Population Structure and Dynamic Characteristics of the Endangered Plant *Berchemiella wilsonii* and Its Variety *Berchemiella wilsonii* var. *pubipetiolata* (Postprint)

Authors: Pang Jianghao, Wang Yeqing, Tang Yunlong, Zhang Dong, Wu Hao, Wei Xinzeng, Jiang Mingxi

Date: 2024-12-02T00:00:00+00:00

Abstract

Investigating the population structure and dynamic characteristics of the endangered plant *Berchemiella wilsonii* and its variety *Berchemiella wilsonii* var. *pubipetiolata* can provide a scientific basis for the conservation and utilization of their germplasm resources. This study examined the existing recorded wild populations of *B. wilsonii* and *B. wilsonii* var. *pubipetiolata* in Hubei, Anhui, and Zhejiang provinces. Based on population ecological surveys, we constructed population structure diagrams, established static life tables, fitted survival curves, analyzed population viability, calculated population dynamic change indices, and conducted time series prediction analyses to reveal the population structural characteristics and future development trends of the two taxa. The results showed that: (1) The population structure of *B. wilsonii* was pyramidal, with a high proportion of young individuals, but its juveniles experienced high mortality during growth, resulting in fewer adults. The population of *B. wilsonii* var. *pubipetiolata* lacked young individuals, had a high proportion of middle-aged individuals, and few old individuals, presenting a spindle-shaped structure. (2) Model testing revealed that the survival curves of both taxa approximated Deevey-III type, indicating high mortality rates during their juvenile stages. Due to reaching physiological age, mortality rates of both taxa peaked at age class VI. (3) The survival rate and cumulative mortality rate of the *B. wilsonii* population reached equilibrium at age class II, while those of *B. wilsonii* var. *pubipetiolata* reached equilibrium at age class VI, indicating that *B. wilsonii* enters the decline phase earlier. (4) Population dynamic indices revealed that both taxa belong to increasing populations that are susceptible to external disturbances and exhibit high sensitivity to interference. (5) Time series predictions showed that after experiencing 2, 4, 6, and 8 age classes, the number of individuals in the *B. wilsonii* population increased to varying degrees in each age class. In contrast, the *B. wilsonii* var. *pubipetiolata* population lacked young individuals, showed a decrease in middle-aged individuals, and an increase in adult individuals, indicating that the population faces decline. In conclusion, different conservation strategies should be adopted for the two taxa. For *B. wilsonii*, which exhibits high seedling mortality, appropriate thinning should be conducted to increase light availability and promote seedling survival, while simultaneously reducing anthropogenic disturbance. For *B. wilsonii* var. *pubipetiolata*, which has a severe lack of juveniles, research on artificial propagation techniques should be strengthened, and seedlings should be promptly supplemented through reintroduction and conservation to prevent population decline and achieve the conservation and utilization of species diversity resources.

Full Text

Population Structure and Dynamic Characteristics of the Endangered Plant *Berchemiella wilsonii* and Its Variety *B. wilsonii var. pubipetiolata*

PANG Jianghao[12], **WANG Yeqing**[3], **TANG Yunlong**[4], **ZHANG Dong**[1], **WU Hao**[12], **WEI Xinzeng**[12], **JIANG Mingxi**[12]

[1]Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]Hubei Wufeng Houhe National Nature Reserve Administration, Wufeng 443400, Hubei, China
[4]Jixi Management Station of Anhui Qingliangfeng National Nature Reserve, Xuancheng 245300, Anhui, China

Abstract

Investigating the population structure and dynamic characteristics of the endangered plant *Berchemiella wilsonii* and its variety *B. wilsonii var. pubipetiolata* provides a scientific basis for the conservation and utilization of their germplasm resources. This study examined wild populations of both taxa with existing records in Hubei, Anhui, and Zhejiang provinces. Based on population ecological surveys, we constructed population structure diagrams, established static life tables, fitted survival curves, analyzed population viability, calculated population dynamic indices, and conducted time series predictive analyses to reveal the structural characteristics and future development trends of the two taxa. The results showed: (1) *B. wilsonii* exhibited a pyramid-shaped population structure with a high proportion of young individuals, but experienced substantial losses during juvenile development, resulting in fewer adults. In contrast, *B. wilsonii var. pubipetiolata* lacked young individuals, had a high proportion of middle-aged individuals, and few old individuals, presenting a spindle-shaped structure. (2) Model testing revealed that both taxa approximated Deevey-III survival curves, indicating high mortality during juvenile stages, with peak mortality occurring at age class VI due to physiological senescence. (3) The survival and cumulative mortality rates of *B. wilsonii* balanced at age class II, whereas those of the variety balanced at age class VI, suggesting that *B. wilsonii* enters the decline phase earlier. (4) Population dynamic indices indicated that both belong to disturbance-sensitive increasing populations with high sensitivity to external interference. (5) Time series predictions showed that after 2, 4, 6, and 8 age classes, *B. wilsonii* populations would increase across all age classes to varying degrees, while *B. wilsonii var. pubipetiolata* would suffer from a lack of young individuals, decreasing middle-aged individuals, and increasing mature individuals, indicating population decline. We conclude that different conservation strategies should be adopted: for *B. wilsonii*, appropriate thinning should be implemented to increase light availability and promote seedling survival while reducing human disturbance; for the variety, research on artificial propagation techniques should be strengthened to supplement seedling recruitment and prevent population decline, thereby achieving conservation and utilization of species diversity resources.

Keywords: *Berchemiella wilsonii*, *B. wilsonii var. pubipetiolata*, population structure, static life table, survival curve, dynamic index, time series prediction

Introduction

In recent years, species have been going extinct at rates far exceeding estimates due to overexploitation, environmental pollution, and climate warming caused by human activities (Jurriaan et al., 2015; Maeques et al., 2019; Wang et al., 2024). Among China's more than 30,000 higher plant species, 15%–20% are threatened, prompting ongoing conservation research (Qin and Zhao, 2017; Xu et al., 2023; Mallapaty, 2020). Species conservation at the population level represents an effective approach to achieving scientific protection, as population structure and dynamics constitute fundamental characteristics and basic scientific questions in population ecology, particularly crucial for endangered plant research (Zhu et al., 2024; Wang et al., 2024). Population structure involves the age, size, and numerical distribution of individuals within a population, reflecting its survival status (Wang et al., 2018), while population dynamics describes temporal and spatial changes in population size and structure, facilitating predictions of development trends (Wei et al., 2015; Chhetri et al., 2016).

Domestic scholars have conducted extensive research on population structure and dynamics, significantly contributing to endangered plant conservation. For instance, Wang et al. (2022) analyzed the population structure of *Changiostyrax dolichocarpus*, an extremely small population species, and identified decline trends. Yuan et al. (2022) found that population structure changes affect the dynamics of the endangered *Pterospermum kingtungense*. Yu et al. (2018) demonstrated that under ideal environmental conditions, *Ferrocalamus strictus* populations would expand. Static life tables are central to population dynamics research, as their analysis reveals survival status and environmental adaptability, with survival rates, mortality density, and hazard rates directly showing survival ability differences across age stages. Further research on dynamic indices and time series predictions based on life tables can forecast future population trends (Schenk et al., 2003), helping to understand interactions within populations and between populations and their environment, thereby providing scientific foundations for effective conservation strategies.

Berchemiella wilsonii, belonging to the family Rhamnaceae and genus *Berchemiella*, is a nationally protected second-class wild plant. First discovered in Xingshan, Hubei in 1907, the species was once considered extinct until its rediscovery in Houhe Nature Reserve, Wufeng, Hubei at the beginning of this century (Li et al., 2004), with subsequent reports from other areas in Hubei and Zhejiang (Gan and Guan, 2007; Li et al., 2012). This deciduous tree grows in broad-leaved forests at 600–1300 m altitude, associated with dominant species including *Camellia cuspidata*, *Quercus myrsinifolia*, *Phoebe sheareri*, *Phoebe neurantha*, *Quercus oxyodon*, *Schima superba* (evergreen species), and *Diospyros lotus*, *Meliosma cuneifolia*, *Pterocarya hupehensis*, *Dipteronia sinensis*, *Betula luminifera* (deciduous species). As a companion species, *B. wilsonii* prefers warm, moist habitats, occurring in the upper canopy or mid-to-lower sections of well-drained valleys where it receives sufficient sunlight. Current research on *B. wilsonii* focuses on introduction and cultivation (Liu, 2018), gamete development (Wang et al., 2024), and community characteristics (Hu et al., 2003).

Berchemiella wilsonii var. pubipetiolata, a variety of *B. wilsonii*, is mainly distributed in localized areas of Anhui and Zhejiang provinces (Kang, 2006; Zhang et al., 2023). Sharing similar life habits and habitat characteristics, it also serves as a companion species with poor shade tolerance, high water requirements, narrow ecological niches, and minimal niche overlap with dominant species, surviving through niche specialization. Morphological differences include: *B. wilsonii* has petioles 4–5 mm long, glabrous, with leaves slightly pubescent only at vein axils on the underside; the variety has petioles only 2–3 mm long, pubescent, with denser pubescence on leaf undersides. Current research on the variety concentrates on genetic diversity (Xu et al., 2006; Kang et al., 2005, 2006), ecological niches (Shi et al., 2007), seed germination (Dang et al., 2005), and habitat characteristics (Xie et al., 2019).

As population structure and dynamics of both taxa remain unreported, this study investigated their populations using static life tables, survival curves, dynamic indices, and time series predictions to address three scientific questions: (1) What are the quantitative characteristics and survival status of extant populations? (2) What are their future development trends? (3) What are the endangerment mechanisms and conservation strategies? The results will provide scientific foundations for conservation priorities, directions, and utilization, while offering a case study for rare and endangered plant protection.

1.1 Field Investigation

According to literature records, *B. wilsonii* is mainly distributed in the western mountainous areas of Hubei and Shengzhou, Zhejiang, while *B. wilsonii var. pubipetiolata* occurs in localized areas of Anhui and Zhejiang (Figure 1 [Figure 1: see original paper]). Based on existing distribution sites, we conducted field surveys and sampling (Table 1), recording diameter at breast height (DBH), growth status, longitude and latitude, altitude, and habitat characteristics for both taxa.

1.2.1 Population Age Structure Classification

Obtaining wood cores causes substantial damage to individuals in rare and endangered woody plant populations (Liu et al., 2015). The "space-for-time substitution" method is typically employed, using diameter classes instead of age classes to determine age structure (Zhu et al., 1999). Since *B. wilsonii* and its variety are mostly small trees with few branches, DBH at 1.3 m above the base served as the basis for age classification. Based on survey data and field growth conditions, individuals with height <1.3 m and DBH<2.5 cm were designated as class I, with subsequent classes increasing in 5 cm DBH increments (Wei et al., 2008): class II as 2.5 cm $\leq$ DBH $<$ 7.5 cm, and so on, dividing both populations into eight age classes. Population structure diagrams were plotted with age class on the vertical axis and individual numbers per class on the horizontal axis.

1.2.2 Static Life Tables and Survival Curves

Static life tables are compiled from cross-sectional data at a specific time. Due to the scarcity of endangered plant individuals and unstable population sizes and age structures, negative mortality rates may appear in life tables, violating mathematical assumptions. Many studies apply smoothing corrections to avoid negative values (Wu et al., 2000; Zhang et al., 2008; Wang et al., 2015). However, when population sizes vary dramatically across age classes, smoothing can mask real information, and omitting such treatment better reflects actual population status (Zhao et al., 2020; Diao et al., 2020). Considering our data characteristics, we compiled static life tables directly from the classified age-class data without smoothing (Zhang et al., 2014). Survival curves were plotted with age class on the horizontal axis and the logarithm of standardized surviving individuals (lnlx) on the vertical axis. Exponential function equations and power function equations ($ax = a_0x^{-}$) were used to model and test the survival curves, describing Deevey-II and Deevey-III types, respectively. Model fit was evaluated based on coefficient of determination and F-test values (Hett et al., 1976).

1.2.3 Population Viability Analysis

To further reveal structural dynamic changes, we introduced survival rate (S), cumulative mortality rate (F), mortality density (f), and hazard rate (λ) for population survival analysis (Yang et al., 1991), with formulas as follows:

$S = l_{\ 1} / l$
h represents age class width.

1.2.4 Quantitative Analysis of Population Dynamics

Population dynamics were quantitatively described using dynamic indices of individual quantity change between adjacent age classes (V), population dynamic change index without external interference (V), population dynamic change index with external interference (V), and maximum probability of random disturbance risk (P) (Chen, 1998), calculated as:

$V = (A - A_{\ 1}) / \max(A , A_{\ 1}) \times 100\%$
$V = \Sigma(A \times V) / \Sigma A$
$V = \Sigma(A \times V) / (\Sigma A \times \min(S_1, S_2, ..., S))$
$P = 1 / \min(S_1, S_2, ..., S)$

where A and $A_{\ 1}$ are individual numbers in age classes x and x+1, respectively, and K is the number of age classes.

1.2.5 Time Series Prediction of Population Size

A first-order moving average method was used to predict population quantity dynamics after 2, 4, 6, and 8 age classes (Zhang et al., 2004), calculated as:

$M^{(\ )} = (1/t) \times \Sigma_{\ 0}^{\ -1} A$

where x is age class, t is prediction time in years, A is the surviving population number in age class x, and M is the predicted population size in age class x after t years.

2.1 Age Structure

The survey recorded 71 *B. wilsonii* individuals and 56 *B. wilsonii var. pubipetiolata* individuals. The age-class structure of *B. wilsonii* (Figure 2 [Figure 2: see original paper]A) showed an irregular pyramid shape with high proportions of young individuals—age classes I and II accounted for 28% and 27% of the total, respectively—followed by a sharp decline in class III and a gradual decreasing trend thereafter. The variety exhibited a spindle-shaped structure (Figure 2B), with individual numbers first increasing then decreasing, lacking class I individuals, and peaking in classes IV and V at 32% and 27% of the total, respectively.

2.2 Static Life Tables and Survival Curves

Static life tables for both taxa (Table 2) showed that *B. wilsonii* survival numbers decreased with age class, with life expectancy showing fluctuations—particularly low in classes II and VI compared to adjacent classes. The variety showed survival numbers first increasing then decreasing, with life expectancy gradually declining, dropping substantially in classes II and III before stabilizing. Mortality and disappearance rates (Figure 3 [Figure 3: see original paper]) revealed that *B. wilsonii* mortality and disappearance increased-decreased-increased-decreased with age class, with a peak in class II and maximum mortality in class VI, indicating substantial losses during the transition from juvenile to middle age (Figure 3A). The variety showed mortality and disappearance rates that first increased then decreased, with maximum mortality in class VI (Figure 3B).

Survival curve trends differed between the two taxa. *B. wilsonii* showed a declining trend with sharp drops in classes III and VII (Figure 4 [Figure 4: see original paper]A), while the variety first increased then decreased (Figure 4B). Model testing (Table 3) showed that power function models for both populations had higher R^2 values than exponential models, indicating that both survival curves approximated Deevey-III type, characterized by high juvenile mortality.

2.3 Population Viability Analysis

Survival rates for *B. wilsonii* declined gradually with age class (Figure 5 [Figure 5: see original paper]A), while the variety's survival rates increased from class II to III then declined gradually (Figure 5B). Cumulative mortality rates were complementary to survival rates in both taxa. The survival and cumulative mortality rates of *B. wilsonii* balanced in class II, indicating poor seedling survival, low viability, and early entry into the decline phase. For the variety, this balance occurred in class VI, indicating later entry into decline.

The mortality density curve for *B. wilsonii* (Figure 6 [Figure 6: see original paper]A) fluctuated relatively smoothly, with slightly higher early-stage density, while hazard rates increased with age class, showing the first peak in class III and the highest in class VI, indicating substantial survival pressure in these classes. The variety's mortality density curve (Figure 6B) first increased then decreased with age class, with relatively large variation and maximum density in class V. Hazard rates showed small early fluctuations but rose sharply from class V, indicating major survival pressure after class V.

2.4 Quantitative Analysis of Population Dynamics

Table 4 shows that *B. wilsonii* had positive dynamic indices in all classes except IV and VII, while the variety had negative indices in classes I–III and positive indices in remaining classes. Overall dynamic indices V and V were greater for *B. wilsonii* than for the variety, indicating superior population dynamics. Both taxa had random disturbance risk probability maxima (P) of 0.13%, suggesting poor population stability and high sensitivity to external interference.

2.5 Time Series Prediction of Population Size

Time series predictions (Table 5) indicated that after 2, 4, 6, and 8 age classes, *B. wilsonii* would show clear increasing trends across all age classes. In contrast, the variety would exhibit decreasing numbers in classes II–V and increasing numbers in classes VI–VIII, with significant lack of individuals in classes I–III. This suggests that under stable environmental conditions, *B. wilsonii* populations will maintain relatively stable numbers with some growth, while the variety will face decline due to lack of seedling recruitment, with existing individuals gradually transitioning to mature stages, resulting in an aging population.

3.1 Pyramid and Spindle-Shaped Age Structures

Berchemiella wilsonii populations have high proportions of young individuals but fewer middle-aged and mature individuals, forming an irregular pyramid-shaped structure that suggests growth potential. The most notable feature is high mortality during the transition from juvenile to middle age. The variety lacks class I individuals, has scarce young individuals, high proportions of middle-aged individuals, and few old individuals, forming a spindle-shaped structure facing substantial decline risk. Both taxa show Deevey-III survival curves, indicating high seedling mortality—a pattern consistent with studies on other rare plants such as *Tilia amurensis* (Zhang et al., 2022) and *Michelia wilsonii* (Qin et al., 2020)—though the underlying mechanisms differ. *B. wilsonii* has relatively abundant seedling reserves but low survival rates. Research indicates that *B. wilsonii* seedlings have high light and water requirements, preferring sunlight and being shade-intolerant. High canopy density and intense interspecific competition in their habitats hinder normal seedling development (Sun et al., 2022).

The life table shows negative initial mortality for the variety because it lacks class I individuals and has few class II and III individuals, causing juvenile stage data to violate mathematical assumptions. However, this accurately reflects the variety's small population size and unstable age structure. The primary characteristic of the variety's age structure is scarce seedlings and poor recruitment, caused by: poor shade tolerance preventing survival in high-canopy-density habitats; premature seed drop, poor viability, low germination rates, and lack of effective dispersal mechanisms (Dang et al., 2005).

Additionally, as shrubs or small trees, both taxa are disadvantaged in light competition. Field surveys revealed that extant populations primarily grow along riverbanks, ditch sides, roadside slopes, and cliffs where interspecific competition is low and light conditions are adequate, but habitat limitation and high human disturbance intensity substantially restrict population development.

3.2 Decline Characteristics of Both Taxa

Survival function analysis, population dynamic indices, and time series predictions further reflect spatiotemporal variation patterns and distribution patterns (Lai et al., 2006), revealing species-environment interactions. Survival functions indicate that *B. wilsonii* enters decline during juvenile stages, consistent with its high juvenile mortality and scarcity of middle-aged and mature individuals. The variety enters decline at class VI, later than *B. wilsonii*, suggesting different environmental pressures. Both taxa reach peak hazard rates at mature stages, indicating substantial survival pressure during these phases—a conclusion consistent with research on *Syringa pinnatifolia* (Jiang et al., 2018), possibly due to physiological death age or environmental factors such as specialized niche characteristics that hinder transition from middle to mature age.

Both taxa have dynamic indices V and V greater than 0, with V significantly lower than V and random disturbance risk probability maxima (P) approaching 0, indicating they are increasing populations with low disturbance resistance and high sensitivity. Notably, the variety shows negative dynamic indices in classes I–III, indicating clear juvenile stage decline. Time series predictions show that after 2–8 age classes, *B. wilsonii* will exhibit increasing trends across all classes, similar to *Camellia granthamiana* (Lin et al., 2023), indicating stable population numbers with some growth under stable environmental conditions. The variety will show increased numbers in classes VI–VIII but decreases in classes II–V, particularly lacking recruitment in classes I–III, consistent with negative dynamic indices for these classes. This indicates the variety will become increasingly senescent over time and face decline risk without timely seedling supplementation, a conclusion similar to research on *Lindera megaphylla* (Zhan et al., 2023).

3.3 Conservation Strategies

In summary, *B. wilsonii* and its variety share similarities and differences in population structure and dynamics. Similarities include: both experience peak mortality when transitioning from middle to mature age, both have relatively few mature individuals, and both show high sensitivity to external interference. Differences lie in pressures on juvenile stages: *B. wilsonii* has relatively more young individuals but higher mortality with few transitioning to middle age, while the variety clearly lacks young individuals, limiting recruitment and causing population aging. Therefore, different conservation strategies should be implemented. For *B. wilsonii*, thinning and canopy opening measures should reduce canopy density to provide appropriate light for seedlings and improve survival rates while reducing human disturbance. For the variety, research on improving seed germination rates and vegetative propagation techniques should be strengthened to promote population growth. Both require enhanced in-situ conservation to protect native habitats, optimize reserve management, and avoid human disturbance. For example, field surveys revealed that in some areas, local residents cut *B. wilsonii* for firewood. Therefore, public education should be strengthened alongside logging control to enhance conservation awareness, with remedial measures and enhanced monitoring for damaged populations. Ex-situ conservation should be conducted at suitable, manageable, and research-conducive sites (forestry farms, botanical gardens) with rational layout to avoid genetic diversity loss from inbreeding or hybridization (Yang et al., 2014).

Acknowledgments

We thank the national nature reserves and forestry departments at survey sites for their support and assistance with fieldwork. We also thank Professor Li Genyou for his help with field surveys in Zhejiang Province.

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