Characteristics and Driving Factors of Amygdalus pedunculata Communities in Hunshandake Sandy Land (Postprint)

Authors: Jiawei Chen, Chu Jianmin, Gan Honghao, Xu Lei, Gong Shuai, Liu Hao, Wang Yingxin, Yang Hongxiao, Xu Xiaoqing, Qi Danhui

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Abstract

The stability of vegetation communities plays a critical role in community succession and regional ecosystem security. Affected by climate change and human activities, natural communities of Amygdalus pedunculata have severely degraded, with their area continuously decreasing and urgently requiring conservation. Based on data from 35 quadrats of Amygdalus pedunculata communities in the Otindag Sandy Land, this study reveals the driving factors of Amygdalus pedunculata community distribution and the relationships between different community characteristics and environmental factors through Canonical Correspondence Analysis (CCA). The study found that based on differences in site conditions, Amygdalus pedunculata communities can be divided into four types: Community I, Amygdalus pedunculata-Allium mongolicum; Community II, Amygdalus pedunculata-Stipa sareptana var. krylovii-Artemisia frigida; Community III, Amygdalus pedunculata-Eragrostis pilosa; Community IV, Ulmus pumila-Amygdalus pedunculata-Corispermum mongolicum. At a large scale, temperature and elevation are the main environmental factors affecting the distribution of Amygdalus pedunculata communities, with contribution rates of 13.2% and 11.4%, respectively. At a small scale, soil organic matter at 10-20 cm and 20-30 cm and elevation are key factors affecting community structural characteristics. The structural characteristics of Communities II and III are more sensitive to soil factors, while elevation is the main influencing factor for the structural characteristics of Communities I and IV. This study clarifies that temperature, soil, and elevation are the main environmental factors influencing Amygdalus pedunculata communities in the Otindag Sandy Land, while the cross-effects of soil and climate on communities require further research.

Full Text

Association Characteristics of *Amygdalus pedunculata* and Their Driving Factors in the Otindag Sandy Land

CHEN Jiawei[1], CHU Jianmin[1], GAN Honghao[1], XU Lei[2], GONG Shuai[1], LIU Hao[1], WANG Yingxin[3], YANG Hongxiao[4], XU Xiaoqing[1], QI Danhui[5]

[1]Key Laboratory of Tree Breeding and Cultivation, National Forestry and Grassland Administration, Research Institute of Forestry, Chinese Academy of Forestry, Beijing 100091, China
[2]Seed Field of Urumqi, Urumqi 830011, Xinjiang, China
[3]Institute of Ecological Conservation and Restoration, Chinese Academy of Forestry, Beijing 100091, China
[4]College of Resources and Environment, Qingdao Agricultural University, Qingdao 266109, Shandong, China
[5]College of Ecology and Environment, Southwest Forestry University, Kunming 650224, Yunnan, China

Abstract: The stability of plant associations plays a vital role in community succession and regional ecosystem security. Affected by climate change and human activities, the natural associations of *Amygdalus pedunculata* have degraded severely with continuously decreasing area, urgently requiring protection. Based on data from 35 quadrats of *A. pedunculata* in the Otindag Sandy Land, this study used Canonical Correspondence Analysis (CCA) to reveal the driving factors of *A. pedunculata* association distribution and the relationship between different association characteristics and environmental factors. The results showed that based on differences in site conditions, *A. pedunculata* associations can be divided into four types: *A. pedunculata-Artemisia frigida*; *A. pedunculata-Allium mongolicum*; *A. pedunculata-Stipa sareptana* var. *krylovii-Eragrostis pilosa*; and *Ulmus pumila-A. pedunculata-Corispermum mongolicum*. At the large scale, temperature and elevation were the main environmental factors affecting the distribution of *A. pedunculata* associations, with contribution rates of 13.2% and 11.4%, respectively. At the small scale, the structural characteristics of the associations were more sensitive to soil factors, with soil organic matter (10–20 cm) and elevation being the key factors affecting the structural characteristics of the associations. This study identified temperature, soil, and elevation as the main environmental factors influencing *A. pedunculata* associations in the Otindag Sandy Land, while the cross-effects of soil and climate on the associations require further investigation.

Keywords: *Amygdalus pedunculata*; desert ecosystem; association distribution; driving factors; soil organic matter

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Association structure can reflect plant composition, population status, and environmental resource allocation in a region, revealing important information about species-environment interactions and succession trends. The stability of vegetation within associations plays a key role in regional ecosystem stability and security, and is significant for understanding plant ecological adaptability and mechanisms for maintaining vegetation association stability. In meadow steppe, elevation and slope are the main factors affecting species composition, as elevation influences plant association structure by redistributing resources such as temperature, light, and water. In desert regions, climate factors (temperature and precipitation) and soil factors (total nitrogen and organic matter) determine association structure. For example, in arid desert steppe of the Balkan Peninsula, species richness is significantly positively correlated with monthly mean temperature. Additionally, shrubs within associations can affect association structure by influencing nearby climate, soil environment, and herbaceous structural characteristics.

For instance, desert research results show that shrubs create a warm environment for herbaceous seedlings during cold seasons. In desert regions with large diurnal temperature differences, shrubs can absorb heat and provide shade for plants during hot daytime conditions, while releasing heat at night. In South African semi-arid sparse grasslands, shrub presence reduces herbaceous plant richness but increases surface soil nutrient content. In the Horqin Sandy Land, vegetation within associations plays a key role in accumulating soil organic carbon and total nitrogen and maintaining soil fertility.

The Otindag Sandy Land is located in the transition zone from typical grassland regions of northern China to dry farming areas of North China, spanning semi-humid to semi-arid regions, where water limitations form sparse forest grassland, typical grassland, and desert grassland from east to west. In recent years, many scholars have studied the relationship between association structural characteristics and environmental factors in the Otindag Sandy Land. Liu et al. classified plant communities in inter-dune lowlands of this region and explored the relationship between plant distribution and soil environmental factors. Qi et al. examined the relationship between species diversity of different communities and environmental factors in the Otindag Sandy Land. Understanding plant species diversity and its relationship with soil environmental factors is important for studying plant community succession mechanisms and community restoration.

Current research still has some limitations. First, studies have focused on environmental interpretation of association structure, with less research on driving factors for the regional distribution of specific plant associations. Second, environmental interpretation of internal association characteristics has been neglected.

Amygdalus pedunculata is a deciduous shrub of the Rosaceae family, with well-developed root systems, strong drought tolerance, barren resistance, and cold resistance, showing strong adaptability and serving as an excellent species for windbreak and sand fixation. In China, *A. pedunculata* is mainly distributed in Shaanxi and Inner Mongolia, mostly growing on rocky sunny slopes, mountainous areas, and open valleys. As a native shrub in arid, semi-arid sandy lands, and desertified grasslands, it is important for windbreak and sand fixation in China' s arid and semi-arid regions. Due to climate change and human activities, the natural distribution range of *A. pedunculata* associations has continuously shrunk, and it is already endangered, requiring further protective research. Current research on *A. pedunculata* mainly focuses on drought and salt-alkali resistance, oil content, medicinal value, etc., with few reports on the structural characteristics of *A. pedunculata* associations and their environmental influencing factors.

Based on this, this study took *A. pedunculata* associations distributed in different regions of the Otindag Sandy Land as the object, combined with field survey and laboratory measurement data, and used statistical methods such as correlation analysis and Canonical Correspondence Analysis (CCA) to address the following scientific questions: (1) What are the main factors driving the distribution of *A. pedunculata* in the Otindag Sandy Land and differences in association structural characteristics? (2) What are the main factors affecting the structural characteristics of *A. pedunculata* associations in the Otindag Sandy Land? The research results will help understand community succession mechanisms and are significant for degraded land restoration in this region, providing basic data and theoretical support for biodiversity conservation in global arid zones and achieving global sustainable development goals.

1.1 Study Area Overview

The study area is located in the Otindag Sandy Land and its surrounding regions, including western Sonid Right Banner, northern and southern Sonid Left Banner, northeastern Zhengxiangbai Banner, and northwestern Zhenglan Banner. Geographically located at 42°33 ~44°51 N, 112°25 ~115°01 E, the region has a typical temperate continental semi-arid climate. The annual mean temperature is 3.0~5.5°C, annual precipitation is 200~350 mm, evaporation is 2000~2900 mm, average annual wind speed is 3.1~4.9 $\mathrm{m \cdot s^{-1}}$, and annual sunshine hours are 3200.0~3231.8 h. The sample plot in Sonid Right Banner is located in the Duhumu Amygdalus Nature Reserve, with soil mainly brown and chestnut soil, and vegetation dominated by *A. pedunculata* and *Stipa tianschanica* var. *klemenzii*. The sample plot in Sonid Left Banner has chestnut soil, with vegetation including *A. pedunculata*, *Stipa sareptana* var. *krylovii*, *Eragrostis pilosa*, and *Artemisia frigida*. The sample plots in Zhengxiangbai Banner and Zhenglan Banner have aeolian sandy soil, with vegetation mainly *Ulmus pumila*, *A. pedunculata*, and *Corispermum mongolicum*.

1.2 Experimental Sampling

The survey of *A. pedunculata* communities (Figure [Figure 1: see original paper]) was conducted in August 2021. In the study area, 35 quadrats were selected, with 10 m × 10 m shrub quadrats randomly established in each community. Within each shrub quadrat, 1 m × 1 m herb quadrats were established, and

100 m × 100 m tree quadrats were set up in communities with trees. A total of 35 shrub quadrats, 105 herb quadrats, and 2 tree quadrats were established. The naming rule for associations is composed of the constructive species of the community and the characteristic (or dominant) species names of other layers plus qualifiers. In each quadrat, all trees were measured, recording species, number, diameter at breast height, and height. In shrub quadrats, shrub name, crown width, height (estimated using standard plants), coverage, number of clusters, and total quadrat coverage were recorded. In herb quadrats, herb species name, height, species coverage, number of individuals, and total quadrat coverage were recorded. Within each shrub quadrat, three soil sampling points were set along the diagonal, and soil samples were collected at 0–10 cm, 10–20 cm, and 20–30 cm layers using a soil auger with 5 cm diameter, mixed and placed in sealed bags for laboratory analysis.

1.3 Soil Sample Analysis and Determination

Soil pH was measured using a 1:2.5 soil-water ratio extraction method, organic matter (OM) content was determined by the potassium dichromate external heating method, total nitrogen (TN) was measured by the Kjeldahl method, and total carbon (TC) was measured using an elemental analyzer (Vario Macro).

1.4 Meteorological Data

Temperature, precipitation, and wind speed data were obtained from the "China Meteorological Forcing Dataset (CMFD)" to calculate growing season precipitation, growing season mean temperature, and growing season mean wind speed for each quadrat.

1.5 Statistical Analysis

Important Value (IV) was used as the dominance index of plants within the association. Species important value = (relative frequency + relative coverage + relative height)/3. One-way ANOVA was used to analyze differences in association characteristics among different associations. Canonical Correspondence Analysis (CCA) was used for ordination of quadrats and environmental variables. Pearson correlation analysis was used to determine relationships between different environmental and association structural characteristics. Significance level was set at $P < 0.05$. ANOVA, Pearson correlation analysis, CCA ordination, and correlation heatmaps were performed using SPSS 26.0, Canoco 5.0, and Origin 2021 software.

2 Results and Analysis

2.1 Types and Characteristics of *A. pedunculata* Associations in Different Habitats of Otindag Sandy Land

Based on the ecogeographical characteristics of plant communities, *A. pedunculata* associations were divided into four types (Table): Association I, *A. pedunculata-Artemisia frigida*; Association II, *A. pedunculata-Allium mongolicum*; Association III, *A. pedunculata-Stipa sareptana* var. *krylovii-Eragrostis pilosa*; and Association IV, *Ulmus pumila-A. pedunculata-Corispermum mongolicum*. The dominant tree species *Ulmus pumila* appeared in Association IV, the dominant shrub species was *A. pedunculata* with important values of 0.34–0.70, and the herb layer was dominated by Poaceae plants with important values of 0.37–1.25 (Table). There were significant differences in shrub height, crown width characteristics, and herb layer structure among the four associations ($P < 0.05$, Table).

2.2 Relationship Between *A. pedunculata* Association Distribution and Environmental Factors

The first two ordination axes contained more than half (32.14% and 25.84%) of the information, so the first two axes were selected for analysis. CCA ordination showed that the first axis was mainly affected by annual precipitation, annual mean temperature, and soil total carbon (Figure [Figure 2: see original paper]). The second axis was mainly influenced by growing season temperature and 0–10 cm soil organic matter. Overall, temperature and elevation were the most important environmental factors affecting the distribution of *A. pedunculata* associations in the Otindag Sandy Land (Table), with contribution rates of 13.2% and 11.4%, respectively. Soil organic matter content (10–20 cm) and 20–30 cm soil total carbon content followed, with contribution rates of 10.7% and 10.6%, respectively.

2.3 Relationship Between Association Characteristics and Environmental Factors

Shrub abundance was more sensitive to environmental factor responses (Figure [Figure 3: see original paper]). For example, 10–20 cm soil organic matter content was extremely significantly positively correlated with shrub abundance ($P < 0.01$). Herb coverage was mainly affected by elevation ($P < 0.01$) and precipitation ($P < 0.01$). Herb height was more sensitive to environmental factor responses, being extremely significantly negatively correlated with 20–30 cm soil total nitrogen ($P < 0.01$). In Association III, growing season precipitation was extremely significantly correlated with shrub height, shrub abundance, herb coverage, and herb abundance ($P < 0.01$). Herb richness, herb coverage, and 10–20 cm soil organic matter content were extremely significantly correlated with association structure ($P < 0.01$).

3 Discussion

This study incorporated soil factors as important indicators into community classification, which is beneficial for the protection and functional management of *A. pedunculata* in the Otindag Sandy Land. Current classification systems focus more on vegetation and climate, making it difficult to reflect the real habitat conditions of plants. For example, the TWINSPAN classification method based on community indicator species is widely used in ecology, but studies suggest that TWINSPAN' s random classification may separate quadrats with very similar species composition. Research suggests that when one species has a dominance far greater than other species within a community, TWINSPAN cannot identify secondary gradients or other types of structure in the dataset. TWINSPAN classification uses the distance between quadrats combined with vegetation important values as classification basis, but similarly cannot accurately reflect quadrat habitats in practice. Soil, as the material basis for plant growth, directly affects aboveground vegetation growth and development, while vegetation also affects soil physicochemical properties, making them an integrated organic whole. Additionally, soil changes represent different vegetation types, and using soil factors as community classification indicators can eliminate randomness and extremeness in classification systems.

In this study, the four associations had similar plant composition. With increasing important values of *A. pedunculata*, the important values of Poaceae plants showed a decreasing trend, while those of Fabaceae plants showed an increasing trend, consistent with the research results of Ding et al. on *Caragana microphylla* shrub communities. The reason may be that in desert grassland regions, soil is mainly chestnut and brown soil, suitable for Poaceae plants such as *Stipa*, while low shrubs can block livestock grazing, thereby providing protection for Poaceae plant seeds. Additionally, shrubs can increase nighttime temperature through shading and improve soil fertility and moisture through the fertile island effect, thereby increasing herbaceous plant diversity and vegetation coverage. Environmental differences can also lead to opposite results. For example, in areas with sandy soil, Poaceae plants and perennial weeds within quadrats significantly decrease because sand coverage destroys plant ground buds, preventing Poaceae plants such as *Stipa* from developing on a large scale. Overall, soil type reflects differences in soil physicochemical properties. In the Sonid desert region, affected by climate, perennial drought and low rainfall cause soluble salts to accumulate in the surface layer through capillary action, increasing soil salt content and soil pH, weakening plant root water absorption capacity, and resulting in dwarf plants. In this study, sample plots in Zhengxiangbai Banner and Zhenglan Banner had increased soil moisture content, accelerated litter decomposition speed, promoted soil organic matter accumulation, expanded root systems, improved soil texture, reduced soil bulk density, increased porosity, enhanced soil water conservation capacity, and resulted in better vegetation growth, where sparse *Ulmus pumila* forest landscapes began to appear.

Driving factors of vegetation distribution vary with spatial scale, with climate conditions such as temperature and precipitation being the dominant factors of vegetation distribution at large scales, while soil factors regulate small-scale vegetation community structure. In this study, elevation, temperature, and precipitation were the main factors affecting *A. pedunculata* association distribution. Previous studies have found that temperature and precipitation are the main influencing factors of desert vegetation and sandy vegetation in arid and semi-arid regions, while elevation affects association distribution by influencing precipitation and temperature. At small scales, organic matter and total nitrogen are the main factors affecting association structural characteristics, which is basically consistent with this study' s results. Soil organic matter can reflect soil fertility status and indicate the availability of elements such as potassium and phosphorus. Generally, higher soil organic matter content indicates higher soil fertility and higher plant species diversity. In desert regions, perennial drought affects soil microbial activity, inhibiting surface litter decay and decomposition, resulting in low organic matter content and dwarf plants. The environmental factors selected in this study explained 44.6% of association species composition and distribution, which is higher than some similar studies but still leaves 55.4% unexplained. The possible reason is that differences in soil nutrients lead to different plant composition within associations, while vegetation changes cause differences in soil water-fertility conditions and plant species within the system, and grassland ecosystems are systems coupled by multiple factors. Therefore, future research needs to further explore the effects of human factors such as land use patterns and grazing on *A. pedunculata* association characteristics.

4 Conclusion

The *A. pedunculata* associations in the Otindag Sandy Land can be divided into four types: *A. pedunculata-Artemisia frigida* (Association I), *A. pedunculata-Allium mongolicum* (Association II), *A. pedunculata-Stipa sareptana* var. *krylovii-Eragrostis pilosa* (Association III), and *Ulmus pumila-A. pedunculata-Corispermum mongolicum* (Association IV). At large scales, temperature and elevation are the main environmental factors affecting *A. pedunculata* association distribution, with contribution rates of 13.2% and 11.4%, respectively. Soil organic matter (10–20 cm and 20–30 cm) and elevation are the key factors affecting the structural characteristics of the associations. Association III structural characteristics are more sensitive to soil factors, while elevation is the main factor affecting Association IV structural characteristics. This study identified temperature, soil, and elevation as the main environmental factors influencing *A. pedunculata* associations in the Otindag Sandy Land, while the cross-effects of soil and climate on the associations require further investigation.

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References

[1] Shugart H H, Saatchi S, Hall F G. Importance of structure and its measurement in quantifying function of forest ecosystems[J]. Journal of Geophysical Research: Biogeosciences, 2010, 115(G2): G00E13.

[2] Bardgett R D, Bullock J M, Lavorel S, et al. Combatting global grassland degradation[J]. Nature Reviews Earth & Environment, 2021, 2(10): 720-735.

[3] Souza L, Weltzin J F, Sanders N J. Differential effects of two dominant plant species on community structure and invasibility in an field ecosystem[J]. Journal of Plant Ecology, 2011, 4(3): 123-131.

[4] Marini L, Scotton M, Klimek S, et al. Effects of local factors on plant species richness and composition of Alpine meadows[J]. Agriculture, Ecosystems & Environment, 2007, 119(3/4): 281-288.

[5] Song Yongchang. Vegetation Ecology[M]. Shanghai: East China Normal University Press, 2001.

[6] Tuomisto H, Zuquim G, Cárdenas G. Species richness and diversity along edaphic and climatic gradients in Amazonia[J]. Ecography, 2014, 37(11): 1034-1046.

[7] Liu Haijiang, Guo Ke. Relationship between plant community and soil environment on the Inter dune lowland in the middle of Otingdag Sand Land[J]. Chinese Journal of Plant Ecology, 2007, 31(1): 40-49.

[8] Qi Danhui, Yang Hongxiao, Lu Qi, et al. Biodiversity of plant communities and its environmental interpretation in the Otindag Sandy Land, China[J]. Journal of Desert Research, 2021, 41(6): 65-77.

[9] Palpurina S, Chytr M, Tzonev R, et al. Patterns of fine scale plant species richness in dry grasslands across the eastern Balkan Peninsula[J]. Acta Oecologica, 2015, 63(29): 36-46.

[10] Sturm M, Racine C, Tape K. Increasing shrub abundance in the Arctic[J]. Nature, 2001, 411(6837): 546-547.

[11] He Y F, D' Odorico P, De Wekker S F J. The role of vegetation-microclimate feedback in promoting shrub encroachment in the northern Chihuahuan desert[J]. Global Change Biology, 2015, 21(6): 2141-2154.

[12] Eldridge D J, Bowker M A, Maestre F T, et al. Impacts of shrub encroachment on ecosystem structure and functioning: Towards a global synthesis[J]. Ecology Letters, 2011, 14(7): 709-722.

[13] Mogashoa R, Dlamini P, Gxasheka M. Grass species richness decreases along a woody plant encroachment gradient in a semi savanna grassland, South Africa[J]. Landscape Ecology, 2021, 36(2): 617-636.

[14] Su Y Z, Zhao H L, Li Y L, et al. Influencing mechanisms of several shrubs on soil chemical properties in semiarid Horqin Sandy Land, China[J]. Arid Land Research and Management, 2004, 18(3): 251-263.

[15] Li Qingfeng, Hu Chunyuan, Wang Mingjiu. Analysis on the causes of eco-environmental deterioration in Hunshandake Sandy Land region and countermeasures[J]. Journal of Arid Land Resources and Environment, 2001, 15(3): 9-16.

[16] Wang Guohong, Fang Jingyun, Guo Ke, et al. Contents and protocols for the classification and description of vegetation formations, alliances and associations of vegetation of China[J]. Chinese Journal of Plant Ecology, 2020, 44(2): 128-178.

[17] Guo Ke, Fang Jingyun, Wang Guohong, et al. Revised scheme of vegetation classification system of China[J]. Chinese Journal of Plant Ecology, 2020, 44(2): 111-127.

[18] Chu J M, Xu X Q, Zhang Y L. Production and properties of biodiesel produced from *Amygdalus pedunculata* Pall.[J]. Bioresource Technology, 2013, 134(21): 374-376.

[19] Yan Han, Ma Songmei, Wei Bo, et al. Historical distribution patterns of relict shrub *Amygdalus pedunculata* and environmental drivers[J]. Chinese Journal of Plant Ecology, 2022, 46(7): 766-774.

[20] Chu Jianmin, Li Yifu, Zhang Lei, et al. Potential distribution range and conservation strategies for the endangered species *Amygdalus pedunculata*[J]. Biodiversity Science, 2017, 25(8): 799-806.

[21] Li Cong, Li Guoping, Chen Qiao, et al. Fatty acid composition analysis of the seed oil of *Amygdalus pedunculatus* Pall.[J]. China Oils and Fats, 2010, 35(4): 77-79.

[22] Lv Lisha, Cai Hongyu, Yang Yong, et al. Geographic patterns and environmental determinants of gymnosperm species diversity in China[J]. Biodiversity Science, 2018, 26(11): 1133-1146.

[23] Ding Wei, Wang Yubing, Xiang Guanhai, et al. Effects of *Caragana microphylla* encroachment on community structure and ecosystem function of a typical steppe[J]. Chinese Journal of Plant Ecology, 2020, 44(1): 33-43.

[24] Maestre F T, Bowker M A, Puche M D, et al. Shrub encroachment can reverse desertification in semi arid Mediterranean grasslands[J]. Ecology letters, 2009, 12(9): 930-941.

[25] Thompson J A, Zinnert J C, Young D R. Immediate effects of microclimate modification enhance native shrub encroachment[J]. Ecosphere, 2017, 8(2): e1687.

[26] Zhang Peng, Li Ying, Wang Yelin, et al. The positive effect of *Caragana breviflora* shrubs on plant communities and soil microbial communities in the Inner Mongolia desert region[J]. Arid Zone Research, 2021, 38(2): 421-428.

[27] Liu Yongmei, Dong Xingzhi, Long Yongqing, et al. Classification of *Stellera chamaejasme* communities and their relationships with environmental factors in

degraded alpine meadow in the central Qilian Mountains, Qinghai Province[J]. Acta Prataculturae Sinica, 2022, 31(4): 1-11.

[28] Qi Zhengchao, Chang Peijing, Li Yongshan, et al. Effects of grazing intensity on soil aggregates composition, stability, nutrients and C/N in desert shrubland[J]. Arid Zone Research, 2021, 38(1): 87-94.

[29] Lu Rukun. Analytical Methods of Soil Agricultural Chemistry[M]. Beijing: China Agricultural Science Press, 2000.

[30] Zhang Jintun. Numerical Ecology[M]. Beijing: Science Press, 2004.

[31] Belbin L, McDonald C. Comparing three classification strategies for use in ecology[J]. Journal of Vegetation Science, 1993, 4(3): 293-298.

[32] Dufrêne M, Legendre P. Species assemblages and indicator species: The need for a flexible asymmetrical approach[J]. Ecological Monographs, 1997, 67(3): 345-366.

[33] Yu Mengfan. Comparative Study on Numerical Classification of Plant Association: A Case Study in Liaoning Qinglong River Natural Reserve[D]. Beijing: Beijing Forestry University, 2014.

[34] Wang Jun, Liu Maosong, Sheng Sheng, et al. Spatial distributions of soil water salts and roots in an arid arbor herb community[J]. Acta Ecologica Sinica, 2008, 28(9): 4120-4127.

[35] Zuo X A, Zhao X Y, Zhao H L, et al. Scale dependent effects of environmental factors on vegetation pattern and composition in Horqin Sandy Land, Northern China[J]. Geoderma, 2012, 173(45): 1-9.

[36] Gaston K J. Global patterns in biodiversity[J]. Nature, 2000, 405(6783): 220-227.

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