Population Spatial Pattern and Association of the Rare and Endangered Plant Guizhou Red Camellia: A Postprint

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Abstract

Camellia kweichowensis is a synonym of the accepted species name Camellia reticulata under the genus Camellia, and represents a key protected wild plant naturally distributed in Guizhou Province. As a rare and endangered species, investigating the spatial distribution patterns and correlation characteristics of its population holds great significance for strengthening biodiversity conservation and utilization, as well as for studying the mechanisms of plant population development and succession. Based on field surveys, this study employs the pair-correlation function g(r) to conduct point pattern analysis on the distribution characteristics and correlations of plants at various growth stages within the population. The results demonstrate that: (1) Plants at all developmental stages of the Camellia kweichowensis population exhibit clustered distribution at smaller scales. As the study scale increases, the degree of aggregation among individuals gradually decreases, displaying a trend of transitioning from clustered distribution to random distribution, with the fundamental characteristic of significant small-scale clustering and large-scale randomness. (2) At small scales, mutual sheltering among plants enhances population survival rates, with plants at adjacent age stages of the population all showing positive correlations. As the scale increases, the correlation gradually weakens and shifts toward negative relationships. At medium to large scales, middle-aged and adult plants suppress understory regeneration to ensure their growth advantages. Factors such as primitive species development, intense habitat resource competition, strong intraspecific self-thinning constraints, and habitat disturbance constitute important reasons why the Camellia kweichowensis population has difficulty dispersing, exhibits narrow distribution characteristics, and remains rare and endangered. Therefore, improving habitat conditions for naturally distributed populations, implementing appropriate thinning-based forest structure adjustments, and conducting ex-situ conservation along with seedling reintroduction

cultivation are crucial for ensuring the stable reproduction of Camellia kweichowensis populations. The research findings can provide a germplasm foundation and scientific basis for the effective protection and innovative utilization of Camellia kweichowensis plant resources.

Full Text

Preamble

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Population Spatial Patterns and Association of the Rare and Endangered Plant *Camellia kweichowensis*

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Abstract: *Camellia kweichowensis*, taxonomically confirmed as a synonym of *Camellia reticulata*, is a key protected wild plant naturally distributed in Guizhou Province. The species is rare and endangered, and investigating its population spatial distribution patterns and correlation characteristics is crucial for strengthening biodiversity conservation and understanding plant population development and succession mechanisms. Based on field surveys, this study employs the pairwise correlation function g(r) to conduct point pattern analysis of plant distribution characteristics and associations across different growth stages. The results show: (1) Plants at all developmental stages of the *C. kweichowensis* population exhibit clustered distribution at small scales. As the study scale increases, the degree of aggregation between individuals gradually decreases, showing a transition from clustered to random distribution, with the fundamental characteristic of small-scale clustering and large-scale randomness. (2) At small scales, mutual sheltering among plants enhances population survival rates, with plants at adjacent age stages showing positive correlations. As scale increases, correlations gradually weaken and shift toward negative relationships. At medium to large scales, middle-aged and adult plants suppress understory regeneration to ensure their growth advantage. Factors such as primitive species development, high habitat resource competition pressure, strong intraspecific self-thinning, and habitat interference are important reasons why the *C. kweichowensis* population struggles to expand and exhibits narrow distribution characteristics, contributing to its rarity and endangered status. There-

fore, improving habitat conditions for naturally distributed populations, appropriately adjusting forest structure through thinning, and implementing ex-situ conservation and seedling reintroduction are key to ensuring the stable reproduction of *C. kweichowensis* populations. These findings provide a germplasm foundation and scientific basis for the effective protection and innovative utilization of *C. kweichowensis* plant resources.

Keywords: *Camellia kweichowensis*, rare and endangered plant, population distribution pattern, spatial correlation, pairwise correlation function

Introduction

Population spatial patterns refer to the positional distribution states and layout characteristics of individuals within their living space, resulting from the combined effects of plant population biological characteristics, intra- and interspecific interactions, and external environmental factors (Wang & Yu, 2005; Cui et al., 2021). Population spatial distribution patterns are not only fundamental elements of plant community construction but also directly reflect individual distribution status and population dynamic development laws (Qiu et al., 2022). They hold significant importance for studying population competition relationships, disturbance mechanisms, and habitat heterogeneity (Zhang et al., 2007; He et al., 2021). Numerous studies have demonstrated that point pattern analysis can effectively reveal population distribution patterns at different scales and truthfully reflect the processes and characteristic attributes of population individual distribution patterns (McIntire & Fajardo, 2009; Brown et al., 2011; Wiegand & Moloney, 2012). This method has become an important approach for fundamental research in population biology (Baddeley et al., 2015; Ma et al., 2017). In recent years, many scholars have used point pattern methods to study the spatial distribution patterns and ecological characteristics of dominant community plants such as *Quercus aliena* var. *acutiserrata* and *Cyclobalanopsis glauca* (Qiu et al., 2022; Pan et al., 2023), as well as endangered plants such as *Kmeria septentrionalis* and *Camellia rubituberculata* (Guo et al., 2019; Wang et al., 2021). Researchers have found that factors such as differences in spatial scales, variations in disturbance intensity, different species characteristics (Chen et al., 2024), and habitat types (Li et al., 2022) all influence plant population spatial distribution patterns.

Camellia kweichowensis is a relatively primitive species in the Theaceae family from a phylogenetic perspective. It is a small tree, 4–5 m tall, with red to pink flowers 8–15 cm in diameter. Young branches are glabrous, while old branches are grayish-white. Leaves are leathery, shiny, and glabrous, 6–10 cm long and 3–4 cm wide, with slightly pointed or acuminate apices, broad cuneate or subrounded bases, 6–7 pairs of lateral veins, finely serrated margins, and petioles 8–12 mm long. A significant evolutionary characteristic is its ovary with 5 locules or 3–4 locule variations, making it a rare representative species with 5-locular ovaries in the *Camellia* sect. *Camellia* (Zhang, 1998). In the classification systems of *Flora of China* (Min & Bartholomew, 2008) and the *Species 2000/Catalogue of Life China* (Biodiversity Committee, Chinese Academy of Sciences, 2024), this species is merged as a synonym under the accepted species name *Camellia reticulata*. Based on its regional characteristics and morphological-biological advantages, it is a key requirement for species diversity conservation (Hong, 2016). *Camellia kweichowensis* is a rare and endangered plant distributed narrowly in Jiulongshan Forest Park and nearby areas in Guizhou Province (Chen, 2008) and has been included in the list of key protected wild plants in Guizhou Province (Guizhou Provincial People's Government Network, 2023). Investigating its population spatial distribution patterns and correlation characteristics is of practical significance for strengthening biodiversity conservation and provides a scientific foundation for studying its population formation mechanisms and developing species protection measures.

Current research on *C. kweichowensis* has been limited to investigations of species resource status (An, 2005) and studies on its biological characteristics, seedling propagation, and habitat soil properties (Chen, 2008; Hu et al., 2013). However, research on population ecological characteristics is scarce, and issues concerning its population development and evolution mechanisms and intraspecific associations remain unclear. Therefore, based on the actual natural distribution of *C. kweichowensis*, this study takes the Jiulongshan forest vegetation area in Guiyang City, Guizhou Province as the research region. Using the pairwise correlation function g(r) and combining complete spatial randomness (CSR) and heterogeneous Poisson (HP) model tests, we conducted point pattern analysis of spatial distribution and intraspecific associations at different age classes. The aim is to deeply analyze and clarify the spatial patterns and correlation characteristics of naturally distributed *C. kweichowensis* populations, reveal the response mechanisms of population distribution and growth to their natural ecological environment, and provide scientific references for the protection and utilization of *C. kweichowensis* species resources.

1.1 Study Area and Plot Survey

The study was conducted in the Jiulongshan natural vegetation area and Baotashan natural forest protection area in Guiyang City, Guizhou Province [Figure 1: see original paper]. This region is located on the northern side of the Miaoling Mountains, characterized by mid-mountain landforms with deep valleys and large topographic variations, with elevations ranging from 1,192 to 1,762 m. It features a typical subtropical monsoon humid climate with prominent seasonal characteristics. Soils are primarily composed of yellow soil, yellow-brown soil, and limestone soil, with thickness typically between 40–60 cm and weak acidity (pH 4.5–6.0). The vegetation consists mainly of natural secondary forests including evergreen deciduous broad-leaved mixed forests, deciduous broad-leaved forests, coniferous broad-leaved mixed forests, and shrublands, accompanied by small areas of artificial coniferous forests. The secondary nature of vegetation is prominent, with diverse associated plant species. Naturally occurring *C. kweichowensis* populations grow singly or in clusters, typically distributed in the small tree layer, sub-tree layer, and shrub layer within complex forest vertical structures. They often participate in community construction and succession as constructive or accompanying species, showing obvious advantages in evergreen deciduous broad-leaved mixed forests and secondary forests.

Based on comprehensive field surveys and following the principles of staying away from forest edges and not crossing streams or roads (Xie et al., 2022), we selected three 30 m × 30 m standard plots in areas with relatively concentrated distribution and certain representativeness, considering the rarity and relatively concentrated distribution of *C. kweichowensis* populations. Using the quadrat method (Li et al., 2017), we recorded habitat characteristic values including altitude, longitude and latitude, and associated plant composition . To collect more comprehensive data and reduce errors, each 30 m × 30 m plot was divided into nine 10 m × 10 m subplots. Based on these subplots, we conducted complete enumeration of *C. kweichowensis* plants, recording basal diameter data. Using the horizontal subplot values as the x-axis and vertical values as the y-axis, we established a Cartesian coordinate system to measure the spatial relative coordinates of individual *C. kweichowensis* in the plots, with coordinate values expressed in meters (m) to map and analyze the geographic spatial distribution characteristics of the population.

1.2 Data Processing

Based on the growth characteristics of *C. kweichowensis* and plot survey data, we divided the population into three developmental stages (the average DBH of *C. kweichowensis* in the plots was 3.17 cm, with a maximum of 13.9 cm): seedlings with DBH < 1 cm, middle-aged plants with 1 cm $\leq$ DBH < 6 cm, and adult plants with DBH ≥ 6 cm. Considering the rarity of *C. kweichowensis* population samples, data were initially processed using Excel. We used ArcGIS to construct forest Voronoi diagrams and applied the distance buffer method to create a 2 m inward buffer zone along all four edges of the original plots to eliminate edge effects (Li et al., 2014; Liu et al., 2017). We analyzed Voronoi diagram information for each plot and drew edge-corrected population maps [Figure 2: see original paper]. Point pattern analysis of the corrected plot data was performed using the "Spatstat" package in R 4.0.5, and figures were generated using Origin 2018.

The Voronoi diagram intuitively reflects the spatial distribution and "influence zones" of *C. kweichowensis*. As shown in [Figure 2: see original paper], Voronoi polygon areas vary in size, being smaller within clusters and larger outside them, with clusters being dispersed, indicating that the population has a random clumped distribution characteristic. After edge correction, although the clustered area in Plot B decreased, this only removed edge effect interference without changing the overall distribution characteristics of the population.

1.3 Point Pattern Analysis Methods

This study used Ripley's g(r) function to analyze the spatial distribution characteristics and associations of *C. kweichowensis* populations at different scales. The calculation formula is:

[Equation would appear here based on original format]

where g(r) is a derivative function of the K(r) function (Ripley's K). Compared with traditional methods, this approach uses rings instead of circles for calculation, effectively eliminating the "cumulative effect" at small scales and gaining widespread recognition in population spatial pattern studies (Stoyan et al., 1994; Ma et al., 2017).

The study calculated 99% confidence intervals through 99 Monte Carlo random simulations and plotted upper and lower envelope lines. In the formula, r represents spatial scale. When the g(r) value is above the upper envelope line, plants show clustered distribution; when between the upper and lower envelope lines, random distribution; and when below the lower envelope line, uniform distribution.

Using basal diameter data of *C. kweichowensis* as marker values, we employed bivariate pairwise correlation function methods to analyze and calculate spatial association characteristic values among individual plants under different developmental stages (Tuo et al., 2020; Li et al., 2022; Tang, 2022). The calculation formula is:

[Equation would appear here based on original format]

where 1 and 2 represent different developmental stages of the *C. kweichowensis* population. When $g_{12}(r) = 1$, individuals at different developmental stages show no correlation at scale r; when $g_{12}(r) > 1$, positive correlation; and when $g_{12}(r) < 1$, negative correlation.

Although these calculation results can reflect population density effects causing population number reduction and restricted individual growth and development, and can be used to analyze and detect mutual promotion or competition relationships among different individuals within populations, the g(r) function is non-aggregating. Considering the steep geographical environment of *C. kweichowensis* distribution areas where environmental factors may influence population spatial distribution patterns and associations, we adopted complete spatial randomness (CSR) and heterogeneous Poisson (HP) models to verify the deviation degree between actual observed values and theoretical values.

2.1 Population Survey and Spatial Pattern Analysis of *Camellia kweichowensis*

The population spatial distribution pattern is shown in [Figure 3: see original paper]. The *C. kweichowensis* population distribution exhibits obvious clustering overall, with certain differences in individual distribution among populations in different habitats. Survey statistics show that population densities in Plots A, B, and C are 0.2367 plants · m^{-2}, 0.3344 plants · m^{-2}, and 0.2267 plants · m^{-2}, respectively. After edge correction, Plot A contained 189 plants, including 37 seedlings, 128 middle-aged plants, and 24 adult plants. The population showed certain clustered distribution characteristics at small scales (0–5 m), but the degree was relatively weak, transitioning to random distribution as scale increased. Plot B contained 257 plants, including 55 seedlings, 188 middle-aged plants, and 14 adult plants, showing predominantly clustered distribution with relatively high aggregation, but with scarce adult plants and age-class gaps. Plot C contained 176 plants (36 seedlings, 111 middle-aged plants, and 29 adult plants), with mostly clustered distribution but low aggregation and some random distribution at certain scales. Scatter plot analysis can reflect *C. kweichowensis* population distribution in different plots to some extent, but precise determination of distribution types and cluster intensity requires further spatial point pattern analysis.

2.2 Distribution Characteristics of *Camellia kweichowensis* at Different Developmental Stages

The study found that under the complete spatial randomness (CSR) model, plants at all population stages showed strong clustered distribution at small scales, gradually transitioning to random distribution as distribution scale increased. After removing environmental heterogeneity (HP), the scale of clustered distribution expanded. As shown in [Figure 4: see original paper], seedling plants showed predominantly random distribution across the entire study scale but exhibited high-intensity clustered distribution at small scales. After removing environmental heterogeneity, the clustered distribution scale expanded slightly, then transitioned to random distribution as scale increased, with randomness intensity following the order Plot A > Plot C > Plot B.

Middle-aged plant distribution showed significant differences among different habitats. In Plots A and C, strong clustered distribution occurred only at very small scales, with predominantly random distribution at other scales, accompanied by some clustered and uniform distributions at certain scales. In Plot B, middle-aged plants showed clustered distribution across 0–6 m scales, with both cluster scale and intensity higher than in Plots A and C, random distribution at 6–7.5 m, and uniform distribution at 7.5–12 m, with large-scale uniformity weakening after removing environmental heterogeneity. Additionally, the study found that middle-aged plants in all three plots showed certain differences in population distribution characteristics between CSR and HP models, indicating that environmental heterogeneity affects plant growth and development at this stage.

Adult plants showed significantly weaker clustering compared with seedlings and middle-aged plants, with predominantly random distribution that gradually tended toward uniform distribution as scale increased.

2.3 Association Analysis Among Individuals at Different Developmental Stages of *Camellia kweichowensis*

Individual plants of *C. kweichowensis* at different developmental stages showed predominantly positive correlation at small scales, gradually transitioning to no correlation or negative correlation as scale increased, with associations progressively weakening [Figure 5: see original paper]. The seedling-middle-aged plant stage showed large differences among plots. In Plot A, the two stages were predominantly positively correlated at 0–7 m scales, transitioning to no correlation or weak negative correlation at scales >7 m. In Plot B, associations showed a "positive-negative-positive" pattern, with predominantly negative correlation at 3–12.5 m scales. In Plot C, seedling-middle-aged plant correlations were weak, showing only certain positive correlation at very small scales.

Middle-aged-adult plants showed similar spatial associations in Plots A and C, transitioning overall from strong positive to weak negative correlation. In Plot B, approximately 6 m served as the boundary, with significant positive correlation at scales <6 m, no obvious correlation at 6–12 m, and negative correlation at scales >12 m. Adult-seedling plants showed overall positive correlation in Plots A and C, although with some negative correlation at certain scales, while in Plot B they showed alternating "positive-negative" correlations with peaks.

Furthermore, analyzing spatial association intensity among adjacent plants across the three plots revealed that in Plots A and C with relatively complete population structures, correlation change trends among different stages were basically consistent, while in Plot B, spatial correlation changes among different stages varied greatly, indicating relatively poor population structure stability in Plot B.

3 Discussion and Conclusion

3.1 "Small-Scale Clustering–Large-Scale Randomness" is the Main Distribution Characteristic of *Camellia kweichowensis* Population Structure

Plant population spatial distribution patterns represent the response mechanism of populations to their biological characteristics and environmental heterogeneity, including factors such as seed dispersal methods and efficiency, intra- and interspecific competition, and habitat heterogeneity, which collectively construct diverse distribution patterns (Shen et al., 2013). The "small-scale clustering–large-scale randomness" characteristic of *C. kweichowensis* population spatial distribution patterns is significant and similar to most angiosperm species distribution patterns, such as the tree species *Quercus aliena* var. *acutiserrata* (Qiu et al., 2022) and *Artemisia halodendron* (Li et al., 2022), which is driven by species survival requirements.

First, this pattern manifests in seed dispersal limitations. Wild plant populations primarily rely on seed reproduction, and seed functional traits and dispersal methods are important factors affecting species life forms. *Camellia kweichowensis* seeds are capsules, with mature fruits or seeds naturally falling around the mother plant after detachment. Therefore, plant spatial distribution roughly uses 2 m scale as the critical point, forming obvious clustered distribution within the 0–2 m range. This phenomenon is consistent with current research conclusions on capsule-type (or autochorous) species, such as studies on *Sinojackia xylocarpa* (Dong et al., 2022) and *Camellia rubituberculata* (Guo et al., 2019).

Second, regarding species survival mechanisms, *C. kweichowensis* is mainly located in the sub-tree and shrub layers of subtropical evergreen broad-leaved deciduous mixed forests (An, 2005). Seedling plants have weak resource acquisition capacity and low risk resistance, and clustered distribution can enhance population resistance to external interference and resource competition pressure, strengthen group advantages, and increase population survival rates. However, excessive intraspecific self-thinning during population development and diffusion can easily cause populations to fall into a dilemma of facing intense interspecific resource competition while overcoming internal competitive constraints, undoubtedly increasing population diffusion difficulty (Dong et al., 2022). Plant population spatial distribution patterns result from multiple factors, reflecting not only population adaptation strategies to the environment but also revealing complex interspecific interactions and resource allocation mechanisms in ecosystems. As population individual age increases, intra- and interspecific competition intensifies, and density-dependent effects increase sharply, leading to decreasing plant numbers (Xie et al., 2022). Therefore, as the growth cycle progresses, middle-aged stage plants gradually transition from clustered to random distribution.

Population spatial distribution patterns are closely related to population edge effects, human disturbance, species endogenous succession mechanisms, and spatial scales, with significant differences in population distribution characteristics across different scales (Condit et al., 2000). Habitat heterogeneity is often an important factor affecting population spatial distribution (Zhang, 2012). Through further research and analysis, in the HP model that removes external environmental influences, the randomness of *C. kweichowensis* plants at all age stages significantly increased, and the range of clustered distribution at small scales also expanded. Particularly for adult plants, after removing environmental heterogeneity, the uniformity characteristics of spatial distribution gradually became prominent, indicating that environmental heterogeneity is one of the key influencing factors of *C. kweichowensis* population spatial distribution. Habitat factors such as forest edges, gaps, and light spots often accompany resource enrichment and can promote biodiversity enhancement to some extent (Cai et al., 2017), with differences being more significant at smaller plot scales (Yu et al., 2023). Naturally distributed *C. kweichowensis* populations have special survival requirements and obvious narrow distribution characteristics. Edge correction analysis did not change the overall distribution characteristics but made small clump distribution features more obvious while removing edge points to enhance population data accuracy.

3.2 Dynamic Characteristics of "Small-Scale Positive Correlation Gradually Transitioning to Large-Scale Negative Correlation" Within *Camellia kweichowensis* Populations

Spatial association analysis among individuals at different developmental stages within a population is an important method for studying the spatial configuration relationships among population individuals during specific periods (Shields et al., 2014), effectively determining and revealing population survival status and intraspecific competition mechanisms. Generally, the seed setting rate of middle-aged and adult plants in a population plays a decisive role in seedling number and relative spatial distribution, while seedling number and geographic location are core elements for middle-aged and adult plant replenishment and distribution patterns. Therefore, most population plants have certain positive correlations at small scales, particularly for autochorous or capsule species. Due to limited dispersal range, correlations gradually weaken as scale expands. However, in natural populations, as plant maturity increases, the demand for key survival resources such as light, water, and living space increases, population density limitation effects become more obvious, intraspecific competition pressure intensifies, and the mutualistic symbiotic relationship between seedlings and middle-aged/adult plants is gradually replaced by competitive relationships, with individual correlations shifting. This is particularly obvious between middle-aged and adult plants. Middle-aged plants are the core component of *C. kweichowensis* populations and represent the critical period for plant growth and development, with particularly intense intraspecific resource competition. Therefore, most wild plant populations, including *C. kweichowensis*, show obvious dynamic characteristics of "small-scale positive correlation, large-scale negative correlation," with small-scale associations gradually weakening as scale increases until transitioning to negative correlation relationships.

Spatial associations among individuals at different developmental stages within populations are influenced by multiple factors, including habitat conditions, resource competition, and human disturbance. Human disturbance often accompanies blocked population regeneration and development (Liu, 2020). In the primary community of *C. kweichowensis*, Plot C had the most intact natural vegetation protection with minimal human activity impact. Therefore, except for being affected by the species' unique dispersal method at very small scales, $g_{12}(r)$ values at other scales roughly fluctuated around $g_{12}(r)=1$, with no obvious spatial clustering or separation effects. In contrast, Plot B experienced relatively high-frequency human activity interference, particularly selective logging activities that significantly affected competition patterns between middle-aged and adult plants. Under different habitat conditions or human disturbance factors within the same age class population, individual spatial associations also varied. Although logged plants could supplement middle-aged plants to some extent through new sprouting seedlings, showing positive ecological compensation relationships, excessive logging easily destroyed population structure stability and could even directly cause age-class gaps within populations, with relatively weak overall population structure stability under disturbed habitat conditions. Therefore, strengthening in-situ protection in naturally distributed areas of *C. kweichowensis* and appropriately controlling and reducing interference from human production and construction activities are crucial for maintaining plant diversity breeding and healthy population continuity.

3.3 Improving Habitat Conditions in Distribution Areas and Strengthening Ex-Situ Conservation and Reintroduction Are Basic Prerequisites for *Camellia kweichowensis* Protection and Utilization

Seed biological characteristics and natural environmental factors are the main reasons for the narrow distribution and rare/endangered status of *C. kweichowensis*. Conducting in-depth research on rare and endangered plant gene sequences, biological functions, and evolutionary patterns, and scientifically evaluating germplasm resources and exploring new germplasm utilization pathways are crucial scientific propositions at the current stage (Strategic Research Group on Major Cross-cutting and Frontier Areas, Chinese Academy of Sciences, 2011; Chinese Academy of Sciences, 2013). Plant ex-situ conservation is one of the efficient strategies for implementing biological basic research and resource conservation for rare and endangered plants, and an important scientific practice for promoting plant germplasm improvement, innovation, and sustainable development and utilization. Benefiting from its unique geographical and ecological environmental conditions, *C. kweichowensis* has formed distinct species characteristics during plant evolution, with elegant tree posture, beautiful crown, bright flowers, concentrated flowering period, large fruits, and rich nutrient content, showing considerable ornamental characteristics and economic plant development value. However, due to its narrow distribution range and fragile habitat, its population spatial distribution patterns and associations are deeply affected by multiple factors including species biological characteristics, intra- and interspecific interactions, habitat conditions, and human activities. Therefore, as spatial scale expands and developmental stages advance, population distribution gradually transitions to random distribution, with limited numbers of plants successfully growing into middle-aged and adult stages, restricting natural population diffusion and outward expansion. Therefore, we recommend improving habitat conditions in natural distribution areas and strengthening ex-situ conservation and cultivation experiments, nurturing population seedlings and ensuring seedling supply to guarantee stable growth of naturally distributed populations and provide a scientific basis for species diversity conservation and utilization. Simultaneously, seeds from different distribution areas (different plots) should be collected for seedling cultivation and introduction, establishing ex-situ conservation populations that can effectively maintain genetic diversity ($Pn \geq Lf \cdot Ee \cdot Am$) (Zou et al., 2021) for breeding and utilization, promoting efficient protection and innovative application of germplasm resources, and providing germplasm materials and scientific foundations for biodiversity resource conservation and regional economic and social development.

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