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LIFE TABLE ANALYSIS AND SPECTRAL ANALYSIS OF *PHELLODENDRON AMURENSE* POPULATION, AN ENDANGERED-MEDICINAL PLANT, IN THE YUNMENGSHAN PARK

NAIQI SONG[1*] AND JINTUN ZHANG[2]

[1]*School of Chinese Materia Medica, Beijing University of Chinese Medicine, Beijing 102488, China*
[2]*Key Laboratory of Biodiversity Sciences and Ecological Engineering, Ministry of Education;*
College of Life Sciences, Beijing Normal University, Beijing 100875, China
**Corresponding author's email:* lq1063754476@qq.com

Abstract

Study on population structure and dynamics of *Phellodendron amurense*, an endangered-medicinal tree species, is essential and urgent for its conservation in China. The aim of this work is to study the characteristics and dynamic regulations of *P. amurense* population in the Yunmengshan National Forest Park (YMNFP), Beijing, China. A set of systemic sampling plots was established along an altitudinal gradient to collect population data. Life table analysis and spectrum analysis were used to analyze the data set. Results showed that the size and density of amur cork population in YMNFP was low. Its survival curve was between Deevey-I and Deevey-II with a reasonable and stable age structure. It had apparently periodic fluctuation controlled by population biological features. Effective conservation for this population must consider these characters. Population restoration should be treated as the main target of conservation, and disturbance intensity must be controlled effectively. A nature reserve for *P. amurense* population should be suggested and established in YMNFP.

Key words: Endangered-medicinal plant; Population dynamics; Quantitative analysis; Conservation; *Phellodendron amurense.*

Introduction

Plant population dynamics is fundamental and important for conservation of rare and endangered plant species. Population demographic processes such as survivorship, mortality ratio, life-span, and life expectancy are those that affect the size and composition of a population. Life table analysis and spectrum analysis are significant techniques in the study of population dynamics and the results can be used to predict the development trend of the studied population (Zhang *et al.*, 2010; Vasconcelos, 2023). Life tables are tables of data describing survivorship and mortality of individuals within a population. A standard method is to collect data on a cohort, or group of individuals all born in the same time period. Life tables constructed in this way are called cohort life tables. Another life table records the number of living individuals of each age class in a population and called static life table. Static life table is more useful for the study of long living tree population (Preston *et al.*, 2001; Zhang, 2018). Survival curve can be drowned based on a life table to show the living process of population. Generally, there are three types of survival curve: Type I showing a high survivorship throughout their life cycle, Type II having a constant proportion of individuals dying over time, and Type III showing a very high mortality at young ages (Deevey, 1947; de Valpine *et al.*, 2014). Most populations are some mix of these three types.

Spectral analysis (SA) is an analysis in terms of a spectrum of frequencies or related quantities such as eigenvalues. SA quantifies the relationship between various quantities and frequencies, and many physical processes are best described as the sum of individual frequency components (Priestley, 1991). It can be performed on the entire signal such as population life-span, and a signal can be broken into short segments, such as population age class. SA may be applied to these individual segments to study living process of a population and to find the rules of periodic dynamics of population (Welch, 1967; Hayes, 1996).

Phellodendron amurense Rupr. (amur cork) is an endangered-medicinal tree species in the family Rutaceae. It is a second level protected plant species in the ***China's National Protected Plant List*** and is listed in the ***IUCN Red List of Threatened Species*** as a Vulnerable (VU) species (Li *et al.*, 2023). It is well-known for it is the major source of traditional Chinese medicine 'Huangbo', commonly used for the treatment of many diseases such as meningitis, liver cirrhosis, tuberculosis, bacillary dysentery, and pneumonia etc. (Leu *et al.*, 2007; Choi *et al.*, 2021). *P. amurense* is mainly distributed in northern China with limited area (Cui *et al.*, 2008; Song & Zhang, 2017). Due to its high value for medicine, dye and timber, it has been disturbed, over used and damaged seriously by human activities (Ida *et al.*, 1993; Li *et al.*, 2023; Liu *et al.*, 2024). Amur cork individuals can be found in only a few mountains in Beijing with very limited population size. Conservation of amur cork trees is significant and urgent (Zhang *et al.*, 2009). The present work aims to study population variation regulations in the Yunmengshan National Forest Park by life table and spectrum analysis models.

Materials and Methods

Population modelling

Life table analysis: Static life table is commonly used in plant population studies. Suppose n_x is the total number of individuals observed at x DNH (age) class, and n_0 is the initial number of individuals for the studied population. The parameters in the life table analysis can be calculated by following functions.

$$l_x = n_x / n_0 \times 1000 \quad (1)$$

$$d_x = l_x - l_{x+1} \quad (2)$$

$$q_x = l_x / l_{x+1} \quad (3)$$

$$L_X = (l_x + l_{x+1})/2 \quad (4)$$

$$T_X = \sum L_X \quad (5)$$

$$e_x = T_X / l_x \quad (6)$$

$$K_X = \ln l_x - \ln l_{x+1} \quad (7)$$

where x refers to DBH class (age class), l_x refers to standardized number of survival individuals at the beginning of $\boldsymbol{x}$ class, d_x refers to standardized number of died individuals from x class to $x+1$ class, q_x (mortality rate) is the probability of individuals at age x to be die before reaching age $x+1$ class, L_x is number of survival individuals or internal life-span from x class to $x+1$ class, T_x is number of the total survival individuals or total life-span since x class, e_x represents the life expectancy or mean expectant life-span for individuals already at x class, K_x is vanish ratio of individuals at x class.

Spectrum analysis: The Fourier transform of a function produces a frequency spectrum which contains all of the information about the original signal.

$$N_t = A_0 + \sum_{t=1}^{n} A_k \sin(\omega_k t + \theta_t) \quad (8)$$

where A_0 is mean amount of periodic variation; A_k (k=1，2，3，…，p) is the amplitude value of the kth Harmonic, indicating its role; ω_k and θ_k refer to frequency and phase angle of the kth Harmonic respectively; N_t is population size (number of individuals) at t time. Individual distribution of all age classes consists of a time series variation of population. The n is the number of age class representing the total length of the time series. $p=n/2$ is the total number of Harmonics. The parameters in Fourier transform can be calculated by the following models.

$$A_0 = \frac{1}{n}\sum_{t=1}^{n} X_t \quad (9)$$

$$A_k^2 = a_k^2 + b_k^2 \quad (10)$$

$$\omega_k = 2\pi k / T \quad (11)$$

$$\theta_k = \arg tg(a_k / b_k) \quad (12)$$

$$a_k = \frac{2}{n}\sum_{t=1}^{n} X_t \cos\frac{2\pi k(t-1)}{n} \quad (13)$$

$$b_k = \frac{2}{n}\sum_{t=1}^{n} X_t \sin\frac{2\pi k(t-1)}{n} \quad (14)$$

where T is the basic period of the sine wave, representing the longest wave within the time series.

Population data: The study area, Yunmengshan Mountain National Forest Park (YMNFP), is located at 116°40′-116°50′E, 40°26′- 40°38′N in Beijing, China (Fig. 1). YMNFP occupies a total area of 2,208 ha, and its highest mountain peak is 1414 m ASL. Its climate is continental in the warm-temperate zone and deeply affected by subhumid monsoon. The annual mean temperature is about 10ºC. The mean monthly temperature for January and July is -7ºC and 25ºC respectively. The annual mean precipitation varies from 600mm to 700mm. Most precipitation (over 76%) falls from June to September. The main soil types are brown forest soil and mountain drab soil. Vegetation is mainly secondary broad-leaved deciduous forest, with some plantations of coniferous forest. *Phellodendron amurense* lives in the secondary forests in YMNFP with the greatest population size in Beijing (Cui, 2008; Liu *et al*., 2024).

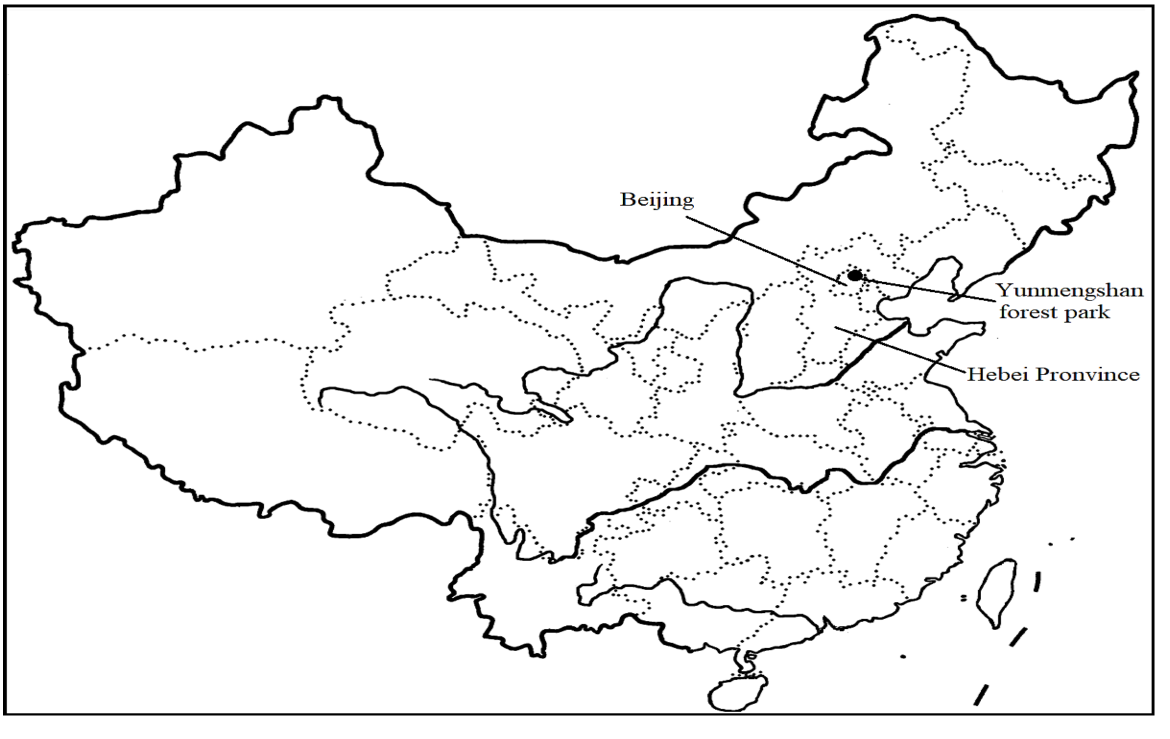

Fig. 1. Geographical location of the Yunmengshan National Forest Park, Beijing, China.

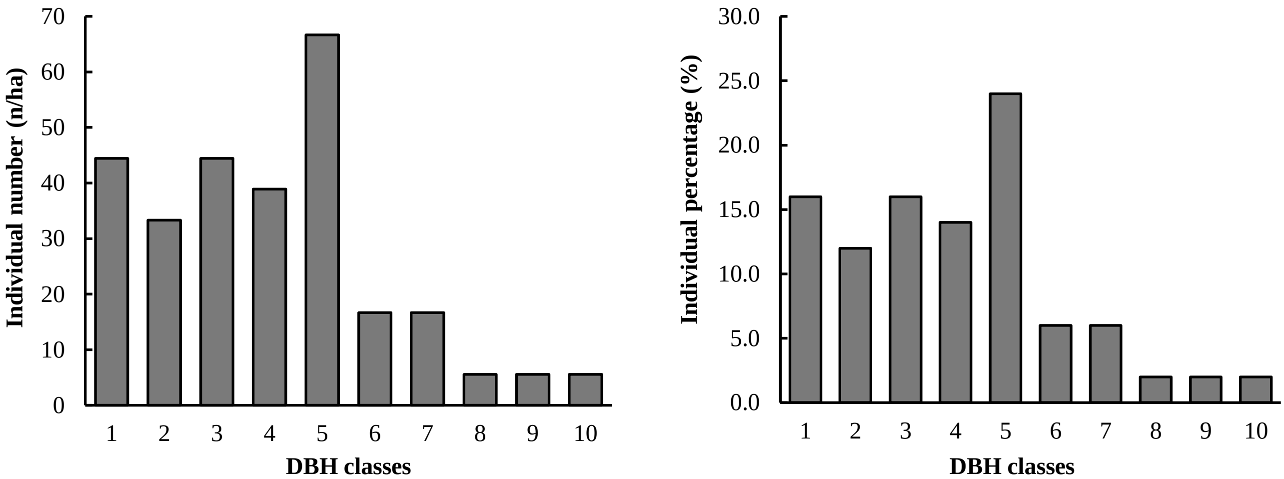

Fig. 2. DBH class structure of *Phellodendron amurense* population in the Yunmengshan National Forest Park, Beijing, China.

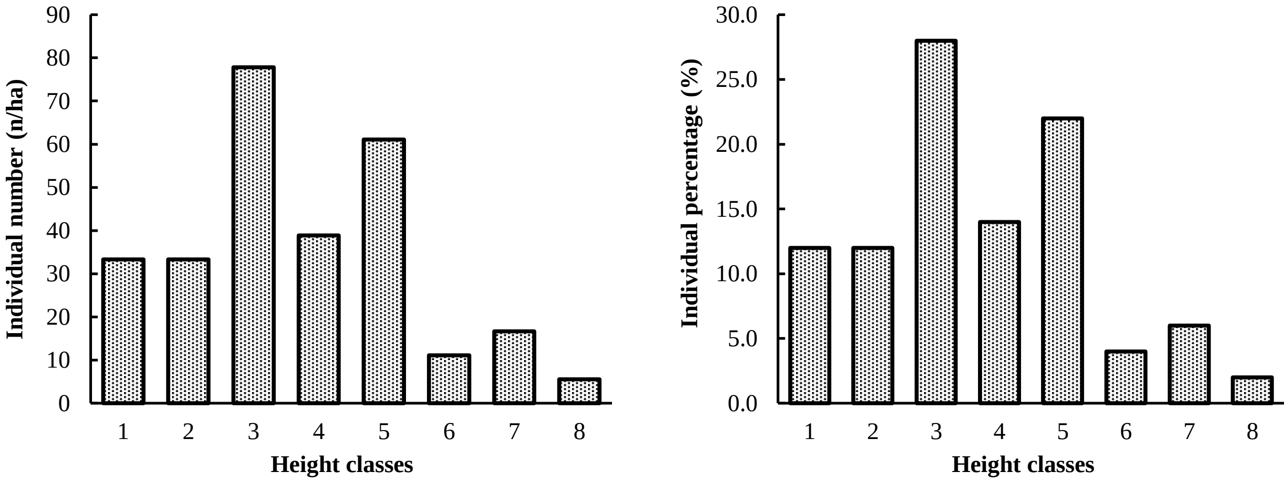

Fig. 3. Height class structure of *Phellodendron amurense* population in the Yunmengshan National Forest Park, Beijing, China.

Based on a general survey, 18 sampling points, each separated by 100 m in elevation, were established from 600 m to 1300 m in YMNFP. One to four plots (20 m × 20 m), according to distribution area of the studied population, around each sampling point were established. These plots included all distribution areas of *Phellodendron amurense* in this park. The plot was divided into four 10 m × 10 m quadrats. All individuals of amur cork were counted, measured and recorded for each quadrat. The cover, height, and diameter at breast height (DBH) for each adult individual and height and cover for saplings/seedlings of amur cork were measured and recorded in each quadrat (Zhang *et al*., 2016). All the 18 plots were put together representing the population of amur cork in YMNFP. Other tree species, scrub and herb species in each quadrat were also recorded.

Age class structures can be used to model many population dynamics. The DBH class was used to replace the age class structure in this study because they were closely correlated with each other for tree species (Zhang *et al.*, 2010). All individuals were divided into 10 DBH classes according to the characteristics of growth regulation and life cycle of *Phellodendron amurense*: class 1, height < 2m and DBH < 1cm; class 2, DBH 1- 5cm; class 3, DBH 5.1- 10cm; class 4, DBH 10.1- 15cm; class 5, DBH 15.1- 20cm; class 6, DBH 20.1- 25cm; class 7, DBH 25.1- 30cm; class 8, DBH 30.1- 35cm; class 9, DBH 35.1- 40cm; and class 10, DBH >40cm. Eight height classes were all separated: 1, height <1m; 2, 1-3m; 3, 3-6m; 4, 6-9m; 5, 9-12m; 6, 12-15m; 7, 15-18m; and 8, >18m. SPSS and Excel were used to carried out the calculations and drawing figures.

Results

Population structure: Population age structure is depicted by the structure diagram that presents DBH classes against individual number and percentage of individuals at each class (Fig. 2). The individual number and its percentage was slightly increased within the first five classes, and reach the maximum value at class 5 and then sharply decreased. The population structure pattern of *Phellodendron amurense* in YMNFP showed a stable form. The height structure was medium-expanding with greater height from class 3 to class 5, but its pattern was consistent with that of DBH structure (Fig. 3).

Life stable analysis: A static life table of *Phellodendron amurense* population in YMNFP was constructed (Table 1).

Data was treated by piecewise smoothing technique in order to avoid negative mortality in the life table. The survival individual number was decreased gradually along the DBH (age) gradient and its survival curve showed a type between Deevey-I and Deevey-II (Table 1, Fig. 4). The mortality rate and vanish rate increased gradually and reached maximum values at class 8 and then decreased sharply along the DBH (age) gradient, and their change curves showed a similar pattern (Table 1, Fig. 5).

Spectrum analysis: The DBH was divided into 10 classes, and therefore p=10/2=5 in equation (8). Spectrum analysis calculated each amplitude value for harmonic A_k (k=1, 2, 3, …, p) to show periodic fluctuation of the studied population (Table 2). A_1 was the fundamental wave representing basic periodic dynamics of the population. The maximum value (A_1=1.767) illustrated that population dynamics was dependent on the intrinsic characteristics of the population. Except for this, *Phellodendron amurense* population also had small periodic dynamic wave, such as A_4 with a value 0.994. A_4 represented class 8, at which mortality rate increased sharply (Table 1, Fig. 5). This indicated that spectrum analysis provided similar results with life table analysis.

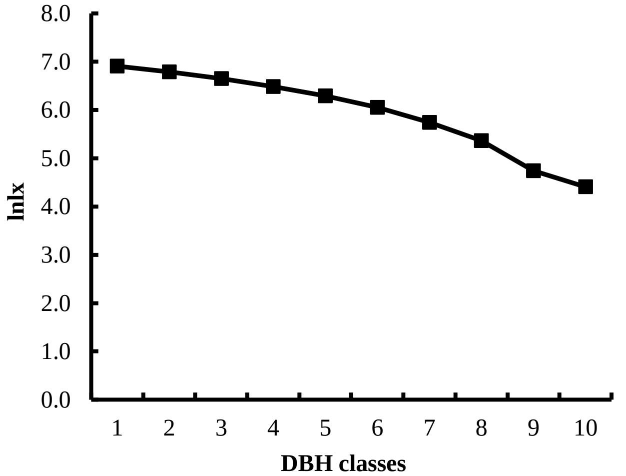

Fig. 4. Survival curve of *Phellodendron amurense* population in the Yunmengshan National Forest Park, Beijing, China.

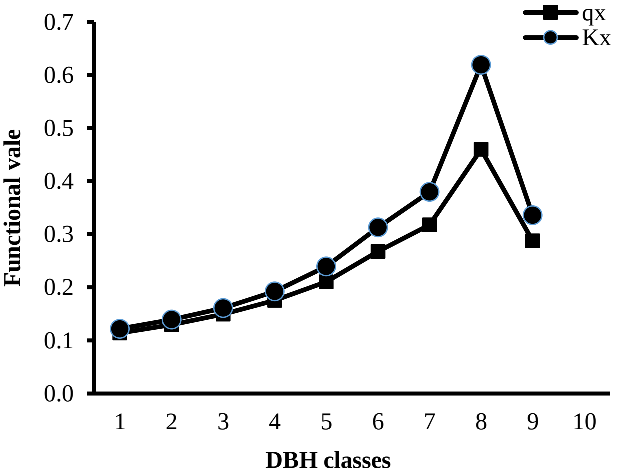

Fig. 5. Mortality rate curve and vanish rate curve of *Phellodendron amurense* population in the Yunmengshan National Forest Park, Beijing, China.

Table 1. Static life table of *Phellodendron amurense* population in the Yunmengshan National Forest Park, Beijing, China.

DBH grade (x)	DBH classes (cm)	n_x	n_x'	l_x	ln l_x	d_x	q_x	L_x	T_x	e_x	K_x
1	<1	44	61	1000	6.908	114	0.114	943	4521	4.521	0.122
2	1-5	33	54	886	6.786	115	0.130	829	3578	4.040	0.139
3	5-10	44	47	771	6.647	115	0.149	714	2749	3.566	0.161
4	10-15	39	40	656	6.486	115	0.175	599	2035	3.102	0.192
5	15-20	67	33	541	6.294	114	0.211	484	1436	2.653	0.239
6	20-25	17	26	426	6.055	114	0.267	369	952	2.233	0.313
7	25-30	17	19	312	5.742	99	0.318	263	583	1.871	0.38
8	30-35	6	13	213	5.362	98	0.460	164	320	1.501	0.619
9	35-40	6	7	115	4.743	33	0.287	107	156	1.359	0.336
10	>40	5	5	82	4.407	—	—	49	49	0.598	—

Note: n_x, survival individual number; n$_x'$, the smoothed value of n_x; l_x, standardized survival individual number; d_x, death individual number; q_x, mortality rate; L_x, life-span; T_x, total life; e_x, life expectancy; K_x, vanish rate

Table 2. Periodic fluctuation of *Phellodendron amurense* population in the Yunmengshan National Forest Park, Beijing, China.

Harmonic	A_1	A_2	A_3	A_4	A_5
Amplitude value	1.767	1.301	0.965	0.994	0.339

Discussion

The size and density of *Phellodendron amurense* population in YMNFP was small and only had 748 individuals in all plots (7200 m^2), even though it was the greatest population in Beijing area compared with that of under 100 individuals in Donglingshan and under 20 individuals in Songshan (Zhang *et al*., 2009; Song and Zhang, 2017). Although the population was small in YMNFP, its DBH (age) structure and height structure were reasonable and it maintained a stable growth form, compared with that of no seedling and sapling for Donglingshan population and almost no adult tree for Songshan population (Li, 2008; Zhang *et al*., 2009). The population in YMNFP is most suitable and valuable for conservation in the Beijing region.

Life table analysis showed that the survival curve of *Phellodendron amurense* population in YMNFP followed a type between Deevey-I and Deevey-II, which suggested that this population was stable and most individuals could reach its physiological life-span (Roach & Carey, 2014; de Valpine *et al*., 2014). The variation of mortality rate and vanish rate also supported this point. This conclusion was consistent with the results of some other long-living tree populations in mountainous area, such as *Larix principis-rupprechtii* population in Pangquangou Nature Reserve (Zhang *et al*., 2010), *Rhododendron chrysanthum* population in Changbai Mountain (Jin *et al*., 2017).

Spectrum analysis showed that *Phellodendron amurense* population in YMNFP had obvious periodic dynamics, and the most important reason for periodic fluctuation was biological characteristics of the population (Wang *et al*., 2015; Song & Zhang, 2017). Other causes, such as climate change, played somewhat roles for the population change (Roach & Carey, 2014).

Life table analysis and spectrum analysis were useful and effective in studying plant population structure and dynamics (Zhang *et al*., 2010; Zhang, 2018; Koltz *et al*., 2022). Their results could predict the change trend of the studied population and provide significant information for management and conservation of endangered populations (de Valpine *et al*., 2014).

Conclusions

Phellodendron amurense population was important and valuable endangered-medicinal tree species in YMNFP and its conservation is urgent. The size and density of amur cork population in YMNFP was small, but it was the greatest population in Beijing area. This population was comparatively stable with a survival curve between Deevey-I and Deevey-II. It had apparent periodic fluctuation controlled by population biological characteristics, other factors such as disturbance also affecting its dynamics. Effective conservation measures should be considered, including prioritizing the restoration of the amur cork population and strictly controlling the intensity of disturbance. It is recommended to establish a nature reserve for conservation of *P. amurense* population in YMNFP.

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