Population Structure and Dynamics of the Endangered Plant Hainan Dragon' s Blood Tree (Dracaena cambodiana) Postprint

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Abstract

Understanding the survival status and dynamic trends of populations is crucial for the conservation of endangered plants. To better protect endangered Dracaena cambodiana populations, we investigated 11 populations in different habitats on Hainan Island; individual basal diameter data were used to establish age structures and static life tables for each population, population age structure dynamic indices were obtained, and population survival curves and survival function curves were constructed, thereby characterizing the population structure and dynamics of D. cambodiana. The results demonstrated that the age structure of D. cambodiana populations is strongly habitat-dependent: the coastal NS and YL populations exhibited declining structures, the LN and CH populations were stable, whereas non-coastal populations were growing and lacked senescent individuals. Among the 11 populations, the EXL population displayed the highest growth potential and greatest stability, while the NS and YL populations showed the poorest stability and extremely low resistance to disturbance. All 11 populations exhibited Deevey-I type survival curves; however, survival function analysis revealed that D. cambodiana populations are vulnerable during early and late life history stages but stable during middle stages, indicating that habitats occupied by D. cambodiana populations are more suitable for adult survival and that existing habitats impose strong environmental filtering on young individuals. Dracaena cambodiana is a depensatory species; given the current survival status of its populations, integrated multiple approaches should be implemented for conservation and restoration.

Full Text

Preamble

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Population Structure and Dynamics of the Endangered Plant *Dracaena cambodiana* on Hainan Island

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Abstract

Understanding the survival status and dynamic trends of populations is crucial for the conservation of endangered plants. To better protect endangered *Dracaena cambodiana* populations, we investigated 11 populations in different habitats on Hainan Island. Using individual basal diameter data, we established age structures and static life tables for each population, calculated population age structure dynamic indices, and plotted survival curves and survival function curves. The results demonstrated that population age structure is closely related to habitat conditions. Populations in coastal habitats (NS and YL) exhibited declining structures, while CH and LN populations were stable, and the remaining seven populations farther from the sea showed increasing trends. Among all 11 populations, the EXL population displayed the highest growth trend and best stability. The survival curves of all 11 *D. cambodiana* populations belonged to the Deevey-I (convex curve) type, with higher survival rates for young individuals compared to middle-aged and old individuals, indicating better survival ability among young plants. However, survival function analysis revealed that early and late life history stages of *D. cambodiana* are fragile, whereas middle-aged stages are stable, suggesting that the habitat is more suitable for adult individuals and exerts strong environmental filtering effects on young individuals. *Dracaena cambodiana* is a depensation species. Based on the current survival status of its populations, multiple complementary methods should be employed for protection and rejuvenation.

Keywords: *Dracaena cambodiana*; age structure; population dynamic index; survival curve; survival function

Introduction

Population structure is one of the most fundamental characteristics of a population and has long been a core focus of population ecology research. It reflects not only the current status of a population—specifically, the distribution and configuration of individuals of different sizes—but also the fitness between plants and their environment. Analyzing past population structure and disturbance conditions can reveal population dynamics and evolutionary trends. Such studies help us better understand the ecological characteristics, stability, and development trends of populations, which is significant for the regeneration of endangered populations and the restoration of their communities and ecosystems.

Dracaena cambodiana, also known as small-flowered dragon' s blood tree or Cambodian dragon' s blood tree, is a monocotyledonous plant belonging to the family Asparagaceae (subfamily Nolinoideae) and genus *Dracaena*. It is a slow-growing, drought-tolerant, sun-loving plant that grows in crevices of exposed granite and limestone or clings to rock walls in sandy loam soils, making it a typical rock-associated plant. The species is listed as a nationally protected second-class plant and a rare and endangered protected plant in China. Due to its high medicinal and ornamental value, wild resources have been subjected to exploitative harvesting, leaving them extremely scarce and the species in an endangered state.

Current research on *D. cambodiana* has primarily focused on tissue culture, basic research and development based on dragon' s blood resin, and molecular biology. Zheng Daojun et al. investigated the distribution of wild resources, population regeneration, and seed germination. While some studies have reported on the population structure and distribution patterns of *D. cambodiana*, Zhou Wensong et al. only examined populations in Changjiang County, and Li Weijie et al. only studied age structure and distribution patterns without addressing static life tables. This study investigates *D. cambodiana* populations in representative habitats to analyze their age structure, quantitative dynamic characteristics, and survival status, aiming to predict future population trends and provide a basis for conservation and restoration from a population ecology perspective.

1. Field Investigation

Based on literature review and reconnaissance surveys, we conducted field investigations of *D. cambodiana* populations. The species is primarily distributed in limestone and granite habitats in southwestern inland mountainous areas and southern coastal regions of Hainan Island. This study surveyed 11 populations across these two habitat types: limestone habitats in Exianling, Dongfang City; and granite habitats including coastal populations at Nanshan and Yalongwan in Sanya, Lenanshan in Wanning, Changhualing in Changjiang, and inland populations at Sanjialing in Changjiang, Heiling in Dongfang, and three populations in Jianfengling, Ledong County. The geographic locations of each population are shown in [Figure 1: see original paper]. We used route survey methods to investigate individual plants within each population, recording plant height, crown width, and growth form.

1.1 Population Diameter Class Division

Under the same habitat conditions, diameter class and age class of the same tree species show consistent responses to environmental conditions. We employed the space-for-time substitution method, using diameter class to represent age class for analyzing *D. cambodiana* population structure. Based on life history characteristics and field survey data, we divided the age structure into 13 diameter classes (denoted as D): D 3 cm, 3 cm < D 10 cm, 10 cm < D 20 cm, 20 cm < D 30 cm, 30 cm < D 40 cm, 40 cm < D 50 cm, 50 cm < D 60 cm, 60 cm < D 70 cm, 70 cm < D 80 cm, 80 cm < D 90 cm, 90 cm < D 100 cm, 100 cm < D 150 cm, and D > 150 cm. For convenience, individuals with D 10 cm were classified as young, 10 cm < D 50 cm as middle-aged, 50 cm < D 100 cm as mature, and D > 100 cm as old.

2. Population Age Structure and Dynamics

We used Chen Xiaode' s quantitative analysis method for population structure dynamics to quantitatively describe the dynamic indices of *D. cambodiana* population age structure. The dynamic index V between adjacent age classes reflects the growth or decline dynamic relationship between populations or adjacent age class individuals. The formulas are:

$$V = (S - S) / \max(S , S) \times 100\%$$

where S and S are the numbers of individuals in age class n and n+1, respectively. V values range from -1 to 1, with positive, zero, and negative values indicating growth, stability, and decline, respectively.

The quantitative dynamic index of population age structure (V) and the dynamic index considering population age class number and individual numbers (V') were calculated as:

$$V = (V) / K \quad V' = (S V) / (S) \times (1/K)$$

where K is the number of age classes. Higher V values indicate greater growth trends, while higher V' values indicate greater resistance to disturbance and better stability.

3. Static Life Table and Survival Curves

We compiled static life tables for *D. cambodiana* populations following the specific time life table method. The static life table includes: x (age), A (number of individuals in age class x), a (smoothed data of A), l (standardized number of survivors at age x), d (standardized number of deaths from x to x+1), q (mortality rate from x to x+1), L (number of individuals surviving during age interval x to x+1), T (total number of individuals from age class x to all older age classes), e (life expectancy of individuals entering age class x), and K (disappearance rate). Since static life tables are compiled from all individuals collected during the same period, they reflect a specific time point in the age dynamics of multiple overlapping generations rather than tracking the entire life history. Negative mortality rates may occur in life table compilation, so we applied smoothing techniques to process A values as described in the literature.

4. Population Survival Analysis

Population survival analysis employed four functions: survival rate function S(t), cumulative mortality function F(t), mortality density function f(t), and hazard rate function (t). The formulas are:

S(t) = P × P × P × ···× P F(t) = 1 - S(t) f(t) = [S × h × (1 + S)] / 2 (t) = 2(1 - P) / [h (1 + S)]

where P is survival frequency and h is age class width. The survival rate function describes population survival patterns as the probability of individuals surviving longer than time t, showing a monotonic decreasing curve. The cumulative mortality function describes overall mortality status during the survival period, showing a monotonic increasing function. These two functions describe survival patterns from different perspectives. The mortality density function characterizes death probability during specific periods, while the hazard rate function characterizes instantaneous mortality when individuals reach survival time t, directly reflecting individual death conditions.

2. Results

2.1 Population Age Structure

The age structures of *D. cambodiana* populations are closely related to their habitats. Populations in coastal granite habitats (NS, YL, CH) lack young individuals but contain certain proportions of middle-aged and old individuals, with old individuals accounting for 27%, 46%, and 30% of total individuals, respectively. These populations have declining structures. The NS population, lacking young individuals and having a higher proportion of old individuals, shows the poorest stability. The LN population, located at Lenanshan in Wanning, has 25% young, 25% middle-aged, and 25% mature/old individuals, classifying it as a stable population. The CH population, located at Changhualing in Changjiang, has proportions of 25% young, 25% middle-aged, and 25% mature/old individuals, also indicating a stable population structure.

Populations on granite mountain slopes, including JF, JFH, JFM in Jianfengling and SJL in Changjiang, show no old individuals, very few mature individuals, and middle-aged proportions of 7% (JF), 0% (JFH), and 5% (JFM). These populations concentrate individuals in young and middle-young age classes, classifying them as increasing populations. The EXL population in limestone Exianling area shows 100% young individuals, indicating the highest growth trend and best stability.

2.2 Dynamic Changes in Population Age Structure

Based on quantitative analysis of population dynamics, we analyzed dynamic changes between adjacent age classes and overall quantitative changes across all 11 populations. The results show significant fluctuations in individual numbers between age classes across all populations, indicating unstable structures. Most populations exhibited negative growth dynamics between age classes, particularly during transitions from age classes I-IV, where severe environmental filtering occurs. Fewer decline phenomena appear between middle age classes, suggesting more suitable environmental conditions during these transitions. When the dynamic index equals or exceeds zero, the stage is relatively stable.

The overall dynamic change index (V) analysis reveals that most populations are increasing types. The EXL population shows the highest V value at 84.89%, indicating the strongest growth trend. Populations with V values greater than 20% include JFM (52.63%), EX (42.14%), JF (18.98%), and CH (17.63%). However, V' values vary significantly: EXL has the largest V' at 46.57%, showing excellent resistance to disturbance and stability. In contrast, NS and YL populations have extremely low V' values (0.45% and 0.67%, respectively), indicating poor stability and low anti-interference capacity despite having some mature individuals. The SJL and JFH populations, while showing growth trends, also have very low V' values (1.04% and 3.33%), suggesting poor stability.

2.3 Static Life Tables and Survival Curves

The static life tables for *D. cambodiana* populations are presented in . Mortality and disappearance rate curves are shown in [Figure 4: see original paper]. Survival curves provide intuitive descriptions of population death processes. Using standardized survival individuals (l) on the y-axis and age class (x) on the x-axis, we plotted survival curves for each population. Smoothing techniques can mask certain ecological phenomena in population fluctuations, so we compared both smoothed and unsmoothed survival curves.

All 13 *D. cambodiana* populations belong to the Deevey-I type, showing continuously decreasing trends with age, with more significant declines in older age classes. Life expectancy (e) decreases with increasing age class, typically showing little difference between young and middle-young individuals but declining sharply in old age classes. This indicates good survival ability for young and middle-young individuals but poor survival near old age.

2.4 Population Survival Analysis

The mortality and disappearance rates of young individuals are lower than those of middle-aged individuals. Populations NS, YL, CH, EX, and LN show relatively high initial cumulative mortality values (0.2-0.4), while JF, JFH, and

JFM show lower initial values (0.2). The EXL population has the highest initial cumulative mortality at 0.67.

Cumulative mortality curves show distinct patterns: NS, JF, JFH, JFM, SJL, and EXL exhibit fluctuating changes with large amplitude variations in early and middle stages that decrease in later stages. CH, EX, LN, and HL populations show consistent variation amplitude across early, middle, and late age periods. The mortality density and hazard rate curves are generally similar across populations, with large fluctuations during age class transitions that stabilize between classes. Most populations show hazard rates that decrease initially then increase, indicating that *D. cambodiana* populations are stable in middle life history stages but fragile in early and late stages.

3. Discussion

3.1 Population Structure and Survival Status

Plant population age structure results from the combined effects of biological characteristics and environmental factors. Our comprehensive analysis of age structures and dynamic indices for 11 *D. cambodiana* populations across different habitats revealed that seven populations are increasing types, two are stable types (CH, LN), and two are declining types (NS, YL). This differs somewhat from previous studies, likely due to differences in age class division standards, survey regions, and research methods.

Because many *D. cambodiana* individuals lack obvious main stems, we used basal diameter rather than diameter at breast height (DBH) for age classification, with D 10 cm classified as young individuals. This standard may classify more individuals as young compared to previous studies. Our broader survey region found more young individuals in JF and LN populations, and we observed numerous seedlings in Jianfengling populations within protected areas—a phenomenon not seen in other populations.

Lack of regenerating young individuals leads to population decline. *Dracaena cambodiana* regenerates through seed regeneration, root sprouting, and stump sprouting (the latter two being asexual). Current research shows few seedlings in populations, with asexual reproduction dominating. Our results align with previous findings: only JF and LN populations contained ~1-year-old seedlings, while other populations rarely showed seedlings. Seedlings found were mostly root or stump sprouts emerging from cut trees. Seed germination and seedling growth depend heavily on habitat, requiring certain shade conditions, yet no seedlings were found in well-shaded NS and YL populations, which lack young individuals and are declining.

Populations JF, JFM, JFH, HL, EXL, and EX contain only early age class individuals or lack middle-old age classes, indicating they formed relatively recently and are developing populations.

3.2 Dynamic Trends of *D. cambodiana* Populations

Life tables are important indicators for determining plant population development trends. Static life tables and survival curves showed all 11 populations have Deevey-I type survival curves, with better survival ability for young individuals than middle-aged and old individuals. However, survival function analysis revealed vulnerability in early and late life history stages, with middle stages being stable. This suggests that while existing habitats are suitable for adult *D. cambodiana* survival, they exert strong environmental filtering on young individuals, which is unfavorable for seedling establishment despite the seedlings' inherent survival capacity. This aligns with Zheng Daojun et al.' s findings.

Plant population development is a long, complex process involving intra- and interspecific competition and adaptation to abiotic environments. *Dracaena cambodiana* has adapted to harsh rock habitats during its long evolutionary history. Comprehensive analysis of population distribution, structure, and dynamics suggests that coastal populations are ancient and either stable or declining, while inland populations are younger and increasing. This implies that *D. cambodiana* populations may be shifting from coastal to inland rock habitats—a hypothesis requiring verification through molecular biology and biogeography studies.

3.3 Conservation and Restoration Measures

Species can be categorized as compensation species, neutral species, or depensation species based on population aggregation levels. Compensation species are not prone to extinction, while depensation species are vulnerable to extinction when population size falls below the minimum viable population. *Dracaena cambodiana* shows clumped distribution in limestone habitats and uniform distribution in granite habitats. As a depensation species listed in China' s Rare and Endangered Plant Catalogue, it faces extinction risk from exploitative harvesting and habitat destruction.

Current literature and our surveys indicate no more than 15 wild *D. cambodiana* distribution points exist, with most populations containing few individuals. Only populations at Sanya' s Nanshan (coastal), Changjiang' s Changhualing, and Wanning' s Dazhou Island exceed 100 individuals, with the Dazhou Island population being the best-preserved. Conservation efforts are urgently needed to prevent extinction.

Three main conservation approaches exist: in-situ protection, ex-situ protection, and modern biotechnology-based protection. With the implementation of the Minimum Viable Population Wild Plant Rescue and Protection Project, a new method—near-situ protection—has been proposed. This involves establishing artificial protection sites with similar climate and habitat conditions near existing distribution areas. Comparative studies by Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, demonstrate this method is significantly more effective than conventional ex-situ protection for rare and endangered plants.

For in-situ protection, artificial assistance can address vulnerable life history stages. Laboratory-assisted seed germination and seedling cultivation followed by transplantation back to the original population can help populations lacking young individuals, such as NS, YL, SJL, JFH, and HL populations. For populations in habitats vulnerable to human disturbance (NS, YL), ex-situ or near-situ protection can preserve genetic diversity. For protected populations (EXL, JF, JFH, JFM, HL), artificial measures can enhance natural regeneration by removing competing shrubs around mother trees and seedlings, adding soil nutrients to promote seed fall and increase seedling density.

Strengthening research on *D. cambodiana* genetic diversity to clarify intrinsic endangerment causes is crucial. Establishing ex-situ germplasm resource banks to preserve core germplasm is necessary to prevent further genetic diversity loss if existing populations disappear due to human or natural causes.

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