by *t*-test, where $t > t_{0.05}$, confirms the eight aggregation indices. Three model fittings show that the spatial distribution pattern of *L. barbarum* populations conforms also to a clumped distribution. Given the increased intensity of anthropogenic interference and the gradual deterioration of the habitat, this kind of clumped distribution is beneficial for the population and allows it to stabilize the environment and expand the size of the population and guarantees the growth of individual trees. There are two plant species in the herb layer of the *P. euphratica* community (Table 1), among which *Glycyrrhiza uralensis* is a common urban species. Examined by a *t*-test, where $t > t_{0.05}$, the model fitted to the distribution and the aggregation index shows that this species also conforms to a clumped distribution. For the other species, i.e., *Asparagus persicus*, the variance/mean value ratio <1, tested by $t < t_{0.05}$; the aggregation index shows that the species is randomly distributed. Its frequency conforms to a Poisson distribution. Because *A. persicus* is sparsely distributed with a low density, it must be considered a random distribution.

Table 1 Spatial distribution pattern of main tree, shrub and herb population

growth type	species	variance/mean ratio	aggregation intensity	diffusion index	clumping index	Cassie index	Mean crowding	patchiness index	Green's index	distribution type
tree	*P. euphratica*	1.3020*	2.4837	1.3333	0.3020	0.4026	1.0520	1.4026	0.0031	clump
	P. pruinosa	1.2877*	2.8159	1.2809	0.2877	0.3351	1.0977	1.3551	0.0029	clump
shrub	*T. chinensis*	3.0511*	1.3164	1.5345	2.0511	0.7596	4.7511	1.7596	0.0297	clump
	L. barbarum	3.8987*	0.0517	19.0909	2.8987	19.322	3.0487	20.325	0.0420	clump
herb	*G. uralensis*	2.2502*	0.1300	8.0769	1.2502	7.6938	1.4127	8.6938	0.0181	clump
	A. persicus	0.9873	−1.9750	0.0000	−0.0130	−0.5060	0.0123	0.4937	0.0002	random

Note: $t_{191,0.05} = 1.960$; $t_{47,0.05} = 2.016$; $F_{0.05(191,\ \infty)} = 1.170$; $F_{0.05(47,\ \infty)} = 1.351$; * $t > t_{0.05}$

3.2 Taylor's power law model

In Taylor's power law model $y = a\bar{x}^b$, exponent b is an index of aggregation and reflects a particular attribute of the species. If $b = 0$, its distribution is uniform; if $b > 1$, it is a clumped distribution and if $b = 1$, the distribution is random. In the model, a is a sampling and statistical constant (Cheng et al., 2003). Taylor's power law is in essence a regression equation fitted to our measurement data of the *P. euphratica* population, permitting a regression analysis (Table 2). The results indicate that the b values of both *P. euphratica* and *P. pruinosa* are >1 in Taylor's power law model, implying that the spatial distribution pattern of both populations conforms to a clumped distribution

3.3 Iwao's model

In order to reflect the spatial distribution pattern of *P. euphratica* and *P. pruinosa* more accurately, we further carried out a standard regression analysis of m^* to $\bar{x}$ (Table 2). The regression equation of the *Populus euphratica* population is $m^* = 0.7479 + 0.1079\ \bar{x}$, the correlation coefficient is significant at a level of $\alpha = 0.05$ ($r = 0.8571^*$). The value of α is 0.7479 and approaches 1, indicating that the basic composition of the distribution is that of an individual group. The b value, 0.1079, is used to prove a basic spatial composition when it approaches 0. In the test for random variation of m^* and $\bar{x}$, $F > F_{0.01}$, implying again that, based on results of the Iwao model, the spatial distribution pattern of *P. euphratica* conforms to a clumped distribution. Similarly, in the regression equation of the *P. pruinosa* population using the Iwao model, the α value is $0.3807 > 0$ and the b value is $0.2861 > 0$. In the test for random variation of m^* and $\bar{x}$, $F > F_{0.01}$, the results indicate that the spatial distribution pattern of *P. pruinosa* also conforms to a clumped distribution. These results indicate that the spatial distribution pattern of *P. euphratica* and *P. pruinosa* with Iwao's aggregation index of the Iwao model, are highly consistent with the other three theoretical distributions.

3.4 Dynamic analysis of dominant populations

The spatial distribution has limitations not only in time level, but also may change with time series. It changes in different species, and even among the same species under different development stages and different habitats (Lai et al., 2006). By analyzing spatial distribution patterns of populations at different development stages, we can infer the formation of new individuals, death of the adult individuals, and history of human disturbance (Song et al., 2005). According to the 5 m × 5 m size and Qu's method (Qu, 1982), we divided the individuals in the standard plot into four grades (saplings, young, medium, large), and analyzed the dynamic spatial distribution patterns of *P. euphratica and P. pruinosa* at different development stages by five aggregation indices (Table 3). Seen from the patchiness index, the saplings in the *P. pruinosa* population are scarce, and the young, medium and large trees all conform to clumped distribution, but along with increasing tree grade, aggregation intensity weakens gradually. The distribution patterns of *P. euphratica* are different at different development stages. In the sapling stage, it conforms to a random distribution pattern; in the young and medium tree stage, it conforms to a clumped distribution pattern; it turns back to the random distribution pattern again for the large tree stage. The results indicate that increasing with the size class, *P. euphratica* populations tend to have a random distribution. The population distribution pattern of young trees is mainly decided by their own biological and ecological characteristics, while at the large tree stage, it is also restricted by environmental factors (Cheng et al., 2003).

4 Discussion

The spatial distribution pattern is a key aspect of plant population research and is also one of the important structural characteristics of populations. It is an important way to know the population characteristics, interspecific relationships, and the relationship between the population and the environment (Connell, 1963; Greig-Smith, 1983). The spatial distribution pattern is the most direct result of interaction of internal and external factors in a community. It is not merely related to the biological characteristics and the competitive repulsion among populations, but also has close contact with species habitat (Cheng et al., 2003). Many findings revealed that most natural populations obey clumped distribution patterns (Li et al., 2000; Cao et al., 2002; Cheng et al., 2003; Song et al., 2005), and disobey random distribution. Analysis of the main spatial distribution pattern of the *P. euphratica* community in the Tarim Basin show that most populations conform to a clumped distribution

Table 2 Spatial distribution patterns with Iwao regression and Taylor model of dominant tree species

species	Taylor model		Iwao model			
	model	r	model	r	F	$F_{0.01}$
P. euphratica	$y = 0.2084\bar{x}^{1.2812}$	0.9284**	$y = 0.7479 + 0.1079\bar{x}$	0.8571*	546.98	30.82
P. pruinosa	$y = 0.1401\bar{x}^{1.2475}$	0.8412*	$y = 0.3807 + 0.2861\bar{x}$	0.9348**	168.71	30.82

Table 3 Spatial distribution pattern of dominant populations in different diameter classes

species	stage	variance/mean ratio	clumping index	Cassie index	patchiness index	diffusing index	F_0	$F_{(N\text{-}1,\infty)}$
P. euphratica	sapling	0.8987	−0.1013	−0.9001	0.0999	0.0000	0.8985	1.32
	young	1.3218*	0.3219	0.7357	1.7357	1.7479	1.3524	1.24
	medium	1.2111*	0.2111	0.9383	1.9384	1.9694	1.2611	1.24
	large	0.9233	−0.0767	−0.8662	0.1338	0.0000	0.9547	1.24
P. pruinosa	young	1.2912*	0.2912	2.3296	3.3296	3.5556	1.3210	1.24
	medium	1.2041*	0.2041	0.9364	1.9364	1.9675	1.2781	1.24
	large	1.0635	0.0635	0.3175	1.3175	1.3333	1.2536	1.24

Note: $t_{191,0.05} = 1.960$; $^{*}\ t > t_{0.05}$

pattern, and only a few populations do so to random distribution. *P. euphratica* and *P. pruinosa* are constructive species that present clumped distribution under a 5 m × 5 m scale, caused both by their biological characteristics and environmental factors. On the one hand, *P. euphratica and P. pruinosa* are the only arbor trees and heliphilous species in the extreme arid area of Xinjiang, forming the main forest story of community, and the populations are distributed in a ladder shape along the riverside with individuals aggregated; on the other hand, because of the over-cultivation of land and constant change in the river course at the Tarim Basin oasis, underground water level and soil moisture content decreased constantly and litter decomposition rate declined, which resulted in the natural *P. euphratica* seeds not being able to germinate; new individuals could only be produced by asexual propagation. We found that seedlings of *P. euphratica* and *P. pruinosa* were formed from the maternal root system during our understory excavation. Along with the over-exploitation of water and soil resources and human disturbance, the habitats worsened, seedling reserve was insufficient, and the forest tended to regenerate. Two companion species, *Tamarix chinensis* and *L. barbarum*, are easily found in the *P. euphratica* forest, which shows a clumped distribution pattern in the understory vegetation. This may be related to the better understory habitat, where the seeds aggregated nearby the maternal trees and caused the clumped distribution in the early formation of the natural forest. In the field investigation, we found that the *T. chinensis* and *L. barbarum* individuals are much taller and it was very difficult to find seedlings, thus also proving the above-mentioned conclusions. The spatial distribution pattern of *Glycyrrhiza uralensis* is different from *Asparagus persicus* in the herb layer. The large number and density of *G. uralensis* produce numerous seeds, but they could not germinate because of the low soil moisture (5.5% at 0–20 cm layer) and the thick litter layer, so *G. uralensis* propagated only by horizontal roots and distributed around in a clumped type. We can find many new individuals that grow in the same root and converge to a certain place. In contrast, *Asparagus persicus* has a lower density, and the individuals are distributed dispersedly, so it shows a random distribution.

The distribution pattern of plant populations is not invariable but changes over time and demonstrates a dynamic course (Liu, 1990). Generally speaking, population distribution patterns are decided by many factors such as environmental and biological characteristics of species, intraspecific and interspecific competitions, etc. (Lai et al., 2006). Seen from the dynamic spatial distribution pattern of different grades, the saplings of the *P. pruinosa* population were scarce and the young, medium and large trees all conformed to clumped distribution, but the aggregation intensity descended gradually with the increasing size grade and tended to be of random distribution. The reason for this is that they were restricted by the habitat conditions, and propagated only asexually. This aggregated distribution was kept until the sapling stage. Then, along with the development of the population, individual requirements for the environment were strengthened, especially that for light, which increases intraspecific and interspecific competition and decreases population density. Therefore, when trees grow to the medium and large size stage, the aggregation intensity weakens and tends to present a random distribution. The results show that during this stage, the main factor influencing the population distribution pattern is intraspecific and interspecific competition which might cause the dynamic change in population number. The distribution pattern of the *P. euphratica* population is different in different development stages, which might be related to uneven distribution of individual numbers in each grade. Less saplings of *P. euphratica* (accounting for 13.29% of the total) resulted in the distribution pattern approaching random distribution, while the large number of young and medium trees might have caused an aggregated distribution. At the same time, the habitat deteriorated year by year, however aggregated distribution benefits individual survival, thus also acting as a strategy of ecological adaptation to resist the adverse environment. It can be concluded that there are some relationships between the change in population distribution patterns and the dynamic change in population number, which is worth further study. When trees grow to a large stage, they change into the random distribution pattern, which might be because interspecific and intraspecific competition and repulsion are reinforced, individual requirements for environmental resources are strengthened, and differentiation might have occurred between individuals. Therefore, the survival strategy of the *P. euphratica* population is to satisfy individual expansion, thus making the population occupy and utilize more resources rationally to keep survival and development. This embodies the survival strategy and adaptation mechanism during the population development.

Studies on the spatial distribution pattern and dynamics of the dominant population in the *P. euphratica* community are helpful to master the information on spatial distribution patterns, understand quantitative dynamics and the developmental trend of the population, explore the endangerment mechanism of the *P. euphratica* population, and understand rational conservation measures. The results can guide silvicultural practices. According to the characteristics of population distribution patterns of dominant trees, we can make a reasonable plant configuration and strengthen artificial tending, improve the ecological conditions to accelerate tree growth and improve the tree quality, and at the same time, we can offer the theoretical foundation for further study on synecology and ecosystem.

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References

Cao G Q, Lin S Z, Cao Z L, Ding B (2002). Spatial distribution pattern of Chinese fir and its associated tree species in Mount Hutuo. J Zhejiang For Coll, 19(1): 148–152 (in Chinese)

Cheng Y, Yan S J, Hong W, Wu C Z, Feng L (2003). Analyses of spatial distribution patterns and their dynamics of dominant trees in *Sassafras tsumu* community. J Plant Res Environ, 12(1): 32–37 (in Chinese)

Connell J H (1963).Territorial behavior and dispersion in some marine invertebrats. Res Populat Ecol, 3: 87–101

Dale M R T (1999). Spatial Pattern Analysis in Plant Ecology. Cambridge: Cambridge University Press, 31–49

Eccles N S, Esler K J, Cowling R M (1999). Spatial pattern analysis in Namaqualand desert plant communities: evidence for general positive interactions. Plant Ecol, 142(1–2): 71–85

Forman R T, Hahn C D (1980). Spatial pattern of trees in Caribbean semi-evergreen forest. Ecol, 61: 1267–1274

Gittins R (1985). Canonnical Analysis: a Review with Application in Ecology. Berlin: Springer Verlag, 30–35

Greig-Smith P (1983). Quantitative Plant Ecology. Oxford: Blackwell Scientific Publishing, 101–145

Lai J S, Zhang M, Xie Z Q (2006). Structure and distribution pattern of dominant populations in the evergreen broadleaved forest in Three Gorges Reservoir Area. Acta Ecol Sin, 26(4): 1073–1079 (in Chinese)

Lamont B B, Fox J E D (1981). Spatial pattern of six sympatric leaf variants and two size classes of *Acacia aneura* in a semi-arid region of Western Australia. OIKOS, 37(1): 73–79

Lan G Y, Lei R D (2003). Brief introduction of spatial methods to distribution patterns of population. J Northwest For Univ, 18(2): 17–21 (in Chinese)

Li X K, Huang Y Q, Su Z M (2000). Distribution pattern and its dynamics of *Taxus chinensis* var. *mairei* population on Yunbaoshan Mountain. Chin J Appl Ecol, 11(2): 169–172 (in Chinese)

Liu Z H (1990). A primary study on the structure and dynamics of *Castanopsis fargesii* population on Jinyun mountain, Sichuan province. Acta Phytoecol Geobot Sin, 14(4): 120–128 (in Chinese)

Lu Y (1986). The application of the sampling method to the plant population pattern in the lower subtropical forest. Acta Phytoecol Geobot Sin, 10(4): 272–281 (in Chinese)

Pielou E C (1985). Mathematical Ecology. New York: Wiley-Interserence, 84–193

Qu Z X (1982). Plant Ecology. Beijing: Higher Education Press, 102–118 (in Chinese)

Shang G T, Zhang F (1988). Research on the pattern and associations between dominant of the vegetation in main mountain, Shanxi Province. J Wuhan Bot Res, 6(4): 357–364 (in Chinese)

Song P, Hong W, Wu C Z, Feng L, Fan H L, Zhu H, Lin Y M, Zhang Q (2005). Population structure and its dynamics of rare and endangered plant *Alsophila spinulosa*. Chin J Appl Ecol, 16(3): 413–418(in Chinese)

Su J X, Bi R C, Liu W J, Lu Y P, Suo A C (2002). Preliminary study on community characteristics of *Rosa xanthina*. J Shanxi Teacher's Univ, 16(1): 66–71(in Chinese)

Su Z Y, Wu D R, Chen B G (2000). Structure and spatial pattern dynamics of dominant populations in a natural forest in north Guangdong Province. Chin J Appl Ecol, 11(3): 337–341 (in Chinese)

Wang X G, Hong W, Wu C Z, Feng L, Cheng Y, Liao C Z, Lan B (2003). Study on the spatial distribution pattern of dominant population *incastanopsis carlessii* forest in Wuyishan mountain. J Henan Agric Univ, 37(1): 44–48 (in Chinese)

Wu C Z, Hong W, Wu J L, Huang Y (2000). Spatial distribution pattern of the endangered and rare plant *Tsuga longibracteata*. J Plant Res Environ, 9(1): 31–34 (in Chinese)

Xu H C, Fan Z F, Wang S (1994). A study in spatial patterns of trees in virgin *Larix gmelini* forest. Acta Ecol Sin, 14(2): 155–160 (in Chinese)

Zhang J T (1995). The Methods in Plant Quantitative Ecology. Beijing: Chinese Science and Technology Press, 10–25 (in Chinese)

Zhang W H, Wang Y P, Kang Y X, Liu X J (2005). Spatial distribution pattern of *Larix chinensis* population in Taibai Mountain. Chin J Appl Ecol, 16(2): 207–212 (in Chinese)

Zheng S F, Zheng D Z, Liao B W (1992). Study on the distributive pattern of principal tree populations in *Bruguiera sexangula* and *B. gymnorrhiza* communities. For Res, 5(2): 149–157 (in Chinese)

Zhou J L, Zheng S Z, Yang C (1992). Plant Population Ecology. Beijing: Higher Education Press, 95–115, 231–238 (in Chinese)