Study on Plant Community Configuration Patterns of Protective Green Spaces in Arid Gravel Desert Areas (Postprint)

Authors: Zhou Jing, Yan Cheng

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Abstract

Taking 27 plant community configuration patterns in protective green spaces of the alluvial fan gravel desert area in southern Urumqi as the research object, and combining the Analytic Hierarchy Process with fuzzy comprehensive evaluation, this study conducted a comprehensive evaluation and ranking of the ecological effects of different plant community configuration patterns. The results showed that the configuration patterns of Pinus sylvestris var. mongolica-Atriplex cana-Chondrilla piptocoma+Seriphidium transiliense, Ulmus pumila-Hippophae rhamnoides subsp. turkestanica-Chondrilla piptocoma+Clematis songarica, Ulmus laciniata-Hippophae rhamnoides subsp. turkestanica-Chondrilla piptocoma+Acroptilon repens, and Elaeagnus angustifolia-Atriplex cana-Chondrilla piptocoma exhibited good ecological performance. Based on the similarity of ecological effects among plant communities and landscape functional requirements, diversified expansion analysis was conducted on optimized configuration patterns, and optimized plant community configuration patterns composed of trees and shrubs with large three-dimensional green volume, high coverage, and strong adaptability, along with natural herbaceous plants, were proposed, providing theoretical basis and technical support for the construction of protective green spaces in arid gravel desert areas.

Full Text

Study on Plant Community Allocation Modes for Protection Greenbelts in Arid Gravel Desert Regions

ZHOU Jing[1,2], YAN Cheng[1,3], GUO Ruizeng[1,2], YAN Ziyan[4]

[1]State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang,

China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]National Engineering Technology Research Center for Desert-Oasis Ecological Construction, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China
[4]College of Prataculture and Environmental Science, Xinjiang Agricultural University, Urumqi 830011, Xinjiang, China

Abstract

This study examined 27 plant community allocation modes in a protection greenbelt located in the alluvial fan gravel desert area of southern Urumqi. Using the analytic hierarchy process (AHP) combined with fuzzy comprehensive evaluation, we assessed and ranked the ecological effects of different plant community allocation modes. The results indicated that several configurations demonstrated strong ecological performance: *Pinus sylvestris* var. *mongolica*–*Atriplex cana*–*Chondrilla piptocoma* + *Seriphidium transiliense*, *Ulmus pumila*–*Hippophae rhamnoides*–*Chondrilla piptocoma* + *Clematis songorica*, *Ulmus laciniata*–*Hippophae rhamnoides*–*Chondrilla piptocoma* + *Acroptilon repens*, and *Elaeagnus angustifolia*–*Atriplex cana*–*Chondrilla piptocoma*. Based on the similarity of ecological effects among plant communities and landscape functional requirements, we conducted a diversified expansion analysis of optimal allocation modes. The proposed optimal configurations consist of tree-shrub communities with large tridimensional green biomass, high coverage, and strong adaptability, combined with natural herbaceous layers. This study provides a theoretical basis and technical support for protection greenbelt construction in arid gravel desert regions.

Keywords: plant community; ecological effect; optimized allocation mode; gravel desert region; Urumqi

Gravel desert represents one of the desertified soil types in arid regions, widely distributed across the margins of northwestern basins and the upper/middle sections of alluvial plains at mountain foothills, accounting for 6.14% of China' s total land area. Severe soil gravel desertification significantly constrains regional economic development and ecological construction. Cities in China' s arid zones are primarily located in piedmont plains, valleys, or basin margins, with extensive gravel deserts surrounding urban peripheries. As urban expansion continues, residents increasingly demand better environmental quality, making ecological construction in gravel desert areas urgent. Establishing a protection greenbelt ecological system to improve urban environmental conditions and maintain sustainable development of green space ecosystems is critically important.

Gravel desert soils are scarce and infertile, with limited adaptable tree species available. Unsystematic afforestation methods and overly simplistic allocation modes result in poor ecological effects of plant communities. Therefore, accelerating research on protection greenbelt allocation modes in gravel desert areas to maximize ecological benefits and identify optimal plant community configurations is imperative.

The primary functional requirement of protection greenbelts in gravel desert areas is to maximize plant community ecological effects. The rationality of plant community allocation critically influences the healthy and stable development of protection greenbelt ecosystems; more rational allocation yields superior ecological effects. Optimizing plant allocation can enhance structural stability of protection greenbelt plant communities and improve urban living environments. Current research on plant community allocation primarily focuses on urban green space patches, comparing and quantitatively analyzing differences in community structure characteristics, climate regulation capacity, and landscape aesthetics among different green space types to propose corresponding optimization modes. However, although previous studies have examined plant species adaptability and community diversity in gravel desert areas from single aspects, comprehensive ecological effect evaluations encompassing multiple dimensions of community structure, ecological function, and landscape remain limited.

The protection greenbelt in the southern Urumqi alluvial fan gravel desert area has formed relatively stable artificial-natural composite plant communities after a growth period. This study investigates different artificial-natural composite plant community allocation modes, conducts comprehensive quantitative evaluation and ranking of their ecological effects, performs diversified expansion analysis based on ecological effect similarity and landscape functional requirements, and proposes plant community optimization allocation modes with good ecological performance to provide theoretical basis and technical support for protection greenbelt construction in arid gravel desert regions.

1. Study Area Overview

The study area is located in the alluvial fan gravel desert region on the southern outskirts of Urumqi, with geographical coordinates of 87°28 –87°31 E, 43°32 – 43°37 N. The region has a temperate continental climate with an elevation of approximately 1200 m and annual precipitation of 150–200 mm. The soil type is gray-brown desert soil. Vegetation is sparse with coverage less than 5%, dominated by xerophytic sparse shrub desert vegetation. Main plant species include *Caragana roborovskyi*, *Atriplex cana*, *Anabasis salsa*, *Chondrilla piptocoma*, and *Seriphidium transiliense*, along with ephemeral and short-lived plants.

The protection greenbelt was established in 2003 through artificial greening, primarily using arbor species with some shrubs interplanted. Main species include *Pinus sylvestris* var. *mongolica*, *Ulmus pumila*, *Elaeagnus angustifolia*, *Malus pumila*, *Acer pictum* subsp. *mono*, *Amorpha fruticosa*, and *Syringa oblata*. Allocation modes include pure forests and mixed forests. After 15 years of growth, these woodlands have formed relatively stable artificial-natural composite plant communities. Planting configurations use fixed spacing of 3-4 m × 3-4 m. The irrigation method is unified drip irrigation conducted during April–October with a cycle of 10–15 days and an annual irrigation volume of 300 m^3 per 667 m^2.

2.1 Sample Plot Setup and Survey

The study area is located in a protection greenbelt within the alluvial fan gravel desert region, with generally consistent site conditions. In this area, 27 plant community allocation types with obvious forestation effects were selected (Table 1). In October 2018, typical plot methods were used for vegetation surveys of each plant community allocation type, with three replicate plots established for each type. Arbor sample plots measured 10 m × 10 m, shrub plots 5 m × 5 m, and herbaceous plots 1 m × 1 m. Following vegetation ecology survey methods, we recorded plant species, individual numbers, plant height, branch height, crown width, and coverage within each plot.

2.2 Evaluation Index System Construction and Weight Determination

Plant community evaluation is primarily influenced by natural, social, and economic factors. Following the principles of "systematic approach, scientific rigor, feasibility, and goal orientation," we selected 15 evaluation indicators through frequency analysis and expert consultation, constructing a comprehensive evaluation system for plant community ecological effects. Referencing the *Standard for Assessment of Urban Landscaping and Greening* (GB/T 50563-2010) and other relevant studies, we determined grading standards and value ranges for each indicator.

Weights were determined using the analytic hierarchy process. Each hierarchical indicator was pairwise compared using the 1–9 scaling method to establish judgment matrices. After normalization, weights were obtained by calculating maximum eigenvalues and eigenvectors, followed by consistency testing of hierarchical ranking. The weight results show that tridimensional green biomass (C_1) has the highest weight, as it reflects the original indicator of ecological benefits from green space ecosystems. Plant growth condition (C_2) ranks second, representing basic vegetation characteristics—better growth indicates stronger adaptability. Vegetation coverage (C_3) is the third important indicator, reflecting community structure rationality and overall quality. Other indicators have different weights, reflecting varying importance in comprehensive ecological effect evaluation.

2.3 Fuzzy Relationship Matrix of Evaluation Indicators and Grades

Fuzzy comprehensive evaluation was used to assess plant community ecological effects. The basic model is B = A × R, where B is the fuzzy comprehensive evaluation result vector, A is the evaluation index weight vector, and R is the membership degree matrix at each level. Qualitative indicators C_{16}–C_{19} used percentage statistics, while quantitative indicators used the descending semi-trapezoidal distribution function to obtain criterion layer membership matrices (Table 3). The comment set was assigned values αj = {5, 3, 1} (j = 1, 2, 3), and evaluation indices were calculated: Y = Σ(bj × αj)/Σbj, where Y is the evaluation index at each level, bj represents evaluation grades, and αj represents grade assignments. Final weighted averaging produced the comprehensive evaluation value for plant community ecological effects, where higher scores indicate better ecological performance. Table 3 shows that different sample plots have varying membership degrees to evaluation grades at the criterion layer, with greater membership to "good" corresponding to higher comprehensive scores.

3. Results

3.1 Comprehensive Evaluation of Plant Community Ecological Effects

Comprehensive evaluation of plant communities is important for improving green space quality and ecological effect performance. Based on evaluation factor weights and grading standards, we obtained comprehensive scores and rankings for 27 plant communities (Table 4). Different plant community allocation modes show varying ecological effects. Sample plots 1, 2, 3, and 4 had the largest membership degree to "good" in ecological effect evaluation, with comprehensive scores of 4.46, 4.39, 4.37, and 4.36, respectively, indicating these community allocation modes have significant advantages in green biomass and maintain high levels for other indicators. Sample plot 27 showed the largest membership degree to "poor" with a score of 2.51, performing poorly in tridimensional green biomass and vegetation coverage. Most species in these communities belong to suitable plants for oases in arid regions but have weak adaptability in gravel desert areas. The remaining 22 plant communities showed the largest membership degree to "fair," with structures including tree-shrub-herb, tree-herb, or shrub-herb types that can be targeted for optimization based on evaluation results.

3.2 Optimal Allocation Modes of Plant Communities

Based on evaluation rankings, the ecological effects of sample plot 1 (with the highest comprehensive score) were used as the optimization target. The top four communities all exceeded 4.35 points (4.46/5 × 100 = 87.89%), demonstrating good ecological effects and serving as optimal allocation modes for protection greenbelts in arid gravel desert regions (Table 5). In these optimal modes, community structure is tree-shrub-herb type. Species such as *Pinus sylvestris* var. *mongolica*, *Ulmus pumila*, *Ulmus laciniata*, *Elaeagnus angustifolia*, and *Hippophae rhamnoides* subsp. *turkestanica* are common greening species in arid desert regions that grow well locally and can be selected as preferred species. *Atriplex cana* is a typical constructive species in arid regions with strong drought and salt tolerance. The herbaceous layer consists entirely of natural vegetation that adapts well to local environmental conditions and different woodland spaces, forming an important component of community diversity.

4. Discussion

The six optimal plant community allocation modes proposed in this study are all tree-shrub-herb types. Multi-layer community structures follow niche theory, maximizing resource utilization of light and nutrients and effectively increasing green biomass and ecological effects. Multiple allocation modes increase species richness and heterogeneity. In the optimal modes, *Pinus sylvestris* var. *mongolica* exhibits strong drought and cold resistance with excellent windbreak and sand fixation effects, making it the best evergreen arbor for wind protection in arid regions. Communities dominated by *Ulmus* species (especially *Ulmus pumila* and *Ulmus laciniata*) are most numerous. Elms are light-loving with well-developed root systems, tolerant to drought and barren conditions. *Elaeagnus angustifolia* grows rapidly with strong stress resistance and high adaptability to gravel desert habitats, showing greater average crown width and plant height than other species, resulting in high vegetation coverage and large tridimensional green biomass. *Hippophae rhamnoides* subsp. *turkestanica* grows well, with pure plantations showing higher ecological effects than some tree-shrub communities. Its fruits provide high economic value while enhancing community aesthetics.

Evaluation results of species adaptability in Urumqi protection greenbelts show that *Ulmus pumila*, *Ulmus laciniata*, *Pinus sylvestris* var. *mongolica*, *Elaeagnus angustifolia*, and *Hippophae rhamnoides* are preferred greening plants for gravel desert protection greenbelts. The natural herbaceous layer under forests positively influences arbor seedling establishment and development, playing an active role in community succession and regeneration. Additionally, herbaceous layers increase soil organic matter and nutrient content, improving soil fertility. Local herbaceous plants such as *Chondrilla piptocoma*, *Acroptilon repens*, and *Seriphidium transiliense* have cold and barren tolerance characteristics with strong adaptability to gray-brown desert soil in gravel desert regions, reflecting the harsh habitat conditions of the study area.

Beyond the species in the proposed optimal modes, diversified expansion was conducted based on ecological effect similarity and landscape functional requirements. Using the *Pinus sylvestris* var. *mongolica*–*Atriplex cana*–*Chondrilla piptocoma* + *Seriphidium transiliense* community as the ecological optimization target, comprehensive utilization of light, heat, and water resources can also prevent pest and disease occurrence and spread. Protection greenbelts require not only good ecological effects but also aesthetic functions. At forest edges and along roadsides, ornamental tree-shrub communities should dominate, with flowering shrubs selected for configuration and tree-shrub ratios of 1:1–1:1.5.

Gravel desert environments are fragile with barren soils, requiring high plant adaptability. Native plants have strong adaptability and serve as important carriers for characteristic landscapes. Simulating regional native species community configurations can increase community stability and stress resistance. Among surveyed communities, highly-ranked configurations such as *Ulmus pumila*–*Sy-*

ringa oblata, *Ulmus pumila*–*Rosa rugosa* 'Purple Branch' , and *Ulmus pumila*–*Amygdalus triloba* are dominated by native species with good adaptability and distinctive regional landscape features, suitable for direct application at forest edges or roadsides.

During the 15-year growth period of artificially planted communities in protection greenbelts, some natural herbs (e.g., *Chondrilla piptocoma*, *Acroptilon repens*, *Seriphidium transiliense*) successfully invaded and established under artificial forests, developing into new strata, while others unsuitable for artificial forest environments disappeared, ultimately forming the current stable artificial-natural composite plant communities. Understory natural herbs serve as dominant factors for soil fertility restoration and are crucial for maintaining health of protection greenbelt plantations. Therefore, artificial herbaceous supplementation should be considered in ecological construction of other protection greenbelts with similar environmental conditions.

The proposed optimal plant community allocation modes all consist of trees and shrubs with large tridimensional green biomass, high coverage, and strong adaptability, combined with natural herbaceous layers. By fully utilizing native tree species and natural herbs and arranging community structures according to appropriate species ratios, maximum ecological effects of plant communities in gravel desert protection greenbelts can be achieved.

5. Conclusions

1) A comprehensive evaluation system for artificial-natural composite plant community ecological effects was established. Using fuzzy comprehensive evaluation, we identified that *Pinus sylvestris* var. *mongolica*–*Atriplex cana*–*Clematis songorica*, *Ulmus laciniata*-*Hippophae rhamnoides*–*Acroptilon repens*, and *Elaeagnus angustifolia*–*Atriplex cana*–*Chondrilla piptocoma* communities demonstrated good ecological performance, providing technical support for protection greenbelt construction in arid gravel desert regions.

2) Based on ecological effect similarity and the need to increase species richness, mixed arbor forests should be planted within forest belts. Species selection includes *Pinus sylvestris* var. *mongolica*, *Ulmus pumila*, *Ulmus laciniata*, *Ulmus laevis*, and *Elaeagnus angustifolia* at 3 m × 4 m spacing. Within protection greenbelt interiors, evergreen arbor *Pinus sylvestris* var. *mongolica* should serve as the dominant species mixed with elms in rows, with evergreen and deciduous individuals at a 1:3 ratio to increase species richness and enhance seasonal landscape variation. In mixed forests, species should be interplanted according to different ecological amplitudes to maximize resource utilization.

3) Based on landscape requirements at forest edges and roadsides, ornamental flowering shrubs should be selected, including *Hippophae rhamnoides* subsp. *turkestanica*, *Rosa rugosa* 'Purple Branch' , *Amygdalus triloba*,

and *Syringa oblata*, with tree-shrub ratios of 1:1–1:1.5. Existing plant community allocation modes with good ecological effects and distinctive regional landscape features, such as *Ulmus pumila*–*Syringa oblata* and *Ulmus pumila*–*Rosa rugosa* 'Purple Branch', can be directly applied.

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