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RESEARCH ARTICLE

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Spatial pattern of a plant community in a wetland ecosystem in a semi-arid region in northwestern China

Abstract The spatial distribution characteristics of plant communities in a wetland-dry grassland ecosystem in arid and semi-arid regions in northwestern China and the main factors affecting the distribution pattern were studied. The Siertan wetland in the Haba Lake Nature Reserve was the study area. Four transect lines, each about 1 km long, were set up in the growing season along the biotope gradient in four directions: east, northeast, west and northwest. Attributes measured include frequency of occurrence, height, density, coverage, biomass and environmental soil factors. The data were analyzed using a two-way indicative species analysis (TWINSPAN), detrended correspondence analysis (DCA) and Spearman correlation coefficients. On this basis, the vegetation in the Siertan wetland was classified into three types and 14 associations. The first vegetation type was halophytic marsh vegetation, mainly distributed in the wetland zone. This type largely contains halophyte and hygric plants and its representative association is *Phragmites communis* + *Kalidium foliatum*. The second type was meadow vegetation, distributed in the ecotone. The meadow vegetation species are mainly mesophytic and their representative association is *Nitraria tangutorum* + *Pennisetum flaccidum*. The third vegetation type is grassland vegetation, which mainly consists of mesophytic and xerophytes, distributed in the arid grassland zone. The representative association of the third vegetation type is the association of *Anaeurolepidium secalium* + *Saussurea runcinata*. Correlation analysis between the axes of DCA and environmental soil factors shows that soil moisture content, organic matter, soil salt content and total nitrogen are the main environmental factors affecting the pattern of vegetation distribution along the biotope gradients from wetland to arid grassland. Other factors affecting the vegetation are microtopography and grazing pressure. Additionally, we have reported modifications and improvements to the importance value methodology.

Keywords plant community, spatial distribution, TWINSPAN quantitative classification, DCA ordination, environmental interpretation

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1 Introduction

Wetland is the integrated body formed by the interaction between water and land. It is one of the important survival ecosystems with a rich biodiversity landscape for mankind (Chen, 1995) and is also called the "kidney of the earth" (Mitsch and Gosselink, 1986). Wetland vegetation is one of the components of wetland ecosystems and is one of the key attributes of wetlands. The structure, function and ecological characteristics of wetland vegetation can present basic wetland environmental and functional characteristics (Chen, 1995). Wetland studies started in Russia and many studies have been carried out since the 1950s by European and American researchers (Johson and Gage, 1997; Obeysera and Rutchey, 1997; Toner and Keddy, 1997; Jay and Suzanne, 1999; Flower et al., 2001). Studies have been also carried out in China in the past decades, but less attention has been paid to arid and semi-arid regions, especially on wetland community ecology. He (2003) has taken one wetland station belonging to the Chinese Academy of Sciences (CAS) and carried out research on the Sangjiangyuan wetland, in northeastern

China. Systemic research has been carried out on community ecological processes of wetland plants. It provides a theory supporting wetland community protection. Yu (1994) has carried out 10 years of field observations and station monitoring in a wetland in northeastern China on hydrophyte community dynamics and succession. The zone distribution rule in longitude and latitude has also been investigated. Li et al. (2003) studied cold wetland vegetation in the Qilan mountains and showed that it degraded from swamp wetlands to meadow wetlands because of increases in temperature, declining rainfall as well as anthropogenic factors. Tian (2005) studied high plateau wetlands in the Ruo-Er-Gai region and showed that as water decreases, plant community succession followed the path of hydrophyte vegetation → swamp vegetation → swamp meadow vegetation → meadow vegetation. Wu et al. (2005) adopted a two-way indicative species analysis (TWINSPAN) classification and detrended correspondence analysis (DCA) order methods on vegetation community research in the Hutuohe River wetland and qualitative studies have been carried out on factors affecting the spatial distribution of wetland vegetation.

Wetlands in the arid and semi-arid regions of China are a rare sight. They also play an important role in maintaining ecosystem equilibrium in given regions (Li et al., 2006). Therefore, they are very important in arid and semi-arid wetland vegetation studies. We have investigated the Siertan wetland in the Haba Lake Nature Reserve as our study area using TWINSPAN classification and DCA order methods to study vegetation attributes of spatial distribution patterns. At the same time, the impact of soil conditions on the spatial vegetation distribution pattern was also studied. This work aims to provide basic data and methods for arid and semi-arid wetland studies and theoretical support for wetland protection and the re-establishment of the Haba Lake Nature Reserve.

2 Study site

Yanchi County (37°04′–38°10′N, 106°30′–107°41′E) is situated in the eastern part of the Ningxia Hui Autonomous Region and has an area of 6700 km^2. The landform is a denudate peneplain, which is high in the south, low in the north, and has an elevation of 1295–1951 m. The physiognomy falls clearly into two landforms units: the loess bearing hills in the south and the gentle Ordos bearing hills to the north. It has a typical continental climate in the intermediate temperate zone, with an average annual temperature of 8.1°C. The annual frost-free period is 165 days, while annual precipitation is 250–350 mm. Precipitation decreases from the south to the north and from the southeast to the northwest. Most agrotypes are sierozem, calcic kastanozems and aeolian sandy soils, with a few solonchak and planosol soils. Vegetation types include shrubs, grassland, meadows and semi-desert vegetation, of which shrubs, grassland and semi-desert vegetation take up a high percentage with large distributions. Grasslands are categorized into arid grassland and desert steppe. The plant communities are xeromorphic and meso-xeromorphic.

The Haba Lake National Nature Reserve was established to protect wetlands as its main objective. It is located within Yanchi County. The Siertan wetland is one of the largest wetlands in the Haba Lake Nature Reserve, located 8 km south of the centre of Yanchi County. As a marsh with striking seasonal accumulated water, the water surface area of the wetland is largely affected by precipitation. Due to serious salinization, damp tolerant plants and saline-alkali tolerant plants such as *Phragmites communis*, *Kalidium foliatum* and *Nitraria tangutorum* are distributed in the area, mainly along the border. As for the grassland ecosystem, because of poor water conditions, common species are xerophytes and meso-xerophytes such as *Sphaerophysa salsula* and *Sophora alopecuroides*. Since the ecotone has better soil water conditions, plant species, including *Glaux maritima* and *Diarthron linifolium* found in the study area, are richer. The whole study area is divided into a wetland zone, an ecotone and an arid grassland zone according to habitat characteristics and vegetation types, which are referred to as "the three strips" (Fig. 1).

3 Study methods

3.1 Field investigation

Combined with the National Natural Science Foundation of China (30771764) and the National Desertification Position Monitoring Project of China, the research selected the Siertan wetland-arid grassland ecosystem of Haba Lake Nature Reserve of Yanchi County as a position monitoring site. Field investigations were carried out during the growth season from July to August over a number of years. In 2005, field work was done in late July and early August. The items investigated were species names, the number of plants of each species, coverage, height and biomass. A line-transect method was used. With the wetland as the center, four transect lines were set radially towards the west, the northwest, the east and the northeast (Fig. 1). Each line was more than 1 km long and covered the representative saline (the wetland zone), the entire ecotone and the representative arid grassland zone. Quadrates of 1 m × 1 m were used in our study. A total of 123 quadrates were investigated, of which 33 were in the east line and 30 each in the northeast, the west and the northwest lines. Most plants are annual herbage.

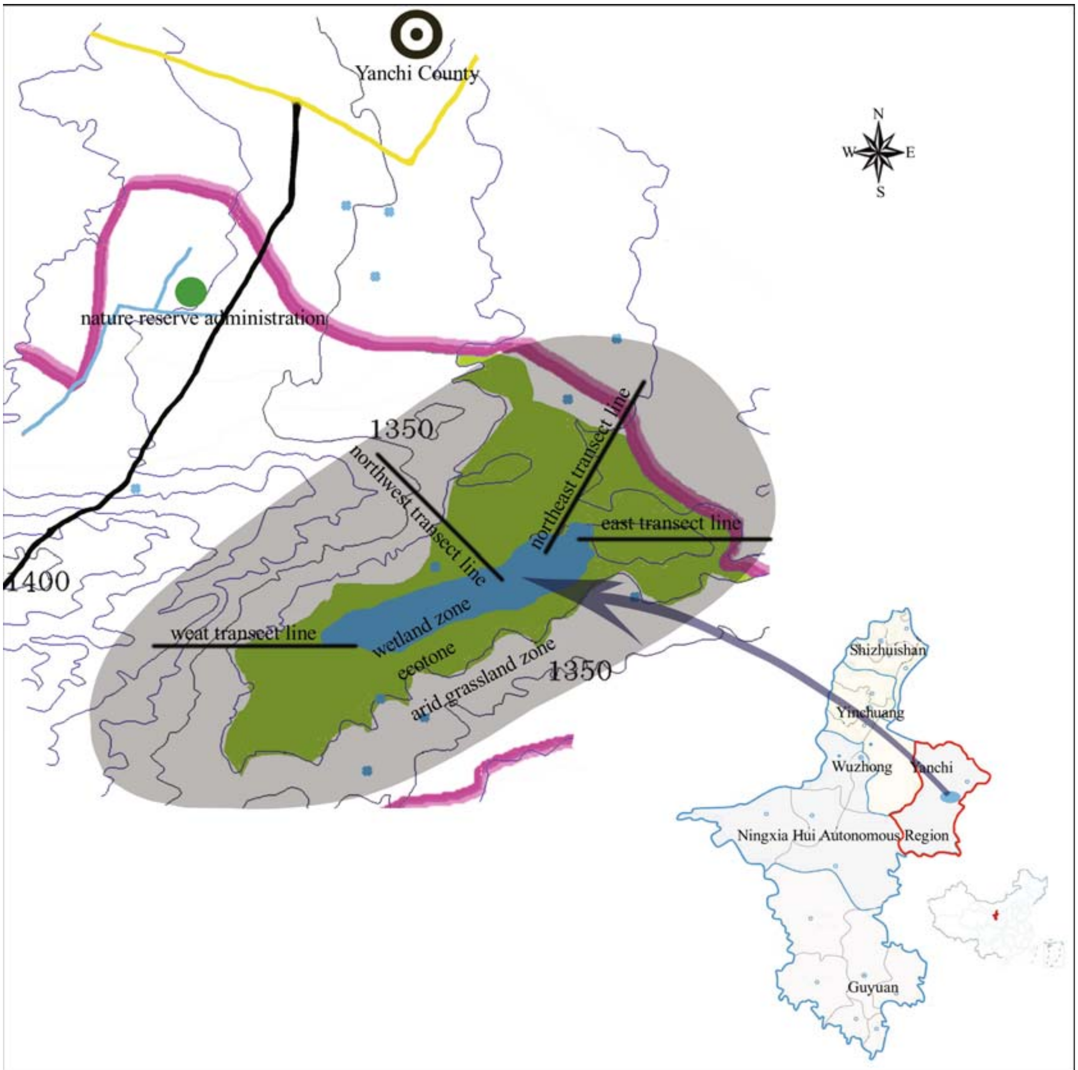

Fig. 1 Sketch of research area site and pattern of transect lines

During our investigation of the plant community, soil samples were collected from every second quadrate at 0 to 30 cm depth. In total, 65 soil samples were collected along the four lines. Soil test items include total N, effective P, effective K, organic matter as well as the rate of conductance.

Because of the impact of human factors such as agriculture, residential sites and grazing, vegetation in these areas is not representative. For example, the grassland zone was developed as farmland, with farmland grass growing in this area. The lower terrain with better water conditions in the southern part of the wetland also led to the growth of *Kalidium foliatum*. Therefore, field investigations were not carried out towards the south and southwest.

3.2 Data analysis

3.2.1 Vegetation importance value

Most scientists use a relative coverage ratio and relative density in calculating grassland importance value, but fresh biomass is seldom used. The method of measuring weight in the field has less error and can be easily standardized among groups. Therefore, relative biomass was used in our calculations. For integrated consideration of biological and ecological characteristics of plant species with features from the research site, the following five characteristic values were used in calculating plant importance values:

$$\text{Relative abundance } (R_A) = (A_i/A) \times 100 \qquad (1)$$

where A_i is abundance of a given plant i and A is abundance of all plants.

$$\text{Relative height } (R_H) = (H_i/H) \times 100 \qquad (2)$$

where H_i is mean height of all plants of species i and R is the mean height of all plants.

$$\text{Relative coverage } (R_C) = (C_i/C) \times 100 \qquad (3)$$

where C_i is coverage of a given plant i and C is coverage of all plants.

$$\text{Relative biomass } (R_B) = (B_i/B) \times 100 \tag{4}$$

where B_i is biomass of a given plant i and B refers to the biomass of all plants.

$$\text{Relative frequency } (R_F) = (F_i/F) \times 100 \tag{5}$$

where F_i is frequency of a given plant i and F is the sum of the frequencies of all plants.

$$\text{Frequency } (F) = (N_i/N) \times 100 \tag{6}$$

where N_i is the frequency of plants in quadrate number i and N is the sum of all frequencies of all plants.

$$\text{Importance value} = \frac{R_A + R_C + R_F + R_H + R_B}{5} \tag{7}$$

3.2.2 Classification and ordering

TWINSPAN method was adopted to classify a plant community by using importance values from 41 plant species and 123 quadrates to establish a 41 × 123 matrix. The TWINSPAN classification method is widely used in plant ecology; it can also classify sample sites and species. Details are provided by Zhang (1995). The DCA method was adopted for ordination, also used worldwide. All calculations were implemented using the WinTWINS software and DCA in the CANOCO software package.

4 Results and analysis

4.1 Plant community classification of a wetland-grassland ecosystem

The TWINSPAN classification results are shown in Fig. 2. The number on the left side is the plant number (Table 1), at the top is the quadrate number, at the bottom the grouped result of quadrates and on the right are classified results of plants. In the center is the classification level, where "-" stands for the plant existing in the quadrate, "1" is one time classified result, and "0" is another group.

By using a four-grade-classification, vegetation in the Siertan wetland can be divided into 14 community types, which is equal to a classification at the association level. A three-class classification system, i.e., vegetation type (top level classification unit), vegetation group (middle level classification unit) and associations (the basic classification unit) was used in "Chinese Vegetation" (Wu, 1980). Based on field investigation data, the Siertan wetland-arid grassland ecosystem can be divided into three vegetation types: swamp vegetation, meadow vegetation and grassland vegetation. Because of higher saline-alkalization, swamp vegetation in the Siertan wetland consists mainly of the *Phragmites communis* + *Kalidium foliatum* group, while meadow vegetation featured meadow plant groups. Grassland vegetation consists mainly of the *Pennisetun flaccidum* group, which is grass of root-caudex type species in grasslands. Minimal modification was carried out to TWINSPAN classification results; the 123 quadrates of the Siertan wetland-arid grassland ecosystem were divided into three types and 14 associations.

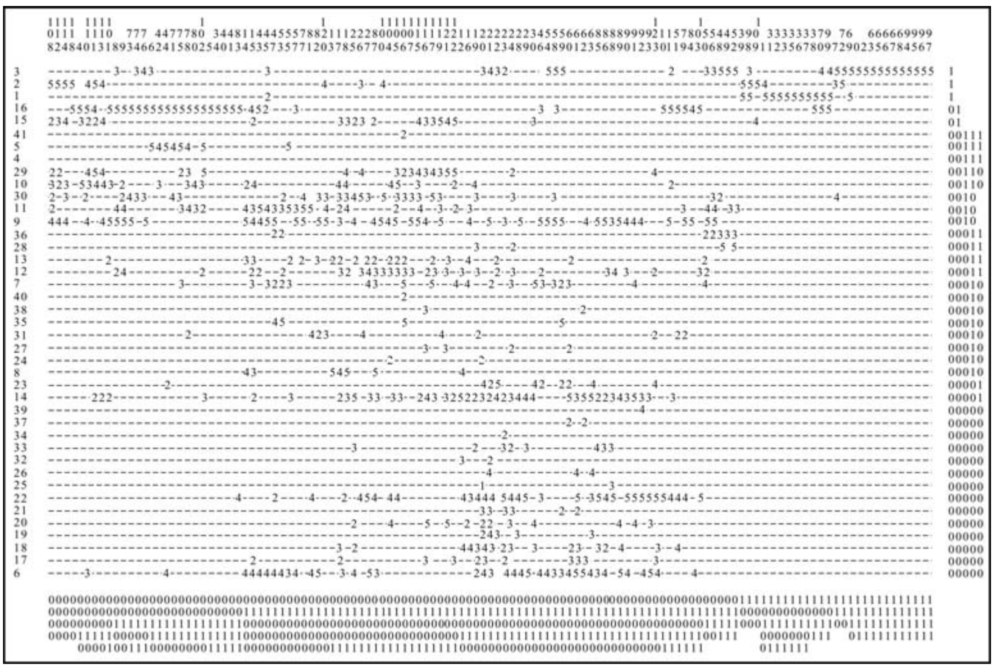

Fig. 2 Quantitative classification matrix in the Siertan wetland-arid grassland ecosystem

Table 1 Serial number of plants on the Siertan wetland-arid grassland ecosystem

serial number	plant name	serial number	plant name
1	*Kalidium foliatum*	22	*Pennisetum flaccidum* Griseb
2	*Suaeda salsa* (L.) Pall	23	*Peganum harmala* Linn
3	*Phragmites communis*	24	*Ixeris chinensis*
4	*Limonium anreum*	25	*Chinops gmelini* Turcz.
5	*Achnatherum splendens*	26	*Astragalus melilotoides*
6	*Sophora alopecuroides*	27	*Setaria viridis*
7	*Thermopsis shischkinii* Czefr	28	*Glaux maritima*
8	*Sphaerophysa salsula*	29	*Haplophyllum dauricum*
9	*Anaeurolepidium secalium*	30	*Polgonum sibiricum*
10	*Chenopodium glaucum*	31	*Artemisia hedinii*
11	*Saussurea runcinata*	32	*Oxytropis pasmmocharis*
12	*Sonchus brachyoutus* DC.	33	*Cynanchum komarovii*
13	*Saussurea amara*	34	*Polygala tenuiplia*
14	*Salsola sinkiangensis* A.J.Li	35	*Agropyrom mongolicum* Keng
15	*Bassia dasyphylla* O.Kuntze	36	*Taraxacum mongolicum*
16	*Nitraria tangutorum*	37	*Incarvillea sinens*
17	*Artemisia ordosica* Thunb	38	*Eragrostis poaeoides* Beauv
18	*Heteropappus altaicus*	39	*Olgaea Leucophylla* (Turcz.) Iljin
19	*Lespedeza davurica*	40	*Ajania parvi flora* (Grii.) Ling.
20	*Corispermum mongolicum* Iljin	41	*Diarthron linifolium*
21	*Euphorbia esula* L		

1) Marsh vegetation: I Ass. *Kalidium foliatum*, *Suaeda salsa*; II Ass. *Nitraria tangutorum*, *Kalidium foliatum*-*Phragmites communis*; III Ass. *Phragmites communis*, *Suaeda salsa*; IV Ass. *Phragmites communis*, *Kalidium foliatum*; V Ass. *Phragmites communis*, *Glaux maritime*-*Taraxacum mongolicum*.

2) Meadow vegetation: VI Ass. *Nitraria tangutorum, Pennisetum flaccidum*; VII Ass. *Suaeda salsa, Anaeurolepidium secalium*, *Bassia dasyphylla*-*Chenopodium glaucum*-*Ajania parvi flora*; VIII Ass. *Chenopodium glaucum*, *Nitraria tangutorum*, *Bassia dasyphylla*; IX Ass. *Nitraria tangutorum, Anaeurolepidium secalium, Polgonum sibiricum*; X Ass. *Achnatherum splendens*, *Nitraria tangutorum*, *Chenopodium glaucum*; XI Ass. *Saussurea runcinata*, *Anaeurolepidium secalium*-*Sophora alopecuroides*.

3) Grassland vegetation: XII Ass. *Anaeurolepidium secalium*, *Saussurea runcinata*; XIII Ass. *Anaeurolepidium secalium*, *Haplophyllum dauricum*-*Polgonum sibiricum*, *Bassia dasyphylla*; XIV Ass. *Sophora alopecuroides*-*Pennisetum flaccidum*, *Salsola sinkiangensis*, *Psammochloa villosa*.

From these results, it can be easily deduced that swamp vegetation involves associations I–V, which features sample plant species and mainly consist of *Phragmites communis, Kalidium foliatum* and are halophytic marsh and hygric plants. Meadow vegetation involves associations VI–XI, which mainly consist of hygric and mesophytic plant species such as *Nitraria tangutorum*, *Chenopodium glaucum*, *Suaeda salsa* and *Achnatherum splendens*. Grassland vegetation involves associations XII–XIV, largely consisting of the mesophytic and xerophytic plants *Anaeurolepidium secalium*, *Aaussurea runcinata*, *Sophora alopecuroide* and *Pennisetun flaccidum*. Based on the "Chinese Vegetation" (Wu, 1980), these three vegetation types are the result of a special biological environment. The swamp vegetation type is found in the wetland zone; the meadow vegetation type is distributed in the wetland ecotone and the arid grassland ecosystem zone, while the grassland vegetation type is found in the arid grassland zone. Thus, TWINSPAN quantitative classification results are consistent with the pattern of plant distribution in the field and prove that the system is an effective arid wetland vegetation classification method. The results also show that plant types from wetland to grassland follow a trend from hygric (halophytic) to mesophytic (halophytic and mesophytic) to mesophytic and xerophyte plants.

4.2 DCA ordination of a wetland-grassland ecosystem plant community

Using the DCA method, 123 quadrates in the Siertan wetland were ranked. The eigenvalues of the first four axes were 3.02, 1.82, 1.55 and 1.12. Figure 3 is a two-dimensional graph from the first (AX1) and second axes (AX2) of the four ranked axes. The vegetation can be divided into 14 associations, which is also consistent with the results from the TWINSPAN method. Along AX1, vegetation in the Siertan wetland can be divided into three groups. The first group consisted of halophytic marsh and hygric plants such as *Phragmites communis* and *Kalidium foliatum,* which involved associations I–V and are located in waterlogged, halophytic marshes and wetland zones. The second group consisted of hygric, halophytic and mesophytic species such as *Pennisetun flaccidum*, *Suaeda salsa*, *Achnatherum splendens*, and *Aaussurea runcinata,* which involved associations VI–X, parts of XI, XII and XIII, located in the transition of wetland and grassland. The third group consisted of mesophytic and mesophytic

+ xerophytes species such as *Psammochloa villosa, Anaeurolepidium secalium* and *Sphaerophysa salsula*, which involved associations XIV and parts of XI, XII and XIII. The groupings closely resemble the results from the TWINSPAN method, which are swamp vegetation, meadow vegetation and grassland vegetation. At the same time, DCA results commendably represented gradual changes in the environment. Life type changes from wetland to grassland followed trends of hygric (halophytic) to mesophytic and mesophytic + xerophytes. It also showed that AX1 represented the spatial pattern of plant distributions in the wetland-grassland ecosystem in the Siertan wetland region.

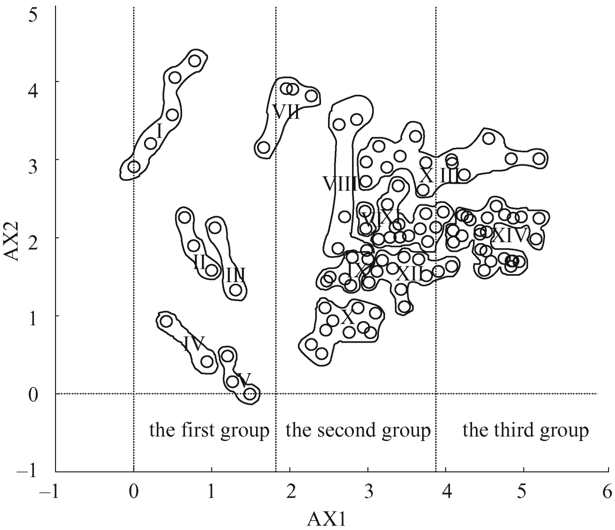

Fig. 3 Two-dimensional DCA ordination of 123 quadrates in Siertan wetland-arid grassland ecosystem

4.3 Plant spatial distribution pattern of a wetland-grassland ecosystem

From the TWINSPAN classification and DCA ordination results, it is easily established that the spatial pattern of plant distribution of the wetland-grassland ecosystem in the Siertan wetland from wetland to grassland followed a trend from swamp vegetation to meadow vegetation to grassland vegetation. The key environmental factors of the spatial pattern of plant distribution in the wetland can be obtained by analyzing the relationship of environment factors and ordination axes. The AX1 and AX2 Spearman correlation coefficients of the DCA ordination axes and soil factors is shown in Table 2. AX1 is closely positively related to soil water content with a correlation coefficient of 0.830. Soil water content is one of the key environmental factors that affect the spatial pattern of plant distribution. In general, the soil electro- conductive ratio showed a positive relation to the soil salt content. Therefore, the soil electro-conductive ratio is used directly in representing the degree of soil saline-alkalinity (Tam and Wong, 1998; Hopkins and Richardson, 1999; Ramsis et al., 1999; Heydari et al., 2001; Zhang et al., 2003). We have shown the feasibility of the soil electro-conductive ratio in the representation of the soil salt content. Table 2 shows that AX1 represented a negative relationship with the soil electro-conductive ratio, with a correlation coefficient of −0.739. It also shows that AX1 and the soil salt content are negatively correlated. This demonstrates that the degree of soil saline-alkalinity clearly affects plant the spatial pattern of plant distribution. From the TWINSPAN classification and DCA ordination results, the first group (swamp vegetation) with less species has a low saline-alkali tolerance. It includes *Kalidium foliatum* and *Phragmites communis* species. Total soil N, effective P, effective K and organic matter are negatively correlated with AX1. The correlation coefficients were –0.510, –0.719, –0.727 and –0.621 respectively. This shows that total soil N, effective P, effective K and organic matter are also affected by the distribution pattern in the Siertan wetland. Due to lower terrain and less water replenishment, the degree of wetland fertility is higher and unfavorable to plant development in this wetland region.

There is no clear correlation between AX2 and soil factors compared to AX1 and only total soil N has a negative correlation with AX2, with a correlation coefficient of −0.468. This demonstrates that soil factors have no clear

Table 2 Spearman's correlation between DCA ordination axes and soil factors

	total N	effective P	effective K	organic matter	conductance ratio	soil water content
AX1	–0.510*	–0.719**	–0.727**	–0.621**	–0.739**	0.830**
AX2	–0.468*	–0.053	–0.415	–0.378	–0.201	0.348

Note: *$p < 0.05$ means correlation is significant at the 0.05 level (two-tailed test), **$p < 0.01$ significant at the 0.01 level (two-tailed test).

Table 3 Main soil factors in three vegetation zones in the Siertan wetland-arid grassland ecosystem

	soil water content	total N	effective P	effective K	organic matter	conductance ratio
wetland zone	12.2	0.052	6.934	240.425	0.794	7.548
ecotone	5.6	0.029	4.591	174.045	0.376	1.498
arid grassland zone	3.8	0.028	4.144	124.300	0.339	0.344

impact on AX2. Thus, the analysis of other factors affecting DCA ordination in AX2 should consider the rising terrain and its effects on plants (Fig. 1). It also can be found that the east and northeast lines are lower than the 1350 m contour, while the west and northwest lines are above 1350 m; the west line lies above 1360 m. At same time, grazing was also another factor affecting plant pattern along the lines (Li et al., 2006). The effects of terrain and grazing on the spatial plant pattern can also be represented in the AX2 and DCA ordination of all four lines.

From the TWINSPAN classification and DCA ordination results (AX1), the changing trend of plants in the wetland-grassland ecosystem was along the wetland zone-ecotone-arid grassland zone. This pattern is affected by soil water, soil salt content and soil fertility. Table 3 shows the mean values of the main soil factors in the three vegetation zones in the Siertan wetland-arid grassland ecosystem. The trend in soil water content, conductance ratio (salt content), total N, effective P, effective K and organic matter decreased from the wetland zone to the ecotone to the arid grassland zone. The trends of salt content and soil water content were particularly remarkable. The salt content in the wetland zone is five times that in the ecotone and 21 times that in the arid grassland zone. This is one of the factors that led to spatial plant differences; the soil water content has also clearly changed in response to changes of plant life type from hygric (halophytic) to mesophytic (halophytic-mesophytic) and to xerophytes. Vegetation type changed from swamp vegetation to meadow vegetation and to grassland vegetation.

5 Conclusions and discussion

Importance value is an integrated index describing relative importance among plant species. In herbage plant studies of grassland vegetation, one to three indices, such as coverage and height, are used by most scientists (Zhang et al., 2001; Cheng et al., 2004; Zhao et al., 2005). For regions with better vegetation, one to three indicators can basically represent plant importance. But for regions with poor vegetation or simple plant species, fewer indicators cannot comprehensively and truly represent plant importance values. At the same time, some human errors also occur in field investigations, such as errors in coverage rate estimation among groups. The Siertan wetland is not very large in size, but covers three types of ecosystems of wetland, grassland and the ecotone of wetland and arid grassland. Different environmental conditions such as water content and degree of saline-alkalinity lead to differences among species diversities. In the wetland zone, the high degree of saline-alkalinity restricts plant growth and the variety of species in this zone is indeed the least among the "three zones" (Li et al., 2006). If we only were to use relative coverage as a characteristic value in calculating plant importance values, some errors would appear. Given this condition, relative frequency is one of the important indicators in calculating plant importance values. Ecotones with better vegetation and a rich variety of perennial herbage plants, such as *Achnatherum splendens* and *Psammochloa villosa,* predominated because of their height, but with less biomass compared with the fleshy herbage plant *Suaeda sals*. Usually, researchers do not adopt biomass to calculate plant importance value due to the difficulty in estimating biomass, especially in a forest community. But in arid regions, biomass field weighing could objectively represent plant importance value, because it could be easily carried out with fewer errors. Therefore, biomass should be used as an indicator in calculating plant importance values. Hence, five characteristic values — height, coverage, abundance, biomass and frequency — have been used in calculating plant importance values while integrating plant biological and ecological features as well as wetland conditions. The results are an objective reflection of the importance of plants in the community. Classification and ordination are based on importance values and therefore, the objective degree of importance values directly affects the results of classification and ordination, especially in the determination of the main species.

At present, special climate conditions and relief characteristics, which resulted in wetlands being represented in halophytic marshes in the shape of patches (Zhang et al., 2002), have made wetland studies in arid and semi arid regions rare. Such patch distributions lead to wetlands with small areas. Compared with wetlands in the Sanjiang plain in the northeast and other regions of China, inland wetlands of northwestern China are represented more in halophytic marshes with seasonal water accumulation. Thus, hygrophytes are not typical and even absent as standing plants in water areas. The Siertan wetland is a typical marsh wetland in a semi arid region with a high degree of saline-alkalization and low plant species diversity. But because of water supplement, plant species diversity in the ecotone of wetland and arid grassland is higher and plays an active role and is helpful in maintaining a regional ecological equilibrium (Li et al., 2006). Even if the characteristics of wetlands in arid regions restrict studies, more attention has been paid to wetland studies in recent years because of its special environmental conditions. The establishment of the Haba Lake Wetland National Nature Reserve was aimed at wetland diversity protection.

Plant community is the temporal and spatial process in a given region and given period of its environment (Zhang et al., 2002). The vegetation changed radially from the center of the Siertan wetland. Over a 1 km sample line distance, the vegetation types changed from halophytic swamp vegetation and halophytic meadow vegetation to typical grassland vegetation, which covered three types of vegetation; the plant environment changed from wetland to transition to arid grassland, following the same trend as vegetation. Although the Siertan wetland is not vast, it covers three types of vegetation and involved three types of ecological environments. It demonstrates the importance of a wetland ecosystem in a regional ecosystem equilibrium. Soil water content, salt content and soil fertility are the key factors in determining the pattern of plant community in the Siertan wetland. The increments of degree of saline-alkalinity and reduction of water supplements are the key problems to wetlands in arid regions, which directly affect the spatial pattern of plants in wetlands. As the degree of saline-alkalinity in the wetland zone increases, plants with a narrow ecological scope will disappear, leading to a decline in plant species diversity. In addition, increasing increments of drought make water supplements increasingly important. As the soil water content decreases, plant growth in ecotones of wetland and arid grassland would be stunted and arid grassland zones would be expanded, leading to severe desertification and a decrease in plant species diversity. Therefore, in northwest arid and semi arid regions, measures such as protection of water sources are very important in protection of wetlands and their surrounding ecosystem equilibrium (Li et al., 2006). As for wetland protection in the Haba Lake Nature Reserve, future protection should be provided to prevent destruction by neighboring residents, increasing water resource supplements, desertification control, maintaining wetland plant species diversity and the spatial patterns of distribution of plants for positive succession.

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References

Chen Y Y (1995). Wetlands Research in China. Changchun: Jilin Science & Technology Publications, 1–7 (in Chinese)

Cheng Z H, Zhang J T, Zhang F (2004). Difference of ecological dominance of meadow population on different tourism disturbance. Acta Bot Boreal-Occident Sin, 24(8): 1476–1479 (in Chinese)

Flower R J, Dobinson S, Ramdani M, Kraïem M M, Ben Hamza C, Fathi A A, Abdelzaher H M A, Birks H H, Appleby P G, Lees J A, Shilland E, Patrick S (2001). Recent environmental change in North African wetland lakes: diatom and other stratigraphic evidence from nine sites in the CASSARINA Project. Aquat Ecol, 35: 369–388

He Q C (2003). Theory of Plant Ecological Process and its Utilization: Study on Representative Wetland of Sanjiang Plain. Shanghai: Shanghai Science & Technology Publications (in Chinese)

Heydari N, Gupta A D, Loof R (2001). Salinity and sodicity influences on infiltration during surge flow irrigation. Irrigat Sci, 20: 165–173

Hopkins D G, Richardson J L (1999). Detecting a salinity plumb in an unconfined sandy aquifer and assessing secondary soil salinization using electromagnetic induction techniques, North Dakota, USA. Hydrogeol J, 7: 380–392

Jay S W, Suzanne E B (1999). Restoration of a Canadian prairie wetland with agricultural and municipal waste water. Environ Manage, 24: 25–37

Johnson L B, Gage S H (1997). Landscape approaches to the analysis of aquatic ecosystems. Freshwater Biol, 37: 113–132

Li J, Sun H, Xing D X, Wang X G (2003). Characteristics of wetland and its conservation in arid and semi-arid areas in Northwest of China. J Desert Res, 23(6): 670–674 (in Chinese)

Li R, Zhang K B, Wang B T, Yang X H, Qiao F, Yang J J, Yang L (2006). Studies on plant species diversity of wetland-dry grassland ecosystem-an example from Yanchi County, Ningxia Hui Autonomous Region. J Beijing For Univ, 28(5): 12–17 (in Chinese)

Li Y N, Zhao X Q, Zhao L, Wang Q J, Shen Z X (2003). Analysis of vegetation succession and climate change in Haibei alpine marsh in the Qilian Mountains. J Glaciol Geocryol, 25(3): 243–249 (in Chinese)

Mitsch W J, Gosselink J G (1986). Wetlands. New York: van Nostrand Reinhold Company Inc., 89–125

Obeysekera J, Rutchey K (1997). Selection of Everglades landscape models. Landscape Ecol, 12: 7–18

Ramsis B S, Clause J O, Robert W F (1999). Contributions of groundwater conditions to soil and water salinization. Hydrogeol J, 7: 46–64

Tam N F Y, Wong Y S (1998). Variations of soil nutrient and organic matter content in a subtropical mangrove ecosystem. Water Air Soil Pollut, 103: 245–261

Tian Y B (2005). The vegetation type and its distribution regularity under different habitats in Ruoergai Plateau. J Yangtze Univ (Nat Sci Ed): 2(2): 1–6 (in Chinese)

Toner M, Keddy P (1997). River hydrology and riparian wetlands: a predictive model for ecological assembly. Ecol Appl, 7: 236–246

Wu D L, Shangguan T L, Zhang J T, Xue H X (2005). Quantitative classification and ordination of wetland vegetations in the reaches of the Hutuo River. Acta Bot Boreal-Occident Sin, 25(4): 648–654 (in Chinese)

Wu Z Y (1980). Vegetation of China. Beijing: Science Press, 143–156 (in Chinese)

Yu D (1994). Study on the geography of aquatic plants in northeast China. Bull Bot Res, 14(2): 169–178 (in Chinese)

Zhang J J (1995). Methods of Vegetation Quantitative Ecology. Beijing: China Science & Technology Publications, 139–227 (in Chinese)

Zhang L X, Zhang F, Shangguan T L (2001). Quantity analysis of plant communities on Mountain Luya, Shanxi. Chin Bull Bot, 18(2): 231–239 (in Chinese)

Zhang Y B, Deng A Y, Zhuang T C, Lin P (2003). Relation between soil salinity in intertidal zone and electric conductivity. Ecol Environ, 12(2): 164–165 (in Chinese)

Zhang Z G, Wang R Q, Lu J J (2002). Basic characteristics of the psammophytic vegetation on coasts of Shandong Province and the spatial pattern of its keystone species. J Shandong Univ, 37(4): 364–368 (in Chinese)

Zhao L Y, Li Z H, Li F R, Zhao H L (2005). Soil seed bank of plant communities along restoring succession gradients in Horqin Sandy Land. Acta Ecol Sin, 25(12): 3204–3211 (in Chinese)