Postprint: Interspecific Associations of Dominant Tree Populations in Quercus acutissima Community in Qiaoshan Forest Area

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Abstract

Using the variance ratio method (VR), Chi-square test based on 2×2 contingency tables, association coefficient (AC), percentage of co-occurrence (PC), and point correlation coefficient Φ, interspecific associations among the top 17 arborous populations by importance value in the Quercus acutissima community of Qiaoshan forest region were measured and analyzed. The results indicated that: the 17 major arborous populations in the Quercus acutissima community of Qiaoshan forest region showed overall non-significant negative association, with species tending toward independence and the community being overall unstable; Chi-square test results revealed that among 136 species pairs of the 17 major species, positive associations comprised 44.85%, negative associations comprised 55.15%, with the vast majority being non-significant associations, suggesting weak interspecific associations and that the community was in an unstable successional stage; analyses of both association coefficient AC and percentage of co-occurrence PC demonstrated that the 17 major species had differing overall habitat requirements, with low probability of simultaneous occurrence for species pairs; point correlation coefficient Φ measurements showed 62 positively associated species pairs (45.59% of total pairs) and 74 negatively associated species pairs (54.41% of total pairs); based on population cluster analysis, interspecific association measurements, and ecological habits, the 17 major populations were classified into three ecological species groups.

Full Text

Preamble

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Interspecific Association of the Main Tree Populations of the *Quercus acutissima* Community in the Qiaoshan Forest Area

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Abstract

This study analyzed the interspecific associations among the 17 dominant tree populations in the *Quercus acutissima* community of the Qiaoshan forest area using the variance ratio (VR) method, chi-square (²) test, association coefficient (AC), percentage co-occurrence coefficient (PC), and point correlation coefficient (Φ), all based on 2×2 contingency tables. The results showed that the 17 tree populations exhibited no significant negative correlation overall, with species tending toward independent distribution and the community displaying instability. Among the 136 species pairs of the 17 dominant populations, 44.85% showed positive association and 55.15% showed negative association, with the vast majority being non-significant. This indicates weak interspecific associations among tree populations and an unstable successional stage. Analysis of AC and PC revealed that the 17 main populations had different habitat demands, with low probability of simultaneous occurrence for most species pairs. The Φ measurement showed that 62 species pairs (45.59%) had positive association and 74 pairs (54.41%) had negative association. Based on cluster analysis, interspecific association results, and ecological characteristics, the 17 main populations were divided into three ecological species groups.

Keywords: Qiaoshan forest area; *Quercus acutissima* community; interspecific association; ecological species groups

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Introduction

Interspecific association refers to the spatial correlation among different species within a community, encompassing both spatial distribution relationships and functional dependencies between species. It describes the external manifestation of species relationships and reflects the outcomes of interspecific competition or

the current state of the community. As a fundamental characteristic of community structure and a basis for community classification, interspecific association is crucial for understanding species interactions, community composition, and dynamics. It not only reflects the structural characteristics of community composition at the current stage but also largely indicates future community dynamics, successional trends, and processes.

Ecological species groups represent combinations of species with similar ecological habits within a community, reflecting relationships among species and their adaptation to environmental factors and dominant ecological conditions. *Quercus acutissima*, a deciduous tree of the Fagaceae family, is widely distributed in warm temperate and subtropical regions. Due to its drought tolerance and strong sprouting ability, it serves as one of the main zonal forest-forming tree species in the Qiaoshan forest area, playing important roles in local soil and water conservation, biodiversity protection, and regional ecological security.

Numerous scholars have studied interspecific associations in various plant communities. Research on *Castanopsis* communities in the Three Gorges Reservoir area indicated low interspecific association during early successional stages, sometimes showing strong negative associations. Studies on *Castanopsis fargesii* communities in Jinyun Mountain showed that as communities approach climax stages, species often achieve coordination with distinct positive associations. Research on *Pinus armandii* natural secondary forests in the Qinling Mountains revealed significant interspecific associations among dominant species in tree and herb layers, suggesting that higher proportions of positive associations indicate more stable community structures. Studies on *Taxus yunnanensis* communities in northwestern Yunnan found extremely significant positive correlations between association coefficients and niche overlap values.

Previous research on *Q. acutissima* has primarily focused on carbon density and spatial distribution patterns, aboveground nutrient accumulation and allocation, leaf photosynthetic characteristics, and environmental and genetic effects. However, no studies have reported on interspecific associations in *Q. acutissima* communities. This study examines natural secondary *Q. acutissima* forests in the Qiaoshan forest area, using variance ratio, chi-square test, percentage co-occurrence, and point correlation coefficient to analyze interspecific associations among dominant tree populations. The objectives are to clarify current community structure characteristics, predict future dynamics and successional trends, and provide a basis for forest management and stand improvement by dividing ecological species groups and revealing correlations within them.

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1. Study Area Overview

The study area is located in the Shuanglong Forest Farm of Qiaoshan Forestry Bureau, Yan' an City, northern Shaanxi Loess Plateau (108°31 -109°11 E, 35°30 -35°50 N). The region has a warm temperate monsoon climate with an

average annual temperature of 9.4°C, extreme minimum temperature of -23°C, extreme maximum temperature of 38°C, average annual precipitation of 677.4 mm, and annual sunshine duration of 2,528 hours. The frost-free period lasts 190–225 days. The main soil types are forest brown soil and gray-cinnamon soil. The area is covered by natural secondary forests, with dominant tree species including *Quercus acutissima*, *Q. wutaishanica*, *Q. aliena*, *Pinus tabuliformis*, and *Betula platyphylla*. Major shrub species include *Lespedeza formosa*, *Spiraea salicifolia*, *Acanthopanax senticosus*, *Cotoneaster multiflorus*, *Sophora viciifolia*, and *Elaeagnus pungens*. Principal herbaceous plants are *Carex lanceolata*, *Imperata cylindrica*, *Rubia cordifolia*, *Sanguisorba officinalis*, and *Anemone hupehensis*.

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2. Sample Plot Setup and Data Statistics

Typical sample plots of *Q. acutissima* community were established in the Shuanglong Forest Farm of Qiaoshan forest area. Stand factors such as slope position were recorded, and all tree species with diameter at breast height (DBH) 1.3 m were surveyed. The frequency, density, and number of plots where species pairs occurred were calculated. Important value (IV) was used to represent species dominance in the tree layer, calculated as: (relative frequency + relative density + relative dominance)/3. Species with IV 1.00 were selected as dominant, sub-dominant, and companion species for interspecific association analysis. Species with IV < 1.00 were considered rare species and excluded from the main analysis.

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3. Overall Interspecific Association Test

3.1 Variance Ratio Method

Schluter' s variance ratio method was used to determine overall community association. The formulas are:

$$\sigma_T^2 = \sum_{i=1}^{S} p_i(1-p_i)$$

$$S_T^2 = \frac{1}{N}\sum_{j=1}^{N}(T_j - \bar{t})^2$$

$$VR = \frac{S_T^2}{\sigma_T^2}$$

where $p_i = n_i/N$ is the probability of species i occurring, n_i is the number of plots where species i occurs, N is the total number of plots, T_j is the total number of target species in plot j, and $\bar{t}$ is the mean number of species per plot. VR > 1 indicates overall positive association, VR < 1 indicates overall negative association, and VR $= 1$ indicates no association. The statistic $W = N \times VR$ tests the significance of deviation from the null hypothesis of no association. If W falls within the ^{2} distribution boundaries ($\chi^2_{0.95} < W < \chi^2_{0.05}$), the association is non-significant.

3.2 2×2 Contingency Table for Interspecific Association

A 2×2 contingency table was established for testing interspecific association degrees .

Table 1. The 2×2 contingency tables of interspecific association determination

	Species B Present	Species B Absent	Total
Species A Present	a	b	a+b
Species A Absent	c	d	c+d
Total	a+c	b+d	N

3.3 Chi-square Test

The ^{2} value was calculated using Yates' continuity correction:

- $^2 < 3.841$: non-significant association, independent distribution
- $3.841 \quad ^2 < 6.635$: significant association
- $^2 \quad 6.635$: highly significant association

Positive association indicates species pairs tend to co-occur, while negative association indicates mutual exclusion.

3.4 Association Coefficient (AC)

To overcome limitations of ^{2} test, AC was calculated as:

$$AC = \frac{a - (a+b)(a+c)/N}{(a+b)(a+c)/N} \quad \text{if } ad \geq bc$$

$$AC = \frac{(a+b)(a+c)/N - a}{(a+b)(a+c)/N} \quad \text{if } ad < bc \text{ and } d \geq a$$

AC ranges from [-1, 1]. Values approaching 1 indicate strong positive association; values approaching -1 indicate strong negative association; AC = 0 indicates complete independence.

3.5 Percentage Co-occurrence (PC)

PC was used to avoid bias from d values:

$$PC = \frac{a}{a+b+c}$$

PC ranges from 0 to 1. PC = 0 indicates no co-occurrence; PC = 1 indicates co-occurrence in all plots. Higher PC values indicate stronger association.

3.6 Point Correlation Coefficient (Φ)

Φ reduces effects of ^{2} test limitations:

$$\Phi = \frac{ad - bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

Φ ranges from [-1, 1]. Values approaching 1 indicate strong positive association; values approaching -1 indicate strong negative association; values near 0 indicate weak association.

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4. Dominant Species Composition

Statistical analysis of the *Quercus* community in Qiaoshan forest area identified 17 tree species with important value 1.00 for interspecific association analysis .

Table 2. Species composition and important value of the tree layer

Species	Relative Density	Relative Dominance	Relative Frequency	Important Value
Quercus acutissima	28.93	13.47	40.64	16.13
Quercus wutaishanica	14.46	12.21	12.24	28.01

Species	Relative Density	Relative Dominance	Relative Frequency	Important Value
Acer ginnala	13.94	···	···	···
···	···	···	···	···

5. Overall Correlation

The variance ratio test yielded ^{2}_T = 0.7334 < 1, indicating overall negative association. The test statistic W = 15.40 fell between ^{2}_{0.95(21)} = 11.59 and ^{2}_{0.05(21)} = 32.67, showing non-significant negative association among the 17 main tree populations. Species tended toward independent distribution, indicating community instability and fluctuation.

6. Pairwise Interspecific Association

6.1 Chi-square Test

Among the 17 species forming 136 pairs, ^{2} test showed: - Positive association: 61 pairs (44.85%) - Negative association: 75 pairs (55.15%) - Significant association: 5 pairs (3.68%) - Non-significant association: 131 pairs (96.32%)

Significant positive associations occurred between *Q. acutissima*–*A. ginnala*, *A. ginnala*–*Pyrus betulifolia*, and *Betula platyphylla*–*Swida walteri*, indicating similar habitat/resource requirements. Significant negative associations occurred between *Q. aliena*–*P. betulifolia*, showing habitat differentiation and mutual exclusion [Figure 1: see original paper].

Figure 1. Semi-matrix diagram of ^{2} correlation test

6.2 Association Coefficient and Percentage Co-occurrence

AC analysis revealed: - AC 0.5: 3 pairs (2.21%), strongly positive - 0.2 AC < 0.5: 18 pairs (13.24%), moderately positive - -0.5 AC < -0.2: 19 pairs (13.97%), moderately negative - AC < -0.5: 25 pairs (18.38%), strongly negative

Most species pairs showed non-significant correlation, indicating loose associations. PC analysis showed: - PC 0.6: 9 pairs (6.62%), significantly associated - 0.2 PC < 0.6: 23 pairs (16.91%), moderately associated - PC < 0.2: 104 pairs (76.47%), independent distribution

High PC values (e.g., *Q. acutissima*–*A. ginnala*: 0.84; *B. platyphylla*–*Populus davidiana*: 0.79) indicated high similarity in environmental adaptation [TABLE:3, TABLE:4].

Table 3. Matrix diagram of association coefficient (AC)

Table 4. Matrix diagram of percentage co-occurrence (PC)

6.3 Point Correlation Coefficient (Φ) Analysis

Φ matrix analysis showed: - Φ 0.3: 2 pairs (1.47%), strong positive association - 0.2 Φ < 0.3: 6 pairs (4.41%), moderate positive association - -0.3 Φ < -0.2: 6 pairs (4.41%), moderate negative association - Φ < -0.3: 101 pairs (74.26%), weak association

Most species pairs showed weak associations, confirming independent distribution patterns .

Table 5. Matrix diagram of point correlation coefficient (Φ)

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7. Division of Ecological Species Groups

Ecological species groups are combinations of plant species with similar ecological habits. Based on species distribution across different micro-topographic conditions (elevation, slope aspect, slope position), a binary data matrix was constructed and subjected to hierarchical cluster analysis using SPSS 23.0. Relative frequency represented environmental adaptation similarity.

Cluster analysis of the 17 main tree species, combined with interspecific association results and ecological characteristics, divided them into three ecological species groups [Figure 2: see original paper]:

Figure 2. Clustering analysis of 17 major tree species of *Q. acutissima* community in the Qiaoshan forest area

Table 6. Species composition of the three ecological species groups

Group I: Dominant or sub-dominant species in the tree layer, mostly showing positive associations. *Q. acutissima* is the absolute dominant species and main zonal forest-forming tree, with strong shade tolerance and independence.

Group II: Pioneer species of early successional stages, including *Populus davidiana* and *P. simonii*. These light-demanding species rapidly colonize barren lands and disturbed sites but are eventually replaced by climax species like oaks and pines. They show negative associations with Group I species.

Group III: Mid-successional species including *Pinus tabuliformis* and *Carpinus turczaninowii*. These species show weak associations, indicating ongoing community development.

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8. Conclusion and Discussion

Interspecific association indices provide static descriptions of species relationships that vary with successional stages, reflecting species interactions and environmental relationships. The ^{2} test correctly identified the significance levels of associations among main populations in the *Q. acutissima* community. The degree of population association reflects community stability—higher positive:negative association ratios indicate greater stability and more advanced successional stages.

Results showed: 1. **Overall association:** Non-significant negative correlation (VR $<$ 1, W = 15.40), indicating weak associations, independent distribution, and structural instability. 2. **Pairwise associations:** 96.32% of species pairs were non-significantly associated, with a positive:negative ratio of 0.81, suggesting an unstable, immature community in active succession. 3. **Methodological comparison:** AC and PC complemented ^{2} by showing association strengths for non-significant pairs, while Φ reduced biases from extreme values. Integrated analysis provides more accurate assessment. 4. **Key species pairs:** *B. platyphylla–P. davidiana* showed strong positive association (PC = 0.79, Φ significant), indicating similar habitat requirements as pioneer species. *Q. acutissima* showed weak positive associations with most species, suggesting moderate competition and good population stability. 5. **Management implications:** The weak interspecific associations indicate low community stability, making the community vulnerable to disturbance. Near-natural management is recommended to minimize artificial interference, protect biodiversity, and promote positive succession.

Management Recommendations: - Select target trees based on ecological species groups - Conduct tending operations centered on target trees to reduce interspecific competition - Choose species within the same ecological group for afforestation to accelerate succession - Moderately thin pioneer species (Group II) to promote late-successional species (Groups I and III) - Protect species diversity to maintain long-term stability

The division into ecological species groups reflects species-environment relationships and provides scientific basis for forest management and vegetation restoration in the Qiaoshan forest area.

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