Population Structure and Dynamics of the Psammophyte Eremurus anisopterus under Different Disturbance Intensities: Postprint

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Abstract

Intensifying human activities have led to habitat fragmentation for Eremurus anisopterus (Kar.et Kir.) Regel on the southern edge of the Gurbantunggut Desert, forming numerous patch populations of varying sizes. To deeply understand the survival status of Eremurus anisopterus populations in patches with varying degrees of fragmentation, a total of 19 sampling sites were selected to analyze their age-class structure, compile static life tables, plot survival and mortality curves, and introduce four survival analysis functions. The results indicate that on the southern edge of the Gurbantunggut Desert, the population dynamics of Eremurus anisopterus in different sample plots exhibit distinct structural characteristics and change trends due to differences in human disturbance and habitat fragmentation levels; the age-class integrity of Eremurus anisopterus populations varies across sample plots, with populations in highly fragmented plots showing incomplete or discontinuous age classes. The age structures of populations in type b and type c patches, which experience moderate and weak human disturbance respectively, belong to stable-to-decline and growth types, while the population structure in type a patches (with the strongest disturbance) shows strong fluctuations and a higher risk of population decline. Survival curves and the four survival function curves demonstrate that type a populations are stable in the early and middle stages but decline in the later stage; type b populations decline in the early stage but stabilize in the middle and later stages; type c populations grow stably. This suggests that the decline of Eremurus anisopterus populations may be caused by habitat fragmentation; therefore, for declining populations experiencing strong human disturbance, anthropogenic interference should be urgently reduced, and scientific and practical conservation and restoration strategies should be formulated based on the disturbance factors and population survival status in different habitats.

Full Text

Preamble

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Structural and Dynamic Characteristics of *Eremurus anisopterus* Populations Under Different Disturbance Levels

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Abstract

Intensifying human activities have fragmented the primary habitat of *Eremurus anisopterus* in the southern Gurbantunggut Desert, resulting in numerous discrete population patches of varying sizes. To understand the survival status of this species in fragmented habitats, we surveyed 19 plots and analyzed population age structure, constructed static life tables, and generated survivorship, mortality, and survival analysis function curves. Our results indicate that population dynamics of *E. anisopterus* exhibited distinct structural characteristics and trends across plots due to varying levels of human disturbance and habitat fragmentation. Age-class completeness differed among plots, with highly fragmented patches showing missing or discontinuous age classes. Based on fragmentation and disturbance levels, the age structures of type b and c patches were classified as stable-to-declining and growing types, respectively, while the most heavily disturbed type a patches showed greater instability with higher risk of decline. Survivorship curves and four survival functions revealed that type a populations were stable in early phases but declined in intermediate phases, type b populations declined early then stabilized, while type c populations remained stable throughout. Plant population structure reflects both individual survivability and environmental conditions, providing important information on species regeneration. The decline of *E. anisopterus* populations likely results from habitat fragmentation. Type b populations showed strong fluctuations, with higher risk of decline compared to type c. For declining populations under heavy human disturbance, immediate reduction of anthropogenic impacts is urgently needed. Scientific and practical conservation strategies should be formulated based on disturbance factors and population status in different habitats.

Keywords: habitat fragmentation; *Eremurus anisopterus*; age structure; life table; survival curve

Introduction

Habitat fragmentation refers to the division of originally large, continuously distributed natural habitats into isolated habitat islands or fragments through human activities and natural disturbances [1]. This process results from interactions among physical, social, and biological factors, affecting interspecific gene flow and leading to reduced total habitat area, isolated metapopulations, and altered population viability, species interactions, and ecological processes [2-5]. While habitat change is a natural phenomenon, human activities have accelerated fragmentation [6-7], causing changes in microclimate, edge effects, and other biotic and abiotic conditions that influence plant metapopulation dynamics [2,8-9]. Habitat fragmentation, degradation, and loss are widely recognized as primary causes of species extinction, making it increasingly important to identify conservation patterns and methods for endemic species from human-nature interactions.

Eremurus anisopterus (Kar. et Kir.) Regel is a perennial ephemeroid geophyte herb that grows on fixed and semi-fixed sand dunes along the southern Gurbantunggut Desert and the northern foothills of the Tianshan Mountains, representing an important early-spring species for sand stabilization [10]. This species forms new individuals from underground buds and completes its entire life cycle from germination to seed production rapidly during early spring using melted snow water [11-12]. Despite its brief life cycle, it is a major contributor to windbreak and sand fixation in the Gurbantunggut Desert and plays a vital role in maintaining desert ecosystem stability [10,13-14]. However, large-scale reclamation, grazing, and oil/gas development in northern Xinjiang have significantly impacted the desert ecosystem, creating obvious habitat patchiness and increased patch isolation for *E. anisopterus*.

Previous research on *E. anisopterus* has focused primarily on reproductive strategies and karyotype analysis [15-19], while little is known about population distribution and dynamics after habitat fragmentation. Wang et al. [16] analyzed seed morphological characteristics in fragmented habitats, finding that seeds in disturbed habitats were smaller with longer wings and higher proportions of small seeds, indicating that disturbance had already affected seed morphology. Continuous anthropogenic disturbance likely also impacts population structure and dynamics, potentially causing degradation or local extinction under severe, persistent disturbance, while populations under light or no disturbance may show stable growth trends.

Population structure and dynamics are fundamental characteristics that reflect not only population status and trends but also relationships between populations and environments, as well as their roles in communities [20-21]. Demographic analysis can reveal population responses to environmental conditions, estimate past disturbances, and predict future trends [22-27]. This study investigates *E. anisopterus* populations in fragmented habitats of the Gurbantunggut Desert to analyze age structure characteristics, examine interactions between population dynamics and both intrinsic life-history traits and extrinsic disturbance conditions, explore population renewal and maintenance mechanisms, and provide scientific basis for rational utilization and conservation of this psammophytic species.

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1. Study Area Overview

The Gurbantunggut Desert (44°11 -46°20 N, 81°31 -90°00 E) is China' s largest fixed and semi-fixed desert, covering over 70% of its area with fixed and semi-fixed aeolian soils. The landscape is dominated by dendritic sand ridges with relative dune heights of 10-50 m. The region has a typical inland arid climate with annual accumulated temperature of 3000-3500°C and annual precipitation of 70-150 mm, with 30-45% falling in winter and spring. Stable snow cover lasts 100-160 days with maximum depths around 20 cm, providing favorable conditions for early-spring ephemeral plants [28-29]. Groundwater is generally buried too deep (>10 m) to be utilized by plants, which rely primarily on precipitation. The study area is located on the southern margin of the Gurbantunggut Desert, concentrated in three towns (Paotai, Xigucheng, and Shihutan) where *E. anisopterus* distribution is most abundant. The terrain includes sand dunes, interdune flats, and reclaimed land, with vegetation dominated by common Xinjiang desert species including *Eremurus anisopterus*, *Eremurus inderiensis*, *Ceratocarpus arenarius*, *Salsola arbuscula*, *Seriphidium terrae-albae*, and *Reaumuria soongorica*.

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2. Plot Selection

After comprehensive field surveys and considering habitat characteristics and human disturbance factors, we established plots in Paotai, Xigucheng, and Shihutan during March-April. We selected patches with different fragmentation and disturbance levels on sand ridges or interdune areas, totaling 19 patches with large inter-patch distances. For each plot, we recorded: patch length per unit area (ED), relationship with surrounding environment (classified as fully open, three-sides-open, or open-closed balanced), presence of closely related species (*E. inderiensis*), disturbance duration, and other factors. Patch openness directly affects landscape edge effects and reflects fragmentation degree. Using SPSS 17.0, we standardized initial patch data and performed hierarchical cluster analysis for plot classification.

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3. Plot Classification

Cluster analysis of 19 environmental factors from 19 plots using SPSS 17.0 with Euclidean distance and Ward' s method produced a dendrogram [Figure 1: see original paper]. Plots were classified into three types:

Type A (high fragmentation): Six plots (P1, P5, P7, P15, P17, P19) with small areas (196-682 m^2), high edge development (ED values), nearly fully open configuration, and high fragmentation scores (0.5-0.6). These experienced multiple disturbances including desert roads, grazing, irrigation wells, farms, and wineries, with some mixed growth of *E. inderiensis*.

Type B (moderate fragmentation): Six plots (P2, P3, P4, P8, P13, P18) with medium areas (1464-2925 m^2), moderate edge development, rectangular shapes, few closely related species, and moderate fragmentation scores (0.5).

Type C (low fragmentation): Seven plots (P6, P9, P10, P11, P12, P14, P16) with relatively large areas, poorly developed edges, nearly closed configurations, rare occurrence of related species, and low fragmentation scores (<0.5), representing low-fragmentation patch types.

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4. Age-Class Classification

We used the quadrat method to study *E. anisopterus* populations, establishing 10 m × 10 m quadrats in each plot and surveying every individual for leaf whorl number, leaf length, and plant height. Population age structure is crucial for population dynamics research. While woody plants use diameter or height, age determination in perennial herbs is challenging. Literature shows that for Liliaceae plants, leaf length and whorl number can serve as age indicators [30-31]. We used measured whorl number to define age classes, with three leaf whorls representing one age class. We plotted age structure pyramids with relative age (age class) on the vertical axis and individual numbers on the horizontal axis.

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5. Static Life Table

As *E. anisopterus* is a perennial ephemeroid, we compiled static life tables using the "space-for-time" substitution method [25-27]. Life table parameters include [32]: x (midpoint of age class), a (existing individuals in age class x), l (standardized survivors at start of age class x, typically scaled to 1000), d (standardized deaths from x to $x+1$), q (mortality rate from x to $x+1$), L (survivors during interval x to $x+1$), T (total individuals from age x onward), e (life expectancy for individuals entering age x), and K (loss rate). These parameters are interrelated, with l or d calculated from measured a values.

Static life tables compiled from all individuals collected simultaneously reflect age dynamics across multiple cohorts at a specific time rather than tracking a single cohort throughout its life history. Systematic survey errors can produce negative mortality rates, which, while violating mathematical assumptions, indicate populations are not static but rapidly developing or declining, providing useful ecological records [33].

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6. Survivorship and Mortality Curves

Using age class as the horizontal axis and standardized survivors (l) and mortality rates (q) as vertical axes, we plotted survivorship and mortality curves to visualize population trends.

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7. Survival Analysis Methods

To better analyze population dynamics and survival patterns, we introduced four survival analysis functions: survival rate function $S(i)$, cumulative mortality function $F(i)$, mortality density function $f(i)$, and hazard rate function (i), calculated as follows [34]:

$S(i) = S(i\text{-}1) \times (1 - h(i))$
$F(i) = 1 - S(i)$
$f(i) = 2q(i) / [h(i)(1 + S(i))]$
$(i) = 2q(i) / [h(i)(1 + S(i))]$

where $S(i)$ is survival rate, $q(i)$ is mortality rate, and $h(i)$ is age class width. We plotted survival, cumulative mortality, mortality density, and hazard rate curves using Microsoft Excel 2003 and Origin software.

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1. Age Structure Analysis

By counting *E. anisopterus* individuals in each age class across plots and calculating averages for the three plot types, we constructed age structure diagrams [Figure 2: see original paper]. Type A plots had the fewest individuals, with missing age classes, particularly among older classes. Type B plots showed relatively complete age structures except for one plot, with individuals distributed across all age classes in a spindle-shaped, normal distribution (small at both ends, large in middle). Type C plots exhibited pyramid-shaped age structures with absolute dominance of seedlings (averaging 43.85% of total individuals), indicating typical growing populations well-adapted to local conditions.

Type A plots, under strong human disturbance, had small populations with insufficient seedling reserves and missing older age classes, showing unstable development and high decline risk. Type B plots, under moderate disturbance, appeared stable but had high seedling mortality and low seedling reserves, classifying them as stable-to-declining populations that could recover quickly with strict protection. Type C plots, under light disturbance, had large populations with abundant seedlings and sufficient recruitment resources, maintaining healthy growth status.

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2. Static Life Table

Following static life table protocols, we compiled tables using average survivors from each plot type (Table 1). These reflect a specific time period in the population' s age dynamics, representing fundamental life-death patterns. Negative d and K values occurred in Type A (age class I) and Type B (age class III) where survivors in one age class were fewer than in the next older class, indicating rapid population change [33].

Type C populations had abundant seedlings but high mortality in age classes I, III, IV, and V, reflecting seedling scarcity during these stages. Life expectancy (e) was highest in middle age classes (3.48–3.49), indicating strongest survival capacity during these stages. After intense intraspecific competition and natural selection, surviving individuals showed strong life expectancy.

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3. Survivorship and Mortality Curves

Using leaf whorl number as the horizontal axis and standardized survivors (l) and mortality rates (q) as vertical axes, we plotted survivorship and mortality curves [Figure 3: see original paper]. Type A showed a Deevey III survivorship curve: high seedling mortality causing rapid population decline, followed by stable population size at low mortality until physiological senescence, indicating light human interference throughout the life cycle after establishment.

Type B showed a different pattern: survivorship peaked at middle age classes then declined, indicating high seedling mortality from harsh natural conditions and severe human impacts (land reclamation, roads, exploration). Type C lacked older age classes, showing prolonged, intense disturbance. Mortality curves reflected these dynamics: Type A had extremely unstable mortality due to strong human disturbance and high fragmentation; Type B showed gradually declining mortality after age class V, indicating environmental filtering; Type C showed a small mortality peak at age class V, rising sharply thereafter toward maximum lifespan.

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4. Survival Analysis

Plotting the four survival functions against age class revealed distinct patterns [FIGURE:4, FIGURE:5]. In Type A, survival and cumulative mortality curves decreased and increased monotonically except at age class III, where survival increased and mortality decreased, indicating instability. Type B showed monotonic changes with stable, gradual trends, indicating stable growth. Type C showed survival decreasing and mortality increasing from age class I, with mortality density curves remaining flat and hazard rates increasing monotonically.

3. Discussion

Population age structure directly reflects population-environment relationships, while life tables describe survival dynamics. Studying these characteristics is crucial for understanding population roles in communities and predicting future trends [35]. In *E. anisopterus* distribution areas, different disturbance intensities produce varying age structures. Strong and moderate human disturbance cause missing age classes and population instability, with high extinction risk under continued disturbance and lack of protection. Populations struggle to pass through strong environmental filters to reach replacement stages.

In Type A plots (heavy disturbance), age structure fluctuated greatly with high mortality risk for younger age classes, making regeneration difficult and potentially leading to local extinction. Type B plots (moderate disturbance) had fewer young individuals due to trampling and grazing, concentrating individuals in middle age classes and causing stable-to-declining trends. Type C plots (light disturbance) in continuous sand ridges had abundant seedlings and moderate middle-age individuals, showing significant growth potential.

Static life tables compiled from field data represent real, disturbed populations. Negative mortality rates, while mathematically problematic, indicate non-static populations undergoing rapid development or decline [33,39]. The overall Deevey III survivorship curve with high early mortality and later stability reflects intense early competition that eliminates weaker individuals, benefiting population evolution. Field observations confirm that historical reclamation and livestock grazing on annual and perennial plants explain these fluctuations. Maintaining stable populations requires creating suitable conditions for seed germination and seedling establishment [40].

Habitat fragmentation reduces original habitat area and carrying capacity, limiting population dispersal and affecting future dynamics. Studies in Amazonian forests [41] and on *Euonymus chloranthoides* [42] show that fragmentation reduces species richness and reproductive success. Research in Estonian calcareous grasslands [43] and Horqin sandy lands [44] similarly demonstrates negative effects of fragmentation on species richness and population structure, consistent with our findings. For *E. anisopterus* populations in heavily disturbed and grazed habitats, active measures including grazing restriction and enclosure for forest regeneration are needed, while also considering potential for both sexual reproduction and vegetative recovery through underground organs.

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4. Conclusion

Eremurus anisopterus populations in the southern Gurbantunggut Desert exhibit different structural characteristics and trends depending on human disturbance and habitat fragmentation levels. All analyses consistently show that heavily disturbed, highly fragmented populations decline rapidly with greater future extinction risk, while lightly disturbed, low-fragmentation populations grow stably. As an important component of the desert’ s ephemeral plant community, *E. anisopterus* plays crucial roles in sand stabilization and ecosystem balance during spring and summer. Conservation should combine population status across different disturbance and fragmentation levels to formulate practical strategies. Populations in highly fragmented habitats require urgent intervention.

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