Population Structure and Distribution Patterns of Cyclobalanopsis glauca in Different Topographic Positions in Maolan Karst Forest (Postprint)

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Date: 2018-06-22T00:00:00+00:00

Abstract

Cyclobalanopsis glauca is one of the constructive and dominant species in subtropical evergreen broad-leaved forests. This study examined Cyclobalanopsis glauca populations in different topographic positions (funnel, slope, valley) of Maolan National Karst Forest Nature Reserve, investigated population structure using diameter class structure as a proxy for age structure, and constructed survival curves for the populations. Aggregation indices including variance/mean ratio method (dispersion index CX), negative binomial parameter (K), clumping index (I), mean crowding (M*), patchiness index (PAI), and aggregation index (Ca) were employed to determine the distribution patterns of Cyclobalanopsis glauca populations, thereby evaluating the structural characteristics and regeneration potential of Cyclobalanopsis glauca populations in Maolan karst forest. The results showed that: among the three topographic positions, Class II saplings of Cyclobalanopsis glauca were absolutely dominant, followed by seedlings, with medium and large trees accounting for a certain proportion; the survival curve approximated Deevey Type III, and the population exhibited strong self-regeneration capacity, characteristic of an increasing population. Among the three topographic positions, except for the valley which had a complete diameter class structure, the funnel and slope had incomplete diameter class structures; however, all showed fewer seedlings than saplings, with sapling individuals being the most numerous and medium and large trees being the least numerous, presenting a diameter class structure that was high in the middle and low at both ends. The distribution patterns of Cyclobalanopsis glauca populations in different topographic positions were random; the distribution patterns changed during population growth, showing that the degree of aggregation weakened with increasing age class, transitioning from clumped to random type, wherein seedlings, saplings, and small trees mostly showed clumped distribution, while medium and large trees mostly showed random distribution. This study provides a scientific basis for the rational conservation of Cyclobalanopsis glauca populations in Maolan Nature Reserve.

Full Text

Studies on Population Structure and Distribution Pattern of *Cyclobalanopsis glauca* at Different Topography Sites in Maolan Karst Forest

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Abstract

Cyclobalanopsis glauca is one of the constructive and dominant species in subtropical evergreen broad-leaved forests and also a dominant species in the karst forest of Maolan National Reserve, playing an important role in the ecosystem. To reveal the population dynamics of *C. glauca*, we selected populations at different topographic sites (funnel, hillside, and valley) in Maolan National Reserve as our research objects. We analyzed population structure using tree class structure as a proxy for age structure and constructed survival curves for the species. Distribution patterns were measured using aggregation indices including variance/mean ratio (deviation index CX), negative binomial parameter (K), clumping index (I), mean crowding index (M*), patchiness index (PAI), and aggregation index (Ca). The results showed that Class II saplings were absolutely predominant across the three topographic sites, followed by seedlings, with some medium and large trees present, indicating strong self-renewal capacity and a growing population. The survival curve tended toward Deevey Type III. Among the three sites, only the valley exhibited a complete diameter class structure, while the funnel and hillside showed incomplete structures. All sites displayed a diameter structure characterized by fewer seedlings than saplings, with saplings being most abundant and medium/large trees least abundant, forming a "high in the middle, low at both ends" pattern. The overall distribution pattern was random across different topographic sites, though this pattern changed during population development, with aggregation intensity decreasing as age class increased and shifting from clumped to random distribution. Specifically, seedlings, saplings, and small trees tended toward clumped distribution, while medium and large trees showed random distribution. This study provides scientific support for the protection and management of* C. glauca* in Maolan karst forest.

Key words: Maolan, karst forest, *Cyclobalanopsis glauca*, population structure, distribution pattern

Population size, age, and distribution pattern are important structural characteristics of plant populations that reflect not only the configuration of different individuals and quantitative features of the population, but also the interactions between the population and its environment (Peng, 1993). *Cyclobalanopsis glauca* is a evergreen arbor species in the Fagaceae family, tolerant of barren conditions and calcium-loving, with shade-tolerant saplings and light-demanding adult trees, making it a neutral light-preferring species. It exhibits strong ecological adaptability with significant ecological functions and economic value, occupying an important position in subtropical forest ecosystems of China (Chen et al., 2011). *C. glauca* is also widely distributed in the karst forest of Maolan, Guizhou, representing one of the dominant arbor species (Long, 2008). Maolan Nature Reserve is located in the transitional slope zone from the Yunnan-Guizhou Plateau to the Guangxi hilly basin, where karst landforms are well developed with various geomorphic forms including sinkholes, funnels, depressions, valleys, and basins, forming complex terrain combinations such as peak-cluster funnels, peak-cluster depressions, and peak-forest basins. Maolan karst forest represents a special forest ecosystem rich in biodiversity that differs significantly from forests on normal landforms in terms of community appearance, properties, floristic composition, succession dynamics, ecological environment, and ecosystem impacts on the environment (Zhu and Yang, 1987). Therefore, the diverse terrain combinations and high heterogeneity of microhabitats in Maolan Nature Reserve provide suitable environmental conditions for *C. glauca* populations, making it an ideal site for studying population structure and distribution patterns in karst forests.

Current research on *C. glauca* has primarily focused on the effects of temperature and soil moisture on seed germination (Zhang et al., 2013), physiological ecology of seed germination (Zeng et al., 2013), growth patterns and biomass distribution (Huang et al., 2017), anti-cancer activity of fruits (Gan et al., 2010), intra- and interspecific competition (Zeng et al., 2016), water physiology comparisons (Deng et al., 2006), and effects of drought stress on seedlings (Zhang et al., 2012). Additionally, studies have examined community structure and species diversity (Liu et al., 2013), population structure and dynamics (Cai, 2000), and population structure and distribution patterns (Hu and Yu, 2003) in evergreen broad-leaved forests. Some research has also addressed karst forest populations, such as structural characteristics of *C. glauca* populations on karst hills in Guilin (Yao et al., 2008) and structure and distribution patterns of dominant arbor populations at different succession stages in Maolan karst forest (Qin and Long, 2016). These studies have laid a foundation for in-depth research on *C. glauca* populations in karst regions, but studies on karst forest populations remain limited compared to those in evergreen broad-leaved forests. The fragile karst habitats in southwestern China feature harsh ecological conditions unfavorable for plant population reproduction and growth, and combined with human disturbance and destruction, karst vegetation degradation is severe. *C. glauca* is one of the important species for vegetation restoration and reconstruction in karst regions (Li et al., 2003). Therefore, studying the population structure and distribution pattern dynamics of *C. glauca* in karst forests to understand its ecological characteristics, regeneration patterns, and community succession trends is of great significance. This study analyzes the topographic differences in population structure and distribution patterns of *C. glauca* in Maolan karst forest across different terrain sites, explores the quantitative characteristics and maintenance mechanisms of the population, and provides a theoretical basis for the rational protection of plant populations and the restoration and reconstruction of degraded karst forest vegetation in Maolan.

1.1 Study Area Overview

The study site is located in Maolan National Karst Forest Nature Reserve in Libo County, southern Guizhou Province (107°52 -108°05 E, 25°09 -25°20 N). The reserve features typical karst peak-cluster landforms with elevations ranging from 430 m to 1078.6 m and an average elevation of approximately 800 m. The parent rock is primarily dolomite and limestone. The mean temperature is 26.4 °C in July, 8.3 °C in January, with an annual average of 15.3 °C and $ $10 °C accumulated temperature of 5727.9 °C. Annual precipitation averages 1320.5 mm with an average relative humidity of 83%. Soils are thin and discontinuous with high bedrock exposure rates. The dominant soil type is black limestone soil rich in organic matter and total nitrogen. The reserve contains evergreen deciduous broad-leaved mixed forests dominated by *Cyclobalanopsis glauca*, *Photinia davidsoniae*, *Machilus rehderi*, *Lindera communis*, *Carpinus pubescens*, *Cladrastis platycarpa*, *Celtis tetrandra*, *Pittosporum crispulum*, and *Euonymus dielsianus*.

Habitat characteristics of the three topographic sites: (1) **Funnel**: Soils are black limestone soil with 95% total coverage. The understory features numerous rock outcrops with well-developed rock fissures and discontinuous soil distribution, but with patches of soil. Soil depth in low-lying areas is 5–20 cm, litter layer thickness is 5–10 cm, with local waterlogging and good moisture conditions but poor light conditions. (2) **Hillside**: Located in the middle and upper parts of slopes, with numerous rock outcrops and large areas of collapsed rock debris. Soils are black limestone soil with 70% total coverage. Rock fissures are well developed, soils are thin and discontinuous, mostly distributed in rock crevices. Soil depth in low-lying areas is 1–3 cm, litter layer thickness is 3–5 cm, with poor moisture conditions but good light conditions. (3) **Valley**: Lower slope position with flat valley bottoms, numerous rock outcrops, black limestone soil with 90% total coverage. Rock fissures are well developed with discontinuous soil distribution but patches of soil present. Soil depth in low-lying areas is 2–6 cm, litter layer thickness is 3–7 cm, with moderate moisture and light conditions (Zheng and Long, 2014).

In May 2014, typical forest communities at three topographic sites (hillside, valley, and funnel) were selected in Maolan Nature Reserve. Ten discontinuous 20 m × 20 m plots were established at each site, with each topographic site covering 4000 m^2 and the total sample area across all three sites being 1.2 ha. GPS was used to locate each plot, and data on elevation, slope, and aspect were recorded. Each plot was divided into 10 m × 10 m quadrats, and all woody plants were surveyed, recording species name, quantity, diameter at breast height (DBH) or ground diameter, height, crown width, and canopy closure.

1.2.2 Population Diameter Class Structure and Survival Curves

The wood of *C. glauca* is tough, making core extraction difficult and age determination challenging. Therefore, we used tree class structure as a proxy for age structure to analyze population structure. Size structure was categorized in two ways: individuals with DBH < 2.5 cm were divided into 2 classes, while those with DBH > 2.5 cm were divided into 4 classes. Based on these criteria, *C. glauca* individuals in the 30 plots were classified as follows (Li et al., 2007; Wang et al., 2008): Class I (seedlings), DBH < 2.5 cm, H < 33 cm; Class II (saplings), DBH < 2.5 cm, H $\geq$ 33 cm; Class III (small trees), 2.5 cm $\leq$ DBH < 7.5 cm; Class IV (first-level medium trees), 7.5 cm $\leq$ DBH < 15 cm; Class V (second-level medium trees), 15 cm $\leq$ DBH < 22.5 cm; Class VI (large trees), DBH $\geq$ 22.5 cm. Survival curves were constructed with standardized survival numbers as the vertical axis and diameter class as the horizontal axis.

1.2.3 Methods for Measuring Population Distribution Patterns

Population distribution patterns and aggregation intensity were analyzed using variance/mean ratio (deviation index Cx), clumping index (I), negative binomial parameter (K), mean crowding index (m*), patchiness index (PAI), and aggregation index (Ca) (Zhang et al., 2016; Zhao et al., 2016).

(1) **Variance/Mean Ratio**: Cx = V/m (where V = (xi - m)^2/(n-1), m = (xi/n)). Here, m is the mean number of individuals per quadrat, n is the number of quadrats, and xi is the number of individuals in the ith quadrat. If Cx > 1, the distribution is clumped; if Cx = 1, random; if Cx < 1, uniform. Significance can be tested using t-test: t = (Cx - 1)/√(2/(n-1)). When t = t0.05, the difference is not significant; when t < t0.05, it follows Poisson distribution (random); when t > t0.05, it follows clumped distribution. The Cx value can determine both distribution pattern and aggregation intensity.

(2) **Clumping Index**: I = V/m - 1. When I < 0, uniform distribution; I = 0, random distribution; I > 0, clumped distribution.

(3) **Negative Binomial Parameter**: K = m^2/(V - m). When k < 0, uniform distribution; when k > 0, clumped distribution. Smaller k values indicate greater aggregation; when k > 8, the population approaches Poisson distribution (random).

(4) **Mean Crowding Index**: m* = m + V/m - 1. When m* > m, clumped distribution; m* = m, random distribution; m* < m, uniform distribution.

(5) **Patchiness Index**: PAI = m/*m. When m*/m = 1, random distribution; m/*m > 1, clumped distribution; m*/m < 1, uniform distribution.

(6) **Aggregation Index**: Ca = m*/m - 1. When C = 1, random distribution; C > 1, clumped distribution; C < 1, uniform distribution.

Data processing was conducted using Excel 2010.

2.1 Analysis of *Cyclobalanopsis glauca* Population Structure

Statistical analysis of *C. glauca* populations at the three topographic sites revealed that Class I seedlings were fewer than Class II saplings but more abundant than other age classes [Figure 1: see original paper]. Class II saplings were distributed across all three sites, accounting for 30.41%, 23.98%, and 45.61% of individuals in funnel, hillside, and valley sites, respectively. Class III small trees occurred only in funnel and valley sites at 40.54% and 59.46%, respectively, with no small trees in hillside plots. Class IV (first-level) medium trees were present at all three sites, with proportions of 39.29% in valley, 32.1% in funnel, and 28.57% on hillside. Class V (second-level) medium trees occurred only in valley (63.16%) and hillside (36.84%). Class VI large trees were found only in valley (57.89%) and funnel (42.11%). These results indicate that only the valley site had a complete diameter class structure, while the funnel site lacked Class V medium trees and the hillside site had the most incomplete structure, with few seedlings and an absence of small and large trees. All three sites showed a diameter structure with saplings most abundant, seedlings second, and medium and large trees least abundant, forming a "high in the middle, low at both ends" pattern.

The survival curves [Figure 2: see original paper] showed that hillside populations lacked Class III small trees and Class VI large trees, while funnel populations lacked Class V individuals, creating breakpoints in their survival curves and discontinuous diameter structures. In valley populations, the transition from Class II saplings to Class III small trees involved a sharp decline in numbers, indicating low survival rates during this stage. All three sites showed saplings as absolutely predominant, followed by seedlings, with fewer small, medium, and large trees, resulting in survival curves approaching Deevey Type III. This indicates that all three populations experienced mortality peaks during growth, with natural regeneration 受阻, but the abundance of seedlings and saplings suggests strong self-renewal capacity and growing population status.

2.2.1 Population Distribution Patterns

The spatial distribution pattern indices for *C. glauca* populations are shown in . The variance/mean ratios for all topographic sites were less than 1 and passed t-tests, indicating low aggregation intensity and random distribution. Deviation index CX, clumping index I, and K values showed the pattern valley >

hillside > funnel, while mean crowding index M* showed funnel > hillside > valley. Patchiness index PAI and aggregation index Ca showed consistent patterns across sites. Therefore, populations at all three topographic sites exhibited random distribution.

Since distribution patterns are strongly influenced by environmental factors, and based on the properties of each index (smaller negative binomial parameter K values and larger mean crowding M*, patchiness PAI, and aggregation Ca values indicate greater aggregation), the comprehensive ranking of aggregation intensity across sites was funnel > hillside > valley.

2.2.2 Dynamics of Population Distribution Patterns

The distribution pattern dynamics across different diameter classes are shown in . In valley sites, Class II saplings showed uniform distribution, while small, medium, and large trees showed random distribution. In funnel sites, saplings, small trees, and medium trees showed clumped distribution, while large trees showed random distribution. In hillside sites, saplings and first-level medium trees showed clumped distribution, while second-level medium trees showed random distribution. Overall, the distribution pattern of *C. glauca* populations showed decreasing aggregation intensity with increasing age class, transitioning from clumped to random distribution. Specifically, seedlings, saplings, and small trees tended toward clumped distribution, while medium and large trees tended toward random distribution.

3.1 Diameter Structure of *Cyclobalanopsis glauca* Populations

Using tree class structure as a proxy for age, our results revealed that *C. glauca* populations in Maolan karst forest had abundant seedlings, with Class II saplings being absolutely predominant and medium and large trees comprising a certain proportion, indicating strong self-renewal capacity and growing population status. Diameter structures varied significantly among topographic sites. Only the valley site had individuals in all diameter classes, while funnel and hillside sites showed missing classes, resulting in incomplete diameter structures. This may be due to environmental filtering that hinders population regeneration, causing high mortality as individuals fail to pass through this filter. Environmental filtering involves multiple factors, possibly including climate and soil conditions (Zou et al., 1995). Population dynamics may also result from intense intraspecific competition (Song et al., 2005), with self-thinning occurring as competition intensifies with age. Survival curves showed sharp declines from saplings to small trees at all three sites, with self-thinning resulting in fewer small and large trees and creating the "high in the middle, low at both ends" diameter structure.

Ecological conditions differed significantly among funnel, valley, and hillside sites in Maolan, particularly in light, soil nutrients, and moisture. Hillside sites had lower canopy closure, stronger light, higher temperatures, and more dramatic microclimate fluctuations, combined with thin soils lacking nutrients and moisture, creating harsh habitat conditions that inhibited seed germination and seedling growth, resulting in fewer seedlings and saplings. Additionally, steep slopes made it difficult for large individuals (Class VI trees) to establish, leading to the most incomplete diameter structure. Funnel sites had thicker soils but insufficient light and excessive moisture. Zhang et al. (2013) demonstrated that soil moisture significantly affects *C. glauca* seed germination rates, and the abundant moisture in funnels favored seed germination. While *C. glauca* seedlings and saplings are shade-tolerant, adult trees are light-demanding, resulting in abundant seedlings and saplings but few or no large trees in funnels. Valley sites had more stable environmental conditions with moderate moisture and light, making them suitable for *C. glauca* individuals of all ages and resulting in the most complete diameter structure.

3.2 Distribution Patterns of *Cyclobalanopsis glauca* Populations

Cyclobalanopsis glauca populations showed overall random distribution across the three topographic sites, but seedlings, saplings, and small trees tended toward clumped distribution with aggregation intensity ranking as funnel > hillside > valley, while aggregation intensity decreased in medium and large trees. This pattern is primarily related to the species' biological characteristics and environmental factors. Topographically, funnel sites are low-lying, and *C. glauca* produces heavy, ovoid or ellipsoidal nuts dispersed by gravity, causing most seeds to accumulate in low-lying areas or near mother trees and resulting in clumped seedling and sapling distribution. Hillside sites are steep, and seeds accumulate in rock grooves, crevices, and channels due to gravity, also leading to clumped seedling and sapling distribution. Valley sites are the most flat among the three terrain types with balanced water and heat conditions, where seed dispersal is less affected by topography, resulting in lower aggregation intensity in seedlings and saplings. Population distribution patterns represent adaptations to the environment (Li et al., 2013). In harsh karst forest ecosystems, sprouting is an adaptation mechanism developed by many species through long-term evolution to compete for survival resources and space (Zheng and Long, 2014). When stems of older individuals break or fall, multiple sprouts and root suckers often emerge from the root collar or root system, enhancing population regeneration capacity and playing an important role in maintaining population stability and continuity. Sprout-derived individuals remain clustered in their original positions. As seedlings grow, competition for water, nutrients, and light intensifies, leading to enhanced intraspecific and interspecific interactions that cause self-thinning or alien-thinning (Li et al., 2010), resulting in transition from clumped to random distribution. Consequently, larger diameter classes of medium and large trees showed random distribution across all sites. Cai (2000) and Hu and Yu (2003) found similar patterns in *C. glauca* populations, with seedlings showing clumped distribution that gradually weakened toward random distribution with population development. Other evergreen broad-leaved species show similar patterns, such as *Cyclobalanopsis multinervis* and *Castanopsis eyrei*, which are clumped at seedling, sapling, and even small tree stages but random at medium and large tree stages (Pan et al., 2013; Xu et al., 2005). Thus, the distribution pattern dynamics of *C. glauca* in Maolan karst forest are consistent with those of other evergreen broad-leaved species.

The karst mountainous region of southwestern China represents a fragile ecological zone where forest vegetation restoration is a primary task for ecological construction (Li et al., 2003; Yao et al., 2008). *Cyclobalanopsis glauca* prefers micro-alkaline or neutral limestone soils, tolerates dryness and barrenness, and is a constructive species in karst ecosystems (Deng et al., 2006). Its population development plays an important role in karst ecological restoration. Therefore, in fragile karst ecological zones or degraded vegetation areas, *C. glauca* seedlings can be planted in early restoration stages, with other species added as the community stabilizes. In middle and late succession stages, appropriate artificial tending measures such as thinning overly dense shrubs, vines, and weeds can increase light availability, improve seedling survival rates, and enhance the potential and speed of degraded karst vegetation recovery. Maolan karst forest features thin soils and well-developed rock fissures, making it difficult for shallow-rooted plants to establish on rock surfaces and in rock grooves. *C. glauca* is a deep-rooted species with well-developed, strong-penetrating root systems that provide growth advantages in harsh karst habitats, making it one of the dominant species in Maolan karst forest. Given the complex and diverse topography and geomorphology of Maolan Reserve, with highly random and heterogeneous microhabitats such as rock surfaces, rock grooves, and rock crevices, maintaining the diversity and integrity of the karst forest ecological environment and utilizing the environmental advantages of different terrains and microhabitats to ensure basic conditions for seed germination and seedling growth are essential for natural regeneration in Maolan karst forest.

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