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RESEARCH ARTICLE

# Point pattern analysis of different age-classes of *Larix principis-rupprechtii* in Luya Mountain Reserve, Shanxi Province, China

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**Abstract** *Larix principis-rupprechtii* forest is an important vegetation formation and has a large distribution area in Luya Mountain Reserve, China. Spatial pattern analysis on individual trees in different age-classes of *Larix principis-rupprechtii* was made in this paper. Here, we employed the technique of point pattern analysis, which could analyze patterns under all scales along a gradient. It was based on spatial mapped points of individual distribution. The results of this study showed that the densities of the five age-classes varied in the order: age-class 3 > age-class 4 > age-class 5 > age-class 2 > age-class 1. Although age-classes 1 and 2 have much fewer individuals than other three age-classes do, the population was stable at present. However, it would be necessary to take some measures for improving population regeneration for a long-time view. The individuals of all age-classes focused on clumping distribution in space; however, their distribution pattern varied with the change of scale. This mainly depended on biological features of *Larix principis-rupprechtii* and forest environments, but it also meant that the scale was an important factor in controlling spatial distribution pattern of tree individuals. The feature of clumping distribution became more significant with the increase of age. The relationships between individuals in different age-classes were almost all significantly correlated with each other. These associations became more significant within the older age-classes. This suggested that the individuals of different age-classes were interdistributed, by which the population could get benefits in resource utilization. The technique of point pattern analysis is effective and easy to be used in species pattern study. Its results are more closer to the reality, especially for community structure.

**Keywords** population pattern, *Larix principis-rupprechtii* forest, point pattern analysis, age-class, historical factors

## 1 Introduction

Spatial distribution patterns of constructive species are important characteristics of forest communities. Pattern analysis on populations is significant in studies on community structure, interaction between populations, and population-environment relationships, and is a hot point in ecology (Legendre and Fortin, 1989; Zhang, 1995, 2004). The distribution patterns of different age-classes for constructive species and their relations result from the long-term interactions between population, communities, and environments. They are symbols of reasonability of population and community structure, dynamics, and stability. However, the studies on patterns of different age-classes and their relations are not sufficient (Frost and Rydin, 2000).

*Larix principis-rupprechtii*, distributed at 112°–117° E, 38°–40°50′ N with an altitude from 1 600 to 2 800 m, is a main constructive species of coniferous forests in semihumid areas of North China. The area of *Larix principis-rupprechtii* forest is 140 000 hm$^2$ in China, and the species mainly occurs in Shanxi, Henan, Hebei Province, China (Edit Group of Shanxi Forests, 1995). *Larix principis-rupprechtii* forests are important timber forests, water-conservation forests, and landscape scenery forests, and are valuable for utilization and conservation. The present paper intends to study the patterns of *Larix principis-rupprechtii* in the Luya Nature Reserve, Shanxi Province, China.

The patterns of plant populations are related to spatial scale, which is noted by many authors (Zhang, 1998). Ecologists have put forward many methods to study patterns at different scales, such as Trend Surface Analysis for large-scale patterns (Gittins, 1968), Two-Term Local Variance

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Analysis for middle-scale patterns (Hill, 1973), and Species-juxtaposition for small-scale patterns (Zhang and Oxley, 1994). We used the method of Point Pattern Analysis, which is able to study patterns at various scales (Riggl, 1977, 1981; Zhang, 1998; Cheng and Zhang, 2002). This method is based on the spatial coordinates of plant individuals, *i.e.* each individual is a point in a two-dimensional space, and all individuals consist of a point map. This map will be used in the pattern analysis, and the method is known as Point Pattern Analysis. This method uses the information of point map sufficiently and has high capacity of test.

## 2 Natural conditions

Luya Mountains, located at 38°36′–39°02′ N, 111°46′–112°54′ E with an area of 21 453 $hm^2$, are a state nature reserve. The mountain body lies from northeast to southwest with the highest peak of 2 772 m and most area over 2 000 m. The Luya Mountains are in the semihumid region, and their climate is continental, i.e. cool and rainy in summer, cold and dry in winter. The annual main temperature is 6°C–10°C, the monthly mean temperature of January and July −8°C to −12°C and 21°C to 36°C, respectively. The annual precipitation varies from 384 to 679 mm, the annual evaporation 1800 mm, annual mean humidity 50%–55%, and the frost-free period 130–170 d. The soils are complicated in this area. The basal soil in eastern slope is gray cinnamon developed from loess parent, but that in western slope is cinnamon soil. The vertical variation of soils is mountain cinnamon soil, mountain eluviation cinnamon soil, brown forest soil, and subalpine meadow soil from the bottom to the top. The vertical change of vegetation in Luya Mountains is clear, and varies in the order of temperate steppe, warm-temperate broad-leaved deciduous forest, cold-temperate coniferous forest, and subalpine shrubland and meadow from the bottom to the top (Zhang, 1989).

The study site is a typical *Larix principis-rupprechtii* forest with canopy cover over 0.9 and *Larix principis-rupprechtii* is absolutely dominant. The accompanying trees are *Betula platyphylla* and *Picea wilsonii*. The common shrubs and herbs are *Lonicera hispida, Cotoneaster multiflorus, Spiraea pubescens, Lonicera ferdunandii, Vitex negundo* var. *heterophylla, Artemisia pronutans, Carex lanceolata, Bupleurum chinense, Sanguisorba officim.* The moss layer and litter layer are deep with nice stand conditions.

## 3 Methods

### 3.1 Sampling

The point pattern analysis required such a large sampling plot that population patterns at various scales could appear in this plot. It was better to take the plot as a square or rectangle. For forest community, plot size should be over 50 m × 50 m. Otherwise, the pattern at large-scale would be neglected (Zhang, 2004). The position of each individual was recorded as coordinates, which could use distance directly, and the distance would be transferred into values between 0 and 1 in the pattern calculation (Riggle, 1981). The data of this study were collected from *Larix principis-rupprechtii* forest at 1700 m in Luya Mountains, China, in July 1999. The age of the forest varied from 80 to 100 years. The plot was 180 m × 200 m. We classified the age-class of trees depending on the diameter of breath height (DBH). Although the age-class and the DBH-class were different, they were identical in responding to environment for the same species under the same conditions. Based on the DBH, five age-classes were identified: age-class 1, DBH < 2.5 cm; age-class 2, 2.5 cm ≤ DBH ≤ 10 cm; age-class 3, 11 cm ≤ DBH ≤ 20 cm; age-class 4, 21 cm ≤ DBH ≤ 30 cm; age-class 5, DBH > 30 cm. The position of individuals of *Larix principis-rupprechtii* at different age-classes was recorded correspondingly. To measure conveniently, the plot was divided into 10 m × 10 m quadrats. Rulers were used to measure the distance, and community characteristics were also recorded during the survey.

### 3.2 Method of point pattern analysis

#### 3.2.1 Patterns of different age-classes

As per mathematics, we know that mean ($m$) and variance ($v^2$) are of first and second orders, respectively. From a one-dimensional set of numbers, density ($\lambda$) and a structure of covariances ($k$) are the first and second orders of a two-dimensional set of numbers. For maps of points, $\lambda$ was the expected number of points of united area, and $k$ a measure of the distribution of the distances between points. The values of $k$ varied with the change of the scale. Diggle (1983) proved that the second-order could be reduced to a function $K(t)$:

$$K(t) = \lambda^{-1} \text{ (the expected number of further points within distance } t \text{ of an arbitrary point)} \quad (1)$$

where $t$ was a distance from 0 to ∞, and λ (estimation of density) could be estimated by $n/A$, where $A$ is the area of study (plot) and $n$ is the total number of points. In practice, $K(t)$ could be estimated with (Diggle, 1983):

$$\hat{K}(t) = \left(\frac{A}{n_2}\right) \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{1}{W_{ij}} I_t(u_{ij}) \quad (i \neq j) \quad (2)$$

where $u_{ij}$ was the distance between point $i$ and point $j$, when $u_{ij} \leqslant t$, $I_t(u_{ij}) = 1$, when $u_{ij} > t$, $I_t(u_{ij}) = 0$; $W_{ij}$ was the proportion of the circumference of the circle with center $i$ and radius $u_{ij}$, which lied within $A$, and was the conditional probability that a point (individual) is observed. It was used to reduce edge effect. In practice, $\hat{K}(t)/\pi$ was easier to use than $K(t)$ because under random-point placement, it stabilized the variance, and it was a linear function of $t$. We used $H_{(t)}$ denoted by $\hat{K}(t)/\pi$:

$$H(t) = \sqrt{\hat{K}(t)/\pi} \tag{3}$$

Using $H_{(t)}$ minus $t$, we got $\hat{H}(t)$: $\hat{H}(t) = \sqrt{\hat{K}(t)/\pi} - t$ (4)

Under random distribution, $\hat{H}(t) = 0$, if $\hat{H}(t) > 0$, it was clumping at $t$ scale, if $\hat{H}(t) < 0$, it was regular at $t$.

Monte-Carlo test of complete spatial randomness could be used to calculate the upper and lower envelopes and to test the goodness-of-fit. Assuming that the study population was random, we used a random model to simulate a group of coordinates, and to calculate $\hat{H}(t)$ for each $t$. In the same manner, a new group of coordinates were simulated, and $\hat{H}(t)$ was calculated for each $t$. This procedure should be repeated certain times (20 times for 95% significance level, and 100 times for 99% level). The maximum and minimum values of $\hat{H}(t)$ were the upper and lower envelope values at $t$ scale.

Using $t$ as horizontal axis and the upper and lower envelopes as vertical axis, the significance was clear. If the $\hat{H}(t)$ calculated from the point data were within the envelopes, the population was random. If it was outside the envelopes, the population was significantly nonrandom. For random model, the $t$ value corresponding to the pattern outside the upper envelope was an estimate of patch size.

### 3.2.2 Relationships between age-classes

To reveal the pattern dynamics and its mechanism of different developmental stages of *Larix principis-rupprechtii*, we analyzed the relations between two age-classes. This was, in fact, the point pattern analysis of the two age-classes, *i.e.* the multivariate point pattern analysis. The point pattern analysis of a single population mentioned above might be thought of as the relation study on a special age-class, and therefore, $K_{(t)}$ for the first species might be noted as $K_{11(t)}$ and for the second species $K_{22(t)}$. Now, we considered the point numbers of the two age-classes within a distance $t$ (scale), and it was to calculate $K_{12(t)}$. The definition and calculation were similar to that of point pattern analysis of single population. $K_{12(t)}$ could be estimated (Diggle, 1983)

$$\hat{K}_{12}(t) = \frac{A}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \frac{1}{W_{ij}} It(u_{ij}) \tag{5}$$

where $n_1$ and $n_2$ were the number of individuals (points) of age-classes 1 and 2, respectively, $A$, $I_t(u_{ij})$ and $W_{ij}$ the same as in formula (2), but $i$ and $j$ represented the individuals of age-classes 1 and 2. In the same manner, we calculated

$$\hat{H}_{12}(t) = \sqrt{\hat{K}_{12}(t)/\pi} - t$$

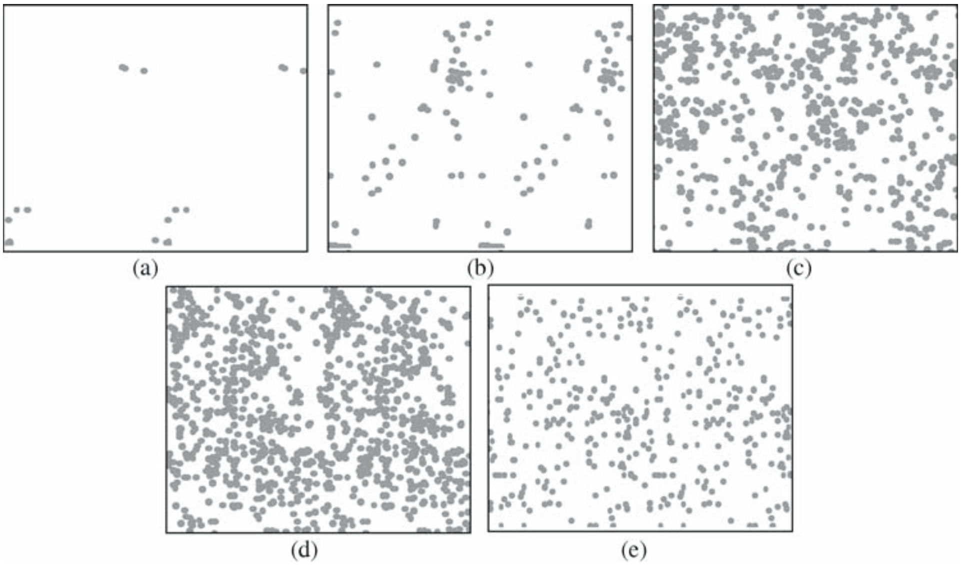
If $\hat{H}_{12}(t) = 0$, the two age-classes were not correlated at $t$. If $\hat{H}_{12}(t) > 0$, the association between the two age-classes were positively correlated. If $\hat{H}_{12}(t) < 0$, their relations were negative.

The Monte-Carlo test was also used to simulate the upper and lower envelopes and to test the significance of the relationships between the two age-classes.

## 4 Results

### 4.1 Pattern analysis on different age-classes

Figure 1 shows the distribution point map of individuals of *Larix principis-rupprechtii* in 180 m × 200 m plot for five age-classes. The horizontal axis represented 200 m, and the vertical axis 180 m. The coordinates of plant individuals used



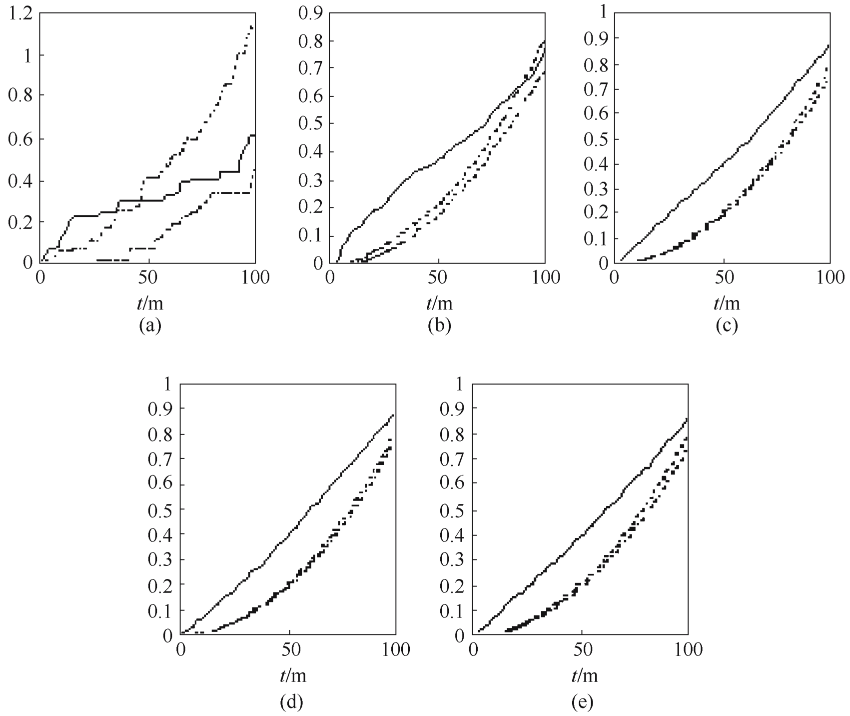
(a): Age-class 1; (b): Age-class 2; (c): Age-class 3; (d): Age-class 4; (e): Age-class 5

**Fig. 1** Point patterns of individuals in plots for different age classes of *Larix principis-rupprechtii* values between 0 and 1, *i.e.* the measured distance for horizontal axis was divided by 200 and the measured value for vertical axis was divided by 180.

We could see that the densities of individuals for the five age-classes were greatly different (Fig. 1). The density of age-class 1 was 617 individuals per $hm^2$ (Fig. 1a), density of age-class 2 3 836 per $hm^2$ (Fig. 1b), density of age-class 3 20 127 per $hm^2$ (Fig. 1c), density of age-class 4 27 733 per $hm^2$ (Fig. 1d), and density of age-class 5 11 342 per $hm^2$ (Fig. 1e). The densities of the five age-classes varied in the order: age-class 3 > age-class 4 > age-class 5 > age-class 2 > age-class 1. The clumping distribution pattern was obvious for all age-classes from Fig. 1. However, the relations between distribution pattern and scales were difficult to be identified in Fig. 1. Plant population might have different patterns in different developmental stages and different ages, which was related to self-thinning process, disturbance pattern, and environmental changes in forest community (Greig-Smith, 1983). That individuals in the same age-class had different patterns under different scales was due to spatial change of environmental conditions. The results of point pattern analysis for the five age-classes of *Larix principis-rupprechtii* are shown in Fig. 2. In Fig. 2, the solid line represents the calculated values of $\hat{H}(t)$, and the dashed lines represent the upper and lower envelopes. The envelope refers to significant levels, and if $\hat{H}(t)$ was over the upper envelope, the individuals were away from random distribution and follow clumping distribution. If $\hat{H}(t)$ was less than the lower envelope, the individuals were again away from random distribution, but following regular distribution. We took 0.01 (spatial distance 2 m) to separate $t$ values, and the maximum $t$ was 0.5 (100 m distance), half of the side length of the plot. The $x$ axis scores ($t$) might use values of 0–1, and might also use distance (m) directly. Here, we selected the latter to show spatial scale directly. Fig. 2a–Fig. 2e were the point pattern analysis for the five age-classes, respectively. For age-class 1, individuals were clumping distributed significantly at scales less than 46 m, but they were random distributed at scales above 46 m. Because the density of the age-class 1 was small, its pattern at large scale kept stable. For age-class 2, individuals were random at scale less than 2 m and above 90 m, but they were significant clumping at scales between 2 and 90 m. For age-class 3, individuals were away from random, but following clumping pattern at all scales. Similar to age-class 3, individuals of age-classes 4 and 5 were clumping at all scales. The spatial patterns of the five age-classes of *Larix principis-rupprechtii* were very clear and had obvious clumping features from Fig. 2. This could also be seen from their point maps (Fig. 1). When trees were young, their individuals were clumping at small scales, and random at large scales. The individuals tended to distribute clumping with the increase of tree age.

## 4.2 Relationships between age-classes

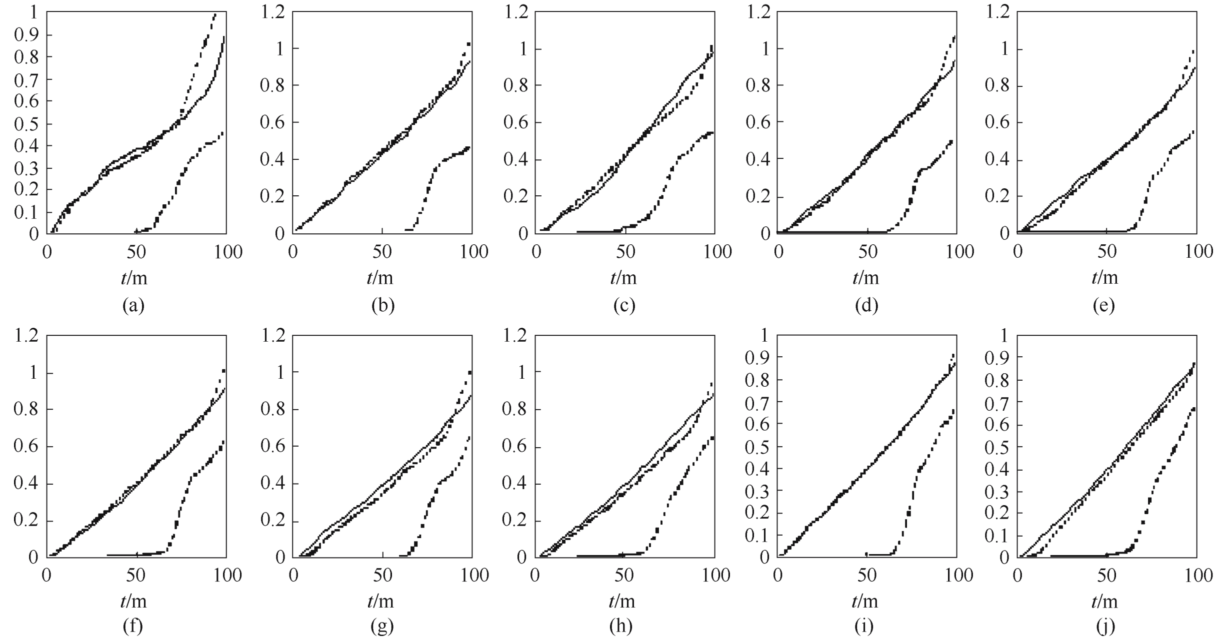
The relationship diagrams between the five age-classes of *Larix principis-rupprechtii* are shown in Fig. 3. The structure of Fig. 3 was similar to that of Fig. 2, *i.e.* solid lines are the calculated values of $\hat{H}_{12}(t)$, and the dashed lines are the upper and lower envelopes. Fig. 3a shows the relationships between age-classes 1 and 2, Fig. 3b between age-classes 1 and 3,



(a) (b) (c) (d) (e)

1), —: $\hat{H}(t)$ 2), ----: Upper and lower envelopes

**Fig. 2** Results of point pattern analyses for five age classes of *Larix principis-rupprechtii*



1), —: $\hat{H}_{12}(t)$ 2), ----: Upper and lower envelopes

**Fig. 3** Point pattern analysis of paired age-class associations of *Larix principis-rupprechtii*

Fig. 3c between age-classes 1 and 4, Fig. 3d between age-classes 1 and 5, Fig. 3e between age-classes 2 and 3, Fig. 3f between age-classes 2 and 4, Fig. 3g between age-classes 2 and 5, Fig. 3h between age-classes 3 and 4, Fig. 3i between age-classes 3 and 5, and Fig. 3j between age-classes 4 and 5. From Fig. 3, we could see that all age-classes of *Larix principis-rupprechtii* were positively correlated with each other, although relations at some scales were statistically significant, but not significant at some other scales. This suggested that the individuals of different age-classes required similar environmental conditions in spite of their existing competition with each other.

The associations between age-classes 1 and 2 were significant or close to significant at scales of 0–76 m, but not significant at scales above 76 m. The relationship curve between age-classes 1 and 3 was almost overlapped with the upper envelope, which meant that their correlations were significant at all scales except that above 90 m. The correlations between age-classes 1 and 4 were significant at scales of 0–20 m and 68–96 m, but not significant at scales of 20–68 m and above 96 m. Similar to relationship between age-classes 1 and 3, the associations between age-classes 1 and 5 were significant at all scales except that above 90 m. From the relationship between age-class 1 and other four age-classes, we could see that their correlations were closer at small scales, and tended to decrease at large scales. This might be related to its distribution patterns that individuals were clumping at small scales and tended to be random at large scales. The relationships between age-classes 2 and 3 were significant at scales under 44 m, and their curve was nearly overlapped with the upper envelope and close to significant at scales above 44 m. The correlations between age-classes 2 and 4 were significant or close to significant at most scales because their curve was interrupted with the upper envelope except scales above 93 m, at which they were not significant. The relations between age-classes 2 and 5 were very significant at scales below 92 m and not significant at scales above 92 m. The relationships between age-class 2 and the other four age-classes were basically positive and significant, but the correlation at scale above 90 m was decreased, with similar trend to age-class 1. The associations between age-classes 3 and 4 were significant at all scales, and the relations between age-classes 3 and 5 were significant or close to significant because their curves were interrupted and overlapped with the upper envelope. The correlations between age-classes 4 and 5 were very significant at all scales. Here we could see that the relationships between age-classes 3–5 were closer. The five age-classes of *Larix principis-rupprechtii* were closely related with each other with significant correlations, but their relations varied with the change of scales.

## 5 Discussion

The densities of different age-classes of *Larix principis-rupprechtii* vary greatly, from 617 to 27 744 individuals per hm$^2$ (Fig. 1). The order of the density size is age-class 3 > age-class 4 > age-class 5 > age-class 2 > age-class 1. The feature of population age structure is that the individuals of age-classes 1 and 2 are less, that of age-classes 3 and 4 greatest, and that of age-class 5 great among the five age-classes. It seems that the population is senescent, but stable, in fact because the individuals of age-classes 3–5 are in the period of high growth and development. This period will last a long term (50–100 years) (Forman, 1995). The individuals of age-classes 1 and 2 are under forest canopy and their growth is limited by light; therefore, their abundance is less. The *Larix principis-rupprechtii* population is a light-like species. From the management point of view, it is useful to create canopy gaps by felling some old trees for its regeneration.

The patterns of individuals of the five age-classes are basically clumping, and the clumping feature is more obvious for large trees. These patterns mainly depend on the biological characteristics of population, as the environmental requirements of individuals of the same population are consistent. The role of environmental conditions on the patterns is small, because the natural conditions in *Larix principis-rupprechtii* distribution area in Luya Mountains do not change greatly (Edit Group of Shanxi Forests, 1995). The individuals of age-classes 1 and 2 are clumping at small scales and random at large scales. This is because they depend on the environmental condition (light condition) under forest canopy created by large trees, *i.e.* they mainly grow under canopy gaps of big trees. Leathwick and Mitchell (1992) studied coniferous forests of more than 200 years old and thought that the difference of patterns between age-classes was mainly due to historical conditions, such as fire, ice age, pest disaster, etc. (Leathwick and Mitchell, 1992). The age of *Larix principis-rupprechtii* forests in Luya Mountains is comparatively younger, and there is no big disaster in history; therefore, the difference of patterns between age-classes is not apparent.

The relationships between age-classes of *Larix principis-rupprechtii* are all positively correlated with each other, and the correlations of individuals between age-classes 3–5 are more significant (Fig. 3). This is due to their consistent biological features, *i.e.* their requirements and adaptation to environments are consistent. This also suggests that the individuals of different age-classes are interdistributed, which benefits the population to utilize resources sufficiently and to grow and develop well. The greater associations between age-classes 3–5 suggests that the inner-relations of population are nice with strong ability of antidisturbance and high capacity of competition, and the population of *Larix principis-rupprechtii* is stable because the main body of this population consists of individuals of age-classes 3–5. The associations between the younger trees and large trees (age-classes 3–5) are significant at small scales, but not significant at large scales, which is related to the distribution patterns of the younger trees (Romme, 1982). Leathwick and Mitchell (1992) thought that the relationships between age-classes are mainly related to the equality of environmental conditions, disturbance, historical factors, etc. Because differences of these variables are not obvious in Luya Nature Reserve, individuals of different age-classes of *Larix principis-rupprechtii* are closely correlated with each other, and their relations are all positive.

Point pattern analysis used in this paper can study patterns at different scales and has advantages. From its results, point pattern analysis describes the characteristics of spatial distribution of various age-classes and relationships between age-classes clearly. Compared with traditional methods, its results are closer to the reality, and hence it is important in studies on community structure. In traditional pattern analysis, only one scale is analyzed (one quadrat size), and result can show clumping, random, or regular distribution at this scale. Associations between species are positive or negative. This kind of analysis describes community structure with skews, such as the description that most species are clumping and very few species are random in community (Greig-Smith, 1983; Zhang, 2004). For the *Larix principis-rupprechtii* forest, clumping is very obvious for the five age-classes, but individuals of age-classes 1 and 2 are random at large scales. The relationships between age-classes are significantly correlated, but some relations are insignificant. These relations are different with the change of scales. Therefore, the community structure described by point pattern analysis is better. At present, the application of point pattern analysis is few in research practice and should be tried more.

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