Postprint: Forest Population Structure and Spatial Distribution Patterns in the Eastern Altai Mountain Forest Region

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Abstract

Taking trees in the Fuyun forest region of the Altai Mountains, Xinjiang as the research object, and using the method of establishing typical sample belts for quadrat surveys, we analyzed tree species composition, diameter class structure of dominant species, habitat characteristics of different-aged stands, and spatial distribution patterns in the eastern forest region of the Altai Mountains. The results showed that: (1) Picea obovata, Larix sibirica, Betula pendula, and Populus tremula were the dominant species in the Fuyun forest region, with individuals accounting for 99.99% of the total number, while rare and occasional species accounted for 0.013% of the total species; (2) The diameter class structure of dominant species was similar to that of all trees, approximately inverted U-shaped, with medium diameter class individuals being predominant; (3) Regarding the relationship between species distribution and environmental factors, elevation and slope aspect had significant influences, while the relationship with soil layer thickness was not significant; (4) The spatial distribution patterns of the four tree species were all clumped distributions, and according to age class division, their young stands were all uniformly distributed. The spatial distribution patterns of tree species in different forest ages are formed through the long-term adaptation of natural forest species to environmental condition changes, reflecting the dynamic changes of forest tree species in this region, competition and diffusion among forest species, and the relationship with the environment, which can provide references for forest protection and management in this region.

Full Text

Preamble

Forest Population Structure and Spatial Distribution Patterns in the Eastern Altai Mountain Forest Region

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Abstract: This study investigated the tree species composition, diameter class structure of dominant species, habitat characteristics of different age forests, and spatial distribution patterns in the Fuyun forest region of the eastern Altai Mountains using typical transect sampling methods. The results revealed that: (1) *Picea obovata*, *Larix sibirica*, *Betula pendula*, and *Populus tremula* were the dominant species in the Fuyun forest region, accounting for 99.99% of total individuals, while rare and occasional species comprised only 0.013% of total species. (2) The diameter class structure of dominant species was similar to that of all trees, showing an inverted "U" shape with medium diameter classes predominating. (3) Altitude and slope aspect showed strong relationships with species distribution, whereas soil thickness showed no clear relationship. (4) All four species exhibited clustered spatial distribution patterns, though their young forests showed uniform distribution when classified by age group. These spatial distribution patterns reflect long-term adaptation of forest species to environmental changes in this region, revealing forest dynamics, interspecific competition, diffusion processes, and species-environment relationships, which can provide references for forest conservation and management in this area.

Keywords: *Picea obovata*; *Larix sibirica*; diameter class structure; spatial distribution pattern; habitat characteristics; Altai Mountains

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Introduction

Forest population structure and spatial distribution patterns represent the developmental stages of forest communities and the distribution regularities of individuals within a population in space, reflecting forest community development trends and horizontal spatial relationships among individuals. Forest population spatial structure forms through long-term environmental adaptation, influenced by species biological characteristics, stand structure, regeneration patterns, human disturbance, and internal community environmental conditions. Studying forest species spatial distribution patterns can reveal the spatial morphology, competitive status, and dynamic processes of particular species and their growth stages, which is crucial for understanding population ecological characteristics, community stability, and forest ecosystem maintenance.

Siberian larch and Siberian spruce, cold-temperate coniferous species in the arid interior of Asia, represent relatively stable forest vegetation species in the eastern Altai Mountain forest region and play vital roles in water conservation, windbreak and sand fixation, and ecosystem function maintenance in northwestern China. The Fuyun forest region in the eastern Altai Mountains has relatively simple forest species composition, with cold-temperate coniferous forests dominating the forest belt and some broadleaf forests or coniferous-broadleaf mixed forests appearing at lower elevations. This distribution pattern reflects the region’ s cold and arid characteristics.

Previous research on larch has focused on carbon storage and productivity, diameter-at-breast-height (DBH) models, and radial variation. Studies on spruce have concentrated on trait diversity, stand structure and species diversity, and forest biomass. Research on birch (*Betula*) and poplar (*Populus*) has mainly analyzed poplar-birch forests and larch-birch mixed stands. These studies have primarily examined pure or mixed forest ecological characteristics with some descriptive analyses of population regeneration. However, systematic research on habitat characteristics, spatial distribution patterns, and their relationships remains lacking in this region. Therefore, this study conducted extensive field investigations to analyze tree species composition, DBH structure, habitat characteristics of different age forests, and spatial distribution patterns of dominant species in the Fuyun forest region of the Altai Mountains, aiming to deeply analyze the spatial distribution patterns, formation mechanisms, and species-habitat interactions of Siberian larch and other tree species to provide scientific basis for forest ecosystem conservation in this cold-arid region of western China.

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1 Materials and Methods

1.1 Study Area Overview

The Fuyun forest region of the Altai Mountains is located in northern Fuyun County, Altay Prefecture, northern Xinjiang, situated in the central-eastern section of the Altai Mountains. It borders Mongolia to the north and northeast, is bounded by the Zhuo’ erte River to the west, and adjacent to agricultural areas of Fuyun County to the south. Geographical coordinates are 88°30 ~90°05 E, 47°00 ~48°00 N, with a total forest area of 744,609.37 hm^2. The region is the source area of the Irtysh River, with important headwater rivers including the Kuyiertes River in the east, the Kayiertes River in the center, and the Ku’ ermutu and Zhuo’ erte rivers in the west. The study area lies in the high-mid mountain climate zone of the Altai Mountains, with mean annual temperature below -2.0°C and annual precipitation above 500 mm. Forest soils are primarily mountain gray forest soils, with main constructive species including *Larix sibirica* and *Picea obovata*.

1.2 Research Methods

1.2.1 Plot Establishment and Survey Content Based on forest distribution characteristics in the study area, we selected typical vertical transects along three main headwater river directions (Kuyiertes, Kayiertes, and Ku' ermutu rivers) and densely forested areas between the central and western regions. We established a total of 47 transects from low to high elevation (1000-3500 m), setting the first 10 m × 10 m plot at 1000 m and establishing additional plots every 50-100 m elevation gain, totaling 1,100 plots covering the entire Fuyun forest region. We surveyed all trees in each plot, recording species name, species count, DBH, tree height, crown width, and other data, while also recording elevation, soil thickness (averaged from 5 points per plot), slope gradient, slope aspect, and slope position for each plot.

1.2.2 Classification of Stand Age and Topographic Factors We classified age groups based on tree growth characteristics, DBH, and height features: young forest ($ 40years), middle − agedforest(40–80years), near − matureforest(80–100years), matureforest(100–120years), andover − matureforest($120 years). Slope aspects were categorized as north, northeast, east, southeast, south, southwest, west, and northwest (marked as 1-8). Slope positions were divided into ridge, upper, middle, lower, valley, and flat (marked as 1-6). Slope gradients were classified as flat (0-8°), gentle (8-15°), moderate (16-25°), steep (26-35°), very steep (36-45°), and extremely steep (>45°), marked as 1-6.

1.2.3 Data Processing Methods We used SPSS 21.0 for mean tests and variance analysis, and Excel 2020 and Origin 2019 for data processing and graphing. Importance values were calculated using relative height, relative DBH, and relative abundance.

Population spatial distribution patterns were analyzed using the variance-mean ratio (V/m), where $V/m = (\Sigma fx^2 - (\Sigma fx)^2/n)/(\Sigma fx - 1)$, with x representing individual count per quadrat, f representing frequency of quadrats with x individuals, and n representing total sample number. $V/m = 1$ indicates random distribution, $V/m < 1$ indicates uniform distribution, and $V/m > 1$ indicates clustered distribution.

Aggregation intensity was measured using the clumping index (I) and negative binomial parameter (K), calculated as $I = V/m - 1$ and $K = \bar{x}/I$, where larger K values indicate greater aggregation intensity.

2 Results

2.1 Species Composition and Basic Characteristics of Different Tree Species in the Fuyun Forest Region

The study area contained 6 tree species: *Picea obovata*, *Larix sibirica*, *Betula pendula*, *Populus tremula*, *Ulmus pumila*, and *Salix babylonica*. A total of 23,853 individual trees were recorded across all plots, with an average density of 216.8 stems/ha. The four dominant species accounted for 99.99% of total individuals, while rare and occasional species comprised only 0.013% of total species. *Larix sibirica* was most abundant with the highest importance value (63.00%), followed by *Picea obovata* (15.88%). *Betula pendula* and *Populus tremula* had lower importance values, while willow had the fewest individuals. Basic characteristics of the six main tree species are shown in Table 1 .

The DBH structure of main tree species in the study area showed an inverted "U" shape (Fig. 1 [Figure 1: see original paper]). Few trees had DBH below 16 cm. Total stem count increased initially then decreased with increasing DBH, with most trees concentrated in the 26–30 cm DBH class. The DBH distribution of main species (Fig. 2 [Figure 2: see original paper]) showed that *Larix sibirica* and *Picea obovata* were concentrated in the 16–20 cm class, *Betula pendula* in 11–30 cm, and *Populus tremula* in 26–30 cm.

2.2 Tree Age Groups and Habitat Characteristics in the Fuyun Forest Region

The composition of tree age groups and main habitat characteristics (elevation, soil thickness range) are shown in Table 2 . Over-mature forest ($ 120*years*)*accountedfor*40.93 $40 years) only 0.29% of individuals and 0.34% of area. This indicates severe forest aging and weak regeneration capacity. Near-mature forest (80–100 years) had the lowest canopy density, while middle-aged forest had the highest, indicating good crown growth in middle-aged stands.

Larix sibirica age group ratios were 0.24:3.02:26.39:28.42:42.01 (young:middle-aged:near-mature:mature:over-mature). Young and middle-aged forests accounted for very low proportions (below 4%), while over-mature forest exceeded 42%, demonstrating severe aging and weak continuous regeneration. Young *Larix sibirica* had the lowest canopy density (0.24) and narrowest elevation range (1520–2400 m), with no plots below 1520 m or above 2400 m. Middle-aged larch showed similar elevation distribution patterns. Near-mature and mature larch had wide elevation distributions. *Larix sibirica* was distributed on upper, middle, and lower slope positions with steep gradients, primarily on moderate and steep slopes.

Picea obovata age group ratios were 2:14:38.27:28.8:17.13. Near-mature forest had the highest proportion (38.27%) and largest area (44.86%), indicating less severe aging. *Picea obovata* occurred across elevations from 1150–3100 m, with young forest distributed most widely and over-mature forest most narrowly. Near-mature *Picea obovata* had the lowest canopy density, while young forest had the highest. The species occurred on north, northwest, and northeast aspects (shady slopes), primarily on middle and lower slope positions and in valleys, across very steep, steep, moderate, and gentle slopes.

Betula pendula near-mature forest was absent from survey plots. Young birch had the narrowest elevation range (1150–1900 m) with no plots above 1900 m. Near-mature birch had the lowest canopy density (0.29), while young forest reached 0.44. Birch concentrated on north, south, and northeast aspects, primarily on upper, middle, and lower slope positions with steep gradients.

Populus tremula middle-aged forest was absent from survey plots. Near-mature and over-mature forests accounted for large proportions (48.69% and 46.79% respectively), indicating aging. Mature poplar had the highest canopy density. Different age groups occurred across 1050–2140 m elevation, with mature forest having the widest distribution. Poplar concentrated on south and southeast aspects (sunny slopes), primarily on middle and lower slope positions.

Soil thickness was shallow across all age groups (15–61 cm), with no significant difference among age groups, indicating minimal influence of soil thickness on age differentiation.

2.3 Spatial Distribution Patterns of Main Tree Species in the Fuyun Forest Region

Variance-mean ratio tests revealed that all four main tree species showed clustered distribution patterns (Table 4). The negative binomial parameter K was smallest for *Betula pendula*, indicating the most dispersed aggregation. *Picea obovata* and *Larix sibirica* had the largest K values, indicating higher aggregation intensity, consistent with field observations.

Analysis by age group (Table 5) showed that all species exhibited uniform distribution at the young forest stage. *Picea obovata* and *Larix sibirica* showed clustered distribution at other age stages. The clumping index I for *Picea obovata* decreased after the near-mature stage, indicating a trend from clustered toward random distribution. *Larix sibirica* showed similar K values across later growth stages, indicating stable aggregation intensity with increasing I values. *Betula pendula* and *Populus tremula* showed uniform distribution across all age stages, differing from the overall pattern.

3 Discussion

3.1 Relationship Between Species Distribution and Habitat Characteristics

The Altai Mountains form a massive northwest-southeast oriented range spanning hundreds of kilometers across northern Xinjiang. Influenced by cold Siberian climate from the north, the range developed cold-temperate coniferous forest communities dominated by *Larix sibirica* and *Picea obovata*. Located on the southern slope of the Altai Mountains and northern edge of the Junggar Basin, the region' s forest vegetation development is affected not only by dry-hot airflows from the Junggar Basin but also by cross-influences of different continental climates entering through low valley openings from the northwest, west, and southeast. Cold-moist airflows from the Siberian plains enter the Irtysh River valley, airflows from Central Asia' s Kazakhstan enter through low valleys between Tacheng Basin and Shawuer Mountain into the Irtysh and Ulungur River plains, and airflows from Mongolia enter through lowlands in the eastern Altai Mountains into the Ulungur River plain. These three air currents intersect, bringing abundant mountain precipitation and creating humid conditions that influence vegetation development.

Larix sibirica is widely distributed and absolutely dominant in the Altai Mountains, accounting for 63% of total stems and area, indicating strong competitiveness and dispersal ability during early population development. However, young larch showed low canopy density, suggesting weak competitive ability in young stands. Young larch was scarce near human activity areas due to heavy grazing disturbance causing seedling loss, and also scarce at high elevations, possibly due to climate change.

Slope aspect significantly influenced main tree species distribution. Cold-temperate *Larix sibirica* and *Picea obovata* primarily occurred on north, northwest, and northeast aspects, reflecting northern climatic influences and their shade- and cool-preference. The study area' s east-west oriented mountains meant that broadleaf *Populus tremula*, a light-demanding species, was distributed on south and southeast sunny slopes. *Betula pendula*, with strong adaptability and light demand but shade intolerance, could grow on dry, poor soils and thus concentrated on north, south, and northeast aspects at slope bottoms.

Larix sibirica showed the widest elevation distribution (1300–3250 m), indicating adaptation to relatively high altitudes. *Picea obovata* occurred across 1150–3100 m, also showing broad altitudinal adaptation. *Populus tremula* had a large proportion above 2140 m, indicating broadleaf distribution at relatively high elevations. *Betula pendula* occurred at 1150–1900 m, showing lower altitudinal distribution than poplar.

3.2 Relationships Among Forest Diameter Class, Age Group Changes, and Competition-Diffusion

The DBH structure of all trees showed an inverted "U" shape. *Larix sibirica* DBH structure below 20 cm had few individuals, consistent with conclusions from Wang et al. that small-diameter trees were significantly fewer than medium-diameter trees in artificial larch stands, caused by human disturbance, environmental impacts, and pests. *Picea obovata* DBH structure peaked at 20-30 cm, differing from studies on Tianshan spruce that showed mean DBH of 42.53-45.21 cm, likely because Tianshan spruce stands had more mature trees and fewer seedlings.

The severe aging of *Larix sibirica* (over-mature forest >42%) and extremely low proportions of young and middle-aged forests indicate weak regeneration capacity over recent decades, forming an unstable structure deviating from climax community. From a reproductive perspective, Changbai larch in northeastern China begins fruiting at 30-54 cm DBH, with optimal fruiting at 80-140 years and decline after 140 years. Natural regeneration periods generally do not exceed 200 years. Different larch species show considerable variation in reproductive characteristics. Research on *Larix sibirica* seed reproduction remains limited. Ancient trees up to 321-555 years old in western Altai severely affect population regeneration. While increased human activities like grazing and logging have greatly impacted seedling survival in recent decades, the extremely low proportion of middle-aged forest indicates long-standing asymmetrical age distribution. Climate change also significantly affects forest population and community structure, influencing age group composition and interspecific competition.

3.3 Population Spatial Distribution Patterns and Regeneration

All four species showed clustered distribution overall, the most common pattern in forest plant populations, resulting from natural differentiation of suitable microenvironmental conditions for growth, survival, and competition. Li et al. found that *Larix sibirica* primarily showed clustered distribution, consistent with this study. *Picea obovata* showed clustered distribution at later growth stages, differing from some previous studies on spruce populations. However, as a dominant species in this region with importance value only 15.88% (less than one-quarter of larch), its strong survival competitiveness and clustered distribution may provide environmental competitive advantages, improve individual survival opportunities, and maintain population stability through group effects.

At the young forest stage, all species showed uniform distribution, likely due to intense human disturbance (e.g., grazing) severely affecting seedling establishment, resulting in distribution patterns inconsistent with the clustered distribution of mature reproductive populations. Severe population aging may produce allelopathic effects that hinder individual regeneration processes and reduce aggregation of new individuals. The uniform distribution of natural young forests of all four species reflects adaptive balance to various habitat conditions and disturbance intensities, while local hydrothermal environmental changes from global climate change may also reduce survival of small individuals and decrease population aggregation.

Betula pendula and *Populus tremula* showed uniform distribution across all age stages, differing from the overall pattern. This may relate to small sample sizes or represent natural uniform distribution to compete for light, soil moisture, and nutrients. However, overall aggregation across all age groups remained clustered, consistent with most forest species spatial patterns.

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4 Conclusion

Based on analysis of tree species composition, dominant species DBH structure, habitat characteristics of different age forests, and spatial distribution patterns in the eastern Altai Mountain forest region of Xinjiang, we conclude:

1) The eastern Altai Mountain forest region has relatively few tree species. *Picea obovata*, *Larix sibirica*, *Betula pendula*, and *Populus tremula* are dominant species, accounting for 99.99% of individuals, with rare and occasional species comprising only 0.013% of total species. *Larix sibirica* is the most important species (importance value >63%), followed by *Picea obovata* (~15.88%). *Betula pendula* and *Populus tremula* have lower importance values.

2) Tree DBH in sample plots showed an inverted "U"shape, with the 26–30 cm DBH class having the most individuals. *Betula pendula* DBH concentrated in 11–30 cm, and *Populus tremula* in 26–30 cm. Dominant species DBH structure was similar to overall tree DBH structure, showing inverted "U" shape with medium DBH classes predominating.

3) Regarding species distribution-environment relationships, young forests were scarce above 2400 m and below 1300 m elevation. *Larix sibirica* showed the most severe aging. Soil thickness showed no clear relationship with age groups, while slope aspect showed obvious differences among species and age groups.

4) Dominant tree species in the eastern Altai Mountains showed clustered spatial distribution patterns, with young forests showing uniform distribution when classified by age group. *Larix sibirica* represents a declining, unstable population with clustered spatial distribution, while *Picea obovata* and *Larix sibirica* showed clustered distribution at middle-aged, near-mature, mature, and over-mature stages.

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