Chin. Geogra. Sci. 2012 Vol. 22 No. 3 pp. 288–301
doi: 10.1007/s11769-012-0536-y
www.springerlink.com/content/1002-0063

Vegetation-environment Relationships Between Northern Slope of Karlik Mountain and Naomaohu Basin, East Tianshan Mountains

ZHANG Haiyan[1], QIAN Yibing[1], WU Zhaoning[2], WANG Zhongchen[3]

(*1. Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China; 2. College of Geology and Exploration Engineering, Xinjiang University, Urumqi 830046, China; 3. Environmental Development Center of Ministry of Environmental Protection, Beijing 100029, China*)

Abstract: Based on data from 22 sample plots and applying the Canonical Correspondence Analysis (CCA), this paper discusses the vegetation-environment relationships between the northern slope of Karlik Mountain and Naomaohu Basin, which is situated in the easternmost end of the Tianshan Mountains, Xinjiang Uygur Autonomous Region, China. For the zonal vegetation, community diversity of mountain vegetation is higher than that of the desert vegetation due to environmental factors. The CCA ordination diagram revealed that the composition and distribution of vegetation types are mainly determined by altitude, soil pH and soil salt content. With increasing elevation, the soil pH and total salt content decrease but the contents of soil organic matter, soil water, total nitrogen and total phosphorus increase gradually. In the CCA ordination diagrams, the sample plots and main species can be divided into five types according to their adaptations to the environmental factors. Type Ⅰ is composed of desert vegetation distributed on the low mountains, hills, plains and deserts below an elevation of 1900 m; type Ⅱ is distributed in the mountain and desert ecotone with an elevation of 1900–2300 m, and includes steppe desert, desert steppe and wetland meadow; type Ⅲ is very simply composed of only salinized meadow; type Ⅳ is distributed above an elevation of 2300 m, containing mountain steppe, meadow steppe, subalpine meadow and alpine meadow; type V only contains salinized meadow. The results show that with increasing elevation, species combination changes from the xerophytic shrubs, semi-shrubs and herbs distributed in the low altitude zone with arid climate to the cold-tolerant perennial herbs growing in the high altitudinal zone with cold climate.

Keywords: vegetation pattern; environmental factors; canonical correspondence analysis (CCA); vegetation-environment relationships; Tianshan Mountains; Xinjiang

Citation: Zhang Haiyan, Qian Yibing, Wu Zhaoning, Wang Zhongchen, 2012. Vegetation-environment relationships between northern slope of Karlik Mountain and Naomaohu Basin, East Tianshan Mountains. *Chinese Geographical Science*, 22(3): 288–301. doi: 10.1007/s11769-012-0536-y

1 Introduction

Plant communities are the results of interactions between vegetation and environment (Zhang *et al*., 2004). Generally, vegetation distribution patterns are mainly controlled by environmental factors such as climate, topography and soils at a regional scale (Meelis *et al*., 2004; Van de Ven *et al*., 2007). However, vegetation patterns can influence variations in both soil water content and soil nutrients (Liu *et al*., 2003). The analysis of vegetation-environment relationships has been a central issue in geobotany, with researchers attempting to determine the factors that control the distribution and variation of vegetation composition for over a century (Michel *et al*., 2011; Miller and Hanham, 2011).

Vegetation patterns in arid regions are affected by environmental factors more intensively than that in humid areas (Fossati *et al*., 1999). So it would be more meaningful to explore the relationships between environmental factors and vegetation distribution in arid regions. Many studies on vegetation-environment relationships have been conducted in arid and semi-arid regions in

Received date: 2011-09-26; accepted date: 2012-02-27
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 41171157)
Corresponding author: QIAN Yibing. E-mail: dt6@ms.xjb.ac.cn

North America, Australia, and other desert regions, such as Egypt, India and Iran (Zuo *et al*., 2008).

Mountain ecosystems are very complicated with particular structures and functions, and have abundant biodiversity resources, water resources and tour resources, and possess high ecological significance (Stirling and Wilsey, 2001). Studying the relationships between vegetation and environment could inform environmental protection in mountain regions, and could provide important theoretical and practical information for research into the response of vegetation distribution to climate change in the context of global changes (Fang *et al*., 2004; Shaheen *et al*., 2011). Deserts contain fragile ecosystems, which are extremely vulnerable to human disruptions. Due to the long-term effects of human activities, the environmental problems caused by desertification, such as decreasing the area of land available for agriculture and increasing mobile dunes have led to declining land productivity. In recent years, desertification has become the main problem that desert ecosystems have to face (He *et al*., 2007; Zuo *et al*., 2009). Researching the vegetation-environment relationships and determining the main environmental factors that influence the vegetation distribution patterns could provide a theoretical basis to control desertification and better manage the desert ecosystem in arid regions (He *et al*., 2007).

Vegetation distribution is the result of many ecological processes related to the topography, climate, community productivity, soil physical and chemical properties, and other environmental factors (Enright *et al*., 2005). For the mountain areas, elevation, slope aspect and slope degree are the three main topographic factors that affect the vegetation distribution patterns indirectly (Huang, 2002). Among these three factors, elevation is very important because an altitudinal gradient contains varying climatic factors such as temperature, precipitation, humidity and sunlight, and the change of these factors with increasing altitude is 1000 times as fast as that of the latitudinal gradient (Tang and Fang, 2004). Elevation in many respects determines the microclimate and the microclimate affects the spatial patterns of vegetation (Johnson, 1981; Allen and Peet, 1990; Sang, 2009). Zhu *et al*. (2009) studied the vegetation-environment gradient correlation in the Qinling Mountains based on GIS, and the results showed that altitude gradient is the dominant ecological gradient to determine the mountain vegetation distribution. With the increase in elevation the multiple gradients of water and heat are formed, influencing corresponding transformations in the types of vegetation.

As arid zones are usually characterized by minimal precipitation and frequent droughts, availability of water is one of the primary factors controlling the vegetation distribution patterns (Mabbutt, 1977). However, the most critical gradients in abiotic factors may be related to water availability (including annual precipitation, elevation, soil properties and topography) (Parker, 1991). Soil is the outcome of climate, biology and terrain, and plays an important part in the development and distribution of plants (Yair and Danin, 1980). Research into the correlation of soils and vegetation become more and more important for investigations of vegetation distribution (El-Ghani and Amer, 2003). In previous studies, soil has been reported to affect vegetation composition through levels of salinity (Abbadi and El-Sheikh, 2002; Xu *et al*., 2006), soil pH and calcium carbonate (Parker, 1988; El-Ghani, 1998; Ozkan *et al*., 2009), organic matter and total nitrogen (He *et al*., 2010). In different regions, soil can influence the vegetation distribution by different properties and to different degrees.

When influenced by continental climate, vegetation in arid zones is relatively homogeneous at a large spatial scale but heterogeneous at a small spatial scale, and therefore, previous works concerning environment-vegetation relationships in arid zone were usually conducted at a small spatial scale (Rietkerk *et al*., 2002). Furthermore, most of these studies mainly concentrate on a single region, such as a mountain, desert, forest and steppe (Enright *et al*., 2005; Bisigato *et al*., 2009). However, vegetation distribution varies greatly along environmental gradients. The geographic site and altitude affect plant species composition; their effects on vegetation patterns can be demonstrated from South to North Poles and from sea level to mountain top (Gaston, 2000). So it is important and meaningful to study the relationships between vegetation and environment in large-scale mountain-oasis-desert ecosystems (Xu *et al*., 2006; Sang, 2009).

The region between the northern slope of Karlik Mountain and Naomaohu Basin is located in the easternmost part of the Tianshan Mountains, and lies on both the massif of the Junggar Basin and the geological fold-uplift belt of the Tianshan Mountains, Xinjiang Uygur Autonomous Region, China. Its plant geography belongs to the Central Asian Desert Sub-kingdom, as revised by Xinjiang Review Term of Chinese Academy of Sciences and the Botany Institution of Chinese

Academy of Sciences (1978). The arid landscape in this region formed by unique mountain-oasis-desert landscape complex, is quite different from other parts of the world. In recent years, land and vegetation degradation at different levels have appeared in this region due to extensive disruptions by humans activities. Many researches on relationships between vegetation patterns and environmental factors have been carried out on the mid-section and on the west of the Tianshan Mountains (Lou, 1998; Lou and Zhou, 2001; Li *et al*., 2007; Li *et al*., 2008; Sang, 2009; Xu *et al*., 2011), but seldom on the East Tianshan Mountains with drier climates and fragile environments. In the previous studies, we have researched the species diversity, plant flora, soil grain size, and soil physical and chemical properties between the northern slope of Karlik Mountain and Naomaohu Basin (Zhang *et al*., 2009; Wang *et al*., 2010; Zhang *et al*., 2010; Qian *et al*., 2011; Wang *et al*., 2011). The study of vegetation-environment relationships in this region is further, integrated research building on our previous studies, and it can also provide abundant information to further study in the Tianshan Mountains.

Multi-statistical analysis methods occupy an important position in ecological research (Miller and Hanham, 2011). Among them, the ordination technique is a good method for both studying the ecological relationships between plant communities, and for analyzing the mutual relationships of plant species, plant communities and environmental factors (Van de Ven *et al*., 2007). Canonical correspondence analysis (CCA) has been widely used in research into vegetation-environment relationships for a long time (Braak, 1991; Van de Ven *et al*., 2007). In this paper, we analyze the relationships between vegetation distribution and environmental factors in the region between the northern slope of Karlik Mountain and Naomaohu Basin using CCA, and discuss the vegetation distribution from quantitative aspects in order to provide a scientific basis for species conservation and ecological rehabilitation.

2 Study Area and Methods

2.1 Study area

The region between the northern slope of Karlik Mountain and Naomaohu Basin is located in the border area between Xinjiang Uygur Autonomous Region and Mongolia, including the northern slope of Karlik Mountain, Qianshan pediment zone, Yanchi Basin, Tuhulu Basin, Yiwu River Valley, Weizixia Mountain Valley and Naomaohu Basin, with the geographical coordinates of 43°07′26″–43°48′41″N and 93°57′34″–95°02′38″E (Fig. 1). The Karlik Mountain is situated at the easternmost end of the Tianshan Mountains. The elevation of Karlik Mountain is relatively low and the piedmonts in the south, north and east of the mountain join the surrounding gobi and sand deserts. One hundred and twenty two glaciers are located in the Karlik Mountain, of which 49 glaciers are situated on the northern slopes, in the Dabaiyanggou, Ketuoguolegou and Turgangou gullies. In the mid 1980, these 49 glaciers covered a total area of 49.29 km^2 and had an ice volume of 2.63 km^3 (Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1986). The melt-water and alpine precipitation are the main sources of surface water and groundwater recharge in this region. The middle region of the study area is a mountain basin influenced by both the massif of the Junggar Basin and the geological fold-uplift belt of the Tianshan Mountains. The Naomaohu Basin lies between the Tianshan Mountains and Altay Mountains with elevation increasing from the south to the north.

The climate in the study area varies greatly from the mountain land to the basin. The average annual temperature ranges from –6℃ to 11℃, the maximal temperature is higher than 40℃, and the minimal temperature is lower than –40℃. The annual accumulated temperature of ≥ 0℃ (i.e. $\sum \geq 0$℃) is 1800℃–4600℃ and the annual total sunshine time is 2500–3300 hours. The annual precipitation is low and unevenly distributed, with 74% of rainfall occurring in May to August, with a decreasing trend from the southwest to northeast. The annual precipitation is over 300 mm in the southern mountains and about 100 mm in the middle basin. In the Naomaohu Basin, the annual precipitation is only 19 mm. The average annual evaporation ranges from 2000 mm to 4400 mm, and the non-frost period is less than 175 d. The soil types in this region include grey-brown desert soil, chestnut soil, meadow soil, subalpine meadow soil and solonchak.

2.2 Methods

Based on the habitat conditions and types of vegetation, representative sampling plots were chosen as investigation and sampling quadrats (Yue *et al*., 1999). In this

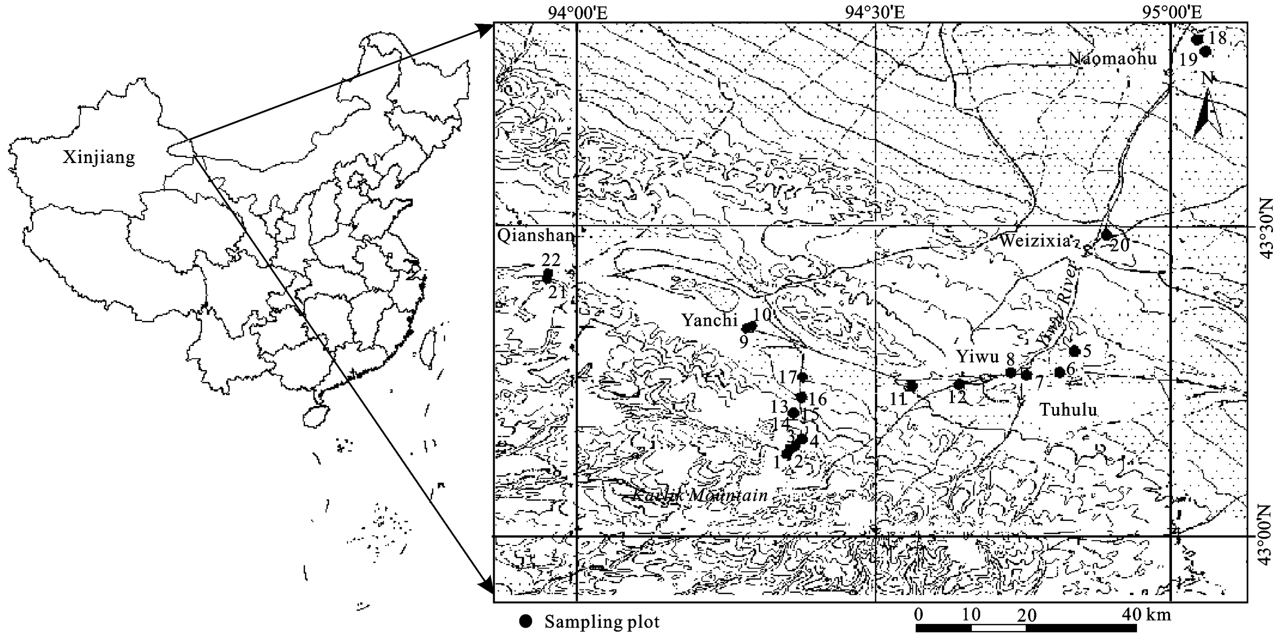

Fig. 1 Geomorphological types and sampling plots in study area

study, 22 sampling plots were set up to systemically measure the characteristic parameters of plants, and these sample plots were located with GPS to obtain the altitudes (Fig. 1). In these sampling plots, the quadrats of 5 m × 5 m were chosen for shrub species. On a diagonal, and nested with each shrub quadrat, three quadrats of 1 m × 1 m, were arranged for herbaceous species. At each sampling plot, we recorded the species category and presence, plant height, vegetation cover and habitat factors (altitude, slope direction, geomorphology and soil type). In each quadrat, the cover of herbaceous species was measured by using the ocular-estimate method (Ren, 1998), and the cover of shrub species (%) (Zhang *et al.*, 2002) was calculated as follows.

Cover of shrub species = [(east-west crown diameter × south-north crown diameter) / quadrat area] × 100% (1)

In each sampling plot, 2–4 soil samples were taken at 0–60 cm sampling depth according to the natural development of soil profiles, but soil samples were not taken in plot 1 and plot 14 because of high gravel contents. Soil organic matter, total nitrogen, total phosphorus, total potassium, total salts, and pH value were measured by using routine methods (Nanjing Institute of Petrology, 1978). Soil water content was calculated by using the method of weighing soil samples in aluminium sampling boxes before and after drying. Soil particle size distribution was analyzed with Malvern Laser Analyzer (Malvern Mastersizer 2000, UK), and the parameters were computed based on the formula of Folk and Ward (1957).

Vegetation distribution patterns can be analyzed by spatial variation of species diversity indices. The results of previous researches indicated that Simpson dominance index (C) and Shannon-Wiener diversity index (H) have a preferable representation in describing species diversity between plant communities in this region (Zhang *et al.*, 2009; Qian *et al.*, 2011). Specific calculation formulas of species diversity indices are as follows (Ma *et al.*, 1995; Zhang *et al.*, 2002).

Species importance value of a shrub = (relative height + relative cover + relative density) / 3 (2)

Species importance value of a herb = (relative height + relative cover) / 2 (3)

$$C = \sum N_i^2 \Big/ N^2 \quad (4)$$

$$H = -\sum P_i \ln P_i \quad (5)$$

where C is Simpson dominance index; N_i is the importance value of species i in each sampling plot; N is the sum of importance values in each sampling plot; H is Shannon-Wiener diversity index; and P_i is the relative importance value of species i in each sampling plot.

Hao and Guo (2003) found that the species importance values and the environmental data after standardizing analysis are suitable to measure the indices for

CCA. Therefore, in this study we chose the species importance values and environmental data as the data sources for CCA. The computer software CANOCO4.5 was used for all ordinations and the figures of CCA were drawn by CANODRAW4.0 to obtain the ordination diagrams of the plots-environments and species-environments.

3 Results

3.1 Spatial distribution characteristics of vegetation

According to the field investigation, 33 families, 93 genera and 133 species were observed in the study area. Of these species, Gymnospermae includes 2 species in 2 genera of 2 families, and Angiospermae includes 129 species in 91 genera of 31 families. The plant species in this region are mainly from 11 families, including Compositae, Gramineae, Chenopodiaceae, Leguminosae, Cyperaceae, *etc*. In terms of the quantity of species in a genus in the study area, there are only 7 genera that include more than 3 species, and they are *Carex*, *Potentilla*, *Zygophyllum*, *Saussurea*, *Artemisia*, *Stipa* and *Ephedra*. Characteristics of vegetation types and soils in the study area are shown in Table 1, and the main plant species in different sampling plots could be found in Table 2. All the serial numbers of species in the subsequent figures are consistent with Table 2.

Table 1 Characteristics of vegetation types and soils in study area

Vegetation type	No. of sampling plot	Geographical coordinate	Altitude (m)	Community type	Plant cover (%)	Soil type
Alpine meadow	1	43°07′26″N 94°21′10″E	3524.8	*Waldheimia glabra*, *Lagopsis eriostachys*, *Silene karaczukuri*	12	Alpine meadow soil
	2	43°07′44″N 94°21′27″E	3405.8	*Carex melanocephala*, *Polygonum viviparum*	99	Alpine meadow soil
	3	43°08′15″N 94°21′57″E	3357.3	*Halerpestes sarmetosa*, *Poa attenuata* subsp. *botryoides*	40	Alpine meadow soil
	4	43°08′49″N 94°22′36″E	3245.5	*Carex karoi*, *Polygonum viviparum*	92	Alpine meadow soil
Subalpine meadow	13	43°11′27″N 94°21′51″E	2836.0	*Androsace dasyphylla*, *Inula aspera*	72	Subalpine meadow soil
	14	43°11′28″N 94°21′51″E	2841.5	*Carex liparocarpos*, *Inula aspera*	72	Subalpine meadow soil
	15	43°11′28″N 94°21′59″E	2824.0	*Poa attenuata* subsp. *botryoides*, *Aconitum rotundifolium*, *Stellaria uda*	90	Subalpine meadow soil
Meadow steppe	21	43°25′03″N 93°57′34″E	2370.7	*Potentilla bifurca*, *Melica transsilvanica*, *Carex stenocarpa*	30	Gray cinnamon soil
Mountain steppe	16	43°12′59″N 94°22′44″E	2530.5	*Stipa caucasica* subsp. *desertorum*, *Arenaria meyeri*	31	Chestnut soil
	22	43°25′19″N 93°57′42″E	2309.4	*Stipa sareptana*, *Carex enervis*	62	Gray cinnamon soil
Desert steppe	17	43°15′04″ N 94°22′51″E	2259.7	*Artemisia* sp., *Stipa caucasica* subsp. *desertorum*, *Lagochilus diacanthophyllus*	14	Chestnut soil
Steppe desert	11	43°14′09″N 94°33′34″E	1932.8	*Caragana pumila*, *Ajania fruticulosa-Stipa tianschanica*	19	Chestnut soil
Desert	5	43°17′35″N 94°49′35″E	1616.8	*Ephedra przewalskii*, *Zygophyllum xanthoxylon*, *Sympegma regelii*	35	Grey-brown desert soil
	6	43°15′33″N 94°48′14″E	1637.2	*Reaumuria soongorica*, *Sympegma regelii*	21	Alkalinized grey-brown desert soil
	20	43°29′07″N 94°52′55″E	1086.4	*Iljinia regelii-Zygophyllum pterocarpum*	6	Grey-brown desert soil
Wetland meadow	8	43°15′18″N 94°43′32″E	1627.6	*Blysmus sinocompressus*, *Glaux maritima*, *Halerpestes ruthenica*	97	Wetland meadow soil
	12	43°14′24″N 94°38′13″E	1771.8	*Blysmus sinocompressus*, *Glaux maritima*, *Halerpestes ruthenica*	90	Swamp soil
Salinized meadow	7	43°15′16″N 94°44′50″E	1631.5	*Caragana pumila*, *Clematis songarica-Achnatherum splendens*	36	Fluvo-aquic soil
	9	43°19′54″N 94°17′17″E	1880.9	*Nitraria sibirica-Achnatherum splendens*	51	Salinized meadow soil
	10	43°20′02″N 94°17′48″E	1884.8	*Nitraria sibirica-Achnatherum splendens*	95	Salinized meadow soil
	18	43°48′31″N 95°01′52″E	577.9	*Phragmites australis*, *Alhagi sparsifolia*, *Glycyrrhiza inflate*	20	Solonchak
	19	43°47′20″N 95°02′38″E	593.0	*Phragmites australis*	32	Solonchak

Table 2 Main plant species in study area

No.	Plant species	Sampling plots of species	No.	Plant species	Sampling plots of species
1	*Taraxacum* sp.	2, 12, 15, 21	25	*Koenigia islandica*	3
2	*Taraxacum longipyramidatum*	8	26	*Potentilla bifurca*	13, 14, 17, 21
3	*Ajania fruticulosa*	5,11	27	*Ranunculus nephelogense*	3
4	*Artemisia* sp.	7, 11, 16, 17, 21, 22	28	*Halerpestes sarmentosa*	3
5	*Inula aspera*	13, 14	29	*Halerpestes ruthenica*	8, 12
6	*Lagochilus diacanthophyllus*	17	30	*Clematis songarica*	7
7	*Arenaria meyeri*	13, 16, 21	31	*Aconitum rotundifolium*	15
8	*Stellaria uda*	15	32	*Caragana pumila*	7, 11
9	*Melica transsilvanica*	13, 21	33	*Alhagi sparsifolia*	18
10	*Poa attenuata* subsp. *botryoides*	3, 15, 21, 22	34	*Glycyrrhiza inflata*	18
11	*Stipa caucasica* subsp. *desertorum*	5, 6, 16, 17	35	*Ephedra przewalskii*	5
12	*Stipa tianschanica*	11	36	*Ephedra glauca*	7
13	*Stipa sareptana*	21, 22	37	*Zygophyllum xanthoxylon*	5
14	*Agropyron sinkiangense*	16, 21	38	*Zygophyllum pterocarpum*	7, 20
15	*Achnatherum splendens*	7, 9, 10	39	*Nitraria sibirica*	9, 10
16	*Leymus yiunensis*	10, 21	40	*Sympegma regelii*	5, 6, 11
17	*Phragmites australis*	18, 19	41	*Iljinia regelii*	20
18	*Carex melanocephala*	2	42	*Lepidium ruderale*	6, 9
19	*Carex karoi*	4	43	*Reaumuria soongorica*	6, 11
20	*Carex stenocarpa*	4, 17, 21	44	*Glaux maritima*	8, 12
21	*Carex liparocarpos*	13, 14	45	*Androsace dasyphylla*	13, 14
22	*Carex enervis*	22	46	*Waldheimia glabra*	1
23	*Blysmus sinocompressus*	8, 12	47	*Lagopsis eriostachys*	1
24	*Polygonum viviparum*	2, 3, 4	48	*Silene karaczukuri*	1

Figure 2 shows the variation of dominance index and diversity index based on the different plant communities as the variables of horizontal axis, and the corresponding sampling plots are listed in Table 1. The dominance index shows an opposite trend to the diversity index. In terms of the zonal vegetation, vegetation gradually inclines to the communities with lower diversity index (Fig. 2). Generally, the species diversity index of mountain vegetation is higher than the desert vegetation, and the dominance index shows an opposite trend. However, in non-zonal vegetation the pattern is uncertain.

3.2 Results of canonical correspondence analysis (CCA)

Vegetation distribution patterns are constrained by environmental factors, including elevation and soil factors (Liu *et al.*, 2003), and related parameters are altitude, average soil particle size (Mz), soil sorting index (σ), soil water content (SM), soil organic matter (OM), total nitrogen (TN), total phosphorus (TP), total potassium (TK), total salts (TS) and pH. Soil samples were not taken in plot 1 and plot 14 because of high gravel contents, so the two plots did not be included in the CCA

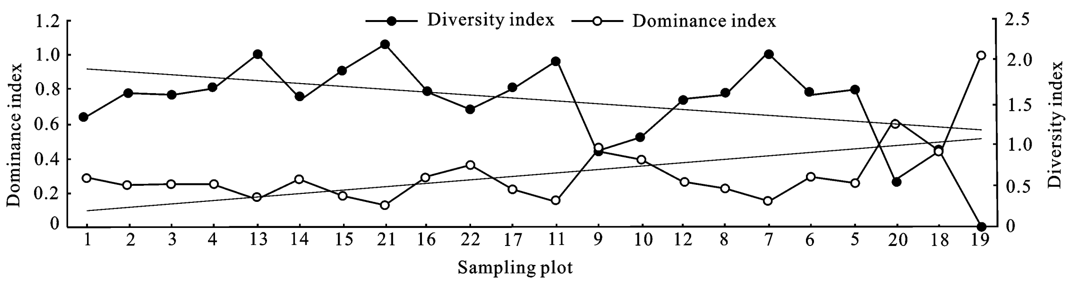

Fig. 2 Dominance and species diversity indices of sampling plots in study area

ordination. As a result, there are a total of 20 sample plots in the CCA ordination diagram.

The results of CCA show that the eigenvalue of Axis 1 is 0.984 and Axis 2 is 0.918, and the species-environment correlation coefficient of Axis 1 is 0.998 and for Axis 2 is 0.996 (Table 3). The correlation coefficient between the species Axis 1 and Axis 2 is –0.001, and the correlation coefficient between the environment Axis 1 and Axis 2 is 0 (Table 4), so the two ordination axes are almost vertical. All these can reflect that the results of CCA are credable (Braak, 1991).

Correlative analysis of 10 environmental variables of the study area shows that, the altitude is significantly, positively correlated with the OM and TN, and negatively correlated with soil pH and TS (Table 5). In addition, there is a significant positive correlation between the σ and TP, and a negative correlation present between the σ and Mz.

Based on the species importance value, Fig. 3 and Fig. 4 are the results of CCA ordination of plots-environment and species-environment in the region between the northern slope of Karlik Mountain and Naomaohu Basin. In the CCA ordination diagram, the first ordination axis is correlated to the TS, pH, Mz, σ and altitude, and the second ordination axis is positively correlated with soil pH, and negatively correlated with altitude, TN, and OM

Table 3 Eigenvalue, species-environment correlation coefficients and cumulative percentage variance of ordination axes

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalue	0.984	0.918	0.869	0.801
Species-environment correlation coefficient	0.998	0.996	0.995	0.992
Cumulative percentage variance of species data	7.300	14.000	20.500	26.400
Cumulative percentage variance of species-environment relation	12.700	24.600	35.800	46.100

Table 4 Correlation coefficients among species and environment ordination axes

		Species				Environment			
		Axis 1	Axis 2	Axis 3	Axis 4	Axis 1	Axis 2	Axis 3	Axis 4
Species	Axis 1	1.000							
	Axis 2	–0.001	1.000						
	Axis 3	0.001	–0.005	1.000					
	Axis 4	0.001	–0.008	0.006	1.000				
Environment	Axis 1	0.998	0.000	0.000	0.000	1.000			
	Axis 2	0.000	0.996	0.000	0.000	0.000	1.000		
	Axis 3	0.000	0.000	0.997	0.000	0.000	0.000	1.000	
	Axis 4	0.000	0.000	0.000	0.992	0.000	0.000	0.000	1.000

Table 5 Correlation coefficients among environmental variables in study area

	Altitude	Mz	σ	SM	OM	TN	TP	TK	TS	pH
Altitude	1.000									
Mz	–0.475*	1.000								
σ	0.439	–0.497*	1.000							
SM	0.084	–0.435	–0.008	1.000						
OM	0.743**	–0.293	0.326	0.119	1.000					
TN	0.769**	–0.316	0.330	0.134	0.997**	1.000				
TP	0.439	–0.214	0.581**	0.000	0.544**	0.531*	1.000			
TK	–0.122	–0.210	–0.071	–0.173	–0.402	–0.373	0.031	1.000		
TS	–0.583**	0.131	–0.442	–0.045	–0.179	–0.209	–0.191	–0.069	1.000	
pH	–0.811**	0.256	–0.473*	–0.098	–0.805**	–0.815**	–0.696**	0.251	0.442	1.000

Notes: *, $P < 0.05$; **, $P < 0.01$

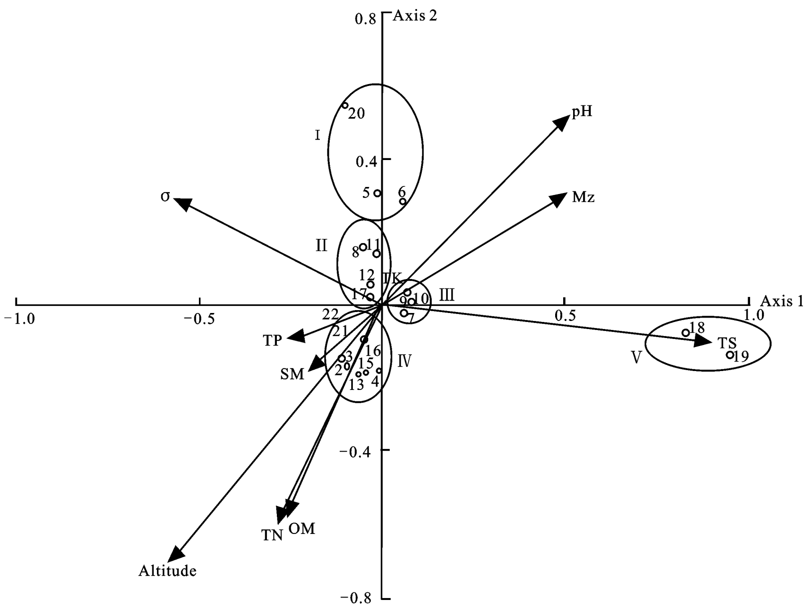

Fig. 3 Canonical correspondence analysis (CCA) ordination diagram of 20 sampling plots in study area

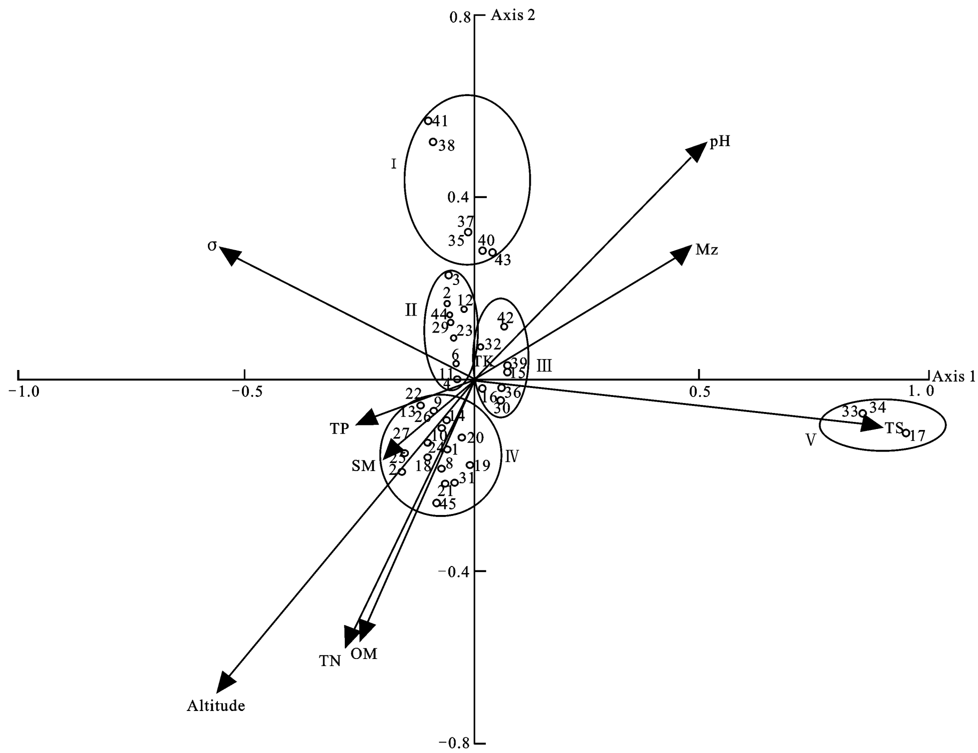

Fig. 4 Canonical correspondence analysis (CCA) ordination diagram of main plant species in study area

(Table 6). According to the distribution of environmental factors in the CCA ordination diagram, it can be concluded that the main factors that influence the composition, structure and distribution of vegetation in the study area are altitude, soil pH and TS.

Influenced by environmental factors, 20 sample plots in the study area form 5 series or 5 types (Fig. 3) along the altitude gradient, and 45 main species also can be divided into five groups in the CCA ordination diagram (Fig. 4).

Type I contains plots 5, 6 and 20, which are composed of desert vegetation distributed on the low mountains, hills, plains and deserts below an elevation of 1900 m. The main plant species are the super-xerophytic

Table 6 Correlation coefficients between environmental variables and ordination axes

	Species ordination axes				Environment ordination axes			
	Axis 1	Axis 2	Axis 3	Axis 4	Axis 1	Axis 2	Axis 3	Axis 4
Altitude	–0.576**	–0.694**	0.036	0.361	–0.577**	–0.696**	0.036	0.364
Mz	0.470*	0.285	0.115	–0.183	0.471*	0.286	0.115	–0.184
σ	–0.575**	0.294	0.090	0.540**	–0.576**	0.296	0.090	0.544**
SM	–0.206	–0.176	0.438	–0.217	–0.207	–0.177	0.439	–0.219
OM	–0.258	–0.574**	0.401	0.499*	–0.258	–0.57	0.403	0.503*
TN	–0.279	–0.597**	0.393	0.486*	–0.279	–0.599**	0.394	0.490*
TP	–0.253	–0.096	0.389	0.096	–0.253	–0.096	0.390	0.097
TK	0.032	0.036	–0.632**	–0.460*	0.032	0.037	–0.634**	–0.464*
pH	0.502*	0.513*	–0.469*	–0.086	0.503*	0.515*	–0.471*	–0.087
TS	0.895**	–0.101	0.045	0.022	0.897**	–0.101	0.045	0.022

Notes: *, $P < 0.05$; **, $P < 0.01$

plants, including *Iljinia regelii*, *Zygophyllum pterocarpum*, *Zygophyllum xanthoxylon*, *Ephedra przewalskii*, *Sympegma regelii* and *Reaumuria soongorica*. The growth environments present high soil pH (alkaline), and low altitude, TS, SM, OM and TN (Table 7).

Type Ⅱ is comprised of plots 8, 11, 12 and 17, distributed in the mountain and desert ecotone with an elevation of 1900–2300 m. The vegetation types includes steppe desert, desert steppe and wetland meadow. Among them, steppe desert and desert steppe are mainly composed of drought tolerate species growing in the low and mid altitudinal zone with alkalinized soil, low TS and poor σ. Typical species include *Ajania fruticulosa*, *Stipa tianschanica*, *Lagochilus diacanthophyllus* and *Stipa caucasica* subsp. *desertorum*. The wetland meadow is mainly dominated by the hygrophilous plants, and accompanied by mesophytic perennial herbs, such as the *Glaux maritima*, *Blysmus sinocompressus*, and *Halerpestes ruthenica*. Species of Type Ⅱ are approximately distributed in the mid-section of the CCA ordination diagram. The altitude, and contents of OM and TN of this type are all higher than that of in Type I (Table 7), so many xerophytic and xerophytic-mesophytic herbs exist in the vegetation composition of Type Ⅱ.

Type Ⅲ contains plots 7, 9 and 10, and salinized meadow is the main vegetation type. Salinized meadow is mainly comprised of alkali-saline tolerant plants distributed in low and mid altitudinal zones with alkaline soils. The typical species include *Nitraria sibirica*, *Achnatherum splendens*, *Clematis songarica* and *Lepidium ruderale*. Their development presents a positive relationship with Mz, soil pH, and TS (Table 7).

Type Ⅳ is composed of plots 2, 3, 4, 13, 15, 16, 21 and 22, and all distributed above an elevation of 2300 m. The vegetation assemblages or types are abundant, containing mountain steppe, meadow steppe, subalpine meadow and alpine meadow. These mainly consist of xerophytic-mesophytic and mesophytic perennial herbs

Table 7 Environmental variables in different vegetation types

	Vegetation type	Altitude	Mz	σ	SM	OM	TN	TP	TK	TS	pH
I	Desert	1447	0.103	2.437	9.184	0.309	0.016	0.087	1.519	0.054	8.383
Ⅱ	Steppe desert	1933	0.065	2.199	7.025	1.034	0.054	0.075	1.501	0.097	8.475
	Desert steppe	2260	0.063	2.250	9.640	4.183	0.249	0.059	1.570	0.058	8.260
	Wetland meadow	1700	0.085	1.910	39.918	4.935	0.224	0.067	1.194	0.252	8.063
Ⅲ	Salinized meadow	1799	0.071	1.804	16.210	1.123	0.061	0.076	1.763	1.160	8.359
Ⅳ	Mountain steppe	2420	0.062	1.999	12.833	3.542	0.185	0.059	1.515	0.218	8.137
	Meadow steppe	2371	0.046	2.084	10.798	8.291	0.397	0.085	1.806	0.159	7.740
	Subalpine meadow	2833	0.052	1.992	30.227	6.716	0.332	0.077	1.551	0.140	7.875
	Alpine meadow	3336	0.061	2.322	14.170	21.908	0.920	0.107	1.274	0.068	7.198
V	Salinized meadow	585	0.135	1.442	10.429	1.631	0.062	0.061	1.424	12.274	8.938

which grow in neutral to alkaline soils with relatively high SM, OM, TN and TP (Table 7). The typical plants are *Potentilla bifurca*, *Carex liparocarpos*, *Carex melanocephala*, *Agropyron sinkiangense* and *Polygonum viviparum*.

The composition of Type V is very simple, only including plots 18 and 19. Their vegetation composition is mainly that of salinized meadow, containing *Phragmites australis*, *Alhagi sparsifolia* and *Glycyrrhiza inflata*. These sampling plots are distributed in the Naomaohu Basin with the lowest altitude, alkaline soils, lower OM and the highest TS (Table 7). Compared with other species, the distributed position of these plants in the ordination diagram is peculiar, brought about by the fact that they are the most salt-tolerate species in the study area.

4 Discussion

4.1 Vegetation distribution

The vegetation type in this region shows a vertical, zonal distribution, however, the vertical, zonal spectrum is incomplete. There is no mountain meadow developed in this study area. Compared with other mountains on the northern slopes of the Tianshan Mountains, the boundary between steppe and meadow on the Karlik Mountain are higher. Forest area in this region is very small and mainly composed of *Larix sibirica*, and here is the natural distribution boundary of *Picea schrenkiana*. The vegetation types in the mid and west Tianshan Mountains are complete, including desert, desert steppe, mountain steppe, mountain meadow and steppe, mountain forest, subalpine steppe, subalpine meadow and alpine meadow (Lou and Zhang, 1994; Xu *et al*., 2011). Furthermore, the mountain forest in the mid Tianshan Mountains is mainly composed of *P. schrenkiana* (Lou and Zhang, 1994). The reason for these differences is because that the Karlik Mountain is located in the easternmost end of the Tianshan Mountains, and the moisture from the westerly air current which enters Xinjiang is less than those other sections of Tianshan Mountains. Therefore, the Karlik Mountain is more drought-prone.

In the study area, species diversity of mountain vegetation is greater than the desert vegetation. This is due to the difference of the climate at different altitudes, as well as the result of long-term adaptation and evolution of the species to environmental factors. The diversity index is high in the mountain region because of the favorable allocation of heat, temperature, precipitation and relatively high SM, OM, TN and TP. Meanwhile, the utilization efficiency of environment resources is also optimum and higher than that in desert region. Therefore, there are large numbers of plants species distributed on the northern slope of Karlik Mountain. These are mainly composed of xeromorphic-mesophytic herbs and cold-tolerant, perennial mesophytes, including *C. liparocarpos*, *Aconitum rotundifolium*, *Stellaria uda* and *P. viviparum*. By comparison, the diversity index in desert ecosystems is low, because these are communities with simple structure and indigent species that mainly consist of super-xerophytic and salt-tolerate plants. Vegetation in the oasis is mainly a combination of both shrubs and herbs, so some plant communities possess rich species composition, such as plot 11. In the Naomaohu Basin with the lowest altitude, the dominant species of plant communities are salt-tolerate and super-xerophytic plants. The Naomaohu Basin is located in the downstream section of the Yiwu River, which is the influx area for surface water and ground water from the south, west and north. The meteorological characteristics of this basin are low precipitation and high evaporation. Groundwater with high salinity moves up to the surface through soil capillaries due to the effect of evaporation, accumulating salts on the soil surface. Since this area is seldom leached, accumulated salt has caused the formation of salinized soils.

4.2 Interactions between vegetation and environment

Vegetation distribution and environmental factors are interactive. On the one hand, the distribution of vegetation is determined by environmental factors. Under the specific habitat conditions and influenced by the environment, plants often present aberrant phenomena in the process of evolution. Usually, they are inclined to retain their advantageous characteristics after natural selection that allows them to adapt to accord with the environment (Ma *et al*., 2006). For example, *Z. xanthoxylon* is a super-xerophytic shrub belonging to the Zygophyllaceae and *Zygophyllum*. It is mainly distributed in the desert and steppe desert with arid climate and sparse vegetation. *Z. xanthoxylon* can survive well in such an arid environment mostly because of its peculiar physiological structure. The leaves of *Z. xanthoxylon* can be classified into the type known as ring-palisade. Ring-palisade is an advanced adaptation in xerophytic plants to desert environments, and it can provide a very low ratio of surface area to volume in the leaves of *Z. xanthoxylon*, and well developed water-storage parenchyma exists in the palisade tissue and circle around the vein. In addition, there are cell masses distributed in the water-storage parenchyma of caudexes, and sclereids exist in the root parenchyma (Huang *et al*., 1997). Due to these characteristics, *Z. xanthoxylon* can adapt well to the arid environment and become a dominant species in the desert. In another example, *N. sibirica* is a deciduous and salt-tolerate shrub belonging to the Zygophyllaceae and *Nitraria*, which can adapt well to salinized soil by osmotic adjustment. *N. sibirica* has a high degree of alkali-saline tolerance, and is a dominant species of salinized meadows in the study area. The non-photochemical quenching (NPQ) in *N. sibirica* showed no significant differences under various levels of soda saline-alkaline stress (Chen *et al*., 2011). It is suggested that *N. sibirica* could keep a high level of NPQ to adapt to the saline-alkaline stress in soils.

Sometimes plant species can bring some positive feedback mechanisms to their environment. They can make use of their ecological advantages to optimize the ecosystem function. Alpine meadow, subalpine meadow and meadow steppe distributed in the region of the northern slope of Karlik Mountain possess high grass productivity for their high vegetation covers. Although extensive human disturbances (e.g. grazing and tourism) exist in this region, the underground biomass is several times greater than the aboveground biomass. Therefore, every year a large amount of organic plant debris enters the soils, increasing the activities of soil microorganisms and, in turn, improving soil fertility. However, the content of OM in the Naomaohu Basin is low because of its low vegetation cover, bare soils, shallow soil layers, lower vegetation productivity, and especially the low underground biomass of plants. *N. sibirica* can absorb and accumulate a certain amount of salt from soils and then utilize the salts in osmo-regulation substances, thereby decreasing the salt content in the soil (Zhao *et al*., 2002). It indicated that *N. sibirica* could be a useful salt absorption plant and could be used to improve alkali-saline soils.

4.3 Vegetation-environment relationships

Lou and Zhou (2001) studied the vegetation-environment relationships in the mid-range of the Tianshan Mountains. They found that the distribution of desert vegetation at the foot of the mountains is mainly restricted by altitude, soil pH and average temperature in July, while the main factors that determine the development of alpine meadow and subalpine meadow are altitude, SM, OM, soil pH, $CaCO_3$ content of soil, and average temperature in January and July. They also found that desert vegetation develops in alkaline soils, while the vegetation of alpine meadows and subalpine meadows grow in acidic soils. Our results from this study area differ from those from the mid-range of the Tianshan Mountains. In this study, alpine meadows developed on neutral soils while other vegetation types occurred on alkaline soils. Soil pH is controlled by the landform, vegetation, precipitation and other climate factors (Meelis *et al*., 2004). Generally, soil pH is low in humid areas and high in arid regions. The climate of Karlik Mountain is more drought prone than the mid-range of the Tianshan Mountains, so the soil pH is higher than that of the mid Tianshan Mountains.

The spatial patterns of vegetation are determined by many ecological factors, and altitudinal patterns of vegetation types largely depend on the co-variation and interaction of these factors (Wang *et al*., 2002). In previous studies of the Tianshan Mountains, elevation and soil properties (e.g. soil size, soil pH, TN, TP) were considered as the important factors affected vegetation distribution. Xu *et al*. (2006) studied the desert vegetation patterns at the northern foot of the mid Tianshan Mountains, and the results showed that TS, soil pH, and soil mechanical composition significantly affected vegetation patterns. Research into the distribution pattern of plant species diversity in the West Tianshan Mountains showed that the distribution of plant species on the northern slope was affected by such factors as elevation, TN, TP, SM and OM (Xu *et al*., 2011). Our findings are similar to the previous studies on the Tianshan Mountains. It revealed that the main factors influencing the vegetation distribution of the Tianshan Mountains are almost homogeneous at a large spatial scale, but differences still exist at the small spatial scale. The reasons for the differences at the small spatial scale between the East Tianshan Mountains and other sections of the Tianshan Mountains are thought to be mainly due to the climate and landform. Human activities such as overgrazing have imposed a significant impact on the vegetation diversity and structure in the mid Tianshan Mountains (Zhao *et al*., 2007). The same phenomenon exists in the East Tianshan Mountains, but extended future research is needed to ascertain the severity and effects of such impacts.

5 Conclusions

The region between the northern slope of the Karlik Mountain and Naomaohu Basin is located in the easternmost part of the Tianshan Mountains, with unique mountain-oasis-desert ecosystems. In this paper, we quantitatively discussed the vegetation distribution and the relationships between vegetation and environmental factors in the study area, providing the scientific information for further study both in this region and the whole Tianshan Mountains.

First, for the zonal vegetation in the study area, community diversity of mountain vegetation is obviously greater than that of the desert vegetation because of environmental factors. The main factors influencing the vegetation distribution are altitude, soil pH and TS. In the CCA ordination diagrams, the sampling plots and main species can be divided into five types according to their adaptations to the environmental factors.

Secondly, the spatial heterogeneities of environmental factors in the region between the northern slope of Karlik Mountain and Naomaohu Basin have caused the vegetation succession: desert → steppe desert → desert steppe → mountain steppe → meadow steppe → subalpine meadow and alpine meadow along an altitudinal gradient. With increasing elevation, species combinations change from the hyper-xerophytic species in the low altitude zone with arid climate to the xerophytic species in the mid altitudinal zone, and then to the cold-tolerant perennial herbs with the highest altitude and cold climate. The results of CCA ordination have well distinguished the spatial succession of species and vegetation types along an environmental gradient, and have assisted in the characterisation of the trends in vegetation patterns from the deserts to the mountains in vertical gradient.

Acknowledgement

We are grateful to Mr. Adrian Williams for his work on the English text.

References

Abbadi G A, El-Sheikh M A, 2002. Vegetation analysis of Failaka Island (Kuwait). *Journal of Arid Environments*, 50(1): 153–165. doi: 10.1006/jare.2001.0855

Allen R B, Peet R K, 1990. Gradient analysis of forests of the Sangre de Cristo Range, Colorado. *Canadian Journal of Botany*, 68(1): 193–201. doi: 10.1139/x06-104

Bisigato A J, Villagra P E, Ares J O *et al*., 2009. Vegetation heterogeneity in Monte Desert ecosystems: A multi-scale approach linking patterns and processes. *Journal of Arid Environments*, 73(2): 182–191. doi: 10.1016/j.jaridenv.2008.09.001

Braak C J F, 1991. *Canoco—A Fortran Program for Canonical Community Ordination by Partial Canonical Correspondence Analysis, Principle Component Analysis and Redundancy Analysis*. New York: Cornell University Press.

Chen Zhiqiang, Li Qingjian, Shi Ruiting *et al*., 2011. Effects of soda saline-alkaline stress on photosynthesis and growth of *Nitraria sibirica*. *Journal of Beijing Forestry University*, 33(3): 31–37. (in Chinese)

El-Ghani M M A, 1998. Environmental correlates of species distribution in arid desert ecosystems of eastern Egypt. *Journal of Arid Environments*, 38(2): 297–313. doi: 10.1006/jare.1997.0323

El-Ghani M M A, Amer W M, 2003. Soil-vegetation relationships in coastal desert plain of southern Sinai, Egypt. *Journal of Arid Environments*, 55(4): 607–628. doi: 10.1016/S0140-1963(02)00318-X

Enright N J, Miller B P, Akhter R, 2005. Desert vegetation and vegetation-environment relationships in Kirthar National Park, Sindh, Pakistan. *Journal of Arid Environments*, 61(3): 397–418. doi: 10.1016/j.jaridenv.2004.09.009

Fang Jingyun, Shen Zehao, Cui Haiting, 2004. Ecological characteristics of mountains and research issues of mountain ecology. *Biodiversity Science*, 12(1): 10–19. (in Chinese)

Folk R L, Ward W C, 1957. Brazos river bar: A study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, 27(1): 3–26. doi: 10.1306/74D70646-2B21-11D7-8648000102C1865D

Fossati J, Pautou G, Peltier J, 1999. Water as resource and disturbance for wadi vegetation in a hyperarid area (Wadi Sannur, Eastern Desert, Egypt). *Journal of Arid Environments*, 43(1): 63–77. doi: 10.1006/jare.1999.0526

Gaston K J, 2000. Global patterns in biodiversity. *Nature*, 405(6783): 220–227. doi: 10.1038/35012228

Hao Zhanqing, Guo Shuiliang, 2003. Canonical correspondence analysis on relationship of herbs with their environments on northern slope of Changbai Mountain. *Acta Ecology Sinica*, 23(10): 2000–2008. (in Chinese)

He M Z, Zheng J G, Lia X R *et al*., 2007. Environmental factors affecting vegetation composition in the Alxa Plateau, China. *Journal of Arid Environments*, 69(3): 473–489. doi: 10.1016/j.jaridenv.2006.10.005

He Mingzhu, Zhang Zhishan, Li Xiaojun *et al*., 2010. Environmental effects on distribution and composition of desert vegetations in Alxa Plateau: I. Environmental effects on the distribution patterns of vegetation in Alxa P1ateau. *Journal of Desert Research*, 30(1): 46–56. (in Chinese)

Huang K Y, 2002. Evaluation of the topographic sheltering effects on the spatial pattern of Taiwan fir using aerial photography and GIS. *International Journal of Remote Sensing*, 23(10): 2051–2069. doi: 10.1080/01431160110076207

Huang Zhenying, Wu Hong, Hu Zhenghai, 1997. The structures of 30 species of psammophytes and their adaptation to the sandy desert environment in Xinjiang. *Acta Phytoecologica Sinica*, 21(6): 521–530. (in Chinese)

Johnson E A, 1981. Vegetation organization and dynamics of lichen woodland communities in the Northwest Territories, Canada. *Ecology*, 62(1): 200–215. doi: 10.2307/1936682

Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences, 1986. Glacier Inventory of China Ⅲ–Tianshan Mountains (Interior Drainage Area of Scattered Flow in East). Beijing: Science Press, 26–28. (in Chinese)

Li Kaihui, Hu Yukun, Wang Xin *et al*., 2007. Relationships between aboveground biomass and environmental factors along an altitude gradient of alpine grassland. *Chinese Journal of Applied Ecology*, 18(9): 2019–2024. (in Chinese)

Li Kaihui, Wang Wanlin, Hu Yukun *et al*., 2008. Relationships between belowground biomass of alpine grassland and environmental factors along an altitude gradient. *Chinese Journal of Applied Ecology*, 19(11): 2364–2368. (in Chinese)

Liu Shiliang, Ma Keming, Fu Bojie, 2003. The relationship between landform, soil characteristics and plant community structure in the Donglingshan Mountain region, Beijing. *Acta Phytoecologica Sinaca*, 27(4): 496–502. (in Chinese)

Lou Anru, 1998. Ecological gradient analysis and environmental interpretation of mountain vegetation in the middle stretch of Tianshan Mountain. *Acta Phytoecologica Sinica*, 22(4): 364–372. (in Chinese)

Lou Anru, Zhang Xinshi, 1994. The preliminary analysis of the distribution of vegetation on the middle stretch of Tianshan Mountains of Xinjiang. *Journal of Beijing Normal University* (*Natural Science*), 30(4): 540–545. (in Chinese)

Lou Anru, Zhou Guofa, 2001. Relationships between environment and spatial pattern of vegetation types in the mid Tianshan Mountains. *Acta Phytoecologica Sinica*, 25(1): 385–391. (in Chinese)

Ma Keping, Huang Jianhui, Yu Shunli *et al*., 1995. Plant community diversity in Dongling Mountain, Beijing, China Ⅱ: Species richness, evenness and species diversities. *Acta Ecologica Sinica*, 15(3): 268–277. (in Chinese)

Ma Miao, Li Bo, Chen Jiakuan, 2006. Convergent adaptation of desert plants to their arid habitats. *Acta Ecologica Sinica*, 26(11): 3861–3869. (in Chinese)

Mabbutt J A, 1977. *Desert Landforms*. Cambridge, MA: MIT Press.

Meelis P, Aveliina H, Nele I *et al*., 2004. Conservation of Northern European plant diversity: The correspondence with soil pH. *Biological Conservation*, 120(4): 525–531. doi: 10.1016/j.biocon.2004.03.025

Michel P, Overton J M, Mason N W H *et al*., 2011. Species–environment relationships of mosses in New Zealand indigenous forest and shrubland ecosystems. *Plant Ecology*, 212(3): 353–367. doi: 10.1007/s11258-010-9827-5

Miller J A, Hanham R Q, 2011. Spatial non-stationarity and the scale of species–environment relationships in the Mojave Desert, California, USA. *International Journal of Geographical Information Science*, 25(3): 423–438. doi: 10.1080/13658816.2010.518147

Nanjing Institute of Petrology, 1978. *Physical-chemical Analyses of Soil*. Shanghai: Science and Technology Press, 62–146, 196–233, 466, 481–489. (in Chinese)

Ozkan K, Senol H, Gulsoy S *et al*., 2009. Vegetation-environmental relationships in Mediterranean Mountain forests on limeless bedrocks of Southern Anatolia, Turkey. *Journal of Environmental Engineering and Landscape Management*, 17(3): 154–163. doi: 10.3846/1648-6897.2009.17.154-163

Parker K C, 1988. Environmental relationships and vegetation associates of columnar cacti in the northern Sonoran Desert. *Vegetatio*, 78(3): 125–140. doi: 10.1007/BF00033422

Parker K C, 1991. Topography, substrate, and vegetation patterns in the northern Sonoran Desert. *Journal of Biogeography*, 18(2): 151–163. doi: 10.2307/2845289

Qian Y B, Zhang H Y, Wu Z N *et al*., 2011. Vegetation composition and distribution on the northern slope of Karlik Mountain to Naomaohu Basin, East Tianshan Mountains. *Journal of Arid Land*, 3(1): 15–24. doi: 10.3724/SP.J.1227.2011.00015

Ren Jizhou, 1998. *Research Methods of Pratacultural Science*. Beijing: China Agricultural Press. (in Chinese)

Rietkerk M, Ouedraogo T, Kumar L *et al*., 2002. Fine scale spatial distribution of plant and resources on a sandy soil in the Sahel. *Plant and Soil*, 239(1): 69–77. doi: 10.1023/A:1014970523241

Sang W G, 2009. Plant diversity patterns and their relationships with soil and climatic factors along an altitudinal gradient in the middle Tianshan Mountain area, Xinjiang, China. *Ecological Research*, 24(2): 303–314. doi: 10.1007/s11284-008-0507-z

Shaheen H, Khan S M, Harper D M *et al*., 2011. Species diversity, community structure, and distribution patterns in western Himalayan Alpine Pastures of Kashmir, Pakistan. *Mountain Research and Development*, 31(2): 153–159. doi: 10.1659/MRD-JOURNAL-D-10-00091.1

Stirling G, Wilsey B, 2001. Empirical relationships between species richness, evenness, and proportional diversity. *American Naturalist*, 158(3): 286–299. doi: 10.1086/321317

Tang Zhiyao, Fang Jinyun, 2004. A review on the elevational patterns of plant species diversity. *Biodiversity Science*, 12(1): 20–28. (in Chinese)

Van de Ven C M, Weiss S B, Ernst W G, 2007. Plant species distributions under present conditions and forecasted for warmer climates in an arid mountain range. *Earth Interactions*, 11(9): 1–9. doi: 10.1175/EI205.1

Wang G H, Zhou G S, Yang L M *et al*., 2002. Distribution, species diversity and life-form spectra of plant communities along an altitudinal gradient in the northern slopes of Qilianshan Mountains, Gansu, China. *Plant Ecology*, 165(2): 169–181. doi: 10.1023/A:1022236115186

Wang Zhongchen, Qian Yibing, Zhang Haiyan *et al*., 2010. Distribution characteristics of soil grain size and cause in the region of the northern slopes of Karlik Range in East Tianshan Mountains-Naomaohu Basin. *Journal of Glaciology and Geocryology*, 32(5): 1035–1043. (in Chinese)

Wang Zhongchen, Qian Yibing, Zhang Haiyan *et al*., 2011. Spatial distribution of soil physical-chemical properties in the region of the northern slopes of Karlik Range in East Tianshan Mountains to Naomaohu Basin. *Arid Land Geography*, 34(1): 107–114. (in Chinese)

Xinjiang Review Term of Chinese Academy of Sciences, the Botany Institution of Chinese Academy of Sciences, 1978. *The Vegetation of Xinjiang and Its Utilization*. Beijing: Science Press, 229. (in Chinese)

Xu L H, Liu H Y, Chu X Z *et al*., 2006. Desert vegetation patterns at the northern foot of Tianshan Mountains: The role of soil conditions. *Flora*, 201(1): 44–50. doi: 10.1016/j.flora.2005.04.003

Xu Y J, Chen Y N, Li W H *et al*., 2011. Distribution pattern of plant species diversity in the mountainous region of Ili River Valley, Xinjiang. *Environmental Monitoring Assessment*, 177(1–4): 681–694. doi: 10.1007/s10661-010-1665-3

Yair A, Danin A, 1980. Spatial variation as related to the soil moisture regime over an arid limestone hillside, northern Negev, Israel. *Oecologia*, 47(1): 83–89. doi: 10.1007/BF00541779

Yue Ming, Ren Yi, Dang Gaodi *et al*., 1999. Species diversity of higher plant communities in Foping National Reserve. *Chinese Biodiversity*, 7(4): 263–269. (in Chinese)

Zhang Haiyan, Qian Yibing, Duan Shimin *et al*., 2009. Study of the species diversity of plant communities in the northern slopes of Karlik Range-Naomaohu, East Tianshan. *Journal of Glaciology and Geocryology*, 31(5): 976–985. (in Chinese)

Zhang Haiyan, Qian Yibing, Duan Shimin *et al*., 2010. Study on flora in the region of the northern slope of Karlik Mountain-Naomaohu Basin, East Tianshan Mountains. *Arid Zone Research*, 27(4): 550–558. (in Chinese)

Zhang Linjing, Yue Ming, Zhao Guifang *et al*., 2002. Plant community species diversity on oasis-desert ecotone in Fukang of Xinjiang and comparison of its measurement. *Acta Botanica Boreali-Occidentalia Sinica*, 32(2): 350–358. (in Chinese)

Zhang Wenhui, Lu Tao, Ma Keming *et al*., 2004. Analysis on the environmental and spatial factors for plant community distribution in the arid valley in the upper reach of Minjiang River. *Acta Ecologica Sinica*, 24(3): 552–559. (in Chinese)

Zhao Kefu, Fan Hai, Jiang Xingyu *et al*., 2002. Improvement and utilization of saline soil by planting halophytes. *Chinese Journal of Applied and Environmental Biology*, 8(1): 31–35. (in Chinese)

Zhao W Y, Li J L, Qi J G, 2007. Changes in vegetation diversity and structure in response to heavy grazing pressure in the northern Tianshan Mountians, China. *Journal of Arid Environments*, 68(3): 465–479. doi: 10.1016/j.jaridenv.2006.06.007

Zhu Xiaoqin, Liu Kang, Li Jianguo, 2009. Analysis on vegetation-environment gradient correlation in Qinling Mountain based on GIS. *Research of Soil and Water Conservation*, 16(2): 169–175. (in Chinese)

Zuo X A, Zhao H L, Zhao X Y *et al*., 2008. Plant distribution at the mobile dune scale and its relevance to soil properties and topographic features. *Environmental Geology*, 54(5): 1111–1120. doi: 10.1007/s00254-007-1104-0

Zuo X A, Zhao X Y, Zhao H L *et al*., 2009. Spatial heterogeneity of soil properties and vegetation-soil relationships following vegetation restoration of mobile dunes in Horqin Sandy Land, northern China. *Plant and Soil*, 318(1–2): 153–167. doi: 10.1007/s11104-008-9826-7