Vegetation species diversity and its influencing factors in mountain desert communities in northern Xinjiang China

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Abstract

The desert covers 46.9% of the grassland in Xinjiang Uygur Autonomous Region of China (including Southern and Northern Xinjiang). In the present study, 527 plots (about 4,500 quadrats)were taken from the Junggar Desert of northern Xinjiang.The purposes of this paper are: (1) to study the composition and distribution characteristics of the main species in the Northern Xinjiang desert; (2) to estimate the diversity index of species α of different communities in different desert areas; (3) to determine the spatial distribution law of species diversity of communities in the Northern Xinjiang desert by ArcGIS 10. 1 to provide a decision-making basis for the protection and planning of plant species in the Northern Xinjiang desert.The results of this study show that: (1) the overall diversity index of plant communities is not high; the average Shannon-Wiener's diversity index is 1.79, ranging from 0.21 to 3.33; (2) the average Pielou's evenness indexes of life forms of different plants in the communities of different regions are 2.25 (3) the Simpson's dominance index of the west in Northern Xinjiang desert is lower than that of the east; Patrick's richness, Pielou's evenness and Shannon-Wiener's diversity index of the west are higher than those of the east.

1 Introduction

As an important part of the terrestrial environment, the desert ecosystem has the functions of carbon fixation, sand fixation, biodiversity protection and soil protection[1] and is also one of the most vulnerable ecosystems. Desert ecosystems are rare in number but high in biodiversity[1]. Xinjiang has a large desert area that formed in the Paleogene. It is part of the subnon-desert area, accounting for more than 42% of the total territory. Ancient desert flora, such as *Anabasi*s Salsa and *Nanophyton Erinaceum*, have been found in this region. Neogene to Quaternary desert flora such as *Haloxylon persicum* and *A.borotalensis* have also been found in the field. Desert plants in northern Xinjiang generally have special structures and functions to help adapt to drought, high temperatures and barren conditions. The unique topography, climate conditions and plant distribution pattern of Xinjiang play an important role in maintaining the desert ecosystem, preventing wind erosion and further desertification of soil, providing a habitat for animals and protecting endangered animal and plants[2]. Therefore, the study of desert ecosystems has higher theoretical value and practical significance. Desert biodiversity research in the region is significant due to the biological ecology characteristics of Xinjiang desert plant's general development trend toward the direction of xerophytic characteristic; under strong drought climate controls, desert plants forme the adaptive mechanism, causing the desert plant diversity to improved and enhancing desert plants inside the region. Interspecific competition, cause the desert ecosystem to become more stable and healthy. It plays an important role in controlling desertification, preventing wind erosion and maintaining global and regional ecological balance.

Xinjiang is an important animal husbandry area and minority community in China. Therefore, the development of animal husbandry is the main method of local economic development and political stability. The development of animal husbandry depends on the improvement of grassland ecosystems and is also the core of the sustainable development of grasslands[3]. To maintain the sustainable development of grassland ecosystems, plant diversity research is indispensable[4]. Studies on plant likeability mainly depend on species abundance, that is, the quantitative relationship between species[4]. Analysing the distribution of species abundance among community species is the key to understanding the mechanism of community species diversity[5]. The world is currently experiencing a relatively serious ecological and environmental crisis, and biological extinction is spreading rapidly around the world[6]. The formation and formation of species diversity in a community can be regarded as an adaptation process to the environment and the interaction between species. The species that can settle in a community first go through the screening and filtering process of environmental adaptation before settling in the community[7]. From the perspective of ecosystem functions, a single species does not have all the functions of an ecosystem, and different species are required to provide them to form a relatively complete ecosystem function[8]. Anthropogenic changes to the environment, such as climate warming and habitat conversion, have recently stimulated scientific interest in the causes and effects of biodiversity loss, which is one of the most serious environmental problems caused by human activities and is exacerbated by agricultural intensification[9].The interference of environmental factors and human activities, as well as the interaction between the environment and human activities, are the main factors affecting the species diversity of communities[10,11]. Among them, environmental factors such as longitude, latitude, altitude, climate, topography and landform all have a significant impact on species diversity[11–18]. Existing studies have shown that latitude and altitude are the main influencing factors of species diversity at large scales[19–21], and topography and climate are the main influencing factors at regional scales[22].

At home and abroad, a large number of studies have focused on the study of woody plants and species diversity and are a large scale for genetic research, and different impact factor contribution sizes have been carried out in contrast research[23,24], but the plant species diversity has a large-scale spatial distribution pattern and causes relatively few studies[23]. For desert species diversity, many studies have been carried out, such as that by Zhang Rui on a desert grassland ShaSheng s. grandis community diversity[25], or Wang Ningkun's research on the typical grassland of the Inner Mongolia building group of the l. chinensis genotype diversity[26]; the influence of Dong-ling Niuu's research on the desert Savanes lichen community diversity[27], and Yu *et al.*'s[28] research on selected the Stipa breviflora desert steppe community are used and comparatively to analysed the species composition, diversity and coexistence pattern of community patches. Sun *et al.*[29] conducted a study on species diversity in a desert steppe. However, most of these studies focused on a single community type, and relatively few studies have focused on the species diversity and spatial distribution of desert communities at the regional scale. The main bottleneck restricting the research on the spatial distribution of desert species diversity in Xinjiang is the lack of investigation of the basic data of species distribution in the whole desert region of northern Xinjiang, and previous studies were carried out at the transect scale or point scale. All these are not conducive for further research on the formation mechanism of biodiversity in desert areas. In addition, the current research on species diversity, including the relative to the northeast and Inner Mongolia grassland species diversity research, the study is from the local geographical environment characteristics of grassland resources and production practice, study the diversity of grassland plant community characteristics, its results are difficult to apply to the northwest desert grassland, especially in the vast desert region of Xinjiang where it is difficult to be widely promoted. Therefore, starting from the field regional scale pattern, this study conducted a field regional scale survey and sampling on the desert of northern Xinjiang based on the collection of specimen information and a literature review. Based on the above understanding, this paper used the thermal desert of northern Xinjiang as the research object and analysed the species composition and characteristics of the desert of northern Xinjiang. The spatial distribution pattern of plant diversity of desert plants in different desert areas of northern Xinjiang was investigated, and the influence of environmental factors on species diversity was further studied based on precipitation, temperature, altitude and other environmental data. As northern Xinjiang desert ecosystem versatility and fully understanding the scientific plan of Xinjiang grassland resource management have very important theoretical and practical significance, for the development of desert of northern Xinjiang biodiversity protection policy, the management and administration of Xinjiang grassland resources plans and guides the local herdsmen's scientific and rational use of deserts to provide theoretical and data support.

2 Results

2.1 Community characteristics and distribution of desert vegetation in northern Xinjiang

The species development, structure and species composition in the desert area of northern Xinjiang are adapted to the seasonal dynamics of the climate. This study selected the temperate desert of northern Xinjiang as the research object. The main plant communities in each desert area include *Seriphidium borotalensis,Anabasis salsa,Nanophyton erinaceum et al.* (Table 1and Table 2).

Table 1
Major Desert community types of Northern Xinjiang

Desert	**Plot number**	**Community**
Altay Desert	114	*Seriphidium terrae-albae, Agropyron desertorum, Anabasis salsa, Seriphidium gracilensces, Artemisia arenaria, Ceratoides latens, Reaumuria kaschgarica, Salsolaabrotanoides, Leymus racemosus, Seriphidium Fourr, Caragana, Stipa glareosa, Nanophyton erinaceum, Ceratocarpus utriculosus, Haloxylon ammodendron, Kalidium foliatum, Anabasis brevifolia, Ephedra sinica, Calligonum mongolicum, Halimodendron halodendronVoss, Sueada physophora*
Tacheng Desert	239	*Seriphidium transillense , Festuca sulcata, Seriphidium borotalense, Haloxylon ammodendron, Nanophyton erinaceum, Ceratocarpus utriculosus, Reaumuria kaschgarica, Ceratoides latens, Salsola ruthenica, Horaninowia ulicina, Alhagi sparsifolia, Salsolaabrotanoides, Anabasis aphylla, Suaeda dendroides, Stipa caucasica Schmalh, Halocnermum strobilaceum, Atraphaxis frutescens, Kochia prostrata, Atriplex cana, Tamarix chinensis Lour, Petrosimonia sibirica, Salsola arbuscula, Phragmites australis, Aeluropus littoralis, Aristida adscensionis , Sueada physophora, Convolvulus tragacanthoides,*
Changji-Urumqi Desert	132	*Seriphidium transillense, Petrosimonia sibirica, Nanophyton erinaceum, Haloxylon ammodendron, Reaumuria kaschgarica, Suaeda dendroides, Anabasis aphylla, Ceratoides latens, Caragana, Seriphidium gracilensces, Haloxylon Persicum, Sophora alopecuroides, Phragmites australis, Aeluropus littoralis, Alhagi sparsifolia, Apocynum venetum L, Ephedra distachys, Stipa caucasica Schmalh, Anabasis brevifolia, Ephedra przewalskii, Achnatherum splendens (Trin.) Nevski , Leymus secalinus (Georgi) Tzvel, Haloxylon ammodendron, Convolvulus tragacanthoides, S.glareosa, Kalidium foliatum, Halocnermum strobilaceum, Nitraria tangutorum Bobr, Zygophyllum xanthoxylum, Salsola arbuscula, Phragmites australis, Artemisia arenaria, Ephedra distachys, Ceratocarpus utriculosus*
East Tianshan Desert	42	*Haloxylon ammodendron, Sophora alopecuroides, Ephedra przewalskii, Anabasis aphylla, Convolvulus tragacanthoides, S.glareosa, Iljinia regelii, Salsola arbuscula, Ceratoides latens, Anabasis brevifolia, Gymnocarpos przewalskii Maxim, Iljinia regelii, Convolvulus tragacanthoides, Tribulus terrestris L, Zygophyllum xanthoxylum, Halostachys caspica (Bieb.) C. A. Mey*

Table 2
Diversity index of different communities life-forms in the Northern Xinjiang

Desert community (Aletai region)	**life-forms**	**H**	**JP**	**S**	**R**
Seriphidium schrenkianum	Shrub	2.22	2.86	0.25	6
	Sub shrub	1.22	0.70	0.47	3
	Perennial herb	1.74	2.06	0.46	7
	Annual herb	2.18	2.40	0.32	8
Anabasis salsa	Shrub	1.98	2.55	0.30	6
	Sub shrub	0.43	0.90	0.86	3
	Perennial herb	1.9	2.72	0.31	5
	Annual herb	1.52	1.67	0.49	6
Artemisia arenaria	Shrub	1.58	3.32	0.33	3
	Sub shrub	1.26	0.63	0.47	3
	Perennial herb	1.76	0.95	0.36	5
	Annual herb	2.58	1.52	0.19	7
Haloxylon ammodendron	Shrub	1.42	2.98	0.40	3
	Sub shrub	1.98	3.29	0.26	4
	Perennial herb	1.82	2.60	0.36	5
	Annual herb	2.30	2.73	0.24	7
Ceratoides latens	Shrub	1.81	2.59	0.35	5
	Sub shrub	1.66	2.76	0.39	4
	Perennial herb	1.82	2.60	0.36	5
	Annual herb	2.30	2.73	0.24	7
Desert community **(Tacheng region)**	life-forms	H	JP	S	R
Seriphidium schrenkianum	Shrub	0.93	1.19	0.72	6
	Sub shrub	1.02	2.06	0.62	3
	life-forms	H	JP	S	R

Note: H:Shannon-Wiener; JP : Pielou; S:Simpson; R:Patrick.

Desert community (Aletai region)	**life-forms**	**H**	**JP**	**S**	**R**
(continued 1)	Perennial herb	1.47	2.43	0.45	4
	Annual herb	3.02	2.51	0.20	16
Kochiaprostrata	Shrub	1.52	3.18	0.36	3
	Sub shrub	1.42	2.37	0.45	4
	Perennial herb	2.05	2.86	0.28	5
	Annual herb	2.72	2.71	0.19	10
Reaumuria soongorica	Shrub	2.21	2.62	0.26	7
	Sub shrub	0.99	3.30	0.52	2
	Perennial herb	1.34	2.22	0.52	4
	Annual herb	2.61	2.60	0.21	10
Nanophyton erinaceum	Shrub	1.31	2.17	0.50	4
	Sub shrub	1.38	2.89	0.41	3
	Perennial herb	0.99	3.28	0.51	2
	Annual herb	3.05	2.59	0.16	15
Desert community **(Changji-Urumqi)**	life-forms	H	JP	S	R
Petrosimonia sibirica	Shrub	1.54	1.04	0.35	3
	Sub shrub	0.54	0.60	0.78	2
	Perennial herb	2.87	2.28	0.15	8
	Annual herb	2.35	1.09	0.33	14
Seriphidium schrenkianum	Shrub	0.21	0.15	0.77	4
	Sub shrub	1.25	0.77	0.50	3
	Perennial herb	2.79	1.67	0.17	9
	Annual herb	2.48	1.24	0.26	12
Reaumuria soongorica	Shrub	1.11	2.32	0.51	3
	Sub shrub	1.90	3.16	0.28	4

Note: H:Shannon-Wiener; JP : Pielou; S:Simpson; R:Patrick.

Desert community (Aletai region)	life-forms	H	JP	S	R
	Perennial herb	2.13	2.72	0.30	6
	Annual herb	2.02	2.56	0.32	6
(continued 2)	life-forms	H	JP	S	R
Haloxylon ammodendron	Shrub	1.05	0.63	0.50	2
	Sub shrub	1.87	1.29	0.26	4
	Perennial herb	2.62	1.59	0.15	10
	Annual herb	2.86	1.43	0.24	8
Ceratocarpus utriculosus	Shrub	2.15	3.28	0.26	4
	Sub shrub	1.58	3.31	0.33	3
	Perennial herb	1.55	2.57	0.44	4
	Annual herb	2.75	2.99	0.18	8
Nanophyton erinaceum	Shrub	0.54	1.80	0.78	2
	Annual herb	1.48	2.47	0.40	4
Desert community **(East Tianshan Desert)**	life-forms	H	JP	S	R
Iljinia regelii	Shrub	1.21	2.52	0.48	3
	Perennial herb	1.50	3.15	0.38	3
	Annual herb	0.49	1.65	0.82	2
Ephedra przewalskii	Shrub	0.92	3.05	0.55	2
	Sub shrub	1.24	2.52	0.46	3
	Perennial herb	0.95	3.31	0.50	2
	Annual herb	0.94	3.32	0.50	2
Halostachys caspica	Shrub	1.20	1.42	0.33	5
	Annual herb	1.24	1.44	0.36	6
Note: H:Shannon-Wiener; JP : Pielou; S:Simpson; R:Patrick.					

The average annual temperature in the Altay Desert is 3 ~ 4°C, and the average annual precipitation is approximately 250 mm. The precipitation in the Altay Desert area increases with increasing altitude, while the temperature decreases with increasing altitude. According to relevant literature and field investigations, the Altay Desert is a typical steppe and desert steppe type. The dominant species are *Festuca sulcata* and *Stipa Capillata*. *Seriphidium gracilescens* and *S. terrae-albae* et al are the main components. *Stipa orientalis* and *S. glareosa* are distributed in the eastern Altay Desert area. The desert composed of *S. gobica* and *Seriphidiumsp*. is found in the foothill sloping plain of Qinghe County and its southern area. The communities of *S.glareosa*, *Allium polyrrhizum* and *Nanophyton erinaceum* and the steppe desert formed by *Ceratoides latens* and *S.glareosa* were mainly distributed in some sandy and gravel soils. The desert community of anabasis salsa grows in the stony sloping piedmont plain.

The results also showed that the true steppe (shrub steppe) was dominant in Altai city and rich deserts at altitudes of 800 ~ 1200 m and 1400 ~ 1600 m, and the festica-stipa steppe was mainly distributed in flat mountain valleys. There is shrubby steppe development on the hillside, but the soil layer is relatively thin and contain a higher proportion of gravel. *Spiraea hypericifolia* and *Rosa spinosissima* are the main species of shrubby steppe. Stipa SPP., however, grows in the western part of the region and is relatively abundant. In the northwest of the Altai Mountains, in the lower parts of the low mountainous areas of Habahe County and Buerjin County, the vegetation of mountain steppe is mainly found and distributed in *S.kirghisorum*, *Spiraea hypericifolia*, *Rosa spinosissima* and other shrubs, and the number is relatively large.

Through a literature review and field investigation, it was found that the main vegetation species in the Tacheng Desert included ephemeral plants and artemisia desert, while the Pseudequilaria Desert became a hidden vegetation with sporadic distribution on some low Rocky Mountains. In spring, the lamella of short-growing and perennials is particularly developed. There was a positive correlation between annual herbaceous plants in summer and autumn, and the growth rate of vegetation was significantly affected by temperature ($P < 0.01$). In the Tacheng Desert, the altitude decreased from 1000 m to 500 m, surrounded by mountains in the north, east and south. The survey found that Artemisia desert grew on brown calcium soil, and Artemisia combined with different vegetation on different types of soil to form different communities. For example, Artemisia growing on loamy soil can form communities with perennial short-growing plants such as *Poa Bulbosa*, but Artemisia growing on gravelly soil can form communities with *Kochia prostrata*, while Artemisia growing on gravelly soil at high altitudes can form steppe deserts such as *Achnatherun splendens*is widely distributed on saline meadow soils in the Emin Valley, and *Phragmites australis* is localized in low-lying areas and forms swamps in some of them.

The survey found that in the Yili Desert, the altitude decreased from 700 m to 500 m, and the soil was mostly lime calcium soil. *Seriphidium borotalensis*, poa pratensis and other short perennial plants form deserts on loam lime soil. *Seriphidium borotalensis* and *Kochia prostrata* desert grow on gravel soil. Steppe deserts of *Seriphidium schrenkianum*, *Bothriochloa ischaemum*, and Stipa occur at high altitudes. The desert formed by *Nanophyton erinaceum* is distributed sporadically on gravelly old terraces. The desert formed by *Ceratoides latens* grows on sandy land in the western part of the Yili River valley but is not abundant. This shrub is mixed with *Astragalussp*, and the low-lying water is reed marsh.

The Changji-Urumqi Desert (Shawan County - Qitai County) is flat and sloped to the northwest. By referring to relevant literature in combination with field investigations, it is found that desert calcareous soil is developed in this desert area, and the typical grassland vegetation is the *Reaumuria soongorica* community. In sandy soil, *Reaumuria kaschgarica* and *Petrosimoniasibirica* et al. formed different communities. *Reaumuria soongorica and Halostachys Caspica* and *Kalidium foliatum* formed communities in the highly saline soil near rivers. There are usually patches of *Haloxylon ammodendron* desert in some dry gully sandy soils, and the Anabasis aphylla desert community is distributed on the cracked soil. The survey also found that in the low-lying land with a high groundwater level, there were more Halocnemum plants, which were composed of *Halostachys caspica*,Suaeda microphylla, *S.physophora*,*Kalidium foliatum*, Halocnemum strobilaceum, etc. In western Urumqi, the artemisia desert is often mixed with a considerable number of perennial short-lived plants, such as *Poa pratensis, Tulipa Biflora, Eremopyrum orientale* and *Trigonella arcuata*. Moreover, in some gravelly soils, there are also *Anabasis salsa* ,*Nanophyton erinaceum*or *Suaeda dendroides* desert communities.

The East Tianshan desert includes the Hami Basin, Turpan Basin and other areas. The altitude of the basin is below 500 m, the altitude of the low mountains is over 1000 m, and the altitude of the Gobi is approximately 1000 m. The climate in this desert area is harsh, and the annual precipitation is only 20 ~ 70 mm. By referring to relevant literature and combining with investigation and research, it is found that the plant composition of this desert area is poor. Typical species include *Nitraria sphaerocarpa*, *Zygophyllum xanthoxylum*, *Ephedra Przewalskii* and *Sympegma Regelii*. Saline meadow soil and saline soil are widely distributed in the bottom of Turpan Basin. The *Alhagi Sparsifolia* community and *Cynodon Dactylon* are widely distributed in saline meadow soil. The halophyte communities formed by *Halocnemum strobilaceum* are mostly developed in salinite. In the Hami Basin, when the elevation is reduced to 150–200 m, the plant composition is poor, the desert community is generally composed of *Halocnemum strobilaceum* and *Nitraria sphaerocarpa*, and other desert community species are relatively rare.

2.2 Distribution characteristics of species diversity in different desert communities in northern Xinjiang

2.2.1 Distribution characteristics of species diversity in the Altay Desert communities

As shown in Fig. 1A(a), community dominance could be measured using the Simpson dominance index, and this index showed a significant difference between the communities of *Seriphidium schrenkianum*,*Anabasis salsa* and other communities ($P < 0.05$). As shown in Fig. 1A(b), Pielou evenness variance analysis showed that there were significant differences between the communities of *Seriphidium schrenkianum*,*Anabasis salsa* ,*Agropyron desertorum* and other communities ($P < 0.05$). It was found that there was a negative correlation between the community dominance and evenness index of *Seriphidium schrenkianum*,*Anabasis salsa*. As shown in Fig. 1A(c), there was no significant difference in Shannon–Wiener diversity among the communities of *Seriphidium schrenkianum*,*Agropyron* *desertorum,Haloxylon ammodendron and Ceratocarpus utriculosus* ($P > 0.05$), but there was a significant difference between *Anabasis salsa* and *Seriphidium schrenkianum,Agropyron desertorum,Haloxylon ammodendron and Ceratocarpus utriculosus* ($P < 0.05$). Figure 1A(d) shows that differences in richness existed among communities. Combined with Table 2, it can be seen that the Patrick index of annual and perennial herbs and shrubs and Subshrubs in each community showed opposite results. The richness index of herbs was higher, while that of shrubs and Sub shrubs was lower.

Correlation analysis of Patrick, Pielou, Shannon–Wiener and Simpson indices in the Altay Desert community showed that Shannon–Wiener was significantly correlated with the Patrick index H = 4.241 r-1.964 R2-0.08 ($R = 0.862$, $P < 0.05$) was significantly correlated with the evenness index H = 0.267 + 1.475JP-0.314JP2 ($r = 0.918$, $P < 0.001$) and was negatively correlated with the Simpson index H = 3.425-5.414s + 2.279S2 ($r = 0.897$, $P < 0.01$). It follows that the Patrick index contributes less to diversity than uniformity. In the Altay Desert area, there is a large variation in the microenvironment in the grassland distribution. Although species richness is high in the macro environment, there are few species suitable for growth due to the influence of the microenvironment.

2.2.2 Species diversity distribution characteristics of different community types in the Tacheng Desert

As shown in Fig. 1B(a), *Seriphidium schrenkianum* showed a higher level of dominance, while *Kochia prostrata* showed a lower level of dominance. Figure 1B(b) shows that the evenness level of *Kochia prostrata* is relatively high, while the evenness level of *Seriphidium schrenkianum* is relatively low. There were significant differences in the dominance and evenness index between *Seriphidium schrenkianum* and the other communities ($P < 0.05$). As shown in Fig. 1B(c), the Shannon–Wiener diversity index of *Seriphidium schrenkianum* and *Nanophyton erinaceum* communities was significantly different from that of *Kochia prostrata* and *Reaumuria soongorica* communities ($P < 0.05$), and the diversity index of *Kochia prostrata* communities was higher. Figure 1B(d)shows that *Seriphidium schrenkianum* community was relatively high at the Patrick richness level, and there was a significant difference between the community and other communities ($P < 0.05$).

The results of correlation analysis of Patrick, Pielou, Shannon–Wiener and Simpson indices in the Tacheng Desert community showed that Shannon–Wiener had a very significant linear correlation with richness index H = 0.793 + 0.155r ($R = 0.912$, $P < 0.000$). It also showed a significant linear correlation with evenness (H = 0.854jP-0.159) ($R = 0.75$, $P < 0.05$) and a very significant negative correlation with the dominance index (H = 3.399-4.164s, $R = 0.932$, $P < 0.000$). These results indicated that community richness contributed more to plant diversity than evenness.

2.2.3 Distribution characteristics of species diversity in different community types in the Changji-Urumqi Desert region

As shown in Fig. 2A(a), the Simpson dominance was highest in *Nanophyton erinaceum*, which was significantly different from other communities ($P < 0.05$). As shown in Fig. 2A(b), the evenness of Pielou of *Ceratocarpus utriculosus* community type was higher and lower in *Seriphidium schrenkianum*, and the evenness index of *Nanophyton erinaceum* was significantly different from that of other communities ($P < 0.01$). As shown in Fig. 2A(c), *Haloxylon ammodendron* had the highest Shannon–Wiener diversity index, followed by *Ceratocarpus utriculosus*, and *Nanophyton erinaceum* had the lowest diversity index, and there was a significant difference between *Nanophyton erinaceum* and the other communities ($P < 0.01$). As shown in Fig. 2A(d), the Patrick richness level of *Petrosimonia sibirica*, *Seriphidium schrenkianum*and *Haloxylon ammodendron* communities was relatively high, showing extremely significant differences with that of *Nanophyton erinaceum*,*Reaumuria soongorica* and *Ceratocarpus utriculosus*($P < 0.01$). Meanwhile, there was no significant difference between *Reaumuria soongorica* and *Ceratocarpus utriculosus* ($P > 0.05$), but there was a significant difference between *Reaumuria soongorica,Ceratocarpus utriculosus* and *Nanophyton erinaceum* ($P < 0.05$).The correlation analysis of the Patrick richness index, Pielou evenness index, Shannon–Wiener diversity index and Simpson dominance index showed that there was a significant linear correlation between the diversity index and richness index $H = 0.599 + 0.234R$ ($R = 0.876$, $P < 0.000$), was significantly linearly correlated with the evenness index $H = 0.662 + 0.889JP$ ($r = 0.757$, $P < 0.01$) and was significantly negatively correlated with the dominance index $H = 3.23\text{-}3.84S$ ($r = 0.952$, $P < 0.000$). The results showed that species richness had a greater impact on species diversity in the Changji-Urumqi Desert area, and the contribution rate of evenness was relatively small.

2.2.4 Distribution characteristics of species diversity in different community types in the East Tianshan Desert

As shown in Fig. 2B(a), there was a significant difference in the dominance index between the communities of *Iljinia regelii* and *Ephedra przewalskii* and *Halostachys caspica* ($P < 0.05$), and the dominance index of *Halostachys caspica* community was relatively high, up to 0.36. Figure 2B(b) shows that the Pielou evenness of *Ephedra przewalskii* community was relatively high, and variance analysis showed that the Pielou evenness index of the three communities was significantly different ($F = 3.252$, $P < 0.05$). As shown in Fig. 2B(c), the Shannon–Wiener diversity index of the *Iljinia regelii* and *Ephedra przewalskii* communities in the eastern Tianshan Desert area was not significantly different ($P > 0.05$) but was significantly different from that of *Halostachys caspica* communities ($P < 0.05$). As shown in Fig. 2B(d), there was no significant difference in Patrick richness between *Iljinia regelii* and *Ephedra przewalskii* communities ($P > 0.05$), but there was a significant difference between them and *Halostachys caspica* communities ($P < 0.05$).

The correlation analysis of the Patrick richness index, Pielou evenness index, Shannon–Wiener diversity index and Simpson dominance index showed that there was a significant linear correlation between diversity and richness index $H = 0.414 + 0.301R$ ($R = 0.914$, $P < 0.05$) and was significantly linearly correlated with evenness index ($H = 0.427jP\text{-}0.272$ ($r = 0.897$, $P < 0.006$) and significantly negatively correlated with dominance index (S) ($H = 1.776\text{-}3.145s$ ($r = 0.979$, $P < 0.000$)). This indicated that there was no significant difference in the contribution of community richness and evenness to diversity in the eastern Tianshan Desert, and the contribution of community richness to diversity was slightly higher than that of evenness.

2.3 Influencing factors of desert community species diversity in northern Xinjiang

2.3.1 Impacts of climate and altitude factors on species diversity

The results showed that average annual temperature (MAT), average annual rainfall (MAP) and altitude (ELE) had significant effects on the species diversity of desert communities in northern Xinjiang (Table 3). The patch richness index was negatively correlated with MAT ($P < 0.01$) and altitude ($P < 0.01$) and positively correlated with MAP ($P < 0.01$). Simpson dominance was significantly ($P < 0.05$) and extremely significantly ($P < 0.01$) positively correlated with MAT, MAP and altitude. Pielou evenness was negatively correlated with precipitation and elevation ($P < 0.01$) but not significantly correlated with average annual temperature (MAT). The Shannon–Wiener index showed an extremely significant negative correlation with increasing temperature and altitude ($P < 0.01$), and the increase in annual precipitation showed an extremely significant positive correlation ($P < 0.01$).

2.3.2 Stepwise multivariate analysis of the main driving factors affecting the species diversity of desert communities in northern Xinjiang

The results showed that through multiple stepwise regression analysis of desert species diversity in northern Xinjiang (Table 4) Among the response factors, annual mean rainfall and annual mean temperate altitude were introduced into the regression equation to explain the Patrick index, Simpson index, Shannon–Wiener index and Pielou index. MAP was found to be an important climate influencing factor for the Patrick, Shannon–Wiener and Simpson indices, which accounted for 78% of the richness index, 60.7% of the Shannon–Wiener index and 79.9% of the dominance index. Elevation and annual mean precipitation were introduced into the regression equation of the Pielou index. It was found that the altitude factor, as an important influencing factor, explained 50.7% of the evenness index.

Table 3 Pearson correlation analysis between species diversity indices and climatic factors of Desert communities in northern Xinjian

diversity	mat	MAP	Elevation
Patrick index	-0.243**	0.531**	-0.331**
Shannon-Wiener index	-0.388**	0.726*	-0.534**
Simpson index	0.440*	0.525**	0.268**
Pielou index	-0.015	-0.171**	-0.727**

Table 4 Results of stepwise regression analysis of species diversity of desert communities in northern Xinjiang

Dependent variable	VE	Adjusted R^2	P value
Patrick index	MAP	0.780	0.001
	ELE	0.814	0.020
Shannon-Wiener index	MAP	0.607	0.000
	ELE	0.658	0.005
Simpson index	MAP	0.799	0.000
	MAT	0.871	0.030
Pielou index	ELE	0.507	0.003
	MAP	0.561	0.005

3 Discussion

To address the increasingly serious desertification, although the desert ecosystem has been improved to a certain extent, there are still many challenges that require long-term efforts to realize the sustainable development of the ecosystem.

A. The study showed that the Pielou and Simpson dominance indices and Shannon–Wiener diversity of plant diversity in northern Xinjiang showed a trend of gradual decline, different life types of plants in the community entered the late growing season (September), and the desert composition of Artemisia and Halophyta. Some communities had only 1 or 2 species (Hami area), and the richness of plants decreased significantly, leading to a declining trend of the diversity index as the growing season continued[30–32]. Western Hebei corridor desert species rare, low abundance, simple community structure, uneven distribution of species, species diversity overall level is low, and desert community species diversity was positively related to the overall annual average rainfall. Overall, showed a negative correlation with annual average temperature[20], rainfall affects the species diversity, and ecological system is one of the most important factors[33]. An investigation of the community species diversity in the desert region of Alxa Left Banner in Inner Mongolia showed that the overall species diversity in the desert region was relatively low, with Shannon–Wiener diversity and Simpson dominance indices ranging from 0.25 to 0.75[18]. The overall species diversity of the desert oasis transition zone in Fukang, Xinjiang, was low, and the Shannon–Wiener diversity was 0.4819-1.5689[34].

B. Other studies showed that although the annual mean precipitation and annual mean temperature of desert Gobi in the western part of the Hebei Corridor were positively and negatively correlated with species diversity, the correlation was not significant ($P > 0.05$)[20]. In a study of the desert community in the Altun Mountains Nature Reserve, species diversity showed obvious changes with the altitude gradient[19].

However, this study showed that the overall level of species diversity of desert communities in northern Xinjiang was not high, and the average species diversity index of northern Xinjiang was 1.79. The Shannon–Wiener diversity was the highest in the annual herbaceae in the Desert of Bortala, and the diversity index was 3.33. Annual mean precipitation and elevation gradient were important factors that significantly affected the species diversity of desert communities in northern Xinjiang. Annual mean precipitation was significantly positively correlated with species diversity, while annual mean temperature was significantly negatively correlated, which was consistent with the conclusion of Study A. The reasons for this discrepancy are as follows: (1) species diversity, in addition to the influence of precipitation and temperature, is also affected by the sample survey point to differences in the environment[20]. In a large range of scale, temperature and precipitation are important factors affecting species richness and diversity[35], but the scale range and variety are more easily affected by local factors such as topography and soil. For small-scale plant community species diversity, habitat differences are the main cause of changes in plant community structure and composition[10,19], and there are spatial scale differences in response to environmental factors[36]. However, temperature and water are the most basic factors that affect species diversity[10]. (2) In addition to the impact of different research scales on species diversity, the impact of "species competition" at the quadrat scale should also be considered, which may have an interaction on species diversity[20].

In future studies, information and data on factors influencing species diversity should be obtained as much as possible, such as topographic factors (slope, aspect, etc.), and the main driving factors influencing species diversity should be analysed by combining them with natural environmental factors such as climate and soil and human disturbance factors such as population[11,20].

4 Conclusion

The species diversity of desert communities in northern Xinjiang was relatively low(Table 2).The average diversity index is 1.79, the Shannon–Wiener diversity value ranges from 0.21 to 3.33, and the Pielou average index is 2.25. The Pielou index of shrubs of *Artemisia arenaria* community and sub shrubs of *Haloxylon ammodendron* community in the Altay area,and perennial herbs were dominate in the *Iljinia* *regelii* community, as well as sub shrubs, perennial herbs and annual herbs in *Ephedra przewalskii* community in the East Tianshan Desert,and In the Tacheng area, shrub of *Kochia prostrata* community, sub shrub and perennial herbs of *Reaumuria soongorica and Nanophyton erinaceum* community,and sub shrubs and shrub of *Reaumuria soongorica* and *Ceratocarpus utriculosus* community in the Changji-Urumqi area was higher than that of other community types, ranging from 3.04 to 3.32. The Simpson index of each region was 0.35, and there was a significant difference among the different communities ($P < 0.05$). The Simpson dominance index of sub shrubs of *Anabasis salsa* community in the Altay region and annual herbs in the *Iljinia regelii* community in the East Tianshan Desert were relatively higher. The mean value of Patrick of desert species in northern Xinjiang was 5.8. Annual rainfall and annual temperature and altitude gradients could influence species diversity, and annual rainfall and altitude gradients were the main driving factors.

As shown in Fig. 3, the Simpson level in the western part of the northern Xinjiang desert area is lower than that in the eastern part, the Patrick level in the western part is higher than that in the eastern part, and the Pielou and Shannon–Wiener levels in the western part are higher than those in the eastern part.

5 Methods

5.1 Study area

The study area (41.1°–49.3°N and 79.8°–91.6°E) is located in the desert area of northern Xinjiang (Fig. 4a), with a total land area of 4500×104 hm2, including 3000×104 hm2 of natural grassland. The geographical coordinates are located between 41.1° n ~ 49.3° and 79.8° E ~ 91.6°, and the "alternation" between mountains and basins is the main geomorphic feature of northern Xinjiang. The annual mean temperature of the Junggar Basin is 5-7.5°C, that of the Altay and Tacheng areas is 2.5-5°C, and that of the Turpan and Hami basins is 9.8–13.9°C. The precipitation distribution of desert in northern Xinjiang is greater in the west than in the east and greater in the basin margin than in the centre. The precipitation in the western margin of the Junggar Basin is 200–250 mm, the precipitation in the northern and southern margins is approximately 200 mm, and the precipitation in the centre of the basin is approximately 100–150 mm. Approximately 34.6 mm is in the Hami area, located in eastern Junggar Basin, and the vertical variation in precipitation in the mountain area is significant. The annual average relative humidity in northern Xinjiang is approximately 60%, the dryness in most areas of the Junggar Basin is between 4 and 9, and the dryness in the Hami and Turpan desert areas in eastern Junggar is above 12. The soil in the Tacheng Basin and most of the northern Junggar Basin is dominated by brown calcium soil and transitioned to light brown calcium soil to the south. In the vast area of Yili Valley, the soil is dominated by "grey calcium soil". Regional differences in precipitation and mountain precipitation exhibit clear vertical differences between significant changes in desert vegetation area and zonal distribution. According to the characteristics of northern Xinjiang landform, soil type, climate and desert vegetation distribution characteristics, the research is divided into four deserts: the Tacheng-Yili Desert, the Altay Desert, the ChangjiUrumqi Desert and the East Tianshan Mountain Desert[37].

5.2 Experimental design and sampling

The field survey of desert communities in northern Xinjiang was conducted using the conventional sample method, and the main community types were determined by dominant species and importance values[38]. From July to September 2017 to 2019, 527 representative desert plant communities sample site were selected for investigation (Fig. 4a), including 114 in the Altay Desert, 239 in the Tacheng-Yili Desert, 132 in the Changji-Urumqi Desert and 42 in the East Tianshan Mountain Desert, with a total of approximately 4500 quadrats(Each sample site contained 9 quadrats). Four 100 m typical transect zones were selected for each area, the spacing between transect zones was more than 50 m, and a 1 m×1 m quadrat was arranged at an interval of 25 m. The position and size of each quadrat consisted of a square with sides of 1 m, resulting in an area of 1 m^2 (Fig. 4b). Each quadrat was divided into 100 grid cells (A1-J10, 0.1 m × 0.1 m; Fig. 4b).

5.3 Field vegetation survey and sampling

Field survey sampling was conducted in two stages: the first stage involved the wooden base and eastern Junggar Desert of eastern Tianshan area Barkol County, state, such as the eastern desert vegetation investigation in the Junggar Basin; the second stage involved the Junggar Basin, the northern Junggar Basin and the Junggar Basin in the western desert vegetation investigation. Part of the observation records the ground vegetation quantity characteristics of plants and registration details the types of survey samples of species using the method of "visual" and "measurement" survey, respectively, to evaluate the community coverage (%) samples as well as to the bundle height and density measure (plant/m^2); the statistics of each species in the samples are used to calculate frequency. Then, the samples were collected within minutes (cutting the live ground parts and measuring the live weight (g/m^2) of the plants). After the last cut, all species in the herb samples were collected, litter was collected and withered, and good surface form litter samples were collected and then weighed (g/m^2) into bags and marked in detail using paper wrapped after returning to the lab. The plant samples were placed in an oven for 30 min and then dried at 105°C for 24 h. The dry weight (g/m^2) was measured at 80°C. For the subsurface part of plants, the underground biomass of vegetation (BGB) was measured and recorded. Soil samples were collected with a soil sampler at a depth of 100 cm, and the soil profile method was used to dig the soil in each sample area at depths of 0 ~ 5 cm, 5 ~ 10 cm, 10 ~ 20 cm, 20 ~ 30 cm, and 30 ~ 50 cm. Samples from 50–70 cm and 70–100 cm were stratified (7 layers) in turn (Fig. 4b), and root samples from the same soil layer in each plot were mixed and put into nylon bags (pore size: 2 mm) and brought back to the laboratory for cleaning and obtaining root samples.

5.4 Data processing and analysis

Community species diversity has two meanings: species richness and species diversity, which can reflect important characteristics of community organization structure [32]. Based on the plant diversity calculation formula, α diversity was analysed according to different community types in different desert areas. The common Patrick richness index, Simpson index, Pielou evenness index and Shannon–Wiener index were used to measure diversity.

First, the importance value of species was calculated according to the height, coverage, frequency and density of shrubs and herbs in each quadrat (IV):

Importance value (IV) = (relative height + relative coverage + relative density + relative biomass)/4 (1)

Second, the diversity index was calculated according to the importance value of species in the quadrat:

(1) Patrick index (R_p): $R_p = S$ (2)

where S is the average number of species in the quadrat.

(2) Simpson index $D_s = 1 - \sum_{i=1}^{s} n_i (n_i - 1) / N (N - 1)$ (3)

where S is the average number of species in the quadrat.where N is The total number of individuals of all species in a community,where n_i is Number of individuals of species i。

(3) Pielou index (P): $P = H / H'_{MAX}$ (4)

(4) Shannon–Wienerindex: $H' = -C \sum p_i \log_2 P_i$ (5)

In the above formula, C is a constant, usually set as C = 1, and Pi is the probability of the ith species. When the number of species increases and the number of individuals is increasingly evenly distributed with existing species, the uncertainty increases significantly, and the diversity increases[39]. The normal value of the Shannon–Wiener index is between 1.5–3.5. However, this value is no more than 4.5[40].GPS was used to collect the longitude and latitude as well as altitude values of each sample site. The experimental data were integrated with the meteorological data of the Xinjiang Meteorological Station and Xinjiang Yearbook (2017–2018). We used "Extract Multi Values To" in ARCPY (Arcgis official Python programming data processing function library). The points module extracts the multitemporal temperature and precipitation raster data obtained from the WorldClim (www.worldclim.org/) database. After data extraction, the rainfall and temperature values of each desert sample site are obtained by using the spatial link function of ArcGIS.Pearson correlation analysis between different environmental factors and species diversity was completed by SPSS 21.0, and multiple step-step regression analysis was conducted to determine the main driving factors affecting species diversity. Preliminary data processing and analysis were completed under WPS office19, and graph drawing and processing were completed under R 3.4.1 and Sigmaplot 14.0. Finally, the spatial distribution of biodiversity in desert communities in northern Xinjiang was plotted by inverse distance weighted kriging interpolation using the geostatistical analysis tool ArcGIS10.4.1.

Declarations

Data availability

The datasets generated during and/or analysed during the current study are not publicly available due to [REASON(S) 1.privacy reasons;2.Since our experimental project is still in progress, our research has not been finalized. This study is only a stage of our research results, and we will continue to carry out subsequent investigations and studies to ensure that our research can be successfully completed. Therefore, all data in this study cannot be disclosed.] but On the premise of not violating the privacy principle and not affecting our research, partial data can be obtained from corresponding authors upon reasonable request.

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Author contributions

Conceived and designed the experiments: SZA YQD . Performed the experiments:YQD CF SZA. Analyzed the date: CF YQD . Contributed reagents/materials/analysis tools: YQD CF. Wrote the paper: CF YQD.

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Competing interests

The author(s) declare no competing interests.

Permissions or licenses of collect Desert Plant samples were obtained,and All the plant experiments were in compliance with relevant institutional, national, and international guidelines and legislation.

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Figures

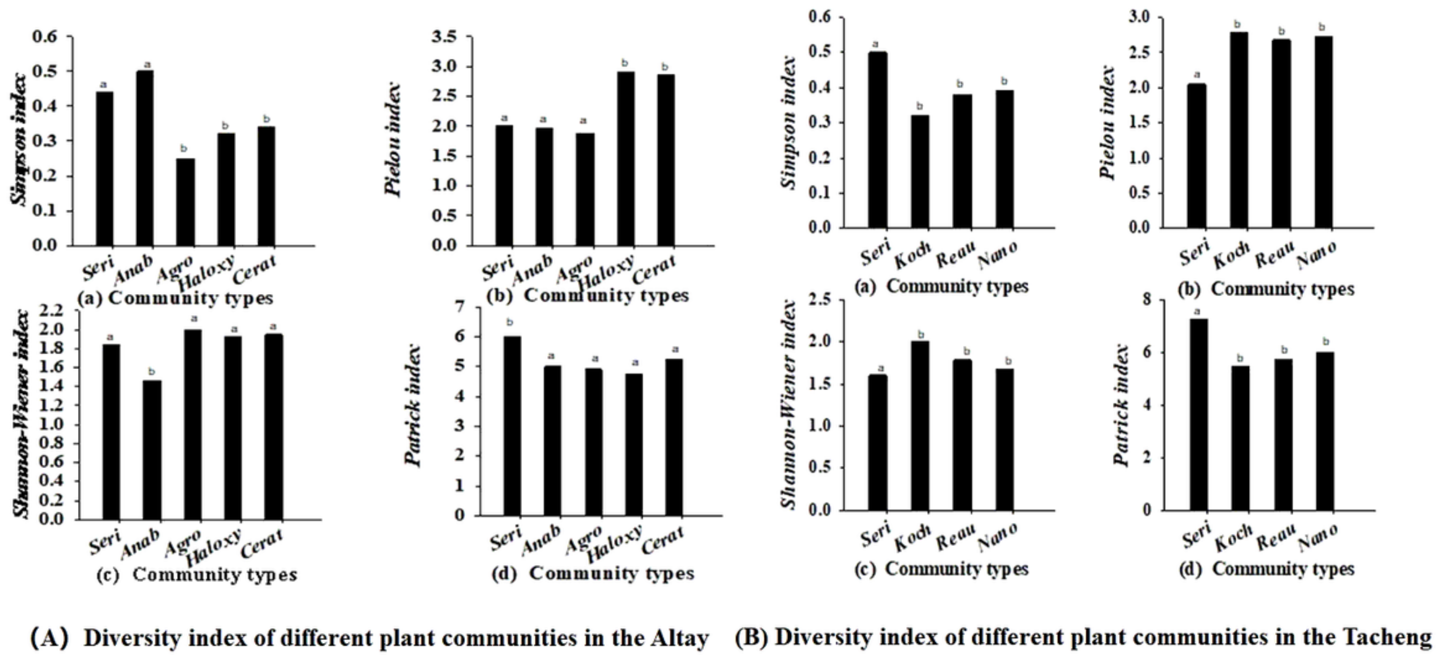


Figure 1

Diversity index of different plant communities in the Altay and Tacheng Desert Region

(A) *Seri---Seriphidium schrenkianum;Anab---Anabasis salsa;Agro---Agropyron desertorum;Haloxy---Haloxylon ammodendron;Cerat---Ceratocarpus utriculosus*

(B) *Seri---Seriphidium schrenkianum;Koch---Kochia prostrata;Reau---Reaumuria soongorica;Nano---Nanophyton erinaceum*

Note: Different lowercase letters show significant differences at the 0.05 level between different communities in the same diversity index, the same below.

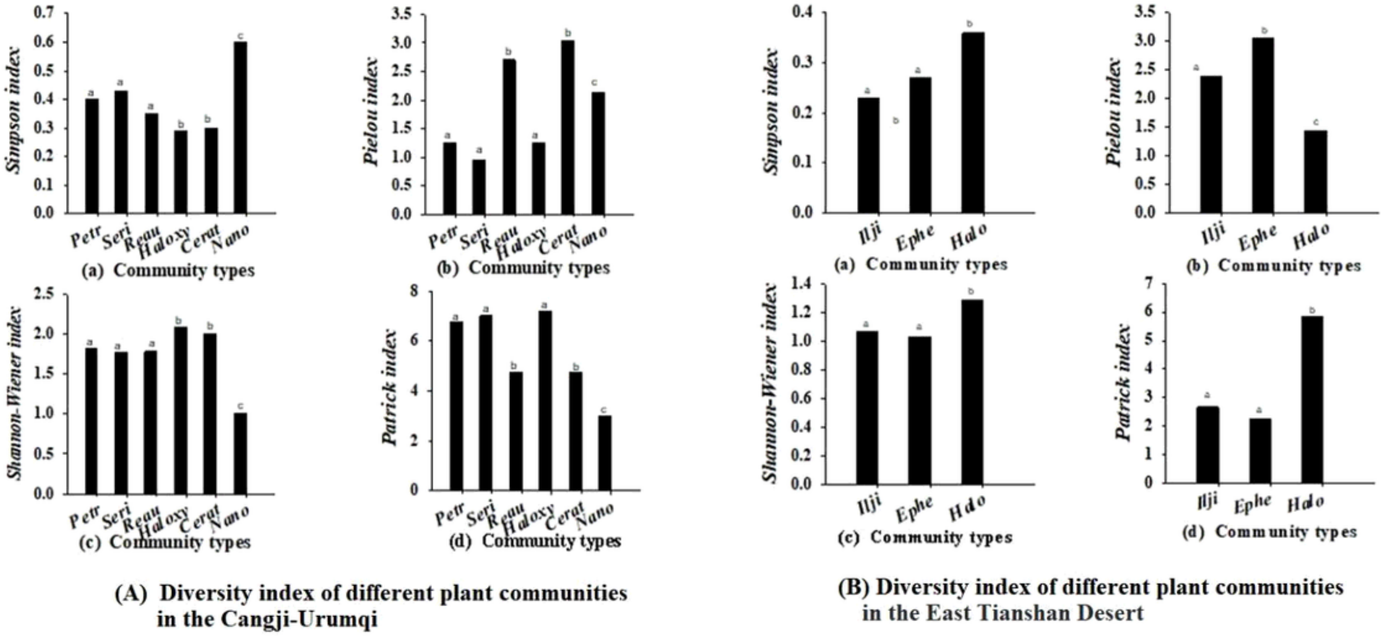


Figure 2

Diversity index of different plant communities in the Cangji-Urumqi and East Tianshan Desert

(A) *Petr---Petrosimonia sibirica;Seri---Seriphidium schrenkianum;Reau---Reaumuria soongorica;Haloxy---Haloxylon ammodendron;Cerat---Ceratocarpus utriculosus;Nano---Nanophyton erinaceum*

(B) *Ilji---Iljinia regelii;Ephe---Ephedra przewalskii;Halo---Halostachys caspica (Bieb.) C. A. Mey*

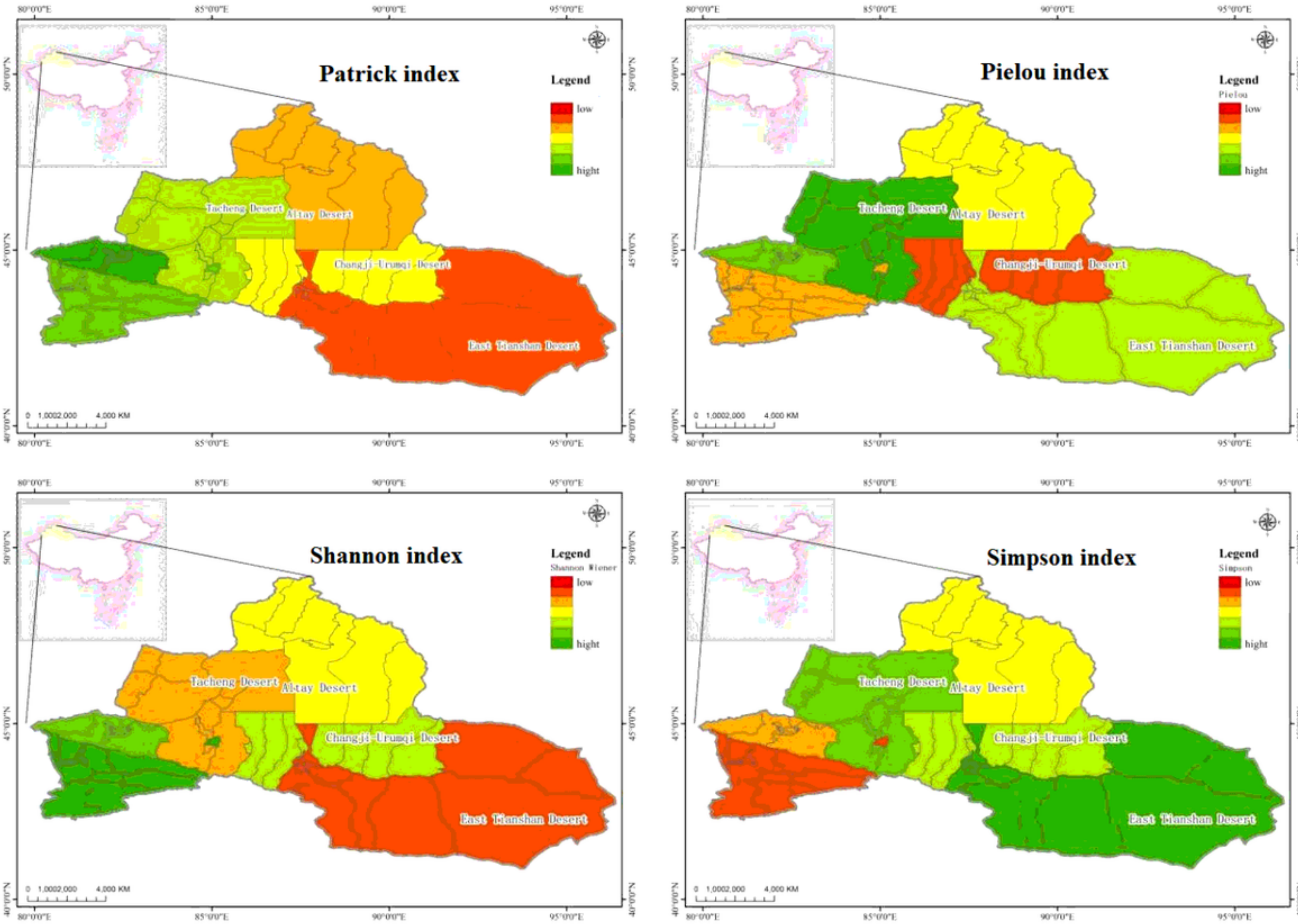
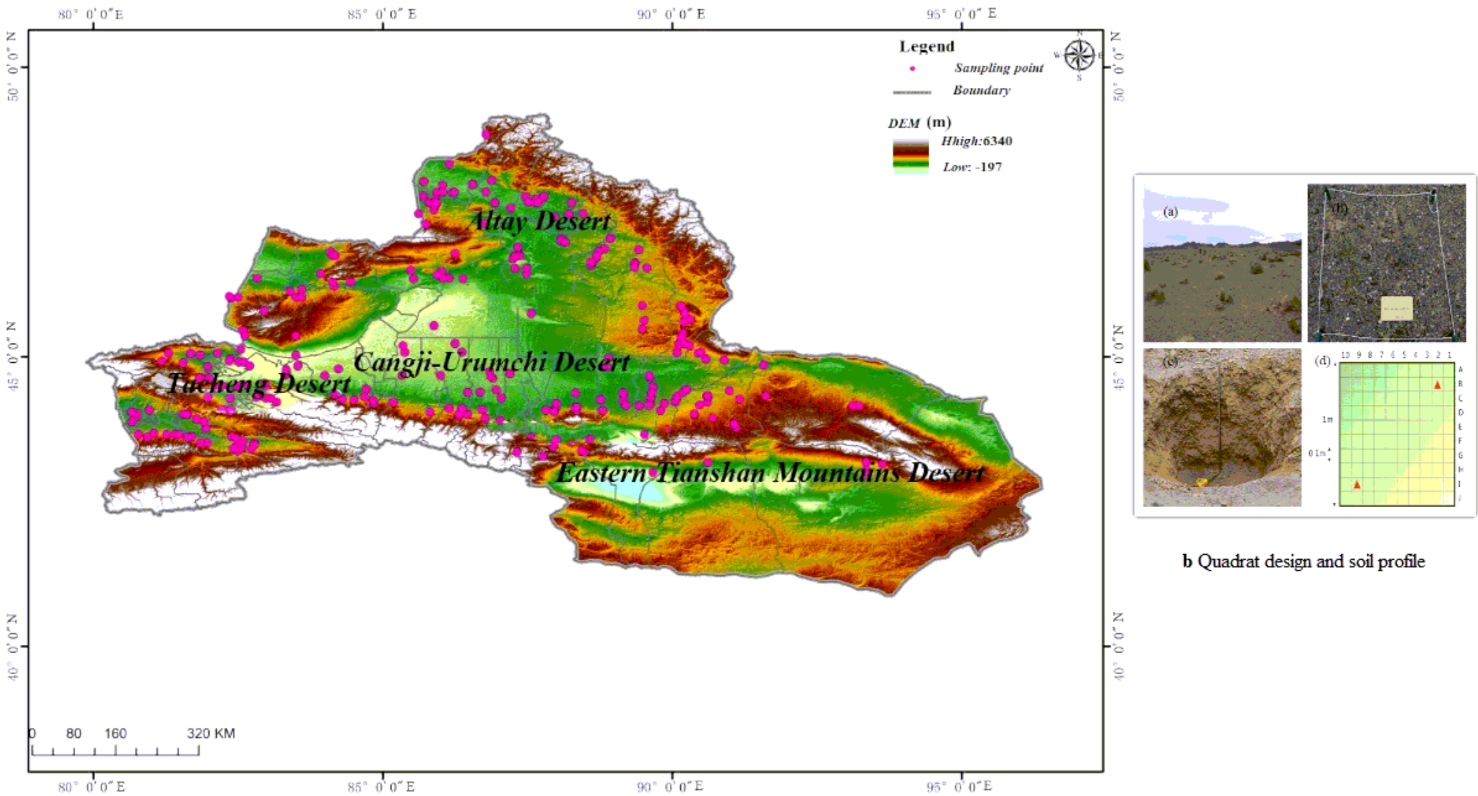


Figure 3

Spatial distribution of desert plant diversity in northern Xinjiang



b Quadrat design and soil profile

a Spatial distribution of the plots in the study area

Figure 4

Spatial distribution of the plots and Quadrat design and soil profile in the study area