

Effects of Different Canopy Densities on the Population Structure of Liaodong Oak in the Huanglong Mountain Forest Area (Postprint)

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Date: 2017-03-22T00:00:00+00:00

Abstract

Quercus wutaishanica is the dominant constructive species in the Huanglong Mountain forest region. Through representative sampling, 16 sample plots were established, and through the construction of age structure, static life tables, survival curves, height class structures, and crown width structures, we investigated its variation patterns in habitats with different canopy densities (0.6, 0.7, 0.8, 0.9) and slope aspects (shady and sunny slopes). The results indicate that the number of *Q. wutaishanica* seedlings in sample plots with canopy densities of 0.6, 0.7, 0.8, and 0.9 accounted for 57%, 64%, 36%, and 47% of the total individuals, respectively. Age structure, static life tables, and survival curves all demonstrated that seedlings had the highest proportion across all four canopy densities, followed by large trees, while saplings and small trees had the lowest proportion. Saplings and small trees represent the regeneration bottleneck stage for *Q. wutaishanica*. The survival curves of *Q. wutaishanica* populations all conform to R. Pearl Type III, with minimal fluctuation at a canopy density of 0.7. Based on the comprehensive performance of indicators including age structure, static life tables, survival curves, height class structure, and crown width structure, the habitat with a canopy density of 0.7 is superior to those with densities of 0.6, 0.8, and 0.9 for *Q. wutaishanica* populations. The proportions of seedlings, saplings, and small trees on sunny slopes are higher than on shady slopes, while the proportion of large trees is lower. Except for height class a, sunny slopes are primarily concentrated in height classes c, d, and e, whereas shady slopes are mainly concentrated in classes d, e, and f. On sunny slopes, distribution occurs across all crown width classes below class 10, while on shady slopes, crown width is primarily concentrated below class 7. Regardless of slope aspect, a canopy density of 0.7 is most suitable for the regeneration and growth of *Q. wutaishanica* and can serve as an ideal condition for tending thinning in northwestern China.

Full Text

Effects of Different Crown Densities on Structure of *Quercus wutaishanica* Populations in Huanglong Mountains, Northwest China

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Abstract

Quercus wutaishanica is a dominant constructive species in the Huanglong Mountain forest region. Through typical sampling, 16 sample plots were selected to investigate population structure changes under different crown densities (0.6, 0.7, 0.8, 0.9) on both shady and sunny slopes. Age structure, static life tables, survivorship curves, height class structure, and crown width structure were analyzed to understand variation patterns across these habitats. Results showed that seedlings accounted for 57%, 64%, 36%, and 47% of total individuals at crown densities of 0.6, 0.7, 0.8, and 0.9, respectively. Age structure, static life tables, and survivorship curves all indicated that seedlings represented the largest proportion across the four crown densities, followed by large trees, while saplings and small trees showed the smallest proportions. Saplings and small trees represent the bottleneck stage for *Q. wutaishanica* regeneration. The survivorship curves for all populations followed R. Pearl's Type III, with the most stable performance observed at crown density 0.7. On sunny slopes, the proportion of seedlings, saplings, and small trees was higher than on shady slopes, while large trees were less abundant. Height classes on sunny slopes were concentrated in classes c, d, and e (except class a), whereas shady slopes showed concentration in classes d, e, and f. Crown width on sunny slopes was distributed across classes d, e, and f, while shady slopes were mainly limited to under 3.5 m. Overall, crown density 0.7 provided optimal conditions for *Q. wutaishanica* regeneration and growth, making it an ideal target for tending and thinning operations in northwestern China.

Keywords: *Quercus wutaishanica*; population structure; crown density; shady and sunny slopes

Introduction

A population is a collection of individuals of the same species occupying a specific space and time. Populations constitute not only the fundamental unit of species but also the basic unit of community structure. Population structure is a critical research focus in population ecology, providing important insights into biological characteristics and ecological features. Age structure analysis reveals the composition of individuals across different age classes and enables assessment

of population dynamics and future trends. Static life tables, constructed from age distributions at a specific time point, are applicable to organisms with overlapping generations and provide statistical documentation of mortality patterns across age groups, revealing survival and reproductive strategies. Survivorship curves, plotting standardized survival against age intervals, reflect how birth and death rates vary with age, showing both life processes and environmental adaptation. Height structure visually describes vertical population distribution, indicating the status and role of individuals at different heights within the community. Crown width, an important canopy characteristic and visual parameter, reflects tree vitality and competitiveness.

Quercus wutaishanica is a key species in the zonal vegetation of warm temperate deciduous broad-leaved forests, significantly influencing community structure, dynamics, and species composition. Pure *Q. wutaishanica* stands and mixed deciduous broad-leaved forests dominated by this species play crucial roles in water conservation, environmental improvement, and biodiversity maintenance. Previous research on *Q. wutaishanica* populations has focused on community composition, regeneration, species diversity, spatial distribution patterns, and population structure. However, the effects of different crown densities on population structure remain unreported. Guided by near-natural forest management theory, this study conducted periodic tending thinnings at intervals to maintain crown densities of 0.6, 0.7, 0.8, and 0.9, investigating population structure changes to clarify cultivation effects and provide a basis for rational management of *Q. wutaishanica* forests in northwestern China.

1. Study Area Overview

The study area is located in Caijiachuan Forest Farm, Huanglong Mountain Forestry Bureau, Yan' an City, on the Loess Plateau of northern Shaanxi Province. This region lies in the transition zone between warm temperate semi-humid and semi-arid climates, with geographic coordinates of 109°38'49" - 110°12'47" E, 35°28'46" - 36°02'01" N, and elevations ranging from 962.6 to 1783.5 m. The mean annual temperature is 8.6°C, with extreme highs of 36.7°C and lows of -22.5°C. Annual precipitation averages 611.8 mm, with a frost-free period of 126-186 days. Zonal vegetation consists of warm temperate deciduous broad-leaved forests, with pure stands or mixed forests dominated by *Q. wutaishanica*, *Pinus tabulaeformis*, *Populus davidiana*, and *Betula platyphylla* distributed in a mosaic pattern. Most natural *Q. wutaishanica* forests in this area exhibit natural tree mortality in the understory. In 2004, harvesting operations were implemented following near-natural management principles, using single-tree selection to create uniform spacing and more rational stand structure. To maintain constant crown densities, tending thinnings were conducted annually with pruning to preserve target densities of 0.6, 0.7, 0.8, and 0.9.

2. Methods

2.1 Sample Plot Setup and Investigation

Following comprehensive reconnaissance of *Q. wutaishanica* forests in Caijiachuan Forest Farm, typical sampling was employed to establish 16 permanent sample plots (20 m × 20 m) across different crown densities and slope aspects (two replicates each for sunny and shady slopes). Each plot contained five 1 m × 1 m subplots at the four corners and center, plus one 5 m × 5 m subplot. In 2015, all trees in each plot were measured, recording diameter at breast height (DBH), tree height, and mean crown width. Herbaceous layer coverage was surveyed in the small subplots, with values scaled up to plot level. Stand characteristics are summarized in .

2.2 Population Age Structure Classification

Due to the hard wood of *Q. wutaishanica*, age determination through growth rings is impractical for fieldwork. Cores are difficult to extract, and no reliable external age indicators exist. Furthermore, for sprout-origin saplings, using sprouting time as age would underestimate their growth rate and spatial resource utilization compared to seed-origin individuals of the same age. Therefore, diameter class structure was used as a proxy for age structure, better reflecting population dynamics. Individuals with DBH < 4 cm were classified as seedlings. For DBH ≥ 4 cm, diameter classes were established at 4 cm intervals: 4-8 cm (Class V), 8-12 cm (VI), 12-16 cm (VII), 16-20 cm (VIII), 20-24 cm (IX), 24-28 cm (X), and ≥ 28 cm (XI). Seedlings were subdivided by height: <0.3 m (I), 0.3-0.6 m (II), 0.6-0.9 m (III), and 0.9-2 m (IV). Classes I-IV were defined as seedlings, V-VII as saplings and small trees, and VIII-XI as large trees.

2.3 Static Life Table and Survivorship Curve Compilation

The space-for-time substitution method was used, treating diameter classes as temporal sequences. Standard static life table parameters were calculated as follows:

$$\begin{aligned} l_x &= (a_x/a_0) \times 1000 \\ q_x &= (d_x/l_x) \times 1000 \\ L_x &= (l_x + l_{x+1})/2 \\ T_x &= \sum_x^\infty L_x \\ e_x &= T_x/l_x \\ K_x &= \ln(l_x) - \ln(l_{x+1}) \end{aligned}$$

Where x is age class, a_x is the number of individuals in age class x , d_x is the number of deaths from x to $x+1$, l_x is standardized survivors at the start of age class x , q_x is mortality rate during the interval, L_x is interval lifespan, T_x is total remaining lifespan for all individuals reaching age x , e_x is life expectancy entering age x , and K_x is the killing power. Negative mortality values occasionally

occur in life table analysis, which while mathematically inconsistent, provide useful ecological information about rapidly developing or declining populations. Survivorship curves were plotted with standardized survivors on the y-axis and age class on the x-axis.

2.4 Height and Crown Width Structure

Height classes were defined as a (<0.3 m), b (0.3–0.6 m), c (0.6–0.9 m), d (0.9–2 m), e (2–5 m), f (5–10 m), and g (>10 m). Crown width was calculated as the average of east-west and north-south measurements, with classes defined as (<1 m), (1–2 m), (2–3 m), (3–4 m), (4–5 m), (5–6 m), (6–7 m), (7–8 m), (8–9 m), and (>9 m). Individuals in each class were counted to construct structure diagrams.

3. Results

3.1 Age Structure under Different Crown Densities and Slope Aspects

Across all four crown densities (0.6, 0.7, 0.8, 0.9), seedlings consistently represented the largest proportion of individuals (57%, 64%, 36%, and 47%, respectively), followed by large trees, while saplings and small trees showed the lowest proportions. This pattern indicates that saplings and small trees constitute the bottleneck stage for *Q. wutaishanica* regeneration. The seedling proportion was highest at crown density 0.7, suggesting this density provides the most favorable conditions for seedling establishment. All age classes were present at each density, indicating stable population structure.

On sunny slopes, the proportion of seedlings, saplings, and small trees was higher than on shady slopes, while large trees were less abundant. The difference in percentage between slope aspects for the same diameter class was minimal, showing overall stability. Populations at crown densities of 0.6, 0.8, and 0.9 showed better continuous development on sunny slopes, though large tree proportions remained lower than on shady slopes. No age classes were missing in any treatment, indicating robust population structure.

3.2 Static Life Tables

Mortality rates were initially high across all crown densities, particularly in age classes I–IV, I–II, I–V, and I–II for densities 0.6, 0.7, 0.8, and 0.9, respectively. As age class increased, mortality gradually decreased. The high mortality duration was shortest at crown density 0.7, making this density most conducive to population renewal. At densities 0.8 and 0.9, high mortality was concentrated in age classes I–II, while density 0.6 showed extended high mortality across more age classes. Negative mortality values occurred in some life tables due to mathematical assumptions, but these still provide valuable ecological records.

On shady slopes at crown density 0.6, mortality was extremely high in early age classes, leading to rapid population decline. In contrast, sunny slopes at

the same density showed more prolonged high mortality across age classes. At crown density 0.7, both shady and sunny slopes exhibited strong regeneration, superior to other densities. The life table data are presented in and .

3.3 Survivorship Curves

All survivorship curves followed R. Pearl' s Type III, indicating high mortality during early life stages followed by relatively stable mortality with some fluctuations. Populations at crown density 0.7 showed the most stable survivorship curves with minimal fluctuation. This pattern held true for both shady and sunny slopes, with density 0.7 again showing the most stable performance across both aspects. The consistency of Type III curves across all treatments confirms that early seedling mortality is a key feature of *Q. wutaishanica* population dynamics.

3.4 Height Class Structure

At crown densities of 0.6, 0.7, 0.8, and 0.9, height class distributions were concentrated in classes c, d, and e, with seedlings (classes a-d) comprising 72.0%, 74.1%, 46.1%, and 51.0% of individuals, respectively. The density 0.7 environment was most favorable for height growth. On shady slopes, height classes were concentrated in d, e, and f, with classes c, d, and e representing 37.67%, 32.08%, 80.0%, and 42.86% of individuals at densities 0.6, 0.7, 0.8, and 0.9, respectively. Sunny slopes showed concentration in classes c, d, and e, with some individuals in class f. Height class distributions were more balanced between slope aspects at densities 0.8 and 0.9, while densities 0.6 and 0.7 showed missing height classes in some slope aspects.

3.5 Crown Width Structure

Across all crown densities, crown width classes were concentrated in classes , , and , representing 66.75%, 68.43%, 47.41%, and 48.61% of individuals at densities 0.6, 0.7, 0.8, and 0.9, respectively. The highest numbers of individuals occurred at crown density 0.7. On shady slopes, crown width was concentrated in classes , , and , with only 2.38% of individuals in classes below . On sunny slopes, crown width was distributed across classes , , and , with some individuals in class . The broader distribution on sunny slopes indicates better crown development under higher light availability.

4. Discussion

4.1 Optimal Crown Density for Population Development

Comprehensive analysis of age structure, static life tables, height class structure, and crown width structure indicates that crown density 0.7 provides superior habitat conditions compared to densities 0.6, 0.8, and 0.9. At this density, enhanced light penetration improves growth, DBH increment, crown development,

and seed production. Soil temperature also increases, benefiting seed germination and seedling establishment. While density 0.6 provides ample light, excessive illumination intensifies water evaporation, creating drought conditions unfavorable for seedlings in the moisture-limited Loess Plateau region. Densities 0.8 and 0.9 reduce light availability, limiting growth. Therefore, crown density 0.7 emerges as the optimal condition for *Q. wutaishanica* management.

4.2 Regeneration Bottlenecks and Slope Aspect Effects

Age structure, life tables, and survivorship curves consistently demonstrate that while *Q. wutaishanica* produces abundant seeds and seedlings across all crown densities, the transition from seedling to sapling stage is critical. Limited environmental resources cause intense competition among seedlings, resulting in high mortality and low sapling recruitment. This bottleneck is most effectively overcome at crown density 0.7.

Sunny slopes support higher seedling and sapling proportions due to adequate light, which benefits this light-demanding species. As individuals mature into large trees, the superior moisture and thermal conditions on shady slopes become more favorable for growth. Height class distributions show sunny slopes concentrate in mid-height classes (c, d, e), while shady slopes show more individuals in taller classes (d, e, f). Crown width development follows similar patterns, with sunny slopes supporting broader crowns due to direct light exposure.

5. Conclusion

Crown density 0.7 provides the most suitable conditions for *Quercus wutaishanica* regeneration and growth in the Huanglong Mountain region. This density balances light availability and moisture conservation, facilitating seedling establishment while supporting growth through subsequent life stages. The species exhibits a typical Type III survivorship pattern with high early mortality, making the sapling stage a critical management focus. Slope aspect significantly influences population structure, with sunny slopes favoring early regeneration and shady slopes supporting mature tree growth. These findings provide a scientific basis for tending and thinning operations in *Q. wutaishanica* forests across northwestern China.

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