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EFFECT ON POPULATION DYNAMICS TO *HALOXYLON PERSICUM* IN DIFFERENT EDAPHIC TYPES

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Abstract

This study investigated the age class structure of *H. persicum* populations in different edaphic types in Gurbantünggüt desert and analyzed the survival rate, mortality rate and spectral analysis characteristics. The results showed that the survival curve of *H. persicum* populations tended to be the type of Deevey-III, the mortality rate of *H. persicum* was high at early stage and low at late stage, There existed 2-4 death peak phases in the whole population life span. The natural regeneration process of the *H. persicum* population can be represented by the fluctuation of the distribution of the number of trees in different age classes. Spectral analysis showed that the fluctuation of *H. persicum* population was multi-harmonic superposition with large periodic containing small periodic, and had more than two periodic fluctuation. Upscaling process of spectral analysis indicated that the periodic fluctuation of *H. persicum* population becomes constant in relatively small sampling plot (4400-5600 m^2), when it is growing under relatively good environmental conditions in the Gurbantünggüt desert. On the other hand, when the growing conditions are poor, large plot (4000-9200 m^2) is needed to obtain constant population. Accordingly, different plot sizes should be used for spectral analysis to reveal the periodic fluctuation on the optimal scale.

Key words: *Haloxylon persicum*, Periodic fluctuation, Spectral analysis, Scaling analysis.

Introduction

Population dynamics is the study of spatial and temporal changes of population, and is the core issue in population ecology (Chapman & Reiss, 2001). The structure and dynamics of plant population are the result of interactions between the viability of individual plants and the external environment (Crawly, 1986). The periodic fluctuation of population has been shown to exist in all vegetations (Poole, 1978). Veblen *et al*. (1980) studied the structure and dynamics of aged forests and proposed that the canopy replacement of dominant species is a cyclical process, rather than a continuous process of development. Spectral analysis is a mathematical tool to explore the distribution of fluctuation in natural populations and their age replacement process. The natural population replacement can be characterized by fluctuations in distribution of the tree number in different age classes, which can provide more information for population statistics (Armesto *et al*., 1992). Some scholars used the spectral analysis to reveal fluctuations in the age distribution of different plants. These results are important for determining the quantitative fluctuations in future populations (Stewart, 1989).

Vegetation community in desert contains a natural class system, and the dominant processes in the system may be different on different scales. The growth of plant is not only related with their biological characteristics, but also affected by environments and their interactions with other species. The interactions occur on various scales. When the spatial and temporal scale changes, the entity of ecosystem and the nature of the processes may change as well, or even more dramatically, showing up the scale domain with breakpoints. Scale upscaling is the core of ecological theory and applications (Chave & Levin, 2003), which can be used to find the nonlinear and critical domain produced during the population fluctuations of *H. persicum*.

H. persicum is a perennial small tree or shrub-like plant distributed on shifting or semi-shifting sand dunes. In China, *H. persicum* is an important component of old Mediterranean flora and is widespread in the Gurbantünggüt desert in Xinjiang. This species is classified as a super xerophyte due to its high drought tolerance. Hence, it has been preferentially selected as a pioneer plant to stabilize sand dunes. During the last five decades, land reclamation and cultivation, over-grazing, over-cutting and engineering activities have resulted in the destruction of *H. persicum*, as a result, have increased mobility of sand dunes that are no longer stabilized by root systems.

Previous studies have largely focused on the *H. persicum* physiological and ecological characteristics, spatial distribution and community structure (Song *et al*., 2005; Wei *et al*., 2007; Song *et al*., 2011). Little was known about the fluctuation periodic of woody plant in Gurbantünggüt desert. The objectives of this study were: (1) to analyze the fluctuation characteristics of *H. persicum* of different edaphic types in Gurbantünggüt desert, to reveal the ecological significance of population fluctuations in desert areas during spectral analysis; (2) to explore the optimal and stable scale for the plant during upscaling process at a specific time series, in order to define the appropriate sampling size.

Materials and Methods

Description of the study sites: Gurbantünggüt Desert is the second largest desert in China with an area of 48, 800 km^2. The desert has an average annual temperature of 5–5.7°C (Table 1). Unlike most other arid zones, this area has an average annual snow cover period of about 95-110days, starting from late November and ending in mid-March of the following year. Stable or semi-stable dunes account for 96% of the total area of the desert. The ground vegetation is dominated by species of *H. ammodendron, H. Persicum C. ewersmanniana* and *P. soongorica.*

Table 1. The Statistics of environment factors in *H. Persicum* communities.

Plot	Wujiaqu (A)	Kuitun (B)	Jinghe (C)
Soil water content (%)	7.9	6.6	5.1
pH	8.2	7.91	7.98.1
Organic matter (g.kg-1)	0.89	0.52	0.58
Total salt content (.kg-1)	0.95	0.89	1.3 9
Annual precipitation (mm)	153.88	191.6	117
Evaporation (mm)	2100	1996.4	2000
Sunlight hours (h)	2700	2 800	2709.6
Wind speed (m/s)	2	2.5	3.7
Annual windy days	128	106	174

Note: The climate factors depended on thirty years from 1984 to 2014

Preliminary investigations revealed that the plant ages of *H. Persicum* were obviously different in three edaphic types in the Gurbantünggüt desert. Three plots were selected randomly in each edaphic type, so that a total of three 80m×200m plots were established as follows: (1) loam (distributed in Wujiaqu, plot A); (2) sandy soil (distributed in Kuitun, plot B); and (3) gravel soil (distributed in Jinghe, plot C). 160 small plots of 10m×10m from each sampling site were selected, with total 480 small plots sampled in three types. For each plot, we recorded and measured the crown width of each shrub and tree ground-level diameter and tree height. Plot positions were fixed by GPS.

Chemical analysis methods: We selected three 1m×1m subplots of each plot along the diagonal (Causton, 1988). Three soil samples from soil layers of 0-30 cm were taken from each plot, Wet and dry weights of all soils samples were used to calculate soil water content. Then, we mixed samples approximately 1kg from one plot into one sample and measured chemical property of soil. The pH was determined in a 1: 2.5 (*w: v*) suspension of soil in water using a pH/ORP/°C meter (hanna, Italy). Total salt content was determined using a EC/TDS/°C meter (hanna, Italy). Organic matter content was determined by the Tyurin method.

Age determination: Respective age equations were developed according to tree ring characteristics, ground-level diameter and tree height in the three edaphic types. Two ages are divided into one class. The *H. Persicum* samples were graded into 15 age classes.

Spectral analysis: Spectral analysis is an expansion of the Fourier series. Fourier showed that complicated cyclical phenomenon may be made up with respective harmonic waves of different amplitudes, which can be written in the form of a sine wave:

$$N_t = A_0 + \sum_{k=1}^{n} A_k \sin(\omega_k t + \theta_k)$$

where A_0 is the average value for the period; A_k is the amplitude of harmonic wave, determining the effect of the wave. The difference between them reflects the difference in effect between the difference periods. k = 1, 2, …., n; ω_k and θ_k are the frequency and phase angle of harmonic wave, respectively; N_t is the population size at time t (Mark & Dale, 1999).

The distribution of individuals in a population in each age class can be considered a time series t, X_t can be used to represent the number of individuals at age series t; n is the total length of the series; $p = n / 2$, and is the total number of harmonic wave, which is known; T is the fundamental period of the sine wave, i.e., the longest period in the time series t, that is, the total length of data where $T = n$, and is known. The following equations can be used to estimate the various parameters in the Fourier expansion:

$$A_0 = \frac{1}{n}\sum_{t=1}^{n} X_t \quad A_k^2 = a_k^2 + b_k^2 \quad \omega_k = 2\pi k / T$$

$$\theta_k = arctg(a_k / b_k) \quad a_k = \frac{2}{n}\sum_{t=1}^{n} X_t + \cos\frac{2\pi k(t-1)}{n}$$

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

Survival rate and mortality rate: The survival curve was plotted based on standardized survival rate against the age class (Southwood *et al*., 1974), the mortality curve was drawn based on standardized mortality at each age class against the age class (Knowles & Grant, 1983; Parker & Peet, 1984; Rundel, 1971).

$$l_x = a_x / a_{max} \times 1000 \qquad d_x = l_x - l_{x+1} \qquad q_x = d_x / l_x \times 100\%$$

where l_x is the standardized number of surviving individuals at the beginning of age class x (generally converted to the number in 1000 trees); d_x is the standardized number of plant died between the age classes x and x+1; q_x is the mortality between age classes x and x + 1 (Begon *et al*., 1981); a_x is the number of plants at age class x; a_{max} is the maximum number of plant, usually the number of surviving plants at age class 1.

Results

Survival and mortality of *H. persicum* populations: The survival curves of *H. persicum* populations (Fig. 1) are similar to Deevey III type (Deevey, 1947). The mortality curves showed that there were higher mortalities at higher age classes (Fig. 2). *H. persicum* seeds germinated well in spring when the sand was wet due to melting snow in the desert and heavier precipitation, which provides excellent germination conditions for the seeds. After mid-May, soil moisture decreased, the temperature gradually increased, resulting in rapid increase in seedling mortality.

Most of the plants at age class I and II usually died due to strong selection from environmental factors, particularly water. On the other hand, plants behind the age class II had varied but lower mortalities. In the sampling plot A, the mortality increased gradually and linearly with increasing age class, while in the sampling plots B and C, the mortalities moved up and down with four peaks as the age class increased. In different sampling plots, the soil conditions were different. The plot A was loam type, where environmental conditions were sufficient enough to meet the need for development of *H. persicum* and mortality was relatively stable. This indicates that the mortality is affected to a large extent by the biological characteristics of plant in the later stage. Environmental conditions in the plots B and C were relatively poor, and the mortalities fluctuated remarkably, suggesting that the mortality is largely affected by environmental factors, particularly by water condition.

Spectral analysis of the population dynamics: Due to large difference in the number of *H. persicum* plant in each age class, the numbers were logarithmically transformed prior to spectral analysis. Xt = ln (ax + 1) was used to replace Xt in the equation A_0 to calculate amplitude value A_k of the respective waves (k= 1, 2, 3, ..., p, p = n / 2); A1 is the fundamental wave, A2 - A7 are harmonic waves with the periods being1/2, 1/3, ….1/p of the fundamental period. Spectral analysis showed that the period of the population fluctuation was not single and overlapped more than two periods (Fig. 3). Investigation on individual stands showed that A_1 was the largest A_k, suggesting that the population dynamics of *H. persicum* was significantly affected by the period of fundamental wave.

According to our survey, plot A had good soil conditions with higher organic matters and soil water content. *H. persicum* grew well in the plot with high coverage (up to 43 %) and less variations in the number of plants among age classes. Thus, A_1 was slightly smaller in the plot A than in the other two plots, suggesting that the plot A was less affected by environmental factors, and it only had a small period A_4. The plots B and C were sandy and gravel with poor retention of soil water. Since the plant was growing in the desert environment permanently, its population number would drop remarkably when the plant encountered a few drought stresses, or would increase if they had years of several heavier precipitations. As a result, the population will fluctuate to short periods form.

Spectral analysis and upscaling of *H. persicum* populations on different scales: The data surveyed from the three plots were classified into 15 scales (800 m^2,1200 m^2, 1600 m^2, 2000 m^2, 3200 m^2, 4400 m^2, 5600 m^2 ... 15200 m^2) and analyzed for spectrum and upscaling individually (Fig. 4).

The plot A had the periods of A_4 and A_5 when the scale was below 2000 m^2 and only the period of A_4 appeared when the scale was over 2000 m^2. It was basically stable when the scale was 4400-5600 m^2 and over. The fluctuation period and magnification of small periods in the plot B were different from those in the plot A. In the plot B, there were clear and small periods of A_4, A_5 and A_7 on the scale of 800 m^2 and each of these periods had similar contribution. On the scales of 1200-3200 m^2 harmonic A_5 was strong. It was stable when the scale was over 5600-6800 m^2. In the plot C, A_1 was smaller on the scales of 800m^2- 1200m^2 and became larger gradually when the scale expended from1600 m^2 to 3200 m^2, suggesting increasing impact of the fundamental wave. On scales over 8000-9200 m^2 the populations were basically stable.

From upscaling based on the soil spectral analysis, it is clear that the fluctuations were greater on small scale in all sampling plots and become less and more stable as the size of scale increased. These results show that the population fluctuation of *H. persicum* is specific to soil conditions.

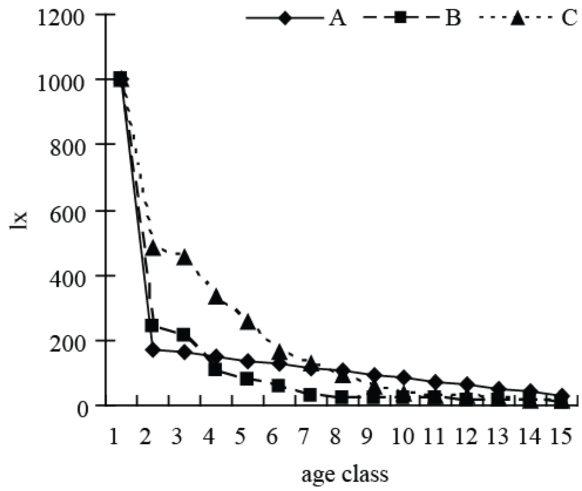

Fig. 1. Survival curves of *H. Persicum* populations in different edaphic types.

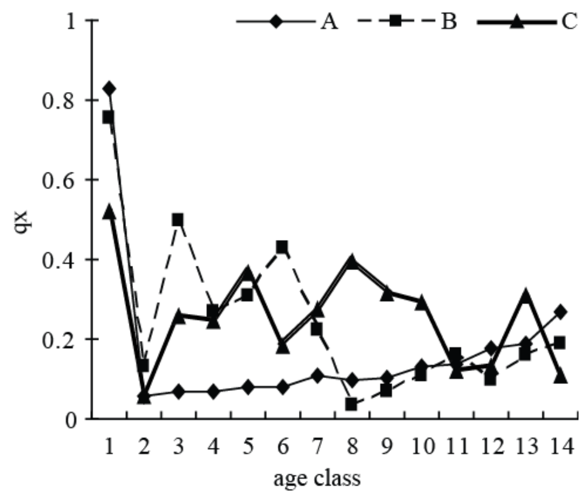

Fig. 2. Dead curves of *H. Persicum* populations in different edaphic types.

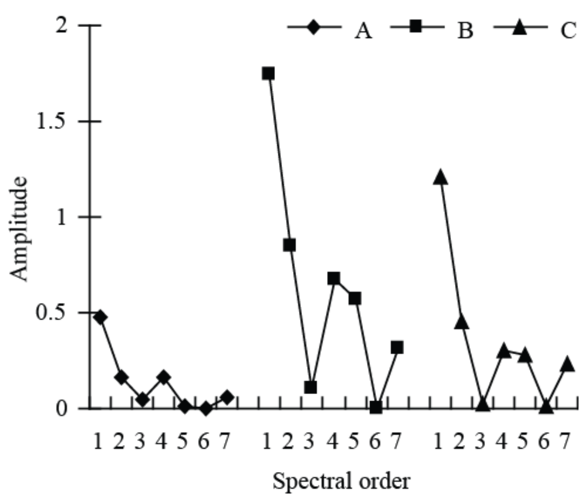

Fig. 3. The periodic fluctuation of *H. Persicum* populations in different edaphic types.

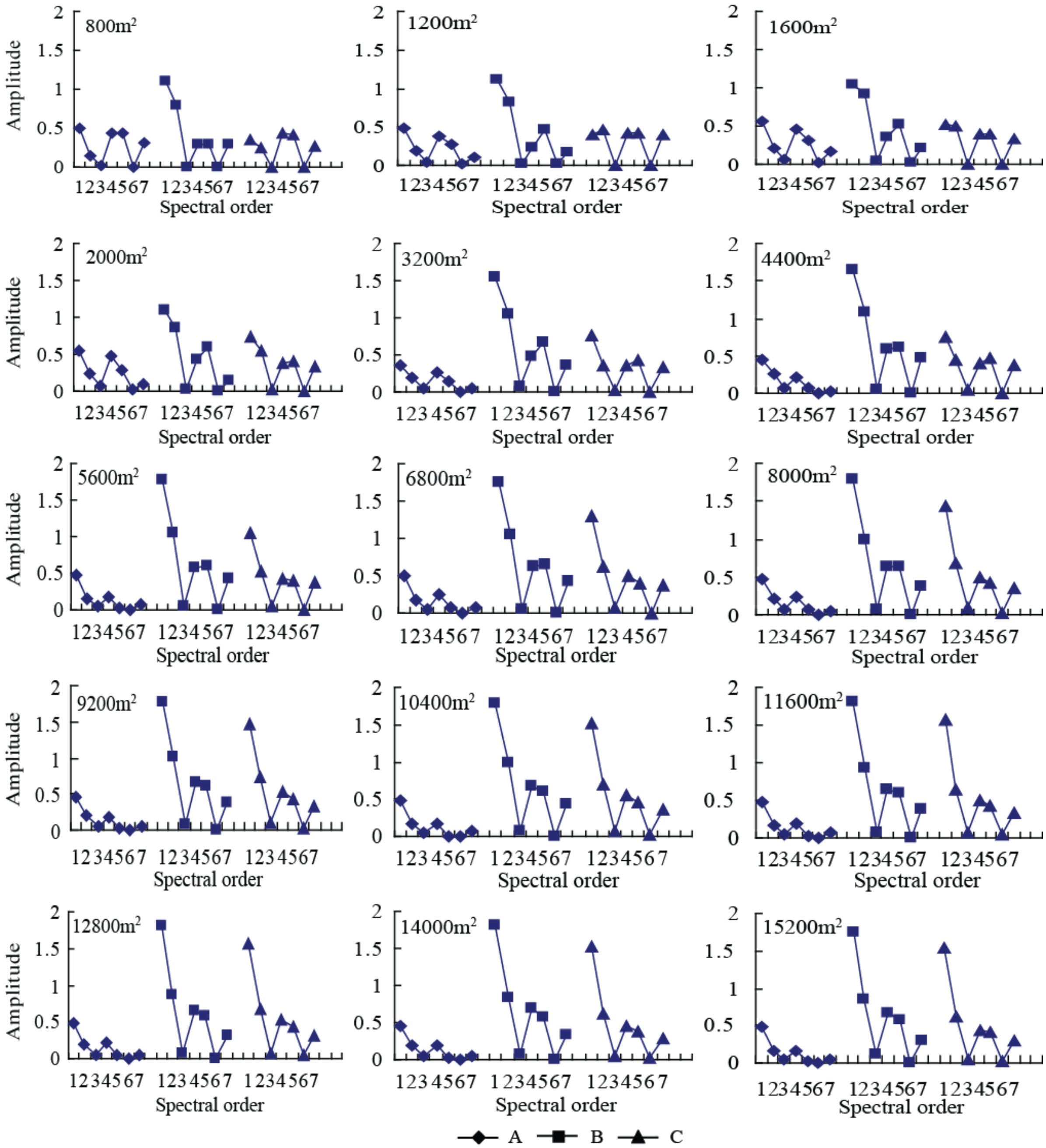

Fig. 4. Upscaleing of periodic fluctuation of *H. Persicum* populations.

Discussion

Periodic fluctuations of *H. persicum* population: The population dynamics of *H. persicum* can be interpreted as advance and development by the replacement of a population with condense distributed periods with population with another period. As such, the changes in population structure and number of the plant have obvious characteristics. Spectral analysis on population fluctuations showed that there are longer periods of fluctuation than shorter periods of fluctuation in the plant, suggested that the alternation of the stands are cycling and periodic. In the plot A, there was only one small population fluctuation in A_4, while in the plot B and C, there were four small fluctuations, which might be a reflection of population regulation by the growth characteristics of the plant and environment during the conversion of seedling to mature plants. We found that spectral analysis was effective method analyzing the intensity of fluctuation in the *H. persicum* population.

The growth of plant is affected not only by their own biological and ecological characteristics, but also by environmental and climatic conditions, such as freezing, drought, abnormal weather phenomena such as El Niño. These environmental factors can lead to plant death (Korner, 1998; Hoch *et al*., 2002). Dong (1987) reported Masson Pine (*Pinus massoniana* Lamb.) population density increases and its rate of growth decreases were governed partly by inherent biological features of *P. massoniana* and partly by the invasion, establishment and development of shade-tolerant evergreen broad-leaved trees. Yuko &Takenori (2014) reported that the life stages of *Aesculus turbinata* Blume had the greatest effect on the population growth rates. These studies suggest that in the area with good environmental conditions, water and nutrient conditions can fully meet the need of the growth of plant of various sizes. In these areas, environmental conditions are less influential on population dynamics. In the Gurbantünggüt desert, abiotic stresses such as water deficit are restrictive to plant growth and reproduction. Due to fluctuations in climate conditions at the seedling stage, most of the plants die often, except in some years when spring precipitations are timely to water the plant, resulting in better seedling survival. In arid area, only a few new seedling additions can be achieved successfully in a century. This leads to the increase of population in a wavy way. Therefore, the *H. persicum* population fluctuations are not only affected by its biological characteristics, but more by hassle environmental conditions.

Due to limited time length investigated, our study is unable to reveal the intrinsic and full length of fundamental period for *H. periscum*. Former surveys showed that before the 1980s, due to deforestation and reclamation, forest area of *H. periscum* dropped dramatically and there was no longer virgin forest within the range of 30-50 km from the Southern Edge of the desert. In addition, due to increased water usage in the cities and the expansion of farmland, the water table has lowered seriously from 1.5-2 m in the 1970s to about 5 m in the late 1980s, about 5m and now below 9-12m. With the falling water table, roots are difficult to absorb groundwater to support the growth of large tree. Thus, in the plots surveyed there is barely *H. periscum* with transition diameter of more than 20cm. So it is not possible to find the fluctuation length of long period within the investigated time length in the investigated time series.

Upscaling of spectrum analysis: Scale upscaling enables the information exchange between different spatial and temporal scales or between organizational levels (Wu, 1999). Under normal circumstances, the scale is similar spatially and temporally, and highly predictable. If the temporal scale is smaller and spatial scale is larger, it is still highly predictable. However, if the temporal scale is larger and spatial scale is smaller, the predictability is poor (Roland, 2000). Because of ubiquitous existence of spatial variability and interference mechanisms such as those from climate and soil factors, functional elements and spatial factors are spatially heterogeneous within the ecosystem, and thus are obviously not linear. The corresponding system dynamics model (including scale upscaling model) often needs to integrate the nonlinear functionality of space parameters and therefore cannot apply small-scale model directly to large scale. Scale upscaling via spectral analysis found that the characteristics of periodic fluctuations in *H. persicum* depends on the scale size, and the stabilized scale size relies on soil conditions. Our results show that in the Gurbantünggüt desert the fluctuations can be stabilized in small sampling plot (4400-5600 m^2) when the plant is growing under good conditions. On the other hand, if the environmental conditions are poor, larger sampling size (4000-9200 m^2) is needed to achieve stable population. Furthermore, under the same soil condition, fluctuations in smaller sampling plot is found to be more sensitive to environmental changes than in larger sampling plots. Therefore, when performing spectral analysis, the sampling size should be determined based on environmental conditions for the best determination of the periodic fluctuation on optimal scale.

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