Front. For. China 2008, 3(4): 434–439
DOI 10.1007/s11461-008-0063-2

RESEARCH ARTICLE

Ruiping HOU, Rui LI, Kebin ZHANG, Yunfang LIU

Edge effect of the ecotone of wetland and arid grassland in a semi-arid region of China

Abstract The edge effect of plant communities was investigated in a wetland-dry grassland ecosystem at the Siertan Wetland in Yanchi County, Ningxia Hui Autonomous Region, China. Four transects lines, with each about 1 km long, were established for a vegetation survey in July 2005, along biotope gradients in four directions: east, northeast, west and northwest. The data was analyzed using TWINSPAN classification method. The vegetation in this wetland was classified into three vegetation types: halophytic marsh vegetation, meadow vegetation and grassland vegetation. Based on the calculation of the community structure indices, the edge effect was studied which revealed distinct differences among those three vegetation zones along each transect line. The ecotone had high richness indices (*R*), a high diversity index (*SW*) and ecological dominance (*SP*). Evenness, as measured by the index (*E*), was less apparent. From the four transect lines, it appears that the ecotone in the northeasterly direction scored higher in each community structure indicator than any of the other directions and those towards the northwest were least. The variation in the edge effect between the different transect lines is caused by human disturbances and topographic uplift.

Keywords wetland, semi-arid, ecotone, edge effect

Translated from *Acta Botanica Boreali-Occidentalia Sinica*, 2007, 27(5): 989–994 [译自: 西北植物学报]

Ruiping HOU
Academy of Forest Inventory, Planning and Design, State Forestry Administration, Beijing 100714, China

Rui LI
The Fourth Survey and Design Institute of China Railways, Wuhan 430063, China

Kebin ZHANG (✉), Yunfang LIU
School of Soil and Water Conservation, Beijing Forestry University, Beijing 100083, China
E-mail: ctccd@bjfu.edu.cn

1 Introduction

The edge effect of ecotones is an important study area in plant ecology and has been extensively studied by both domestic and overseas scientists. Research on species diversity of ecotone of wetland and arid grassland (Li et al., 2006) show species diversity of ecotone was large, medium in arid grassland and less in the wetland. This is a reflection of the edge effect. Burk (1977) found that in the inland freshwater swamps of New England State, USA, species diversity in the ecotone of wetland and highland was the largest, higher than that of the middle of swamps, and the least in ecotone of wetland and water. Miao et al. (2005) reported that, by studying plant communities in the *Larix chinensis* Beissn community ecotone, the edge effect was affected not only by its microclimate, but also by the landform and soil. Li and Pabnov (1999) observed that diversity in the ecotone of conifer and broadleaved forests was higher than in neighboring communities in the plains of Russia. Based on the observation of bird species diversity in Peru, Terborgh (1977, 1985) found that birds appeared more frequently in low-cloud forests, but less in the mountain rain forests, from where 47 types of birds disappeared, reflecting the edge effect. Species diversity in the ecotones of forests and swamps were high and a large number of dominant species appeared along the environmental gradients in the Changbai Mountain forests (Mu et al., 1998). Wang et al. (2002) indicated that ecotones are transition communities under high stress, where the composition and structure of the vegetation differs greatly in energy flows, entropy, information and material flows, and presented these apparently vulnerable zones, so vegetation structure restoration should follow its own special rules. It is rarely reported that the edge effect of the ecotone of wetland and arid grassland in the agricultural-pastoral transition zones in northern areas of China. Taking the wetland-dry grassland ecosystem in the Siertan Wetland, located in Yanchi County, Ningxia Hui Autonomous Region as an example, rules of mutation of wetlands and dry grassland ecotones along the biotope gradient were studied revealing the edge effect and providing a good material basis for the protection and reversion to health of these wetlands.

2 Study site

The study site was located in the Siertan Wetland, about 8 km south from the Yanchi County, Ningxia Hui Autonomous Region, China. This wetland is a swamp, with clear levels of seasonal accumulations of water. The water surface of the wetland is greatly affected by rainfall. Moisture- and alkali-resisting species grow mainly along the edge of the wetland, such as *Phragmites communis*, *Kalidium foliatum* and *Nitraria tangutorum*, given its high degree of salinization. Xerophytes and mesoxerophytes such as *Sphaerophysa salsula* and *Sophora alopecuroides* often appear in the grasslands because of poor water conditions. Because of fertile soils, sufficient water and a rich variety of species, plant species are richer in the ecotones of the wetland and arid grassland, including some special plants such as *Glaux maritima*, *Achnatherum splendens* and *Diarthron linifolium* and all the plant species found in the wetland and in the grassland. According to habitat characteristics and vegetation types, the whole study area was classified into a wetland zone, an ecotone and a dryland zone, which we refer to as the "three-strips". Sketch of research area and location of sample lines reference Zhang et al. (2008).

3 Study methods

3.1 Field investigation

Supported by the National Natural Science Foundation of China (Grant No. 30771764) and the National Desertification Position Monitoring Project, we selected the Siertan wetland-dry grassland ecosystem as the monitoring site using GPS and concrete piles for positioning. Field investigations had been carried out during the growing season from July to September over a number of years. Our investigation dated from mid-July to early August in 2005 and 2006. By using a line-transect method, plant names and the number of plants from each species were recorded and the coverage, height and biomass, etc. were measured. Taking the wetland as the center, four transects lines were set radially as west, northwest, east and northeast. Each line was of more than 1 km long and covered the "three-strips", i.e., the zones representative of the saline wetland, the entire ecotone and the arid grassland. We used quadrats for sampling the area. A total of 123 quadrats have been investigated, of which 33 were on a line towards the east and 30 each on the northeast, the west and the northwest lines. Since most of the plants are annual herbage, quadrats of 1 m × 1 m were adequate for sampling.

3.2 Plant community classification

A two-way indicator species analysis (TWINSPAN) method was adopted to classify plant communities in the wetland and arid grassland community ecotone. Details of this method are provided by Li et al. (2006).

3.3 Community composition indices

The indices to calculate the community composition are ecological dominance (*SP*), diversity index (*SW*), evenness index (*E*) and two richness indices (R_1, R_2).

3.3.1 Richness indices

Richness indices R_1 and R_2 are expressed as follows:

$$R_1 = S \tag{1}$$

$$R_2 = (S-1)/\ln N \tag{2}$$

where S is the number of species and N is the sum of importance values of all plants in the quadrats of wetland.

3.3.2 Diversity index

Definitions and selected indices of species diversity vary according to different study objectives by different scientists. There are ten indices to measure diversity. We selected the Shannon-Wiener diversity index (*SW*), which is considered at present the most effective index.

$$SW = \sum_{i=1}^{S} (-P_i \ln P_i) \tag{3}$$

where $P_i = N_i/N$, N is the sum of importance values of all plants along the transect lines, N_i the importance values of the ith species, P_i the ratio of the importance value of species i; and S the number of plant species.

3.3.3 Ecological dominance

Ecological dominance is an integrated index reflecting the entire community condition. Taking the community as a whole, the appropriate values will be calculated from the species importance values in order to measure the community composition. The Simpson index (*SP*) was suggested by Odum (1981) to measure ecological dominance.

$$SP = \sum_{i=1}^{S} N_i(N_i-1)/N(N-1) \tag{4}$$

$$SP = 1/\sum P_i^2 \tag{5}$$

where the variables are the same as for Eq. (3). Equation (5) was selected for our study.

3.3.4 Richness index

Community diversity will be up to the largest value, when all kinds of plants are distributed evenly. Given the variety and total number of permanent species, the ratio between observed community diversity and maximum diversity is calculated to measure community richness (E):

$$E = \left(e^{SW} - 1\right)/(S - 1) \quad (6)$$

Many scientists (Peng et al., 1998; Zhou et al., 1999; Li et al., 2005) have selected species group abundance as an index. Pielou (1983) suggested that relative coverage, relative importance values and relative biomass should be chosen as diversity indices. As a measure of the importance of plant species, the importance value could best reflect the degree of significance of a species in the community and we have selected it as our index.

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

where R_B is relative biomass, R_C relative coverage, R_A relative abundance, R_F relative frequency and R_H relative height.

4 Results and analysis

4.1 Plant community composition and main types in the Siertan wetland

As is generally known, species diversity in the wetlands is richer than elsewhere. The types of plants are more abundant in the Siertan wetland than in other types of lands, such as cultivated pastures, natural grasslands and waste lands. Twelve families and 41 types of plants were found in the four transects lines in 2005. There were 11 species of the Compositae family, seven Leguminosae, Gramineae and Chenopodiaceae species each and two species of the Zygophyllaceae family, accounting for 26.2%, 16.7%, 16.7%, 16.7% and 4.76%, respectively, of all species. The Primulaceae, Limoniaceae, Euphorbiaceae, Thymelaeaceae, Polygalaceae, Rutaceae and Bignoniaceae families each were represented by one species, collectively accounting for 16.7%. A two-way indicator species analysis (TWINSPAN) method was adopted to classify the plant community from 41 plant species in the 123 quadrats. Combined with the local situation, the plant community in the Siertan wetland-arid grassland ecosystem was classified into three vegetation types and 14 associations.

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*, often appearing in the wetland zone.

2) Meadow vegetation: VI Ass. *Nitraria tangutorum*, *Anaeurolepidium secalium*; VII Ass. *Suaeda salsa*, *Psammochloa villosa*, *Bassia dasyphylla–Chenopodium glaucum-Ajania parvi* flora; VIII Ass. *Chenopodium glaucum, Nitraria tangutorum*, *Bassia dasyphylla*; IX Ass. *Nitraria tangutorum*, *Psammochloa villosa*, *Polgonum sibiricum*; X Ass. *Achnatherum splendens*, *Nitraria tangutorum*, *Chenopodium glaucum*; XI Ass. *Saussurea runcinata*, *Psammochloa villosa–Sophora alopecuroides*, always growing in the wetland and arid grassland ecotone.

3) Grassland vegetation: XII Ass. *Psammochloa villosa*, *Saussurea runcinata*; XIII Ass. *Psammochloa villosa*, *Haplophyllum dauricum–Polgonum sibiricum*, *Bassia dasyphylla*; XIV Ass. *Sophora alopecuroides–Anaeurolepidium secalium*, *Salsola sinkiangensis*, *Psammochloa villosa*, mainly distributed in the dryland zone of the arid grassland.

From these results, it is seen that the plant community in this wetland-arid grassland ecosystem is divided into three vegetation types: marsh vegetation, meadow vegetation and grassland vegetation. In turn, these vegetation types are distributed over three zones: a wetland zone, an ecotone of wetland and arid grassland and a dryland zone. This is the classification, established while doing our field investigation. The community types changed along with the biotope gradient as follows: marsh vegetation → meadow vegetation → grassland vegetation.

4.2 Community structure of "three strips" in the Siertan ecotone of wetland and arid grassland

The results of our calculations of community structure of "three strips" in the Siertan wetland are shown in Table 1. The four community composition indices, i.e. richness indices (R), ecological dominance (SP), diversity index (SW) and evenness index (E) changed consistently within the "three strips" along the four transects lines, the wetland zone, the ecotone and the dryland zone (Table 1). The ecotone scored the highest richness indices, with the least in the wetland zone and in the dryland zone where R_1 and R_2 were in the middle. Especially for the west line, the trend appeared obvious, where R_1 values in the wetland zone, the ecotone and the dryland zone were 5, 24 and 14, respectively, and the R_2 values were 0.901, 5.145 and 2.944. The two richness indices reflect the condition of the species types and total number of species. The results, presented for the four lines, show that the ecotone has a larger number of species types than the other two zones. By and large, the plant species found in the ecotone were the same species as found in the other two zones, reflecting the edge effect of the ecotone community on biodiversity.

Table 1 Community structure of "three strips" in Siertan, Yanchi County

sample line location and zones	richness indices		ecological dominance (*SP*)	diversity index (*SW*)	evenness index (*E*)
	R_1	R_2			
E					
wetland zone	14	2.95	4.5	1.96	0.471
ecotone	22	4.71	10.3	2.60	0.591
dryland zone	19	4.04	9.8	2.56	0.666
NW					
wetland zone	7	1.35	2.4	1.24	0.408
ecotone	20	4.31	7.1	2.32	0.482
dryland zone	9	1.76	5.4	1.85	0.672
W					
wetland zone	5	0.90	1.9	0.86	0.341
ecotone	24	5.15	9.5	2.58	0.530
dryland zone	14	2.94	7.0	2.23	0.638
NE					
wetland zone	14	2.94	4.5	1.92	0.446
ecotone	29	6.29	15.0	2.93	0.633
dryland zone	17	3.59	9.6	2.48	0.684

The ecological dominance (*SP*) and diversity index (*SW*) are indices which synthetically reflect the conditions of the community composition. The ecotone that scored the highest *SP* value was in the northeast line followed by the west line. The highest *SW* value was found in the northeast line, followed closely by the east and west lines. Both indices were consistently the lowest in the wetland zone and those of the dryland zone in between. Especially in the northeast line, the changes clearly show *SP* values were 4.5, 15.0 and 9.6 and the *SW* values 1.917, 2.93 and 2.480 respectively, in the wetland zone, the ecotone and dryland zone.

The changes in the evenness index (*E*) were different from the other indices. The results indicate that this index was consistently the highest in the dryland zone, followed consistently by the values of the evenness index in the ecotone and was always the least in the wetland zone. The changes are most clearly shown in the northwest line, where *E* values were 0.408, 0.482 and 0.672, respectively, in the wetland zone, the ecotone and the dryland zone. The reason for the evenness index in the dryland zone being higher than in the ecotone is that the impact of anthropogenic disturbances on the arid grassland is less because grazing was prohibited in all of Yanchi County. Given this condition, the plant community will enter a new phase where a dominant community eventually will take shape. It is predicted that the natural grassland and cultivated pastures in Yanchi County will change into a semi-shrub climax community, consisting largely of *Artemisia capillaris* Thunb if the prohibition will be in force for five years. Due to serious salinization, the evenness index of the wetland zone was the least and the distribution of plants relatively uneven. The evenness index in the ecotone was lower than in the arid grassland because of the effect of topographic uplift, salinization and uneven water provision in the ecotone.

4.3 Changes of community structure in different directions in wetland and arid grassland ecotone

The community structure results of different transects lines in this wetland-dry grassland ecosystem are shown in Table 2. It shows that the community structure varied considerably along the differently oriented transect lines. The northeast line had the highest richness indices, where R_1 value was 29 and R_2 was 6.29. Both indices were the smallest in the northwesterly direction, where R_1 value was 20 and R_2 was 4.31. The order of ecological dominance along the different transects lines from high to low was: northeast > east > west > northwest and that of the *SP* index was 15.0, 10.3, 9.5 and 9.5, respectively. The order of the changes in the diversity index was similar to that of ecological dominance. The evenness index in the northeast was the highest at 0.633 and the least at 0.482 towards the northwest.

Table 2 Community structure indices in different directions in the Siertan ecotone of wetland-arid grassland

orientation	R_1	R_2	*SP*	*SW*	*E*
E	22	4.71	10.30	2.60	0.59
NW	20	4.31	7.10	2.32	0.48
W	24	5.15	9.52	2.58	0.53
NE	29	6.29	15.00	2.93	0.63

The edge effect of the community ecotone along the four transects lines differs. The *SP*, *SW* and *E* indices were the highest towards the northeast, and the least along the northwest line. There are two reasons to explain these results. On the one hand, during the growing season, the conditions for vegetation clearly improved for coverage and biomass because of the grazing prohibition in all of Yanchi County, but over grazing occasionally occurred which led to an imbalance in the community structure between the different transects lines in this ecotone of wetland and dry grassland. According to our investigation, the west and northwest lines are close to residential areas where frequent human disturbances such as trespassing and grazing by local cattle and goats led to low vegetation cover and biomass and, in the end, seriously destroyed the community and the community structure indices rapidly declined towards the west and northwest. In contrast, the east and northeast lines are far from residential areas and were little affected by human disturbance. On the other hand, because the ecotone of wetland and dry grassland is an open system, material and energy flows are transported from the ecosystem to the ecotone by water, air and biological factors. These amounts of material and energy depends on the degree of topographical uplift, especially those of water input and output (one of the most important ecological factors for plants in arid and semi-arid regions), which led to the unbalance in spatial distribution and obvious differences in community structure in the distinct orientations of the ecotone. The area towards the east and northeast is relatively flat, at an elevation of about 1350 m, while the obvious topographic uplift is towards the west and northwest with elevations over 1400 m. This resulted in an unbalanced spatial distribution of water, material and energy in this wetland, especially in 2005, when there was little rainfall.

5 Conclusions

Because of the edge effect, more and more ecological experts are paying attention to ecotones (Fu et al., 2001). The different scales and types of ecotones show higher biodiversity (Wang et al., 1997). Bi et al. (2004) studied the edge effect of deciduous broadleaved forests in the Huo Mountains of Shanxi Province and came to the conclusion that any edge formed by any kind of mechanism tended to increase species diversity. Our study shows, likewise, that community composition indices in the ecotone of wetland and dry grassland tended to increase more than the surrounding environment. Plant species in the ecotone are richer both in the number of different species and the number of plants within a species, than those found around other biotope communities, so that ecological dominance, diversity and evenness indices in the ecotone are higher than in other neighboring communities. Because of the high ecological dominance and species diversity, the ecotone will be well protected for the foreseeable future. Of course, if the surrounding biotope is destroyed, propagation and microorganisms of the ecotone will be affected, which will make the edge effect of the ecotone decline due to the interdependence of the ecotone with its surroundings. The establishment of the Haba Lake Nature Reserve in Yanchi County aims to protect and improve the natural habitats of plants and animals in the entire ecotone of wetland and dry grassland. The improvement in the conditions for the vegetation in the wetland and its surroundings will resume along with the strength in protection provided. Dominant species will return the community to more stable conditions and the ecological dominance, richness indices and species diversity will increase, so the edge effect of the ecotone will become more obvious.

As one of the more valuable resources in this northwestern arid and semi-arid area, the wetland plays a significant role in keeping the ecological balance of the region. A sufficient amount of water is needed to form and maintain the wetland, which might become dry if water shortages were to gradually become serious. Special water conditions are required for the formation and maintenance of wetlands. If these conditions are destroyed, the wetlands will degenerate and even disappear, especially in this arid area. The material and energy flows around the biotope will be affected when the wetland becomes increasingly arid. The direct results of an increase in this arid ecotone of wetland and dry grassland are the shrinking of the ecotone, a reduced edge effect, more serious desertification and a decrease in ecological dominance, species diversity and richness indices. To protect the wetland, maintenance of a sufficient water supply plays an important role in maintaining the balance between the wetland and its surrounding in the arid and semi-arid region.

Acknowledgements This study was supported by the National Natural Science Foundation of China (Grant No. 30771764).

References

Bi R C, Yang H G, Zhu X J (2004). Study on edge effect of deciduous broad-leaved forest in warm-temperate zone of Mt. Huoshan. Acta Bot Boreal-Occident Sin, 24(8): 1441–1447 (in Chinese)

Burk C J (1977). A four-year analysis of vegetation following an oil spill in fresh water march. J Appl Ecol, 14: 515–522

Fu B J, Chen L D, Ma K M, Wang Y L (2001). The Principle and Application of Landscape Ecology. Beijing: Science Press (in Chinese)

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

Li Q F, Liu W Y, Shen Y X, Liu L H, Xu H Q (2005). Change of plant diversity of different rehabilitated communities on degraded mountainous area of dry-hot valley in Nanjian. J Mount Sci, 23(5): 557–564 (in Chinese)

Li X R, Pabnov B H (1999). A study on composition structure and species diversity in ecotone of coniferous and broad-leaved forest in Russia plain. Chin Biodivers, 7(4): 291–296 (in Chinese)

Miao L Y, Wang X A, Wang Z G (2005). Studies on species diversity of *Larix chinensis* community ecotone. Guihaia, 25(2): 112–116 (in Chinese)

Mu C C, Luo J C, Wang X P, Han J J (1998). Plant diversity of ecotone community between forest and marsh in Changbai Mountain. Chin Biodivers, 6(2): 132–137 (in Chinese)

Peng S L, Fang W, Ren H, Huang Z L, Kong G H, Yu Q F, Zhang D Q (1998). The dynamics on organization in the successional process of Dinghushan *Cryptocarya* community. Acta Phytoecol Sin, 22(3): 245–249 (in Chinese)

Terborgh J (1977). Bird species diversity on an Andean elevational gradient. Ecology, 58: 1007–1019

Terborgh J (1985). The role of ecotones in the distribution of Andean birds. Ecology, 66(4): 1237–1246

Wang G L, Liu G B, Liu F (2002). The vegetative characteristics and ecotone effect of Zhifanggou watershed in Loess Hilly Region. Acta Bot Boreal-Occident Sin, 22(5): 1102–1108 (in Chinese)

Wang Q S, Wang X P, Luo J C, Feng Z W, Li J T, Ma Y H, Su Y H (1997). Ecotones and biodiversity. Chin Biodivers, 5(2): 126–131 (in Chinese)

Zhang K B, Li R, Liu Y F, Wang B T, Yang X H, Hou R P (2008). Spatial pattern of a plant community in a wetland ecosystem in a semi-arid region in northwestern China. doi: 10. 1007/s11461-008-0048-1

Zhou X Y, Wang B S, Li M G, Zan Q J (1999). The community dynamics of the forest secondary succession in Heishiding Natural Reserve of Guangdong Province. Acta Bot Sin, 41(8): 877–886 (in Chinese)