Postprint on Population Structure and Dynamic Characteristics of Natural Haloxylon ammodendron Populations on the Eastern Margin of the Badain Jaran Desert

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Abstract

To investigate the population structure and dynamic characteristics of natural Haloxylon ammodendron forests in the Badain Jaran Desert, reveal the regeneration process and future development trends of this constructive species, and construct static life tables, survival curves, quantitative dynamic change indices, and time series prediction models. The results indicate that: (1) The age structure of the Haloxylon ammodendron population is J-shaped, with abundant seedlings; (2) The survival curve of the Haloxylon ammodendron population follows the Deevey-II type, with fewer individuals in higher age classes; the vanishing rate and mortality rate show consistent trends, with maximum and minimum values occurring at age classes XVII and IV, respectively; (3) The population structure and dynamic change index of Haloxylon ammodendron is greater than zero (Vpi > V'pi > 0), indicating a growing population; (4) Time series prediction analysis shows that the number of individuals in each age class of Haloxylon ammodendron exhibits an increasing trend. The study demonstrates that the natural Haloxylon ammodendron population on the eastern edge of the Badain Jaran Desert is a stable growing population. In response to the low survival rate of young individuals in this population, artificial intervention is recommended to enhance survival rates.

Full Text

Population Structure and Dynamic Characteristics of Natural Haloxylon ammodendron at the Eastern Margin of Badain Jaran Desert

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Abstract

This study investigated the population structure and dynamic characteristics of natural Haloxylon ammodendron forests in the Badain Jaran Desert to reveal the regeneration process and future development trends of this constructive species. A static life table, survival curves, mortality and vanishing rate curves, population dynamic indices, and a time-series prediction model were developed. The results demonstrated that: (1) The age structure of H. ammodendron populations follows a "J-shaped" distribution, with abundant seedlings but low survival rates. (2) The survival curve conforms to the Deevey-II type, with both disappearance and mortality rates showing consistent trends, reaching maximum and minimum values at age classes XVII and IV, respectively. (3) The population dynamic change index exceeds zero (Vpi > V' pi > 0), indicating a growing population. (4) Time-series prediction analysis revealed that individual numbers across all age classes will increase over time. The findings indicate that the natural H. ammodendron population at the eastern margin of Badain Jaran Desert represents a stable, growing population. Given the low survival rate of young individuals, artificial intervention is recommended to improve seedling survival.

Keywords: Haloxylon ammodendron; population; population dynamics; time sequence; Badain Jaran Desert

Introduction

A population comprises all individuals of the same species living in a specific natural area at a given time, representing the fundamental unit of evolution. Population structure and dynamics reflect the changing patterns of populations within defined natural regions, representing the combined result of individual responses and external influences, and constituting a critical research topic in population ecology. Quantifying population structure and dynamics enables the digitization of population status data, assessment of development trends, and understanding of adaptation to surrounding resources and environments, growth characteristics, survival potential, and interspecific relationships, thereby illuminating community succession patterns.

Haloxylon ammodendron, a pioneer species in desert ecosystems, exhibits exceptional drought resistance, stress tolerance, and wind erosion tolerance, playing an irreplaceable role in desertification control. The Tamsag region, located at the eastern edge of the Badain Jaran Desert, represents an ecotone between desert and oasis, harboring 21.5×10^4 hm^2 of natural H. ammodendron forests. The degradation or expansion of plant populations in this transitional zone directly influences oasis dynamics, making clarification of population structure and dynamics essential for understanding natural regeneration and community succession.

Current research on H. ammodendron primarily focuses on population characteristics, spatial distribution patterns, and population dynamics. Climate change and human disturbance have increased drought frequency, causing population degradation and mortality in extremely arid regions, severely impacting ecosystem service functions. Consequently, investigating plant adaptation and response to drought has become an ecological research priority. Due to their inherent drought tolerance, species such as H. ammodendron, Hedysarum laeve, and Hedysarum scoparium have become key research subjects. Previous studies have classified H. ammodendron populations in Minqin Hongshi Desert into three types, all demonstrating strong adaptability to arid conditions. Research on H. ammodendron in Ganjia Lake yielded similar conclusions, indicating that the species exhibits different growth responses according to developmental stages and environmental conditions. However, comprehensive studies on the population structure and dynamics of natural H. ammodendron forests in the Badain Jaran Desert remain scarce. Investigating population dynamics can overcome current bottlenecks in scientific management, informing strategies for growth, regeneration, development, and environmental stability while providing insights into the dynamic interactions between oasis and desert ecosystems at the desert margin, enabling early intervention in degrading areas.

1. Materials and Methods

1.1 Study Area

The study area is located at Chaohengzagan (40°33.06 -40°35.53 N, 103°25.16 -103°27.55 E) in Geriletu Gacha, Tamusag Sumu, Alxa Right Banner, Alxa League, Inner Mongolia, at an elevation of 1,255.8–1,264.3 m. The region experiences a typical arid continental climate with mean annual precipitation of 84 mm, annual evaporation exceeding 3,500 mm, mean annual temperature of 8.4°C, and groundwater depth locally below 500 m (primarily supplied by precipitation). Natural vegetation is sparse, dominated by H. ammodendron, Nitraria tangutorum, Sarcozygium xanthoxylon, and Reaumuria songarica.

1.2 Methodology

1.2.1 Sample Plot Establishment In August 2021, we established study plots in natural H. ammodendron forests at the eastern margin of the Badain Jaran Desert (Fig. 1 [Figure 1: see original paper]). The total study area covered 923 hm^2. Using large-plot survey methodology, we selected areas with dense H. ammodendron distribution as experimental plots, recording coordinates at four corners with handheld GPS. Using the lower-left corner as the origin, we established 200 m × 200 m adjacent grids along horizontal and vertical transects. For every H. ammodendron individual encountered on transect lines, we measured basal diameter and recorded relative coordinates.

1.2.2 Age-Class Structure Classification Due to irregular aboveground stem growth and the inability to accurately determine age from annual rings, we adopted diameter classes as age-class proxies following Li et al. [reference]. Based on classification standards from Cai et al. [reference] and Lü et al. [reference], we divided the population into 16 age classes at 2 cm intervals. These were further grouped into four developmental stages: young (age classes I-IV), middle-aged (V–VIII), mature (IX–XII), and old (XIII–XVI).

1.2.3 Static Life Table Compilation As the study focused on natural forests, we applied smoothing techniques (Smooth Out) to individual counts across age classes before compiling the static life table using standard methods.

1.2.4 Survival Curve Analysis We classified survival curves using Deevey' s mathematical models to describe survival patterns, testing curve types through linear, power, and exponential function fitting.

1.2.5 Quantitative Methods for Population Structure and Dynamics Population dynamic structure analysis followed Chen [reference]:

$$V_n = \frac{S_n - S_{n+1}}{\max(S_n, S_{n+1})} \times 100\%$$

$$V_{pi} = \frac{\sum_{n=1}^{k-1} S_n \cdot V_n}{\sum_{n=1}^{k-1} S_n \cdot k}$$

$$V'_{pi} = \frac{\sum_{n=1}^{k-1} S_n \cdot V_n}{\sum_{n=1}^{k-1} S_n \cdot k \cdot (k-1)}$$

where V_n is the dynamic change index between age classes; V_{pi} and V'_{pi} are population dynamic indices ignoring and considering external interference, respectively; S_n is the number of individuals in age class n; and k is the total number of age classes.

1.2.6 Time-Series Prediction Model We employed a first-order moving average method for simulation and prediction:

$$M_n^{(t)} = \frac{1}{t}\sum_{k=1}^{t} X_k$$

where n is the age class, t is the prediction time, X_k is the number of surviving individuals in age class k, and M_n is the predicted population size.

1.3 Data Analysis

Data analysis and visualization were performed using Excel 2020, Origin 2019, and ArcGIS.

2. Results

2.1 Population Age Structure

We surveyed 1,234 H. ammodendron individuals with maximum basal diameter of 32 cm. The age structure exhibited a "J-shaped" distribution (Fig. 2 [Figure 2: see original paper]), characteristic of a growing population. Young individuals (age classes I-IV) accounted for 56.21% of the total, indicating abundant seedlings and strong growth potential. Age classes V–VIII represented 10.08% and 9.73% of the population, respectively, showing a marked decline from the previous age class and suggesting difficult transition from young to middle-aged stages. Beyond age class IX, individual numbers gradually decreased, with a significant reduction at age class X, indicating that only a small proportion transitions to mature stages. Mature individuals exhibited enhanced vitality, while old individuals (age classes XIII–XVI) comprised only 3.04% of the total population.

2.2 Static Life Table

The static life table (Table 1) revealed that life expectancy (e_x) peaked at age class IV, while mortality (q_x) and vanishing rates (K_x) reached their lowest points, indicating favorable development of young individuals. From age class V onward, q_x and K_x gradually increased while e_x decreased, signaling the onset of senescence. Age class X showed unstable fluctuations. From age class XI, e_x declined continuously to its minimum at age class XVI, while q_x and K_x reached maxima, indicating that the few surviving individuals were in a degenerative phase.

2.3 Survival, Mortality, and Vanishing Rate Curves

The survival curve reflects individual survival across age classes. The H. ammodendron survival curve (Fig. 3 [Figure 3: see original paper]) showed a decreasing trend. Mathematical model testing (Table 2) revealed that the linear function' s coefficient of determination ($R^2 = 0.921$) exceeded those of the power function ($R^2 = 0.873$) and exponential function ($R^2 = 0.851$), indicating the survival curve conforms to Deevey-II type. This aligns with the relatively small variation in survival rates and consistent reduction rates between age classes, corroborating age structure and life table analyses.

Both vanishing and mortality curves (Fig. 4 [Figure 4: see original paper]) exhibited consistent "decrease-increase-decrease-increase" dynamics, with peak values at age classes IV and XVII, and minimum values at age classes I and IX.

2.4 Population Dynamic Indices

Population dynamic indices (Table 3) showed $V_{pi} > 0$ and $V'_{pi} \approx 0$, indicating "growth-stable" dynamics. Ignoring external interference, $V_{pi} > V'_{pi}$ suggests a growing population. Considering external interference, V'_{pi} approaching zero indicates weak growth trends and unstable dynamics. The decreasing individual numbers with advancing age classes confirm these patterns.

2.5 Time-Series Prediction

Time-series prediction (Table 4) demonstrated increasing individual numbers across all age classes after 2, 4, 6, and 8 age-class intervals, indicating sustained population growth.

3. Discussion

Population structure and dynamics reflect both individual development and comprehensive external influences. Harsh natural conditions, scarce water resources, herbivory, and human disturbance represent critical factors driving H. ammodendron population changes in the Badain Jaran Desert.

Our findings reveal a growing age structure with abundant seedlings, consistent with studies by Sun et al. [reference] and Song [reference], indicating favorable natural regeneration and strong growth potential. As individuals enlarge, resource demands increase, intensifying intraspecific competition and self-thinning when environmental carrying capacity is exceeded. Initially, seedlings require minimal resources, exhibiting weak competition. However, competition intensifies as individuals develop. During middle and mature stages, individuals possess strong vitality with minimal environmental constraints; mortality and vanishing rates likely result from external interference such as camel herbivory or wild *Cistanche* collection [reference]. In later stages, few surviving individuals undergo physiological senescence.

The Deevey-II survival curve aligns with Li et al. [reference] and Yang [reference], confirming decreasing numbers with age. The "decrease-increase-decrease-increase" pattern in vanishing and mortality curves reflects enhanced environmental adaptation in adults. Following enclosure measures, reduced grazing pressure benefits old individuals, but mortality gradually increases as they approach physiological limits [reference], consistent with life table and survival curve analyses.

The dynamic index $V_{pi} > V'_{pi}$ indicates a growing population [reference], suggesting favorable natural regeneration without large-scale deforestation. Time-series predictions further confirm stable population growth across age classes, reinforcing the necessity of establishing nature reserves to minimize external interference and enable self-sustaining regeneration.

4. Conclusion

Analysis of population structure and dynamics in natural H. ammodendron forests of the Badain Jaran Desert yields the following conclusions:

1. The age structure follows a "J-shaped"distribution with abundant seedlings but low survival rates. Artificial thinning and supplemental watering during extreme drought are recommended, as water represents the limiting factor determining seedling survival.

2. The survival curve conforms to Deevey-II type, with decreasing numbers across age classes and relatively stable mortality rates between age classes. Combined with population dynamic indices, this confirms a stable, growing population. Establishing natural reserves to minimize external interference is essential for enabling self-sustaining regeneration.

3. Time-series predictions indicate increasing individual numbers over time, further demonstrating the necessity of establishing protected areas to ensure long-term population stability.

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