Postprint: Spatial Pattern of Mongolian Oak (Quercus mongolica) Population in Natural Secondary Forest

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Date: 2018-05-29T00:00:00+00:00

Abstract

Taking the Mongolian oak (Quercus mongolica) population in Mongolian oak natural secondary forests as the research object, two 1hm² sample plots (Plot A and Plot B) with different community composition and structure were established in the Tazigou Forest Farm of Wangqing Forestry Bureau, Jilin Province. Using the adjacent grid survey method, each plot was divided into 100 survey units of 10m×10m, the spatial coordinates (X, Y) of each tree within the units were precisely located, and basic information of all trees with diameter at breast height (DBH) 1cm was surveyed. Using the method of diameter classes as a proxy for age, Mongolian oaks were divided into four different growth stages: Age class I (1cm DBH < 10cm), Age class II (10cm DBH < 20cm), Age class III (20cm DBH < 30cm), and Age class IV (DBH 30cm). Univariate and bivariate pair correlation functions, mark correlation function, and mark variogram were used to analyze the spatial distribution patterns of Mongolian oak populations in different communities at various spatial scales. The results showed that: (1) In both plots, Mongolian oaks showed random distribution at large scales, while clumped distribution was mainly concentrated at small and medium scales, which was primarily caused by the intense aggregation of age class I and II Mongolian oaks at small and medium scales; no uniform distribution pattern was observed in either plot; the scale and intensity of aggregation of Mongolian oaks in Plot A were significantly greater than those in Plot B; (2) In Plot A, positive associations among age class I, II, and III Mongolian oaks were observed at small and medium scales, while negative associations occurred between higher and lower age classes, particularly between age class IV and age classes I and II; whereas in Plot B, almost no negative association patterns appeared, with no association being dominant among age classes, accompanied by small-scale and low-intensity positive associations; (3) The spatial autocorrelation of Mongolian oaks in Plot A was relatively strong, particularly in terms of tree DBH; in contrast, the spatial autocorrelation of DBH and tree height in Plot B was weakened. These results indicate that the spatial scale of the study, the growth stage of the species, and the developmental degree of the community all affect the spatial distribution patterns of Mongolian oak populations. This study helps to deepen understanding of the current status, growth characteristics, and development trends of Mongolian oak and Mongolian oak secondary forests, and can provide references for the sustainable management of large-area Mongolian oak natural secondary forests in the forest regions of Northeast China.

Full Text

Spatial Patterns of *Quercus mongolica* Populations in Natural Secondary Forests

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Abstract

Spatial signatures often reveal ecological processes, and spatial pattern analysis is an important method for studying population characteristics, interspecies relationships, and the relationships between populations and their environment. Due to the distinctive characteristics and current situation of *Quercus mongolica* in China, it is necessary to investigate the ecological processes in *Q. mongolica* populations within *Q. mongolica* stands. To understand the status and development tendency of natural secondary forest, its spatial patterns were studied based on two *Quercus mongolica* permanent sample plots (Plot A and Plot B) with different compositions and structures (i.e., different coenotypes) over an area of $1\ \text{hm}^2$ (100 m × 100 m) in Tazigou Forest Farm of Wangqing Forestry Bureau, Jilin province. The essential features, which include species identity, diameter at breast height (DBH), tree height, clear bole height, crown breadth, and coordinate information of each tree (DBH   1 cm), of the two plots were surveyed by the adjacent grid method (10 m × 10 m). Using the method of diameter class (instead of age), *Q. mongolica* was divided into four different growth stages: Stage I (1 cm   DBH < 10 cm), Stage II (10 cm   DBH < 20 cm), Stage III (20 cm   DBH < 30 cm), and Stage IV (DBH   30 cm). In accordance with spatial point pattern theory, univariate pair-correlation function (UPCF), bivariate pair-correlation function (BPCF), mark correlation function (MCF), and mark variogram function (MVF) were adopted to evaluate the spatial patterns of *Q. mongolica* in different communities at various scales.

The results showed that: (1) All populations in the two plots showed random spatial distribution at large scales, and aggregated distribution was mainly concentrated at medium and small scales. The aggregated distribution at stages I and II at medium and small scales was the primary cause for this phenomenon. Uniform distribution was not observed in the two plots at all scales. The aggregated distribution of *Q. mongolica* in Plot A was stronger than that in Plot B. (2) The spatial associations among stages I, II, and III in Plot A were positive at medium and small scales. The spatial associations between older and younger age classes were negative, especially between stages IV, I, and II. In Plot B, however, negative spatial association was scarcely observed at all scales. The relationships between different stages were mostly uncorrelated with positive spatial association at small scale and low intensity. (3) The spatial autocorrelation of Plot A was stronger than that of Plot B, and the conspicuous expression mainly appears at DBH. The spatial autocorrelation of Plot B for DBH and height was weakened to some extent compared to that of Plot A. These results demonstrated that the spatial patterns of *Q. mongolica* were affected by the space scale of the sample plot, the growth stage of species, and the developmental stage of the community. This helps us to understand the current situation, growth characteristics, and developmental tendency of *Q. mongolica* population and its natural secondary forest, and can provide an important reference for sustainable forest management and ecosystem conservation in the natural secondary forest area of northeast China.

Keywords: natural secondary forest; *Quercus mongolica*; distribution pattern; association; spatial autocorrelation

Introduction

Quercus mongolica (Fagaceae) is the main tree species of mixed broadleaf-conifer forests in Northeast China and the northernmost distributed deciduous oak species in China. Natural secondary forests dominated by *Q. mongolica* account for 15%-20% of forested land area, representing the xerophytic succession result after continuous natural disturbance and anthropogenic destruction of original broadleaf-Korean pine forests [1-2]. Although *Q. mongolica* forests are widely distributed in Northeast and North China, most existing stands show poor growth and inferior timber quality, which does not match the long-standing management objective emphasizing timber production in China. Research on *Q. mongolica* or *Q. mongolica* secondary forests has been insufficient [3]. However, *Q. mongolica* features hard wood, making it excellent industrial and furniture timber, with strong environmental adaptability and significant roles in windbreak, fire prevention, water conservation, and soil retention. As forest ecological benefits receive increasing attention, more in-depth research on *Q. mongolica* and its secondary forests is urgently needed.

Current research on *Q. mongolica* mainly focuses on physiological characteristics [4-5], community structure [6-8], ecological functional features [9-11], growth and yield prediction models [12-13], habitat response and interactions [14-16], and forest management and simulation [17-18], while studies on population spatial distribution and associations remain limited. Population spatial pattern refers to the horizontal spatial configuration of population individuals, which results from the combined effects of biological and abiotic factors within communities. In-depth analysis of population spatial patterns can reveal intraspecific and interspecific relationships, as well as population selection and adaptation mechanisms to habitats. This has important theoretical and practical significance for efficient land use, forest quality improvement, and ecological environment enhancement [19-20].

This study investigates the spatial patterns of *Q. mongolica* populations at multiple scales in different community types, aiming to provide theoretical foundations for ecosystem conservation and sustainable management of *Q. mongolica* forests. Specifically, we: (1) use univariate pair-correlation function (UPCF) to study the spatial distribution patterns of *Q. mongolica*; (2) use bivariate pair-correlation function (BPCF) to analyze spatial associations among different age classes of *Q. mongolica* in different community types; and (3) use mark correlation function (MCF) and mark variogram (MVF) to examine the spatial autocorrelation of *Q. mongolica* tree factors.

1. Study Area

The study area is located in Tazigou Forest Farm of Wangqing Forestry Bureau, Jilin Province (129°56 -131°04 E, 43°05 -43°40 N), belonging to a mountainous and hilly region with temperate continental monsoon climate. The mean annual temperature is 3.9°C and mean annual precipitation is 547 mm. The main vegetation includes *Quercus mongolica*, *Betula platyphylla*, *Populus ussuriensis*, *Tilia amurensis*, *Abies nephrolepis*, *Fraxinus mandshurica*, *Acer mono*, *Pinus koraiensis*, *Ulmus japonica*, and *Betula dahurica.*

2. Plot Setup and Survey

Based on comprehensive reconnaissance, two 1 hm^2 (100 m × 100 m) permanent plots were established in 2016 in areas with concentrated *Q. mongolica* distribution and good stand conditions. Both plots have *Q. mongolica* as the dominant species, but differ significantly in associated tree species composition. According to community structure and succession theory, Plot A represents a more stable community (broadleaf-Korean pine forest), while Plot B contains many pioneer species, indicating an earlier successional stage.

Using the adjacent grid method, each plot was divided into 10 m × 10 m survey units. All trees with DBH 1 cm were measured for species, DBH, height, clear bole height, crown width, and spatial coordinates (X, Y), with each tree tagged individually. Cement markers were buried at the four corners of each subplot, with the southwest corner as the origin. Plot statistics are shown in .

** Basic conditions of sample plots**

Note: “色” = Acer mono, “杨” = Populus ussuriensis, “蒙” = Quercus mongolica, “臭” = Abies nephrolepis, “桦” = Betula platyphylla, “椴” = Tilia amurensia, “红” = Pinus koraiensis, “白” = Betula dahurica*.

Since *Q. mongolica* has hard wood unsuitable for age determination with increment borers, and the sample trees require long-term observation without disturbance, we used diameter class as a proxy for age. Considering that within similar habitat conditions, diameter variations of the same species can reflect age structure and vertical spatial hierarchy [21-22], and based on *Q. mongolica* growth characteristics and static growth process tables from Wangqing Forestry Bureau, we divided *Q. mongolica* into four growth stages: Stage I (1 cm DBH < 10 cm), Stage II (10 cm DBH < 20 cm), Stage III (20 cm DBH < 30 cm), and Stage IV (DBH 30 cm). The distribution of each stage is shown in [Figure 1: see original paper].

[Figure 1: see original paper] Spatial distribution map of *Quercus mongolica* in Plot A and Plot B

3. Data Processing

3.1 Univariate Pair-Correlation Function The univariate pair-correlation function $g(r)$ was used for spatial point pattern analysis of overall and different age classes of *Q. mongolica*. It calculates the probability density function of *Q. mongolica* individuals within a circular ring of radius r and specified width, with any *Q. mongolica* as the center. The formula is given in references [23-25].

Complete Spatial Randomness (CSR) was used as the homogeneous Poisson process null model. Considering the plots are secondary forests where *Q. mongolica* populations with strong adaptability may have potential habitat heterogeneity at larger scales that could affect spatial pattern analysis, we also used Gaussian smoothing function (GSF) as the heterogeneous Poisson process null model to determine density gradients for comparative analysis. Monte-Carlo simulations were used for significance testing of deviations from randomness. If the value is above the confidence interval, trees show aggregated distribution; within the interval, random distribution; below the interval, uniform distribution.

3.2 Bivariate Pair-Correlation Function The bivariate pair-correlation function $g(r)$ was used to analyze spatial associations among different age classes. The formula is given in references [23-25]. In this analysis, i and j represent individuals from different age classes, with other symbols consistent with the univariate formula.

Since older age class trees established earlier in the community, we used the antecedent condition (AC) null model, assuming younger age class distribution is influenced by older age class positions. Monte-Carlo simulations were used for significance testing: values above confidence intervals indicate positive correlation, within indicate independence, and below indicate negative correlation.

3.3 Mark Correlation Function and Mark Variogram The mark correlation function k (r) and mark variogram (r) were used to analyze spatial autocorrelation of *Q. mongolica* populations in different community types. The normalized mark correlation function containing test function f was used to quantify similarity of DBH and height between two trees at scale r. If k (r) is above confidence interval, trees with similar DBH/height tend to aggregate; below indicates aggregation of trees with different DBH/height; within indicates no spatial autocorrelation. Independent marking (IM) was used as the null model. Significance testing was the same as above.

Note that when Type I error occurs, Monte-Carlo simulated confidence intervals cannot accurately provide expected statistical ranges for null models, requiring Goodness-of-fit (GoF) tests. GoF compresses scale-based function statistics into a single index u, representing cumulative deviation between observed and expected statistics across scales. When $P < 0.05$, the difference is considered significant [25-27].

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1. Tree Spatial Distribution Patterns

Preliminary observation shows both plots have clustered distribution of *Q. mongolica* populations, typical of secondary forests, though the clustering forms differ significantly. Statistical analysis confirms significant aggregated distribution in both plots, but with substantial differences in aggregation scale and intensity.

Both plots show significant aggregation at small scales (2-4 m). Plot A also shows significant aggregation at medium scales (17 m, 26 m), while Plot B shows only sporadic weak aggregation at small scales. In terms of aggregation intensity, except for slightly stronger intensity at 17 m and 26 m scales, Plot A' s aggregation intensity gradually decreases and approaches random distribution at other scales. Plot A' s aggregation intensity is generally greater than Plot B' s. As observation scale increases, both plots show weakening aggregation, but Plot B' s decline is more dramatic, suggesting potential habitat heterogeneity in Plot A [Figure 2: see original paper].

[Figure 2: see original paper] Spatial distribution patterns of *Quercus mongolica* in Plot A and Plot B

At the age-class level, both plots show a transition from aggregated to random distribution with increasing age class. Stage IV shows random distribution in both plots. Stages I, II, and III show strong aggregated distribution at relatively large scales and high intensity in Plot A, while Plot B shows smaller distribution scales. The main differences occur at Stage III, where Plot A shows relatively large and strong aggregation, while Plot B shows smaller, weaker aggregation [FIGURE:3, FIGURE:4].

[Figure 3: see original paper] Spatial distribution patterns of each stage of *Quercus mongolica* in Plot A

[Figure 4: see original paper] Spatial distribution patterns of each stage of *Quercus mongolica* in Plot B

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2. Tree Spatial Associations

Statistical results show significant differences in associations among age classes between the two plots. In Plot A, Stages I, II, and III show significant positive associations at medium and small scales, while negative associations occur between older and younger age classes, particularly between Stage IV and Stages I and II. In Plot B, negative spatial associations are scarcely observed at any scale. Relationships among different stages are mostly uncorrelated, with positive spatial associations at small scales and low intensity.

In Plot A, associations among age classes are scale-dependent: positive at small-medium scales, negative at large scales. Except for weak negative associations between Stage IV and Stage I at large scales, other age classes show almost no negative associations, mainly showing uncorrelated and positive patterns. Stages I and II show positive associations at small-medium scales. In Plot B, no significant associations appear among age classes [FIGURE:5, FIGURE:6].

[Figure 5: see original paper] Spatial associations of different stages of *Quercus mongolica* in Plot A

[Figure 6: see original paper] Spatial associations of different stages of *Quercus mongolica* in Plot B

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3. Tree Spatial Autocorrelation

Both plots show some degree of spatial autocorrelation in DBH and tree height of *Q. mongolica*, but with different patterns. In Plot A, significant positive spatial autocorrelation appears at multiple scales (1-18 m, 21-24 m, 28 m, 30 m), with trees showing positive autocorrelation having DBH smaller than the stand average. Plot B shows similar but only sporadic positive autocorrelation at small scales, with values close to the stand average. Spatial autocorrelation for tree height shows weak positive correlation in both plots. The spatial autocorrelation exists mainly in DBH in Plot A and in tree height in Plot B, weakening and disappearing with increasing scale [FIGURE:7, FIGURE:8].

[Figure 7: see original paper] Spatial autocorrelation of *Quercus mongolica* in Plot A

[Figure 8: see original paper] Spatial autocorrelation of *Quercus mongolica* in Plot B

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3. Conclusion and Discussion

This study investigated spatial patterns of *Q. mongolica* populations in different community types at various scales, examining overall and age-class-specific distribution patterns, spatial associations among growth stages, and spatial autocorrelation of DBH and height. This contributes to understanding the survival status, growth mechanisms, and development patterns of *Q. mongolica* populations.

Regarding spatial distribution patterns, both plots show aggregated distribution transitioning to random distribution with increasing observation scale. Plot A has larger aggregation scales and stronger intensity than Plot B, likely related to different community structures and successional stages. Plot A, being closer to the original climax community, is more stable, while Plot B, at an earlier successional stage with unstable community structure and light-demanding pioneer species dominance, shows aggregated patterns at larger scales and intensities. *Q. mongolica* has extremely strong adaptability, and aggregated distribution can improve population resistance to adverse environmental conditions.

Analysis of different age classes shows that the overall aggregated distribution of *Q. mongolica* is mainly influenced by small-medium diameter trees within the population, consistent with findings by Fan Houbao et al. [28] in *Q. mongolica* secondary forests. Neither plot shows uniform distribution at any scale, aligning with previous studies concluding that uniform distribution rarely occurs in natural forests [29].

Regarding spatial associations, Plot A shows negative associations between older and younger age classes at small-medium scales, while Plot B shows almost no negative associations. This aligns with studies on *Quercus liaotungensis* [21] and suggests that habitat heterogeneity intensifies asymmetric competition, accelerating succession. Plot B's lack of negative associations may indicate it has reached a higher successional level than Plot A. The community experiences a relatively long stable period, with most *Q. mongolica* populations having passed the intense density-dependent competition stage, reaching balance among age classes.

Positive associations among low age classes in both plots may result from: (1) *Q. mongolica* seed dispersal mechanisms and strong sprouting ability—large seeds with poor dispersal capacity concentrate around mother trees, and sprouting causes both seedling and sprout regeneration to show strong aggregation; (2) intraspecific asymmetric competition—even after self-thinning and growth differentiation, individuals of similar size maintain coordinated relationships [32].

For spatial autocorrelation, both plots show positive autocorrelation, but Plot A' s is stronger and mainly expressed in DBH, while Plot B' s is weaker and mainly in tree height. As community succession progresses, spatial autocorrelation of dominant *Q. mongolica* populations tends to weaken or disappear, similar to findings in tropical rainforest communities [33]. The weak spatial autocorrelation in tree height in Plot B may relate to community structure and small-scale environmental heterogeneity.

Spatial patterns in both plots change with scale, showing strong scale-dependence. As scale increases, *Q. mongolica* populations move toward stable states of random distribution, no association, and no spatial autocorrelation. Species interactions mainly occur at small-medium scales below 30 m, likely related to crown size and root distribution range. Deviations from null models at scales above 30 m may result from habitat heterogeneity [34].

The two plots differ in successional sequence, with Plot A closer to the original climax community. The spatial pattern of the dominant *Q. mongolica* population reflects the community' s overall spatial pattern and guides community development direction. As succession proceeds, *Q. mongolica* populations and secondary forest communities will develop further toward random distribution and no spatial autocorrelation, eventually reaching a climax dynamic equilibrium, consistent with Jacquemyn et al. [35].

While analyzing *Q. mongolica* spatial patterns can reflect ecological functions and processes from temporal and spatial dimensions, these complex comprehensive effects cannot be fully revealed by this study alone. Further research is needed on relationships between *Q. mongolica* populations and other populations, as well as interactions between habitat factors and *Q. mongolica* populations, to provide more comprehensive theoretical and practical references for sustainable forest management.

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Note: Figure translations are in progress. See original paper for figures.