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Adjustment approach to boundary effect on aggregation index and its application

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Abstract Calculating aggregation index by the sample-plot data used to lead to computing error due to the existence of a boundary effect. Here, we suggest a method for adjusting boundary effect in the analysis of spatial patterns at different stages of development of the broad-leaved Korean pine forest. This method is good for the reasonable management and biological control of the forests. The total station was used to sample the relative coordinates data at four corners of the temporary sample plot and of each tree in the field. Based on the sampling data, a correct approach to the boundary effect on aggregation index was put forward to the spatial pattern analysis of the broad-leaved Korean pine forest in its different stages of development. The results showed that the forest trees grew in a clumped pattern in the stage dominated by the pioneer trees, and that the trees were distributed in a random pattern in the stage dominated by the companion trees or in the mature stage. The spatial pattern of the broad-leaved Korean pine forest changing from clumped to random distribution is influenced by biological characteristic, the adaptive strategy of tree species and the natural disturbance in its entire development.

Keywords forest ecology, aggregation index, boundary effect, broad-leaved Korean pine forest, spatial pattern

distribution models irrelative to distance have been mostly used to determine the spatial pattern for over a decade (Guan and Zhang, 1992; Chen et al., 1996; Jin, 1997; Zheng, 1997; Xie et al., 1999; Zhang and Wang, 2000). The advantage of using these models is not only for their simple calculation but also for explaining a lot of characteristics of the spatial pattern. However, this will sometimes lead to different results when using different approaches, and will even lead to a contradictory conclusion. Different kinds of indexes need to be used to prove each other. It is quite difficult to obtain an index value, when it approaches the marginal value if statistical analysis is not carried out (Zheng, 1997); It was found that index is irrelative to distance affected by the size of the plot (Guan and Zhang, 1992). Collecting data using the index relative to distance based on the traditional method is seldom used in practice because the cost is relatively high and the boundary effect of the sample plot is significant.

The data used in this paper including the localization coordinate of each tree is collected by the advanced localization instrument, TOPCON computer type total station. The boundary effect was adjusted during data processing, which is a practical way for aggregation index analyses. The study result can be used as guideline in the restoration and management of the broad-leaved Korean pine forest.

1 Introduction

Many research approaches on spatial pattern have been reported. The index of distribution type and some theoretical

Translated from *Journal of Nanjing Forestry University*, 2005, 29(3): 57–60 [译自: 南京林业大学学报, 2005, 29(3): 57–60]

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2 Research stand and approach

2.1 Research stand

The research site is located in the typical multiple-generation broad-leaved Korean pine forest in the Dongdapo Nature Reserves in the region of Jiaohe River Forestry Experimental Administrative, Jilin (Hu et al., 2003). Compartments 53, 52 and 54 were investigated in the reserves (Table 1). Compartment 53 was heavily disturbed by human activity and the forest stand was in the development stage dominated by the pioneer tree species. Compartment 52 was moderately disturbed by human activity, and the stand was

Table 1 Basic conditions at different compartments

Compartment	Density /(individuals·hm ⁻²)	Number of species	Species composition	Rate of conifer-broadleaf	Average height /m	Average diameter /cm
53	891	18	2P 2A 2J 1Pin 1Ab 1B 1 others	1:8	16.5	18.9
52	860	16	4J 2A 1Pin 1Ab 1T 1C 1 others	1:9	15.4	19.2
54	815	16	3J 1Pin 1Ab 1Pic 1A 1C 2 others	1:5	15.4	21.0

A-*Acer mono*, J-*Jujlans mandshurica*, P-*Populus* sp., B-*Betula costata*, Pin-*Pinus koraiensis*, Pic-*Picea jezoensis*, Ab-*Abies holophylla*, C-*Carpinus cordata*, T-*Tilia amurensis*

in the stage dominated by companion tree species. The third sample plot, compartment 54, appeared mainly to have a community structure of a primitive forest with at most 2% of trees cut in 1966.

2.2 Research approach

Thirty sample plots were set up in compartments 53, 52 and 54, with each compartment having ten sample plots with plot size 20 m×30 m (Xu and Lin, 1983). The long side of each plot was set up along the contour. The setting of plots was carried out by using a compass and measuring rope. The temporary stakes were placed at the four corners of each plot. Their relative coordinates of each plot, the four corners, height and diameter at breast height of each tree (DBH greater than 3 cm) were obtained by the total station. The data were processed with EXCEL, including calculation of the distances among all trees and the distance from each tree to each side of the sample plot. The nearest adjacent tree of each tree was chosen to identify the possible boundary effect.

3 Revision of boundary effect on aggregation index and analysis of spatial pattern

Aggregation index (R) was given by Clark and Evans and adopted as the spatial pattern analysis related to distance. It is easy to calculate and is often used to make the suitability test of space pattern of the whole stand as a single quantitative index.

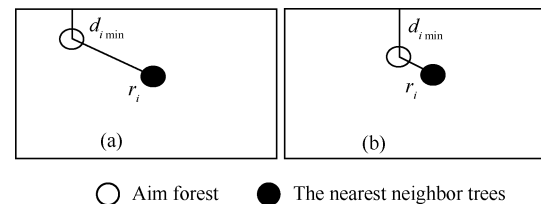
$$R = \frac{\frac{1}{n} \sum_{i=1}^n r_i}{\frac{1}{2} \sqrt{\frac{10000}{N}}} \quad (1)$$

where r_i is the distance from the tree i to its nearest adjacent tree, N is the number of trees per hectare and n is the number of trees in a sample plot.

When using the collected data to calculate the aggregation index, you may find that an individual tree located outside of the sample plot may be the nearest adjacent tree of an individual tree in a sample plot. Therefore, the calculation will be affected by boundary effect so that the value R

is often greater than the actual value. That will lead to the trend of movement of distribution identification, either aggregation distribution towards random distribution or the random distribution towards even distribution. The degree of deviation of the R -value is related to the position of the adjacent individual tree. Therefore, it is necessary to determine whether R needs to be revised, and the method of revision if it is applied.

Suppose r_i is the distance from the investigated target tree i to the nearest adjacent tree j , $d_{i \min}$ is the shortest distance among the ones between target tree to one of four sides of a sample plot. By comparing $d_{i \min}$ to r_i , it will define which tree in a sample plot will be affected by the boundary effect.

**Fig. 1** Border affection schedule

If $d_{i \min} > r_i$ (see Fig. 1b), R will not be affected by the boundary effect and there is no need for it to be revised. However, if $d_{i \min} < r_i$ (see Fig. 1a):

The boundary effect may occur; the value, $r_i - d_{i \min}$, will be the maximum error from the boundary effect if j is not i 's nearest adjacent tree. Accumulating all of those errors gives us:

$$r_m = \sum_{i=1}^m (r_i - d_{i \min}) \quad (2)$$

where r_m is the greatest error forming the boundary effect in a sample plot. The heterogeneity of the natural forest stand (it is impossible that all of those nearest adjacent trees are located closest to the border of a sample plot) will make the R -value smaller if it is directly revised with this error value. Therefore, the average distance among the actual forest trees will satisfy the following:

$$\frac{1}{n} \sum_{i=1}^n r_i \leq d \leq \frac{1}{n} \left(\sum_{i=1}^n r_i - r_m \right) \quad (3)$$

where d means the average distance among the observed nearest individual trees.

Calculating the middle value to the average distance, then:

$$d_0 = \frac{1}{n} \left(\sum_{i=1}^n r_i - \frac{r_m}{2} \right) \quad (4)$$

where d_0 means the average distance among nearest individual trees.

Therefore, the revised aggregation index is:

$$R = \frac{\frac{1}{n} \left(\sum_{i=1}^n r_i - \frac{r_m}{2} \right)}{\frac{1}{2} \sqrt{\frac{10000}{N}}} \quad (5)$$

4 Analysis of spatial pattern of the broad-leaved Korean pine forest

The Aggregation index in each sample plot and compartment was calculated based on the revised formula (5) (Table 2).

It was found that there are certain changes in the R -value among the different sample plots in the same stand (Table 2). This is mainly determined by the disturbance regime at several different sizes of patches, the biological characteristic of forest trees and adaptive strategy of forest tree species in the broad-leaved Korean pine forest. The forest trees in compartment 53, where the pioneer tree species were dominant, appear to have an aggregation distribution. However, it has a random distribution in compartments 52 and 54 at the stages of forest development and climax, respectively, where the companion tree species were dominant, since the R -value approaches 1.

The selection cutting in compartment 53 was about 20% in intensity; the compartment also had the most cases of large patches of clear areas. This caused the large openings in the forest stand, which allowed the pioneer tree species to easily occupy and grow fast. Then, some companion species, such as *Juglans mandshurica*, *Ulmus japonica* and *Fraxinus Manchurian*, appeared by natural regeneration in these areas. The regeneration in the undisturbed area of compartment 53 is still similar to the process as in the primitive forest.

Based on the tree positioning diagram, whatever pioneer

or companion tree species, for the same tree species, 2 individual trees growing in a group occurred in 26 places, a group of 3 trees in 7 places, 4 in 9 places, and 5 and 7 in only one place. Therefore, the forest trees presented the aggregation distribution in compartment 53 with certain changes of the R value in the different sample plots. Almost all of those pioneer and companion trees are able to regenerate by means of vegetative reproduction.

The intensity of selection cutting in compartment 52 was no more than 15%. This type of disturbance was individually selecting only the biggest trees in a forest stand, which will slightly affect the forest environment. The companion broad-leaf trees naturally regenerated. A development stage dominated with companion trees appeared through about 5 to 6 decades. These companion tree species requiring a similar ecological niche suffered from strong competition and the number of clumped trees of each tree species gradually dropped, which changed the spatial pattern of forest tree to a random distribution.

Compartment 54 was slightly disturbed and remained as the climax forest community of that forest type. The trees were randomly distributed to fully obtain the necessary resources in the stand and to maintain the stability of the forest community.

From the distribution of the nearest adjacent trees (Fig. 2), 50% of the nearest adjacent individuals were distanced within a range of 1 m in compartment 53, presenting a highly clumped distribution, and 34% and 35% in compartment 52 and 54, respectively. Some 28% of individual trees fell into the range of the average distance in compartment 53, and 35% in both compartments 52 and 54. Some 21% and 24% of individual trees were in the range of 2–3 m, 10% and 6% in the range of over 3 m in compartments 52 and 54, respectively. The distances among the nearest adjacent individuals vary on a small scale, which presented the trend of random distribution.

The changes of spatial pattern and of the distance among the nearest adjacent individuals resulted from the competition among different individuals of the same population and among different populations of forest tree species. The trees requiring similar ecological niche presents the stronger competition with the shorter distance among individual trees. This leads to a natural thinning of a forest stand to maintain a relatively stable stand for a certain period of time.

Table 2 The values of assembling index R at different compartments

Sample plot	1	2	3	4	5	6	7	8	9	10	Average
Compartment 53	0.83	0.85	0.69	0.63	0.73	0.76	0.79	0.66	0.74	0.84	0.75
Compartment 52	0.93	0.84	0.95	0.89	0.79	0.97	0.89	0.97	0.90	0.88	0.90
Compartment 54	0.94	0.88	0.92	0.89	0.96	0.87	0.88	0.82	0.95	0.94	0.91

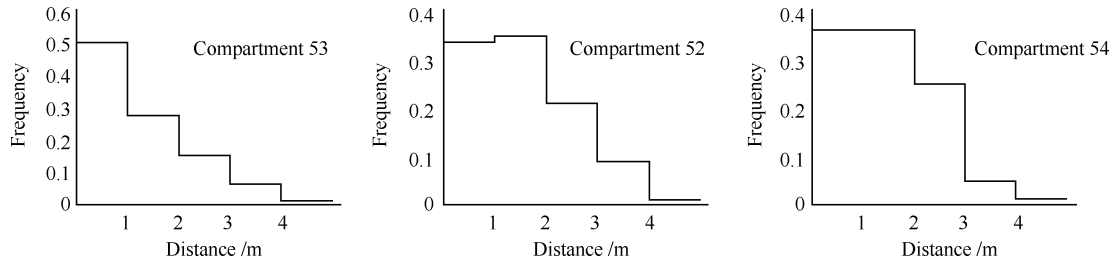


Fig. 2 The distribution frequency of average distance of the nearest neighbor trees

5 Conclusions

1. When calculating aggregation index R based on the data from sample plot, it is necessary to choose, according to data characteristics, a suitable method to adjust the boundary effect.

2. Due to the differentiation of ecological niche in the broad-leaved Korean pine forest, each tree was only a short distance away from the nearest adjacent individual tree. Getting the spatial pattern using aggregation index R obtained by the regular approach will be of limited use.

3. The analysis of the spatial pattern can only be used to explain the positioning of forest trees in the horizontal scale of a stand. It can be used to guide to planting, but can't reflect the mixture of tree species in a broad-leaved Korean pine forest. The forest management measure is suggested be made based on the succession stage of a forest stand and its spatial pattern in that stage.

Acknowledgements The local organizations of Natural Science Fund of Inner Mongolia (200408020521) and the Doctoral Fund of Inner Mongolia Agriculture University (BJ03-01) offered the fund and the kind help both in the field and the office during the fieldwork stage.

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