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RESEARCH ARTICLE

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Spatial distribution pattern, scale and gap characteristics of *Pinus armandii* population in Qinling Mountains, China

Abstract Based on the data collected from 27 plots of the *Pinus armandii* community in Qinling Mountains, we studied the spatial distribution pattern, scale, and gap characteristics of the *P. armandii* population. The results showed that the population had a clumped distribution before age 50. At the age range from 15 to 25, though the population tended to be distributed randomly, the distribution was still clumped. The population distribution at the age range from 40 to 50 was at the transitional stage from clumped to random. After age 50, the population started to be senesced, the distribution pattern turning from clumped to random. The distribution pattern scale of *P. armandii* always changes with the development stage of the population, being 100 m^2 in general. The gap size of *P. armandii* population was similar to its distribution pattern scale, and the gaps of 80–130 m^2 occupied 59% of the total. Because of the better light and nutrient condition in the gap, *P. armandii* seedlings grew well, which helped the population keep its stability through "mobile mosaic circling".

Keywords *Pinus armandii* population, distribution pattern, pattern scale, gap

1 Introduction

The spatial dispersion of individuals of a species is a focus in ecological theory. Patchiness, or the degree to which individuals are aggregated or dispersed, is crucial to how a species utilizes resources, how it is used as a resource, and to its reproductive biology (Condit et al., 2000). Aggregated distribution of plant population always forms different sizes of patches, and these patches enchase each other and distribute in the habitat, and the size of the patch in this case is referred to pattern scale (Lan and Lei, 2003). When an aged tree dies in a closed-canopy forest, or when other occasional factors, such as drought, typhoon, or fire causes the death of the dominant species in the mature forest, this creates a "gap" (Zang and Xu, 1998; Liang and Ye, 2001), a local disturbance that sets in motion a mini-successional sequence called gap-phase regeneration. This culminates in the replacement of the original canopy tree by one or more new trees (Hubbell et al., 1999). According to the theory of forest growth circle, clumped patches and gap can be regarded as different kinds of patches. Gap can be regarded as gap phase of the forest patch circle, and the clumped patches of trees can be regarded as building phase or mature phase of the circle. Clumped patches and the gap enchase each other and helped to maintain the dynamic circle of the forest community.

Pinus armandii, which is very common in the Qinling Mountains, is an important species for timber and plantation use in barren hills (Niu, 1990). In the Qinling Mountains, the benefits of conservation of soil and water, and water resources conservation capacity of the *P. armandii* forest are notable. *Dendroctonus armandi*, a kind of pest beetle, and human activity have both done great harm to the population, which resulted in fewer distribution than before. In the field investigation, we found not only the clumped *P. armandii* population but also clumped seedlings of *P. armandii* in the gaps. There are few reports about the combination of the gap and pattern scale of the population. This study aims to reveal the generation of the population and the mechanism of how *P. armandii* maintains its population stability by studying its clumped pattern scale and gap characteristics.

2 Study site

The study was conducted in the forest areas of Qinling Mountains (32°5′–34°45′ N, 104°30′–115°52′ E) in central

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China. The north slope of Qinling Mountains belongs to a warm temperate subhumid zone, while the south slope belongs to a subtropical humid region. Precipitation occurs mostly in summer and autumn, especially in summer. The south slope receives 200–400 mm more annual precipitation than the north slope (Ying, 1994). *P. armandii*, which is distributed in the bottom of the valley at middle elevations of the mountains, always mixes with other tree species. Pure *P. armandii* forest is very rare in Qinling Mountains. At lower elevations, *P. armandii* mixes with *Populus davidiana, Betula luminifera* and *Pinus tabulaeformis*; at upper elevations, it mixes with *Picea wilsonii, Abies chensiensis*, and *Betula albo-sinensis* (Lan et al., 2004). The investigated area lies in elevations of 1,100–2,100 m. The soil types are yellow soil, brown forest soil and dark brown forest soil.

3 Methods

3.1 Field investigation

Field investigation was conducted from July to September in 2001 and 2002. We investigated 10 counties in Qinling Mountains, namely Mian, Mei, Hua, Zhashui Liuba, Ningshan, Shiquan, Taibai, Luonan and Lantian, including the south slope and the north slope of the mountains. Twenty-seven 20 m × 20 m plots were determined. Elevation, slope aspect, slope degree, and soil moisture were recorded in detail, all trees (including shrubs and lianas) with diameter at breast height (DBH) of more than 3 cm were recorded and their heights were measured. The position of each tree in the plot was also recorded. In each plot, we set four 4 m × 4 m grids for shrub investigating and four 1 m × 1 m grids for herb investigation. A growing tip was used to estimate tree age. Age of *P. armandii* was grouped into the following classes, according to the development stage of the population: 0–15 (saplings), 15–25 (rapid growth in height), 25–35 (rapid growth in diameter), 35–40 (middle age), 40–50 (premature forest), and 50–80 (mature forest).

Due to the growth difference between natural forests and plantations, we conducted gap investigation and sampled randomly only in natural *P. armandii* forests. The length and width of the gap, gap forming pattern, average height of canopy, coverage degree of shrub and herb were all recorded in detail. The properties of gap maker—fallen trees or logged trees, like tree species, decomposition degree and the diameter, were also recorded. We define $S = \pi LW/4$, here S is the gap area, L and W are the length and the width of the gap, respectively (Hartshorn, 1989; Gray and Spies, 1996).

3.2 Plotless sampling method

Proper plot scale and the number of plots are very important in distribution pattern analysis, and different plot scales produce different results, but plotless sampling can grossly diminish the error caused by plot scale (Peng, 1996). In this study, about 50 points were randomly sampled at every development stage of the *P. armandii* population. We define clustering coefficient A as:

$$A = 1/n\sum[(p_1)^2/(p_2)^2]_I,\ I = 1,2,3,4\ldots n$$

where n is the number of random points, p_1 is the nearest distance from the random point to the first tree, and p_2 is the second nearest distance from another tree to a random point. When $A = 0.500,0$, random distribution; $A > 0.500,0$, clumped distribution; $A < 0.500,0$, uniform distribution.

Z value ($Z = (0.500,0 - A)\sqrt{n}\,/\,0.288,7$) was used to test the bias of clustering coefficient A to 0.500,0, where 0.288,7 is the standard error of A value (0.500,0). Z value at confidence 95% is 1.96, and at confidence 99% is 2.58. When $Z > 2.56$, it indicates that the population is not randomly distributed at the 99% confidence level.

3.3 Plot sampling

Each plot was subdivided into four 10 m × 10 m subquadrants, then we got 108 subquadrants from 27 plots. Negative binomial index, Cassie index, diffusion coefficient, etc., were calculated in order to estimate the distribution pattern of the *P. armandii* population.

3.4 Data analysis

Distribution pattern and pattern scale were estimated by using modified Greig-Simth's mean square-block analysis (Xie et al., 1999).

4 Results

4.1 Distribution pattern

The population had different distributions at different development stages. At the ages of 0–15, 25–35, and 35–40, the population had a clumped distribution, but at age 15–25, the population had a random distribution. Due to the lack of seedling recruitment and self-thinning, the population had a random distribution at the age 40–50 and 50–80 (Table 1).

Table 1 Spatial distribution pattern of different age of *Pinus armandii* population

Age	Number of points	A value	Z value	Z value at confidence 95%	Z value at confidence 99%	Distribution type
0–15	55	0.589	–2.286	1.96	2.58	Clumped*
15–25	55	0.564	–1.644	1.96	2.58	Random
25–35	56	0.578	–2.022	1.96	2.58	Clumped*
35–40	56	0.682	–4.718	1.96	2.58	Clumped**
40–50	55	0.571	–1.824	1.96	2.58	Random
50–80	49	0.435	1.576	1.96	2.58	Random

The results of plot sampling method had slight differences to that of the plotless sampling method. From Table 2, we can learn that the population has a clumped distribution at the age 0–50 but a random distribution at the age 50–80. In the whole development of *P. armandii*, the population distribution has a tendency to go from clumped to random.

Table 2 Spatial distribution pattern of different ages of *Pinus armandii* population

Age	Variance	Mean	Diffusion coefficient	*T* value	$t_{0.05}$	Number of plots	Distribution type
0–15	7.574	2.912	2.601	9.266	1.998	68	Clumped
15–25	4.336	2.957	1.466	2.723	1.997	69	Clumped
25–35	7.228	3.815	1.895	5.66	1.993	81	Clumped
35–40	15.309	3.279	4.669	11.959	1.992	86	Clumped
40–50	5.511	3.554	1.551	3.329	1.996	74	Clumped
50–80	1.981	2.750	0.720	1.621	1.998	68	Random

4.2 Pattern scale analysis

Pattern scale of the *P. armandii* population was also analyzed in this paper. From Fig. 1, we can find that at age 0–15, the curve had a peak at the scale 100 m^2. The *t* test was used to check the population distribution, which indicated that the population at the scale 100 m^2 had a clumped distribution, i.e., the population pattern scale was 100 m^2. At age 15–25, the curve peaked at the scale 100 m^2, suggesting that the pattern scale is 100 m^2. At age 25–35, the curve had two peaks at 50 and 400 m^2, and only at the scale 400 m^2 after *t* test, the population had a clumped distribution, so the pattern scale is 400 m^2. At age 35–40, the curve had two peaks at scale 100 and 400 m^2 respectively, and the population all had clumped distribution at scale 100 and 400 m^2. At the age 40–50, the curve had three peaks at 25, 100 and 400 m^2, only at the scale 25 m^2 did the population have a clumped distribution after *t* test, but it did not indicate that pattern scale of the population at this stage is 25 m^2, because 25 m^2 is too small for big trees (at the age 40–50) to form a tree clump. At the age 50–80, the curve had one peak at scale 50 m^2, but diffusion coefficient is 0.96, which is less than 1, so the population at this stage had a random distribution.

4.3 Pattern intensity analysis

Pattern intensity of population can be indicated by conglomeration intensity index (Table 3). At the age 0–15, all indices indicated that the population had a clumped distribution. At the age 15–25, population cluster degree decreased rapidly. We can see by *K* value (6.341, close to 8, when $K > 8$, the population will have a random distribution) that the population at 15–25 years had a tendency of developing from clumped distribution to random distribution. At age 25–35, *K* value decreased, indicating that the populations are more clumped at age 25–35 than at age 15–25. Clump index reached its peak at the age 35–40 (Table 3), which means populations at this development stage were more clumped than those at other development stages.

Table 3 Conglomeration intensity index of different ages of *Pinus armandii* population

Age /year	Negative binomial (*K*)	Cassie index	Clump index	Average crowding degree	Agglomeration index
0–15	1.819	0.550	1.601	4.513	1.550
15–25	6.341	0.158	0.466	3.423	1.158
25–35	4.264	0.235	0.895	4.710	1.235
35–40	2.713	0.369	3.669	6.948	1.369
40–50	6.454	0.155	0.551	4.105	1.155
50–80	–9.834	–0.102	0.280	2.470	0.898

4.4 Gap characteristics

Gap formation ways of *P. armandii* community were classified into the following categories: cutting or dead stand, prostrate stem, wind breaking, bareness rock, and without gap makers (Table 4). As for *P. armandii* forest, cutting or dead stand accounts for the most part (63%). The main reasons are that in the Qinling Mountains, the trunks of *P. armandii* suffer from the gnawing of the pest insect *Dendroctonus armandi.* To protect the other trees from *D. armandi*'s harm, the dead trees should be removed and burned, which thus forms gaps

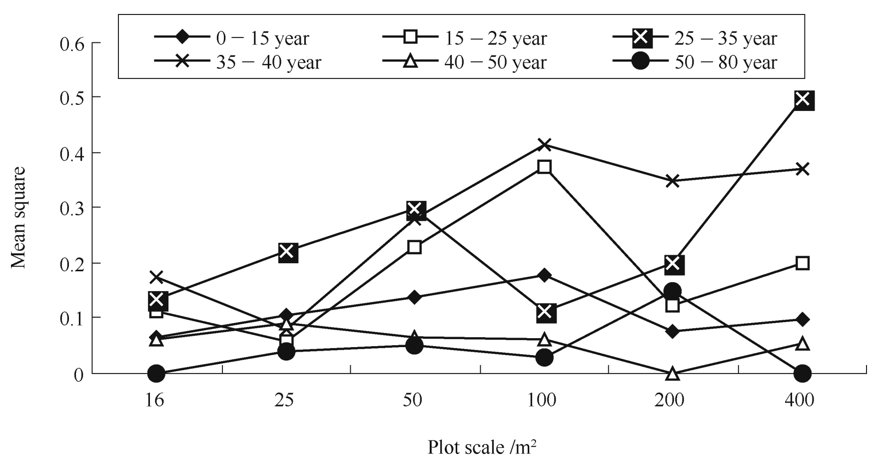

Fig. 1 Mean square-plot scale curve of *P. armandii* population at different ages

in the forest. On the other hand, due to the higher timber quality of *P. armandii*, they were logged by local people for commercial use, which might also contribute to the formation of gaps. The gap size of *P. armandii* forest in this study ranged from 35–160 m^2 and mostly 80–130 m^2.

Table 4 Gap characteristics of *P. armandii* community

Gap characteristics		Percentage /%
Gap size /m^2	35–50	12
	50–80	19
	80–130	59
	130–160	10
Gap methods	Cut or dead stand	63
	Prostrate stem	4
	Broken by wind	12
	Bareness rock or without gap maker	29
Gap maker	*P. armandii*	71
	Quercus aliena var. *acuteserrata*	13
	Others	26

4.5 The relationship between gap characteristics and pattern scale

It was widely recognized that small scale pattern of population was determined by biological characteristics of plants and large scale pattern was determined by environmental factors (Guo et al., 2004). *P. armandii* population had two pattern scales, one is 400 m^2 and the other is 100 m^2, which accounts for the most part. This study revealed that the pattern scale of *P. armandii* population was determined not only by the biological features but also by gap characteristics (especially the gap size). *P. armandii* has big seeds, which cannot be dispersed evenly in the forest to form clumped seedlings. On the other hand, gaps can make the habitats more propitious to seedling growth resulting in the formation of clumped patches of *P. armandii* seedlings in the gap. Therefore, the population pattern scale was mainly determined by the gap size. *P. armandii* is a kind of heliophyte, whose seedlings cannot grow well under the canopy but in the gap, resulting in much more seedlings in gaps. We can hence find a close relationship between pattern scale and gap size. At age 25–35 and 35–40, the population has a pattern scale 400 m^2, mainly because *P. armandii* suffers from *D. armandi*, which leads to the death of the population in patches, and the remaining populations show a clumped distribution. In this case, the pattern scale was determined by the clearing in the forest caused by *D. armandi* gnawing and human disturbance. Because the average tree height of *P. armandii* in this study is less than 20 m, largely between 13–18 m, the space larger than 400 m^2 cannot be considered a gap, but a clearing.

5 Discussion

Damage from *D. armandi* and human disturbance (including sanitation cutting and illegal cutting) may be the most important gap formation cause for the *P. armandii* forest. The two factors help maintain the gap regeneration. Because of the better light and nutrient condition in the gap, *P. armandii* seedlings grow well and form clumped patches in the gap. The size of the gap is similar to the clumped seedling patches. Thus, at age 0–15, the population of *P. armandii* has a clumped distribution. After age 15, due to the fast growth rate of the population, intraspecific competition will lead to self-thinning, which cause a decreased cluster degree of population at this development stage. At this stage, though the population tended to distribute randomly, the distribution was still clumped. The pattern scale is roughly the same as the gap size. At the age 25–35, the cluster degree of population increased, because the mortality of the population decreased and the population has adapted to the environment. Short-term drought do not cause a tree's death. At the age 35–40, the population reached its prime development stage and the cluster degree is higher than at other development stages. After the age 40, the *P. armandii* population became a premature forest, self-thinning was very weak at this stage and the number of the individual trees remained constant. The canopy of *P. armandii* forest was more expanded than before, which caused the cluster index to decrease. The population at the age 40 to 50 was at the transitional stage from clumped to random distribution. After the age 50, growth rate of diameter was slower than before, and the population had a random distribution at this stage. It was believed that plant population will have a clumped distribution at the beginning of spread and development, and random distribution at senesced stage (Peng, 1996). For *P. armandii* population, there might be two reasons for the random distribution after the age 50. The first is that after the 50-year development, the population suffered many factors, which always changed randomly, and these factors can cause the population to distribute randomly. Another reason is that after self-thinning of the population, the residual individuals will have a random distribution (Wu, 1995). New gaps were made after self-thinning (or cutting). Because of the better light and nutrient conditions in the gap, *P. armandii* seedlings grew well, which helped the population maintain its stability through a "mobile mosaic cycling".

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References

Condit R, Ashton P S, Baker P, Bunyavejchewin S, Gunatilleke S, Gunatilleke N, Hubbell S P, Foster R B, Itoh A, LaFrankie J V, Lee H S, Losos E, Manokaran N, Sukumar R, Yamakura T (2000). Spatial patterns in the distribution of tropical tree species. Science, 288: 1114–1118

Gray A N, Spies T A (1996). Gap size, within-gap position and canopy structure effects on conifer seeding establishment. J Ecol, 84: 635–645

Guo Z L, Ma Y D, Zheng J P, Liu W D, Jin Z F (2004). Biodiversity of tree species, their populations' spatial distribution pattern and interspecific association in mixed deciduous broadleaved forest in Changbai Mountains. Chin J Appl Ecol, 15(11): 2013–2018 (in Chinese)

Hartshorn G S (1989). Application of gap theory to tropical forest management: Natural regeneration on strip clear-cuts in the Peruvian Amazon. Ecology, 70(3): 567–576

Hubbell S P, Foster R B, O'Brein S T, Harms K E, Condit R, Wechsler B, Wright S J, de Lao S (1999). Light-gap disturbances, recruitment limitation, and tree diversity in neotropical forest. Science, 283: 554–557

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)

Lan G Y, Lei R D, Chen W (2004). Study on community characteristics of *Pinus armandii* in the Qinling Mountains. Acta Bot Borea1-occident Sin, 24(11): 2075–2082 (in Chinese)

Liang X D, Ye W H (2001). Advances in study on forest gaps. J Trop Subtrop Bot, 9(4): 355–364 (in Chinese)

Niu C S (1990). Forest in Shanxi Province. Beijing: China Forestry Publishing House (in Chinese)

Peng S L (1996). Community Dynamic of South Subtropical Forest. Beijing: Science Press (in Chinese)

Wu N (1995). Spatial pattern and relationship of dominant species in a *Picea brachytyla* community on Gongga mountain. Acta Phytoecol Sin, 19(3): 270–279 (in Chinese)

Xie Z Q, Chen W L, Liu Z Y, Jiang M X, Huang H D (1999). Spatial distribution pattern of *Cathaya argyrophylla* population. Acta Bot Sin, 41(1): 95–101 (in Chinese)

Ying J S (1994). An analysis of the flora of Qinling mountain range, its nature, characteristics and origins. Acta Phytotaxon Sin, 32(5): 389–410 (in Chinese)

Zang R G, Xu H C (1998). Advanced in forest gap disturbance research. Sci Silv Sin, 34(1): 90–98 (in Chinese)