

Population Structure and Dynamic Characteristics of the Endangered Plant *Alseodaphne hainanensis* Postprint

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Abstract

Alseodaphnopsis hainanensis is a wild plant species under national second-class protection. To investigate the survival status of *Alseodaphnopsis hainanensis* populations, static life tables were compiled based on sample plot survey data using diameter class as a proxy for age class to analyze population quantitative characteristics, while population dynamic indices and time series models were applied to analyze and predict population dynamics and future development trends. The results showed: (1) Whether in primary or secondary forests, the population age-class structure of *Alseodaphnopsis hainanensis* exhibited an inverted “J” shape, with individuals distributed across all age classes; compared with primary forest, secondary forest had a greater number of seedlings. (2) In both primary and secondary forests, the dynamic indices of *Alseodaphnopsis hainanensis* populations fluctuated to some extent between adjacent age classes; the dynamic indices V_{pi} and V_{pi} in both primary and secondary forests were greater than zero, indicating that the population is currently in a growth phase, but is relatively sensitive to external disturbance and has poor disturbance resistance; the disturbance sensitivity probability of secondary forest was relatively lower, indicating that the disturbance resistance of *Alseodaphnopsis hainanensis* populations in secondary forest is stronger than that in primary forest. (3) Static life tables revealed that both the survival numbers and individual life expectancy of *Alseodaphnopsis hainanensis* populations in primary and secondary forests gradually decreased with increasing age class; the population survival curve approximated the Deevey-II type. (4) Time series analysis predicted that after 2–3 future age-class periods, the number of individuals in age class III in primary forest would decline; after 2 future age-class periods, the number of individuals in age class III in secondary forest would decline. After 5 future age-class periods, the number of individuals in all age classes in both primary and secondary forests would exhibit stable growth. In summary, whether in primary or secondary forests, *Alseodaphnopsis hainanensis* populations are in a growth

phase, the populations are in a fluctuating state and sensitive to external disturbance; young individuals in the population can compensate for losses caused by mortality at various age classes, thereby maintaining population stability. To promote natural regeneration of *Alseodaphnopsis hainanensis* populations, in-situ conservation measures should be strengthened, and in-depth research on seedling regeneration, breeding, and genetic diversity should be conducted, while moderate anthropogenic measures can be adopted to improve the seedling-to-sapling conversion rate and promote population growth.

Full Text

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Abstract

Alseodaphnopsis hainanensis is a nationally second-class protected wild plant in China. To investigate the survival status of its populations, we conducted field quadrat surveys in Hainan Province and analyzed population dynamics using diameter classes as age-class proxies. We compiled static life tables, analyzed quantitative population characteristics, and applied population dynamic indices and time series models to predict future trends. The results revealed: (1) Both primary and secondary forests exhibited an inverted “J”-shaped age-class structure with individuals distributed across all age classes, though secondary forests contained significantly more seedlings than primary forests. (2) Dynamic indices fluctuated between adjacent age classes in both forest types, with V_{pi} and V_{pi} values exceeding zero, indicating growth-type populations that are highly sensitive to external disturbances with poor resistance. Secondary forests demonstrated relatively stronger anti-disturbance capacity compared to primary forests. (3) Static life tables showed that standardized surviving individuals and life expectancy decreased progressively with age class in both habitats, with survival curves approximating Deevey-II type. (4) Time series analysis predicted that after 2–3 age-class intervals, individual numbers in age class III would decline in primary forests, while secondary forests would experience a similar decline after just 2 intervals. However, after five age-class intervals, all age classes in both forest types showed stable growth. In conclusion, *A. haina-*

nensis populations in both primary and secondary forests are growth-oriented but fluctuating and disturbance-sensitive. Young individuals can compensate for mortality losses across age classes, maintaining population stability. To promote natural regeneration, we recommend strengthening in-situ conservation measures, intensifying research on seedling establishment and breeding, investigating genetic diversity, and implementing moderate anthropogenic interventions to improve seedling-to-sapling transition rates and enhance population growth.

Keywords: *Alseodaphnopsis hainanensis*, endangered plant, population structure, survival curves, survival analysis, dynamic indices

Introduction

Population structure and quantitative dynamics constitute core research areas in population ecology (Zhang et al., 2014; He et al., 2024). Population structure encompasses diameter-class, height-class, and age-class distributions (Hu et al., 2023), reflecting not only the age, size, and abundance of individuals within a population but also revealing demographic dynamics and trends. Key methodological approaches in population demography include survival curves derived from static life tables, quantitative dynamic indices, and time series prediction models. These methods facilitate analysis of current survival status and environmental interactions (Fan et al., 2004), assessment of historical disturbance factors, and—most importantly—prediction of future population trajectories (Omelko et al., 2018; Wang et al., 2021). Comprehensive investigation of population structure and dynamics provides scientific foundations for plant resource conservation and sustainable utilization planning.

Alseodaphnopsis hainanensis (Lauraceae) is a canopy tree species endemic to Hainan Island's tropical montane rainforests, with wild populations occurring only in Hainan, China, and northern Vietnam. It inhabits forest valleys and dense stands at elevations of 700–1,700 m and is classified as a nationally second-class protected wild plant (Chen et al., 2011). Valued for its straight trunk and excellent timber quality, this species has suffered from long-term exploitation, unsustainable harvesting, habitat fragmentation, and frequent regeneration failure, pushing its natural resources toward depletion (Chen et al., 2011). *A. hainanensis* communities occupy two distinct habitat types: (1) primary forests with minimal anthropogenic disturbance that remain relatively pristine and natural, and (2) secondary forests subject to frequent human activities such as logging, cultivation, and pollution. Current research on *A. hainanensis* has focused on habitat and biological characteristics (Huang et al., 2011), interspecific associations (Chen et al., 2011), chemical constituent extraction (Chang et al., 2011), and seedling cultivation (Gou et al., 2017). Tao et al. (2004) identified *A. hainanensis* as a light-demanding species predominantly distributed in young or large forest gaps in Hainan's Bawangling tropical montane rainforest.

Chen et al. (2011) reported that dominant species in *A. hainanensis* communities showed non-significant positive overall associations, suggesting historical disturbance and indicating that *A. hainanensis* populations in Bawangling are narrowly distributed and small in size. However, the current status of *A. hainanensis* populations across Hainan Island remains unclear, limiting conservation effectiveness. Investigating population structure and dynamics is essential for understanding survival status and predicting future trends, thereby informing protection and management strategies. This study surveyed *A. hainanensis* populations across Hainan Tropical Rainforest National Park and surrounding areas using field measurements and typical sampling methods. By analyzing age-class structure, static life tables, survival curves, and time series predictions in both primary and secondary forests, we examined population structure, quantitative dynamics, and primary endangerment mechanisms, revealing current survival status and future development trends to provide scientific foundations for conservation and sustainable utilization.

1.1 Study Area Overview

Hainan Island covers approximately 3.39×10^4 km² (Liu et al., 2015) and features a tropical monsoon climate. Located at the southernmost tip of China (108°37'–111°03' E, 18°10'–20°10' N), the region experiences mean annual temperatures of 22–27°C, with monthly averages reaching 28.4°C during the hottest periods and dropping to 17.2°C during the coldest months (Li et al., 2015). Annual precipitation averages 1,639 mm, with distinct dry (November–April) and rainy (May–October) seasons. Basalt and granite constitute the primary parent materials, with latosols, yellow soils, and lateritic red soils as the dominant soil types (Gong et al., 2004).

Common associated tree species in the *A. hainanensis* canopy layer include *Xanthophyllum hainanense*, *Syzygium hancei*, *Cryptocarya chinensis*, *Gironniera subaequalis*, *Reevesia longipetiolata*, and *Castanopsis carlesii*. Shrub layer species primarily comprise *Psychotria asiatica*, *Gomphandra tetrandra*, *Saprosma merrillii*, *Prismatomeris tetrandra*, *Archidendron lucidum*, and *Ardisia crenata*. Herbaceous layer plants include *Diplazium donianum*, *Selaginella trachyphylla*, *Pronephrium simplex*, and *Blechnopsis orientalis*.

[Figure 1: see original paper] Schematic diagram of the study area and survey points

1.2.1 Sample Plot Setup and Survey Methods

We surveyed *A. hainanensis* populations using field measurements and typical sampling methods. Within Hainan Tropical Rainforest National Park, where *A. hainanensis* occurs in continuous distributions, we established 35 sample plots

(20 m × 20 m) totaling 14,000 m² across Bawangling, Jianfengling, Wuzhishan, Diaoluoshan, and Limushan, including 27 secondary forest plots and 8 primary forest plots. Each large plot was subdivided into four 10 m × 10 m subplots. For all *A. hainanensis* individuals with diameter at breast height (DBH) ≥ 1 cm, we recorded DBH, tree height, and crown width, while using GPS to document plot locations and collecting basic information on elevation, slope, and aspect. Detailed plot characteristics are provided in Table 1. Outside the national park, where *A. hainanensis* has limited distribution and small population sizes, we employed complete enumeration methods, measuring DBH, height, and crown width of all individuals while recording location, elevation, slope, and aspect data via GPS.

1.2.2 Age-Class Structure Classification

Due to limited wild populations and the infeasibility of using increment borers or stem analysis for age determination, we applied the space-for-time substitution principle combined with size-structure analysis to investigate population dynamics. DBH classes served as proxies for age classes (Frost & Rydin, 2000). Based on biological characteristics and field survey results, and following Luo et al.'s (2023) classification method for *Hopea hainanensis* DBH classes, we defined five age classes for *A. hainanensis*: seedlings (age class I, DBH ≤ 2.5 cm), saplings (age class II, 2.5 cm < DBH ≤ 7.5 cm), small trees (age class III, 7.5 cm < DBH ≤ 22.5 cm), medium trees (age class IV, 22.5 cm < DBH ≤ 42.5 cm), and large trees (age class V, DBH > 42.5 cm).

1.2.3 Quantitative Methods for Population Age-Class Dynamics

To objectively and accurately evaluate *A. hainanensis* population dynamics, we applied the quantitative population dynamics method proposed by Chen (1998). The indices V_n , V_{pi} , and V_{pi} reflect population trends, where positive values indicate growth, zero indicates stability, and negative values indicate decline (Shen et al., 2008).

1.2.4 Static Life Table Construction

Life tables are critical indicators for reflecting current survival status and determining population development trends. Following the static life table compilation system (Jiang, 1992), we constructed static life tables for *A. hainanensis* populations comprising nine parameters (Zhang et al., 2015). Since static life tables cannot document complete birth-to-death processes but only reflect dynamic changes across age groups at specific times, non-random errors may occur

during field surveys. Negative mortality rates emerged during life table compilation, which we corrected using smoothing techniques (Xie et al., 2014; Hu et al., 2017) to adjust actual population numbers across age classes.

1.2.5 Population Survival Curves

Survival curves provide visual representation of life table data. When precise birth and death data for specific ages are unavailable, curve morphology can infer population growth and decline patterns (Liu, 1990). We plotted survival curves for the total population, primary forest, and secondary forest by placing age classes on the x-axis and the natural logarithm of standardized survivors ($\ln x$) on the y-axis. Survival curve analysis employed exponential ($N_x = N_0 e^{-\lambda x}$) and power ($N_x = N_0 x^{-\lambda}$) function equations following Hett et al. (1976).

1.2.6 Time Series Prediction of Population Dynamics

We used time series models (Zhang, 1998; Tan et al., 2010; Xie et al., 2014) to simulate and predict *A. hainanensis* age-class structure for the next 2, 3, 4, and 5 years.

2.1 Age-Class Structure of *A. hainanensis* Populations

Our survey documented 474 *A. hainanensis* individuals, including 90 in primary forests (maximum DBH = 71 cm) and 384 in secondary forests (maximum DBH = 87 cm). As shown in Figure 2 [Figure 2: see original paper], both primary and secondary forest populations exhibited individuals across all age classes with overall inverted “J”-shaped structures, indicating growth-type populations. However, age-class distributions differed between habitats, particularly for seedlings—secondary forests contained five times more seedlings than primary forests. Under identical survey methods, secondary forests consistently showed higher mean seedling numbers: using typical sampling, primary forest seedlings averaged 4.63 versus 6.19 in secondary forests; using complete enumeration, primary forest seedlings averaged 0.19 versus 0.51 in secondary forests.

[Figure 2: see original paper] Age class structure of *Alseodaphnopsis hainanensis* populations

Table 2 Mean values of *Alseodaphnopsis hainanensis* seedlings under different habitat types and survey methods

Survey Method	Primary Forest	Secondary Forest
Typical sampling method	4.63	6.19
Method of actual measurement	0.19	0.51

2.2 Age-Class Structure Dynamics of *A. hainanensis* Populations

As shown in Table 3, primary forest populations exhibited positive V_1 and V_3 values, indicating growth trends between age classes I–II and III–IV, while negative V_2 and V_4 values suggested decline between age classes II–III and IV–V. In secondary forests, only V_2 was negative (decline between II–III), with all other age classes showing positive growth relationships.

Without external disturbance, the overall age-class dynamic index V_{pi} was positive for both forest types, confirming growth-type populations consistent with age-structure analysis. Even after accounting for potential external impacts, the adjusted dynamic index V_{pi} remained positive, reflecting sustained growth potential. However, V_{pi} values dropped sharply in secondary forests and fell below those of primary forests. The maximum random disturbance risk probability (P_{max}) was 0.0077 for the total population, 0.10 for primary forests, and 0.0087 for secondary forests, indicating that both habitats exhibit disturbance sensitivity and poor resistance, though secondary forests demonstrated marginally better anti-disturbance capacity.

Table 3 Indices of the dynamics of the age-class structure of *Alseodaphnopsis hainanensis*

Dynamic Index Class	Total Population (%)	Primary Forest (%)	Secondary Forest (%)
V_1			
V_2			
V_3			
V_4			
V_{pi}			
V_{pi}			

2.3 Static Life Table of *A. hainanensis* Populations

The static life table (Table 4) revealed that standardized surviving individuals (l_x) decreased with advancing age classes in both habitats, consistent with approaching physiological longevity and biological characteristics. Life expectancy (e_x) also declined progressively with age class, with highest values in age classes I and II, indicating strong environmental adaptability during seedling and sapling

stages. Mortality rates (qx) showed similar increasing trends with age class, peaking at 94.96% in age class IV of secondary forests, with corresponding maximum vanish rates (Kx), suggesting logging or damage to individuals in this age class.

Table 4 Static life table of *Alseodaphnopsis hainanensis* populations

Type	DBH Class (cm)	Ax	ax	lx	dx	qx	Lx	Tx	ex	Sx	Kx
Total Population	DBH \leq 2.5										
	2.5 < DBH \leq 7.5										
	7.5 < DBH \leq 22.5										
	22.5 < DBH \leq 42.5										
Primary Forest	DBH > 42.5										
	DBH \leq 2.5										
	2.5 < DBH \leq 7.5										
	7.5 < DBH \leq 22.5										
Secondary Forest	22.5 < DBH \leq 42.5										
	DBH > 42.5										
	DBH \leq 2.5										
	2.5 < DBH \leq 7.5										
	7.5 < DBH \leq 22.5										
	22.5 < DBH \leq 42.5										
	DBH > 42.5										

Note: Ax = actual survivors in age class x ; ax = smoothed data; lx = standardized survivors; dx = standardized deaths; qx = mortality; Lx = mean survivors; Tx = total survivors; ex = life expectancy; Sx = survival rate; Kx = vanish rate.

2.4 Survival Curves of *A. hainanensis* Populations

Survival curves showed both consistency and divergence between habitats. Both populations exhibited similar declining trends in $\ln lx$ across the first three age classes (I–III). However, during age classes IV–V, divergence emerged: primary forests showed relatively slower decline rates compared to the more rapid decrease in secondary forests.

Fitted models for primary forest, secondary forest, and total population are presented in Table 5. Exponential function models demonstrated higher R^2 and F values than power functions, indicating better alignment with Deevey-II type survival curves.

[Figure 3: see original paper] Survival curves of *Alseodaphnopsis hainanensis* populations

Table 5 Fitting models for survival curves of *Alseodaphnopsis hainanensis*

Population	Power Function	Exponential Function
Primary forest	$y = 7.280x^{-0.203}$	$y = 7.837e^{-0.089}$
Secondary forest	$y = 8.211x^{-0.477}$	$y = 10.156e^{-0.223}$
Total population	$y = 7.818x^{-0.363}$	$y = 9.130e^{-0.167}$

2.5 Time Series Prediction Analysis of Population Dynamics

Time series analysis (Table 6) revealed that total population numbers in age class III would decline after two age-class intervals, while other age classes showed varying degrees of increase. In primary forests, age class III individuals decreased from 41 to 23 and 28 after 2–3 intervals. Secondary forest age class III individuals similarly declined from 81 to 54 after two intervals. Overall, younger age-class individuals can develop into adults, replenishing and replacing losses in middle and older age classes.

Table 6 Time series prediction of population dynamics of *Alseodaphnopsis hainanensis*

Population	Original	M2	M3	M4	M5
Total Population					
Age Class I					
Age Class II					
Age Class III					
Age Class IV					
Age Class V					
Primary Forest					
Age Class I					
Age Class II					
Age Class III					
Age Class IV					
Age Class V					
Secondary Forest					
Age Class I					
Age Class II					
Age Class III					
Age Class IV					
Age Class V					

Note: M2, M3, M4, M5 represent population sizes after the next 2, 3, 4, and 5 age classes, respectively.

3.1 Age-Class Structure of *A. hainanensis* Populations

Our study demonstrates that *A. hainanensis* populations in both primary and secondary forests exhibit inverted “J”-shaped age-class structures, indicating growth-type populations despite encountering growth bottlenecks at specific age classes. We recorded 474 individuals, with 252 (53.16%) in age class I, demonstrating abundant seedling reserves. Both habitats contained substantial seedling numbers, yet massive seedling mortality occurred during transition to sapling stage, with only a small fraction successfully advancing. Field observations consistently revealed regeneration failure across Bawangling, Jianfengling, Wuzhishan, Diaoluoshan, and Limushan populations. Luo et al. (2023) reported similar patterns for *Hopea hainanensis* in Jianfengling, where inverted “J”-shaped structures faced recruitment limitations that persisted across study sites. Secondary forests contained more adult individuals and seedlings than primary forests, likely attributable to both species biology and habitat differences. Tao et al. (2004) identified *A. hainanensis* as a light-demanding species with high seedling mortality despite abundant recruitment, consistent with our findings. Additionally, secondary forests had lower canopy closure (mean = 0.62) than primary forests (mean = 0.69), providing higher understory light availability. Zhao et al. (2022) found that high canopy closure in primary forests hindered *Tsuga chinensis* var. *tchekiangensis* growth, while Wang et al. (2023) identified insufficient understory light as a barrier to natural regeneration of *Syzygium hancei* seedlings. Collectively, these results suggest that secondary forest light conditions are more favorable for *A. hainanensis* seedling growth.

3.2 Dynamic Characteristics of *A. hainanensis* Populations

Our study reveals that *A. hainanensis* survival curves approximate Deevey-II type, with relatively stable mortality across age classes throughout the life cycle, similar to patterns observed in extremely small populations of *Camptotheca acuminata* (Zhang et al., 2023), *Horsfieldia hainanensis* (Jiang et al., 2017), and the endangered *Davidia involucreata* (Xu et al., 2020). Zhao et al. (2018) and Xiang et al. (2016) identified limited resources and growing space as key factors restricting population regeneration. Seedling and sapling stages represent the most sensitive and critical phases in forest regeneration (Zhang et al., 2014). Field observations revealed that *A. hainanensis* produces large seeds that rarely penetrate the soil after falling, remaining on the surface where they are vulnerable to mold and animal predation. Gravity disperses seeds vertically near maternal trees, creating intense competition that eliminates numerous young individuals and constrains overall population size. Although secondary forests maintain adequate seedling numbers relative to primary forests, extremely low seedling-to-sapling conversion rates undermine population stability. Chronically low transition rates may eventually reverse growth trends, shifting populations from growth-type to decline-type. Previous research indicates that abundant young seedlings form the foundation for increasing individuals across all age

classes, with higher proportions of young seedlings conferring greater growth potential (Zhang et al., 2022). Therefore, appropriate measures are needed to enhance seedling survival and ensure stable population growth.

Time series predictions revealed differential growth rates across age classes between habitats. After five age-class intervals, both primary and secondary forest populations showed gradual increases, demonstrating strong recovery potential given sufficient time. Similar to our findings, Luo et al. (2023) predicted that *Hopea hainanensis* populations in Jianfengling would exhibit good recovery potential after 2–5 age-class intervals if populations and habitats remained undisturbed. Zhang et al. (2022) found that *Pinus koraiensis* seedling populations in eastern Liaoning’s mountainous region could achieve natural regeneration with age-class advancement, though regeneration obstacles persisted.

3.3 Endangerment Causes and Conservation Recommendations for *A. hainanensis*

Endangerment of most threatened plants can be explained through internal and external factors. Internal factors include declining genetic, reproductive, vital, and adaptive capacities that threaten growth and reproduction, while external factors encompass natural and anthropogenic influences (Wu, 2005; Xu & Zang, 2023). This study focused on internal factors. Zhang et al. (2024) collected 35 *Chieniodendron hainanense* samples in Hainan and found that habitat fragmentation reduces population size and increases spatial distances, diminishing gene flow and genetic diversity. *A. hainanensis* exhibits a fragmented distribution pattern in Hainan, suggesting low genetic diversity that may impair adaptive capacity and elevate extinction risk—a hypothesis requiring further investigation. Based on our analysis, primary endangerment causes include: (1) low seed reproduction success rates; (2) weak competitive ability and high young individual mortality; and (3) small distribution range potentially leading to low genetic diversity.

Given these findings, conservation efforts should focus on: (1) strengthening protection management and in-situ conservation monitoring for existing populations. Areas with concentrated adult individuals require enhanced supervision and logging prohibition to protect *A. hainanensis* communities, while seedling-rich areas could benefit from selective canopy pruning to reduce closure and promote natural regeneration. (2) Intensifying research on seedling cultivation and ex-situ propagation techniques, using cultivated seedlings for reintroduction studies to restore populations and expand distribution. (3) Conducting genetic diversity research to understand endangerment mechanisms, investigate genetic composition distribution, and reveal genetic responses to environmental change, providing scientific foundations for targeted conservation measures.

In conclusion, *A. hainanensis* populations in both primary and secondary forests exhibit inverted “J”-shaped structures with individuals across all age classes.

Both population types are growth-oriented with poor disturbance resistance, and survival curves approximate Deevey-II type with consistent mortality across age classes. After 2–5 age-class intervals, both habitats show natural regeneration potential, though obstacles faced by young individuals during regeneration may pose future decline risks. We recommend strengthening in-situ conservation, artificial propagation, and ex-situ protection research, while implementing moderate anthropogenic measures to improve seedling-to-sapling transition rates and promote population growth.

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

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