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POPULATION STRUCTURE AND SPATIAL DISTRIBUTION PATTERN OF DOMINANT TREE SPECIES OF FOREST COMMUNITIES IN THE XIAOWUTAI MOUNTAIN, CHINA

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Abstract

The point pattern analysis was applied for analyzing plant spatial distributions, predicting species associations, and providing an efficient representation of ecological process. *Pinus tabulaeformis* forest, *Betula platyphylla* forest, *Betula albo-sinensis* forest, *Larix principis-rupprechtii* forest in the Xiaowutai Mountain were selected as research objects, and four 50m×50m quadrats were set up. We measured diameter at breast height (DBH) and location of trees, and analyzed population structure, spatial distribution pattern, intraspecific and interspecific associations of dominant tree species in four forest communities by point pattern analysis and Monte-Carlo simulation test, in order to provide a theoretical basis and development strategies for natural resource protection in the areas. The results showed that a total of 166 vascular plant species in 49 families were recorded in quadrats. *Betula platyphylla* had the largest average and maximum of DBH among all plant species. *Betula albo-sinensis* had the largest average tree height, while *Betula platyphylla* had the maximum tree height among all plant species. *Pinus tabulaeformis* presented random distribution within 13.5m and cluster distribution outside 13.5m. *Betula platyphylla* presented random distribution on all the scales. *Betula albo-sinensis* and *Larix principis-rupprechtii* presented cluster distribution on the small scales and random distribution on the larger scales. The study also revealed that *Betula platyphylla* and *Acer mono* on the scale of 2.4m-22.5m, and *Betula albo-sinensis* and *Sorbus alnifolia* on the scale of 3.5m-7.5m had a significant negative correlation. Furthermore, *Pinus tabulaeformis* and *Larix principis-rupprechtii* were expanding populations mainly affected by intraspecific competition. *Betula platyphylla* and *Betula albo-sinensis* were stable populations respectively affected by interspecific competition, intraspecific and interspecific competition. Spatial distribution and species associations of four forest types were regulated by dispersal limitation and environmental heterogeneity in the Xiaowutai Mountain. We should effectively adhere to sustainable principles for protecting natural forest resources.

Key words: Population structure, Point pattern analysis, Forest community, Xiaowutai mountain.

Introduction

Analyzing spatial patterns in forest communities can deepen the understanding of population structure and growth of individual trees, and provide insights in the importance of different processes for community assembly and dynamics (Isabel *et al.,* 2010). Forest community showed plants congregated with physiognomy and structural characteristics in specific habitat. The spatial distribution pattern of dominant trees can reflect specific associations in forest community by point pattern analysis (Suzan-Azpiri *et al.,* 2007). The relationships between species spatial distribution pattern and environmental factors in forest communities have attracted much attention from ecologists (Giorgio *et al.,* 2011; Zunzunegui *et al.,* 2012). Many ecologists evaluated population distributions by point pattern analysis for studying ecological suitability and spatial pattern characteristics (Cheng *et al.,* 2013; Li *et al.,* 2015). Point pattern analysis was also applied in typical natural secondary forest communities for studying tree species associations (Hui *et al.,* 2007).

The population distribution along an age gradient can provide complementary information for forest structural dynamics from the perspective of conspecific interactions (Adewole *et al.,* 2013). The population diameter structure can reflect age structure, level structure, growth status and development trend of the population (Han *et al.,* 2009; Chen *et al.,* 2011). Competition should then increase during the stem exclusion stage, because of higher density and lower recruitment of understory tree species caused by increasing resource limitation, resulting in self thinning among canopy of trees (Bartels *et al.,* 2016). The analysis of the diameter at breast height (DBH) was helpful to understand community development, patch formation, the degree and rate of vegetation restoration, the driving force of succession (Yu *et al.,* 2012; Hansorg, 2002). Some studies showed that the original broad-leaved Korean pine forest was in a stable development state by simulating the dynamic variation of diameters in natural condition (Xie *et al.,* 2011).

The Xiaowutai Mountain is located at the intersection of Taihang Mountain, Yan Mountain, Heng Mountain and it has best preserved warm temperate forest ecosystems in North China. Previous research focused on floristic characteristics, forest community types, ecological niche (Bai *et al.,* 2016; Bai *et al.,* 2017). However, few studies focused on population structures and characteristics of dominant tree species in forest communities. If spatial interactions and mechanisms were indeed important for species coexistence, one would expect not only emergence of distinct intraspecific spatial structures, but also emergence of interspecific spatial patterns between species that could be detected when using appropriate techniques of spatial pattern analysis (Moloney, 1993). Methods of spatial point pattern analysis were ideally suited to analyze spatial association patterns in plant communities (Illian *et al.,* 2008). These methods allowed the quantification of spatial distribution and co-occurrence patterns of mapped positions of individual plants within a given study region. We focused on the structure and characteristics of dominant tree species in four forest types (*Pinus tabulaeformis* forest, *Betula platyphylla* forest, *Betula albo-sinensis* forest, *Larix principis-rupprechtii* forest), explored the reasons of individual distribution patterns, and revealed the population dynamics trend of communities impacted by environmental variation in order to scientifically manage and utilize forest resources in the protected areas.

Materials and Methods

Study area: The Xiaowutai Mountain is located at N39°50′-40°07′, E114°47′-115°29, Northwest of Hebei Province, China. It is the main peak of the Taihang Mountain Ranges, and the altitude varies from 1200 m to 2882m. It is the representative of warm temperate forest ecosystems in north China, and belongs to the warm temperate deciduous broad-leaved forest vegetation zone. The annual mean temperature is 6.4℃, the monthly mean temperatures of January and July are -12.3℃ and 22.1℃, respectively. Its annual rainfall is 400 to 700mm, and the frost-free period is 130 to 170 d. The vegetation of secondary shrub-grass zone, broad-leaved forest zone, mixed coniferous broad-leaved forest zone, subalpine meadow zone changes along the altitudinal gradients (Bai *et al.*, 2017). Rich biodiversity and complex floristic composition of the Xiaowutai Mountain create the unique economic status and important conservation value.

Site selection and data collection: A comprehensive investigation was conducted in the Xiaowutai Mountain from July to October in 2016 and four forest types of *Pinus tabulaeformis* forest, *Betula platyphylla* forest, *Betula albo-sinensis* forest， *Larix principis-rupprechtii* forest were selected as research objects. We selected the uniform and typical distribution quadrats and got four quadrats (50m × 50m). The ecological characteristics and habitat conditions of the four forest communities were shown in Tables 1 and 2. Each quadrat (50m × 50m) was divided into 25 small quadrats (10 m × 10 m), and we measured the spatial position, individual number, DBH, and height of dominant tree species in each small quadrat (Fig. 1). We wrote down every coordinate position of trees in each small quadrat, at the same time, used diameter at breast height caliper to measure DBH and used tree probe to measure tree height. The individual number of trees, shrubs, herbs were recorded and identified with the help of Flora of China.

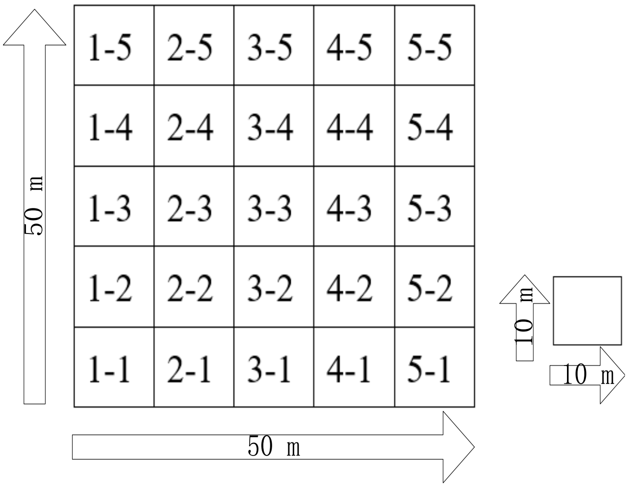

Fig. 1. Quadrats setting method.

Table 1. Community characteristics and habitat conditions of forest communities in the Xiaowutai mountain.

Quadrat No.	Altitude (m)	Slope (°)	Slope aspect	Litter layer thickness (cm)	Coverage of tree layer (%)	Coverage of shrub layer (%)	Coverage of herb layer (%)	Community characteristics	Soil pH
1	1288	27-32	north	8.5	55	25	35	Dominant tree species was uniform in *Pinus tabulaeformis* forest. $\overline{H}$=10.4m. Shrubs and herbs were scarce	7.6
2	1633	46-49	northwest	8	75	35	32	Species in tree layer were various and full of companion species in *Betula platyphylla* forest, $\overline{H}$ =10.27m. Shrubs and herbs were rich and various	6.7
3	1906	42-46	northeast	9	65	15	30	All the *Betula albo-sinensis* growed well and associated with little other species. $\overline{H}$=11.2m. Shrubs were scarce and herbs were various	6.5
4	2284	48-53	West	6	70	10	40	Dominant tree species was uniform in *Larix principis-rupprechtii* forest. $\overline{H}$=7.3m. Shrubs were scarce and uniform, however, herbs were various	6.1

Note: Quadrat 1 is *Pinus tabulaeformis* forest. Quadrat 2 is *Betula platyphylla* forest. Quadrat 3 is *Betula albo-sinensis* forest. Quadrat 4 is *Larix principis-rupprechtii* forest. $\overline{H}$ is average height of tree layer

Table 2. Species of *Pinus tabulaeformis* forest, *Betula platyphylla* forest, *Betula albo-sinensis* forest, *Larix principis-rupprechtii* forest in the Xiaowutai mountain.

	Shrub	Herb
Pinus tabulaeformis forest	*Rhododendron micranthum*	*Thalictrum petaloideum*
	Abelia biflora	*Artemisia sacrorum*
	Spiraea trilobata	*Lilium pumilum*
	Cotoneaster zabelii	*Dendranthema chanetii*
		Artemisia eriopoda
		Saussurea ussuriensis
		Atractylodes Lancea
		Asparagus trichophyllus
		Spodiopogon sibiricus
		Carex siderosticta
Betula platyphylla forest	*Syringa tomentella*	*Clematis macropetala*
	Corylus mandshurica	*Carex breviculmis*
	Betula dahurica	*Adenophora stricta*
	Rosa bella	*Gymnocarpium jessoense*
	Salix wallichiana	*Thalictrum sparsiflorum*
	Spiraea pubescens	*Phlomis umbrosa*
	Rhododendron micranthum	*Polygonatum odoratum*
	Syringa villosa	*Aster ageratoides*
		Pedicularis resupinata
		Veratrum nigrum
		Polygonum bistorta
		Sanguisorba officinalis
		Maianthemum bifolium
		Malus baccata
		Aquilegia yabeana
		Pyrola calliantha
		Artemisia mongolica
		Convallaria majalis
		Orobanche pycnostachya
		Polygonatum stenophyllum
		Lespedeza bicolor
Betula albo-sinensis forest	*Abelia biflora*	*Allantodia crenata*
	Lonicera elisae	*Thalictrum sparsiflorum*
	Rubus saxatilis	*Poa annua*
	Hydrangea bretschneideri	*Cardamine tangutorum*
	Syringa villosa	*Cimicifuga dahurica*
	Ribes mandshuricum	*Carex siderosticta*
	Rosa bella	*Carex hancockiana*
	Ribes himalense var. *verruculosum*	*Artemisia sacrorum*
	Lonicera szechuanica	*Paris verticillata*

Table 2. (Cont'd.).

	Shrub	Herb
		Aster tataricus
		Athyrium sinense
		Athyrium sinense
		Circaea alpina
		Adenophora paniculata
		Angelica cartilaginomarginata var. *foliosa*
		Carum carvi
		Euonymus przwalskii
		Phlomis umbrosa
		Libanotis condensata
		Aconitum barbatum var. puberulum
		Maianthemum bifolium
		Sect. Gracilis
		Angelica polymorpha
		Chionographis chinensis
Larix principis-rupprechtii forest	*Rhamnus utilis*	*Cnidium monnieri*
	Potentilla glabra	*Impatiens noli-tangere*
	Ribes himalense var. *verruculosum*	*Sanguisorba officinalis*
	Salix characta	*Eucalyptus tereticornis*
		Poa nemoralis
		Cortusa matthioli
		Primula maximowiczii
		Saussurea ussuriensis
		Valeriana officinalis
		Ligularia intermedia
		Cerastium arvense
		Pilea pumila
		Myosotis silvatica
		Scrophularia moellendorffii
		Taraxacum mongolicum
		Potentilla chinensis
		Veronica linariifolia
		Papaver nudicaule
		Cystopteris fragilis
		Carex coriophora
		Achnatherum sibiricum
		Bupleurum smithii
		Rhodiola dumulosa
		Galium verum
		Delphinium grandiflorum
		Dianthus superbus
		Silene gallica
		Aconitum monanthum

Data analysis

Population diameter structure class: The diameter at breast height (DBH) structure was used instead of age structure to analyze the population structure and dynamics. The DBH of trees was proportional to the growth age, and the larger DBH represented the older trees (Zhang *et al.*, 2010). The DBH class structure of the dominant species in quadrats were treated as follows (Table 3).

Table 3. The DHB class structure of the dominant species.

Class	DBH(cm)
I	＜2.5
II	2.5-5
III	5-10
IV	10-15
V	15-20
VI	20-25
VII	25-30
VIII	30-35
IX	35-40
X	＞40

Point patterns analysis: The population spatial distribution pattern and interspecific relationship were analyzed by Ripley's *K* function. The upper and lower package traces and confidence space were repeated 20 times to make the confidence level of 95% (Zhang, 2011).

$K(t) = \left(\frac{A}{n^2}\right)\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{I_t(u_{ij})}{W_{ij}}$ (i≠j) , u_{ij} is the distance between two points *i* and *j*. u_{ij}≤t, $I_t(u_{ij})$=1. u_{ij}>t, $I_t(u_{ij})$=0. W_{ij} is the ratio of and the perimeter (*i* as center, u_{ij} as radius) in the area A, $H(t) = \sqrt{\frac{K(t)}{\pi}} - t$. Random distribution, *H(t)*=0. Cluster distribution, *H(t)*>0. Uniform distribution, *H(t)*<0.

Monte-Carlo fitting test was used to calculate the confidence interval, fitting 20 times and confidence level 95%. T is the abscissa, the upper and lower package traces is the ordinate. If *H (t)* is within the package traces, it is random distribution. If *H (t)* is upper the package traces, it is cluster distribution. If *H (t)* is lower package traces, it is uniform distribution (Li, 2014).

Analysis of interspecific relationship

The relationship between the two species was analyzed by using the multivariate pattern analysis method. $K_{12}(t) = \frac{A}{n_1 n_2}\sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\frac{I_t(u_{ij})}{W_{ij}}$, n_1 and n_2 are the number of individuals of species 1 and 2, respectively. *I* and *j* represent individuals of population 1 and population 2, respectively. $H_{12}(t) = \sqrt{\frac{K_{12}(t)}{\pi}} - t$. If *H(t)*=0, two species are unrelated at t scale. If *H(t)*>0, two species are positive correlation. If *H(t)*<0, two species are negative correlation.

Monte-Carlo fitting test was used to calculate the confidence interval, fitting 20 times and confidence level 95%. The t is the abscissa, the upper and lower package traces is the ordinate. If *H (t)* is within the package traces, it is unrelated. If *H (t)* is upper the package traces, it is positive correlation. If *H (t)* is lower package traces, it is negative correlation (Li, 2014).

Results

In all the quadrats, we found 166 vascular plant species belonging to 49 families and 117 genera. Among them, 2 families, 5 genera and 5 species belonged to fern and 47 families, 112 genera and 161 species belonged to spermatophyte. In *Pinus tabulaeformis* forest, IV, V, VI class occupied a large proportion, reaching 75.5%. Among them, the trees in IV class accounted for the largest proportion, reaching 31.9%. The number of seedlings and saplings in II, III class was much larger than the old trees in VIII class. In *Betula platyphylla* forest, there were more IV, VI, VII class of mature trees. Seedlings and saplings were rare and the proportion was only 9.57%. Mature trees and old trees occupied a high proportion, reaching 90.43%. The figure of *Betula albo-sinensis* showed that the middle of DBH distribution was width and both sides were narrow. Saplings and old trees occupied a low proportion, only 10.8%. The proportion of mature trees reached 89.2%. Among them, the tree in the V class accounted for the largest proportion, reaching 36.3%. *Larix principis-rupprechtii* forest consisted of all seedlings, saplings and mature trees, and there were no old trees with DBH more than 25cm. Seedlings and saplings occupied a large proportion, reaching 41.5%. Mature trees occupied 48.5% of all the DBH class (Fig. 2).

In the four forest types, the average DBH of *Betula platyphylla* was the largest, reaching 20.54cm, followed by *Betula albo-sinensis*. *Larix principis-rupprechtii* average DBH was only 11.55cm. The maximum DBH of *Betula platyphylla* was 44cm, followed by *Betula albo-sinensis*, *Pinus tabulaeformis*, and *Larix principis-rupprechtii*. The order of average tree height was *Betula albo-sinensis* (11.22m), *Betula platyphylla* (10.27m), *Pinus tabulaeformis* (10.43m), *Larix principis-rupprechtii* (7.26m). The order of the maximum tree height of the four forest types was *Betula platyphylla* (22m), *Pinus tabulaeformis* (16m), *Betula albo-sinensis* (15.8m), *Larix principis-rupprechtii* (12.8m) (Fig. 3).

Species diversity in tree layer was rich, and the population density was 1148 plants / hm^2. There were 36 species of trees in our survey, and the density of different populations was significantly different. We studied the spatial distribution patterns and interspecific associations of *Pinus tabulaeformis*, *Betula platyphylla*, *Betula albo-sinensis*, *Larix principis-rupprechtii*. Figure 3 showed individual distributions of dominant tree species in quadrats (50 m × 50 m).

Pinus tabulaeformis occupied the whole quadrats and its density was larger. There was only *Pinus tabulaeformis* in *Pinus tabulaeformis* forest, no other tree species. In *Betula platyphylla* forest, the population density was not large because of the companion species such as *Acer momo*, *Populus davidiana*, *Quercus wutaishanica*, *Betula dahurica*, *Ulmus pumila*, *Salix wallichiana*. Among them, *Betula platyphylla* and *Acer momo* were mainly dominant trees, therefore, there were only these two species in the figure. *Betula albo-sinensis* forest showed relatively sizable and regular. There were only *Betula albo-sinensis* and *Sorbus alnifolia* in *Betula albo-sinensis* forest. Forest gap was small and random distribution in the quadrats. *Betula albo-sinensis* associated with a small amount of *Sorbus alnifolia*. In *Larix principis-rupprechtii* forest, forest species density was large. There were no companion species in the tree layer. *Larix principis-rupprechtii* showed random distribution (Fig. 4).

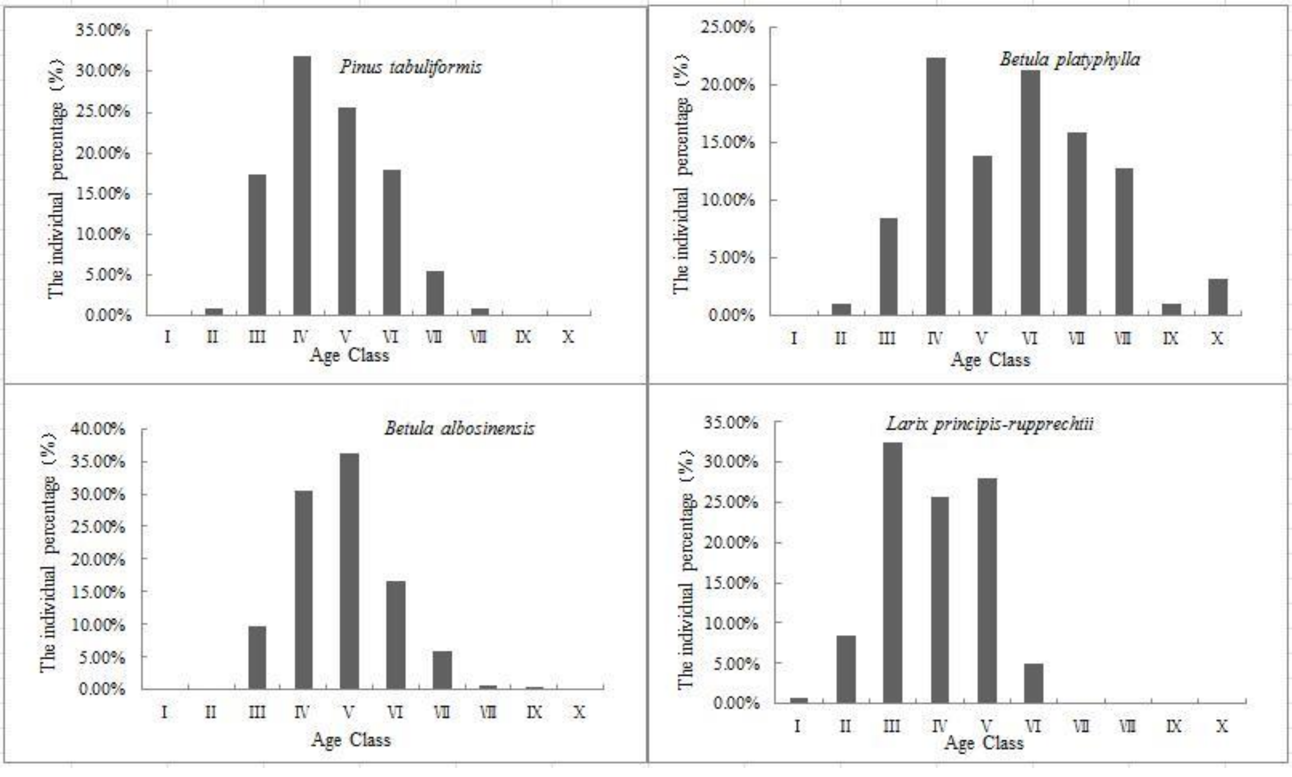

Fig. 2. DBH structures of *Pinus tabulaeformis, Betula platyphylla, Betula albo-sinensis, Larix principis-rupprechtii* in the forest communities.

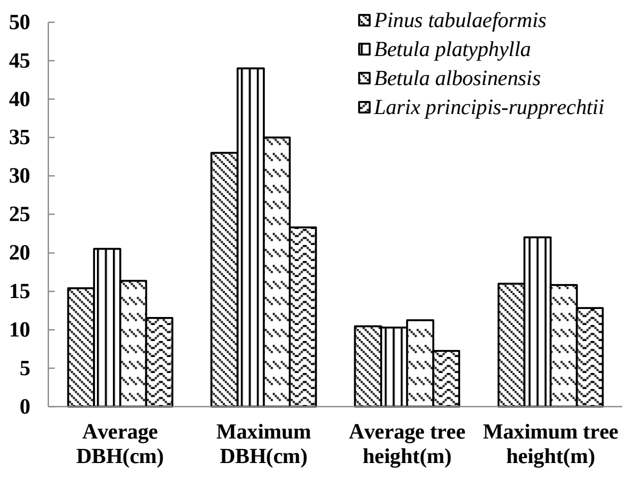

Fig. 3. Average DBH, maximum DBH, average tree height, maximum tree height of *Pinus tabulaeformis*, *Betula platyphylla*, *Betula albo-sinensis*, *Larix principis-rupprechtii* in the forest communities.

The population of *Pinus tabulaeformis* showed random distribution on the scale of 0m-13.5m, cluster distribution on the scale of 13.5m-25m (Fig. 5a). The *Betula platyphylla* population showed random distribution on all scales (Fig. 5b). The *Betula albo-sinensis* population showed a cluster distribution on the scale of 0-5.9 m, and when it was larger than 5.9m it showed a random distribution (Fig. 5c). In *Larix principis-rupprechtii* forest, it showed cluster distribution on the scale of 0-5.5m, and random distribution on the scale of 5.5-25m (Fig. 5d).

Discussion

The comprehensive spatial analysis of species distributions and associations among dominant tree species revealed a variety of spatial structures (Kang *et al.*, 2013). We mainly discussed DBH structure instead of age structure to analyze population development trends. We found that there were number of mature *Pinus tabulaeformis* trees in the communities and they was a stable growing population where seedling regeneration rate was greater than death rate. They were distributed was at low altitude which was sunny and comfortable for growth. They did have large DHB, but they were very tall. Species with the same association usually inhabited the same area, which gave them more opportunity to interact (Luo *et al.*, 2012). *Betula platyphylla* population with weaker updating capability and larger age percentage was affected by many other tree species, mainly with *Populus davidiana*, *Acer momo*, *Quercus wutaishanica*, *Salix wallichiana*, *Salix sinica*. It was a stable population now, but it would be a recession and downward trend in the future. Biology characteristics of the population and habitat conditions decided population structure (Borcard & Legendre, 1994). The height and breast of dominant trees in different forest communities was different and revealed vertical structure characteristics (Hu *et al.*, 2009). *Betula albo-sinensis* was shade-tolerant, mature and high, and they were distributed at high altitude. Their population was a stable population for a long time, so we should keep on reasonable protection. *Larix principis-rupprechtii* with more generated seedlings was an expanding population. They owned smaller DHB and tree height, and distributed at high altitude.

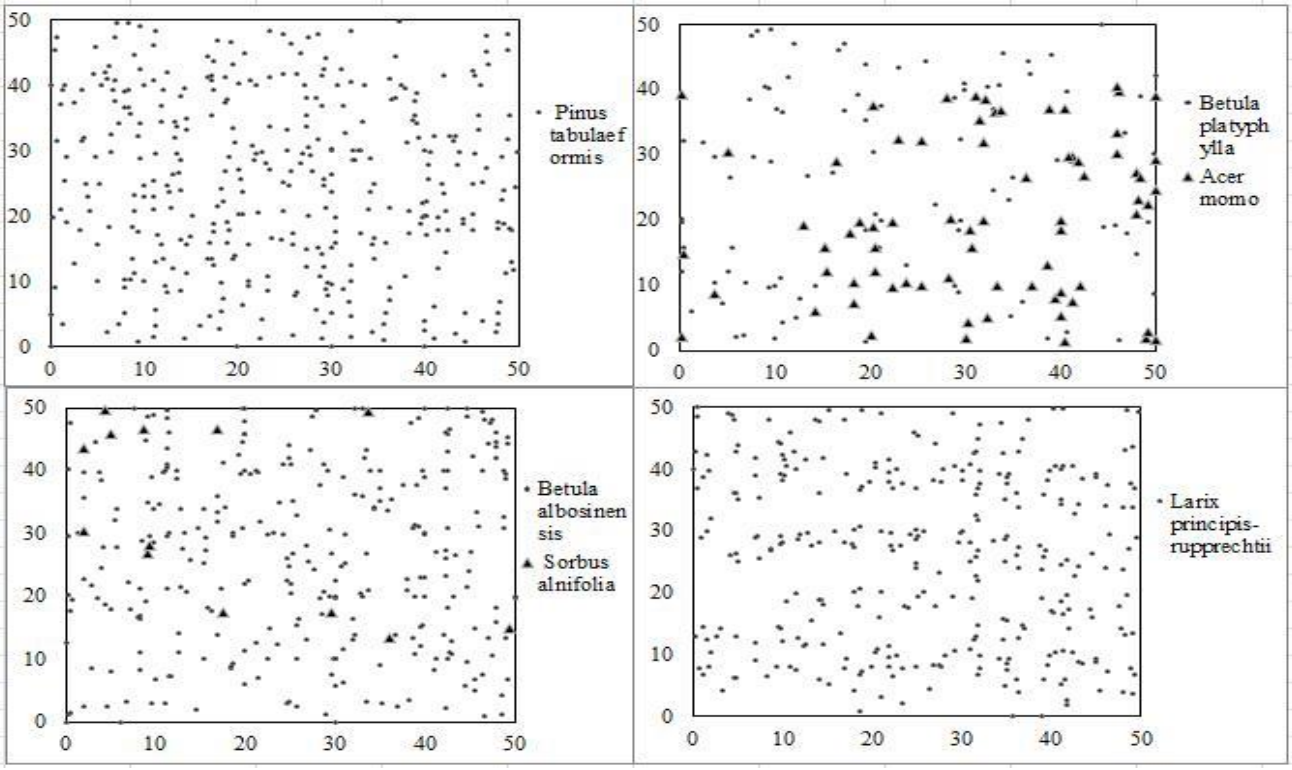

Fig. 4. Spatial distribution of dominant species in *Pinus tabulaeformis* forest, *Betula platyphylla* forest, *Betula albo-sinensis* forest, *Larix principis-rupprechtii* forest (The vertical and horizontal coordinates of the graph represented 50m, and the individual coordinate values of trees were expressed by the measured distance.).

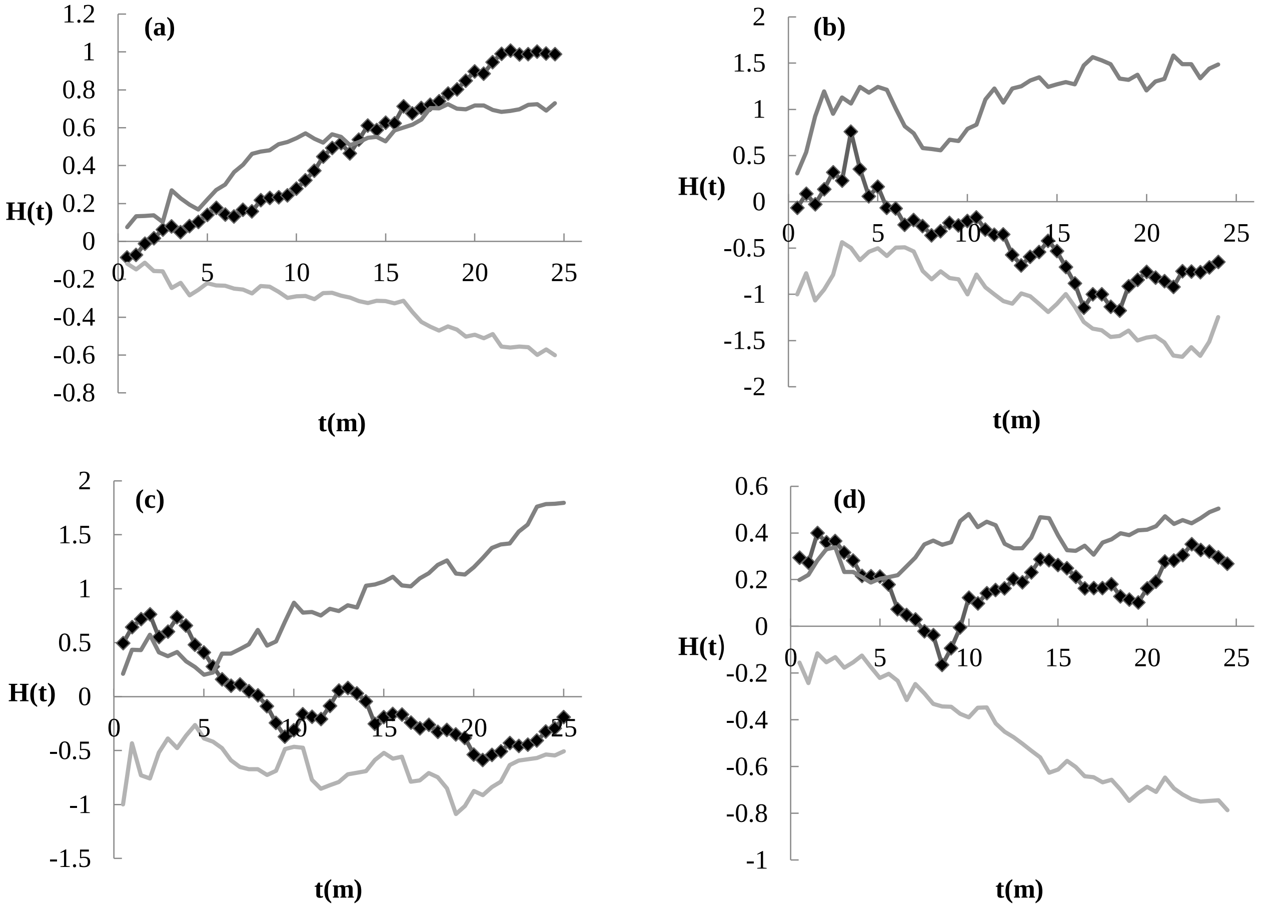

Fig. 5. Point pattern analysis for *Pinus tabulaeformis*, *Betula platyphylla*, *Betula albo-sinensis*, *Larix principis-rupprechtii* forest (X axis means distance scales. Y means determining index values of point distance distribution pattern).

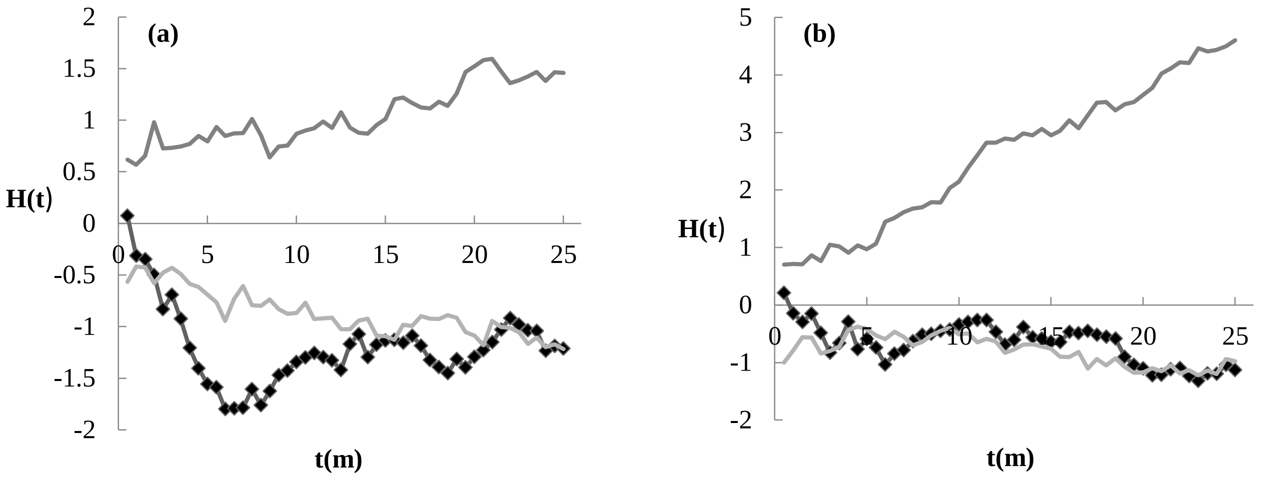

Fig. 6. Point pattern analysis of dominant species associations of the forest communities (X axis means distance scales. Y means determining index values of point distance distribution pattern) Fig. 6 showed interspecific relationship of two groups. There was no significant correlation on the scale of 0-2.4m, 22.5m-25m between *Betula platyphylla* and *Acer mono*. However, they showed a significant negative correlation on the scale of 2.4m-22.5m (Fig. 6a). As for *Betula albo-sinensis* and *Sorbus alnifolia,* there was no significant correlation on the scale of 0m -3.5m and 7.5m-25m. However, they showed a negatively correlation on the scale of 3.5m-7.5m (Fig. 6b).

Whatever coexistence mechanisms are operating in the forest, they should leave a spatial signature. Space can be used as a surrogate for uncovering ecological progress through the study of spatial patterns (Yue *et al*., 2008). We found that main distribution patterns of forest communities in the Xiaowutai Mountain basically characterized by random distribution. Different population spatial distribution pattern showed different trends by scale variation (Kang *et al.*, 2007; Sana *et al.*, 2018). The study revealed that *Pinus tabulaeformis* showed random distribution in a small scale because of moderate slope and uniform community environment. The population continued developing, and required more lights and nutrients. The population density was increasing so that they showed cluster distribution at a large scale. As the increasing scales, the population distribution was affected by intraspecific competition. *Betula platyphylla* had a stronger initiation power and adaptability. The shortage of natural resources caused interspecies competition, such as sunshine, soil and water. There were so many companion species in the *Betula platyphylla* forest and interspecific competition happened more often than intraspecific competition. Therefore, *Betula platyphylla* showed a random distribution in scales. *Betula platyphylla* and *Acer mono* were significantly irrelevant in extremely small scales and large scales. They were negative correlation on the scale of 2.4-22.5m and competition relationship was relatively strong. Community composition and structure were unstable and they were in the transition phase from primary stage to mid-stage of vegetation succession (Kraft *et al.*, 2007; Sehrish *et al.,* 2017). The result was consistent with previous scholars (Guo *et al.*, 2004). *Betula albo-sinensis* and *Larix principis-rupprechtii* were aggregated at small scales, and showed random distribution at larger scales. As the age and size growth of *Betula albo-sinensis*, environmental factors restricted species distribution patterns and intraspecific competition appeared. With the population self-thinning, the transition happened from cluster distribution to random distribution. There was negative correlation between *Betula albo-sinensis* and *Sorbus alnifolia* on the scale of 3.5m-7.5m. *Sorbus alnifolia* had a certain influence on *Betula albo-sinensis* distribution on small scale and then interspecies competition appeared. The quantity of *Sorbus alnifolia* was minimal, and they didn't affect each other on relatively large scales. The number of *Betula albo-sinensis* population was moderate and age structure was stable, so they would exist in this way in a long time accompanied with intraspecific and interspecific interactions. Low frequency of species was a reason that resulted in low percentage of significant species interactions. If most species were present at low abundances relative to the number of species, chance alone would make it unlikely that they encounter each other as neighbors (Perry *et al*., 2009). *Larix principis-rupprechtii* population was in growing stage. Light intensity and temperature leaded to cluster distribution at small scales. Because of interspecific competition, they showed a random distribution in larger scales.

Conclusion

The study analyzed population structures, interspecific associations and spatial distribution patterns of four forest communities in the Xiaowutai Mountain. *Pinus tabulaeformis*, *Pinus tabulaeformis*, *Larix principis-rupprechtii* population were in growing or stable stage, while *Betula platyphylla* population had recession trend in the future. We should effectively protect all kinds of natural resources according to the principle of sustainable development, and strengthen monitoring of forest community structure. Furthermore, plant resources protection is necessary because rich biodiversity and complex floristic composition of the Xiaowutai Mountain can create the unique economic values in North China.

Acknowledgments

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