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ANALYSIS OF HABITAT PATTERN CHANGE OF RED-CROWNED CRANES IN THE LIAOHE DELTA USING SPATIAL DIVERSITY INDEX

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ABSTRACT: Habitat pattern change of red-crowned cranes (*Grus japonensis*) in the Liaohe Delta between 1988 and 1998 was analyzed with the help of Spatial Diversity Index based on remote sensing data and field investigation. The result showed that the influence from human activities on the wetland habitat of red-crowned cranes was prominent with the development of oil and agricultural exploitation, and the habitat pattern of red-crowned cranes had been obviously changed by the human disturbance during the ten years. The areas with high Spatial Diversity values ($SD \geqslant 0.65$) and that with mid-high values ($0.5 \leqslant SD < 0.65$), which constituted the main part of suitable habitat of red-crowned cranes, had reduced to 9142ha and 5576ha respectively, with the shrinking of natural land cover, such as reed and *Suaeda* community. The habitat pattern became more fragmented, which was caused by roads and wells during oil exploration. It was indicated that the suitability and quality of habitat for red-crowned cranes in the Liaohe Delta were degraded in the last decade. The results also showed that diversity index could reflect the habitat suitability of red-crowned cranes quantitatively and describe the spatial pattern of the habitat explicitly. This study will provide a scientific basis for habitat protection of red-crowned cranes and other rare species in wetlands.

KEY WORDS: Spatial Diversity Index; red-crowned crane (*Grus japonensis*); habitat pattern; the Liaohe Delta

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1 INTRODUCTION

The wildlife habitat loss and fragmentation have been linked directly to intensive human disturbance. Many ecologists have focused on analysis of wildlife habitat pattern change and conservation of suitable habitat. In general, landscape pattern is closely linked to ecological function, and numerous pattern indices have been cited to describe habitat pattern and suitability (FRANKLIN and FORMAN, 1987; HANSEN and URBAN, 1992; SCHUMAKER, 1996; RIITTERS *et al.*, 1997; PEARSON *et al.*, 1999; CHEN *et al.*, 1999). With the application of GIS, the methods for habitat analysis have been developed rapidly (PORWAL *et al.*, 1996; ZHANG *et al.*, 1999; YANG *et al.*, 1999; ORTIGOSA *et al.*, 2000; LI and WANG, 2000; HANSEN *et al.*, 2001; DEBELJAK *et al.*, 2001). But little study on wildlife habitat and its spatial diversity from the view of landscape ecology has been made in China. In this paper, Spatial Diversity Index (HEINEN and CROSS, 1983) is introduced to study the habitat pattern of red-crowned cranes (*Grus japonensis*) in the Liaohe Delta of China, in order to describe the spatial diversity of the habitat quantitatively and to reflect the change of the habitat suitability and spatial pattern explicitly. The research results will provide scientific basis for protecting red-crowned cranes and their habitats.

2 STUDY AREA

The Liaohe Delta is a complex fluvial plain of the Liaohe River, the Daliao River and the Daling River in

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Northeast China, and is the fourth largest delta in China, with an area of about 400×10^3ha. It is not only an oil-producing area but also an important food supply base in China (FU *et al.*, 2001). Moreover, it has 100×10^3ha of reed (*Phragmites communis*), which is the largest reed marsh in the world (XIAO *et al.*, 2001). The land exploitation gives priority to oil field, paddy field, reed field and prawn-crab-ponds. Agriculture is developing together with petroleum and heavy industry. Therefore it is obvious and intensive in the disturbance of wildlife habitat caused by human activities.

National Shuangtaihekou Reserve is located in the southern part of the Liaohe Delta. The total area of the delta is 128×10^3ha, including 41×10^3ha of reed marsh and 14.6×10^3ha of *Suaeda hetroptera* community, which are ideal habitat for wild lives. The animal species there include 100 water birds, out of 256 avifauna, 21 beasts, 10 reptiles and 4 amphibians. Five species were in the first-class national protection animal list, and 29 species were in the second-class national protection animal list ①.

Red-crowned crane (*Grus japonensis*) is a first-class national protection species. The Liaohe Delta is the southern site for the breeding of red-crowned cranes, and an important stopover site in their migration route. Therefore this delta plays an important role in the international conservation of cranes (XIAO *et al.*, 2001). Recently, monitoring results shows that there are about 400 red-crowned cranes resting in the Liaohe Delta during migration every year. The number of red-crowned cranes breeding here is over 50. They come at the end of February or early March, inhabit undisturbed reed marsh and *Suaeda* bottomland, and feed on fish, shrimps, crabs, and grass seeds, etc. They leave the Liaohe Delta for the middle or lower reaches of the Changjiang (Yangtze) River in the southern China to live through winter at the end of November (XIAO *et al.*, 2001).

3 MATERIALS AND METHODS

3.1 Basic Data

Land-use change is the leading cause of habitat loss and fragmentation (TURNER *et al.*, 1994; SKOLE *et al.*, 1994). Simple changes in land cover could produce complex changes in the spatial pattern of species habitats (PEARSON *et al.*, 1999). The land cover maps of the Liaohe Delta were selected as basic data layers in this paper.

Land-use information was derived from the remote sensing data of September of 1988 and May of 1998 (TM) based on field investigation. Thirteen land-use types were delineated: built-up area, reservoir-lake, prawn-crab-ponds, dry land, paddy field, reed, forest, *Suaeda* community, *Typha* community, *Tamarix* community, river, beach and salt field (LI, 2000). Red-crowned crane was taken as indicator species. The one-side influence distance of roads and dikes on habitat loss of red-crowned cranes was defined as 410m, while buffer distance for oil wells was defined as 500m (HU, 1997). In GIS the buffer zone maps of roads, dikes and oil wells were generated for 1988 and 1998. Area within the buffer zones was merged into "built-up area" in the land-use maps. The newly created maps were called land-cover maps (Fig. 1) in this study.

3.2 Spatial Diversity Index

The land cover maps were converted into grids to perform habitat spatial diversity analysis in the Arc/Info grid module for red-crowned cranes in the Liaohe Delta. The cell size should be defined according to the habitat characteristics of wild animals and the need of research. In this study the area of the smallest patch, 1ha (100m × 100m), was taken as the cell size.

3.2.1 Interspersion

Interspersion is defined as the "intermixing of units of different habitat types" (GILES, 1978). For the species requiring multi-habitats, the more concentrative the distribution of different kinds of habitat and the more diversiform the food and the shelter are, the more suitable it is for the species to live. The method for measuring Interspersion (HEINEN and CROSS, 1983) is as follows:

Fig. 2 shows an example of cell distribution. Each cell represents a certain land-cover type. Taking each cell as a center surrounded by 8 neighboring cells, which contains the same or different cover types from the center cell. Then the value of Interspersion (I_S) means the number of the cells with different cover types divided by 8. The formula is:

$$I_S = n/8$$

where n is the total number of 8 neighboring cells with different cover types from the center cell. Therefore the value of Interspersion ranges between 0 and 1. The

① Institute of Forestry Investigation and Design, Liaoning Province, 2000. Master Plan of Liaoning Shuangtaihekou National Reserve, 22-23.

Fig. 1 Land cover maps of the Liaohe Delta (a. 1988; b. 1998)

A	B	B
C	A	D
A	D	D

Fig. 2 An example of grid distribution (A, B, C and D represent different land covers)

value of the center cell in Fig. 2 should be: $I_S = 6/8 = 0.75$.

3. 2. 2 Juxtaposition

Juxtaposition is defined as a "measure of the adjacency or proximity of year-round habitat requirements to a site being analyzed for a particular species" (GILES, 1978). It denotes the quality of spatial collocation of different habitat units. The steps of calculation are as follows (HEINEN and CROSS, 1983):

(1) Make sure the edge type of the center cell with each of the 8 neighboring cells. For example, the cover type of the cell center is A, as in Fig. 2, and the cover types of the neighboring cells are A, B, C or D. So the edge types contain AA, AB, AC and AD. At best, there are 8 kinds of edge types for each cell.

(2) Give a numerical rating to each edge type, with 1 assigned to diagonal edges and 2 assigned to vertical or horizontal edges. Thus the total sum of the numerical rating of all edge types for each cell is 12.

(3) According to the requirement for different habitats of wild animals, a relative weight value ranging from 0 to 1 is assigned to each edge type. It represents the quality or importance of the edge type as the habitat of a particular species. In this study the relative weight values are evaluated by experts based on the requirement for habitat of red-crowned cranes and the habitat characteristics in the Liaohe Delta (Table 1).

(4) The relative weight value is multiplied by the relevant numerical rating of each edge type to give a total value of each edge type. The 8 edge types for each cell are divided by 12 to get the value of Juxtaposition index of the center cell. The value is also between 0 and 1.

Again Fig. 2 is taken as an example. Supposing A, B, C and D represent paddy field, reed, *Suaeda* community and built-up area, the sum value of numerical rating of each kind of edge types and the relative weight value form (Table 2). So the value of Juxtaposition $J_S = 2.80/12 = 0.23$.

Table 1 The relative weight values of edge types as the habitat of red-crowned cranes

Land cover type of the center cell	Land cover type of the cells around the center cell												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Built-up area	0	0	0	0	0	0	0	0	0	0	0	0	0
Reservoir-lake	0	0.10	0.20	0	0.20	0.70	0	0.50	0.70	0.30	0.10	0.30	0
Prawn-crab-ponds	0	0	0.25	0	0.30	0.60	0	0.30	0.50	0.10	0.10	0.10	0
Dry land	0	0	0	0	0	0	0	0	0	0	0	0	0
Paddy field	0	0	0.15	0	0.10	0.60	0	0.40	0.50	0	0.20	0.30	0
Reed	0	0.70	0.60	0	0.30	1	0	0.60	0.60	0.40	0.60	0.50	0
Forest	0	0	0	0	0	0	0	0	0	0	0	0	0
Suaeda community	0	0.40	0.40	0	0.20	0.95	0	0.90	0.90	0.50	0.60	0.50	0
Typha community	0	0.30	0.40	0	0.20	0.90	0	0.80	0.90	0.50	0.55	0.30	0
Tamarix community	0	0	0	0	0	0.50	0	0.30	0.50	0.20	0.30	0.40	0
River	0	0.10	0.20	0	0.10	0.70	0	0.50	0.70	0.10	0.20	0.20	0
Beach	0	0.10	0.15	0	0	0.70	0	0.60	0.50	0	0.30	0.40	0
Salt field	0	0	0	0	0	0.1	0	0.05	0	0	0	0	0

Note: 1. Built-up area; 2. Reservoir-lake; 3. Prawn-crab-ponds; 4. Dry land; 5. Paddy field; 6. Reed; 7. Forest; 8. *Suaeda* community; 9. *Typha* communtiy; 10. *Tamarix* community; 11. River; 12. Beach; 13. Salt field

Table 2 The calculation of Juxtaposition

Edge types	Sum value of the numerical rating	Relative weight value	Accumulation
A/A	2	0.10	0.20
A/B	3	0.60	1.80
A/C	2	0.40	0.80
A/D	5	0	0
Sum	12		2.80

Although the adjacency of 2 cells with the same land cover does not form a real edge, it is still given a relative weight value as an edge type, which can be used for embodying the importance of large stands for particular species.

In the original paper of HEINEN and CROSS (1983), the relative weight value of the edge types, AB and BA, was assigned the same value. But we consider that they are different because they represent the differences of resistance for species to move towards different habitats. Therefore different values were assigned to AB and BA as well as other similar edge types.

3.2.3 Spatial diversity

Spatial Diversity is educed from Interspersion and Juxtaposition, so it can represent not only the diversity of habitat but also the connectivity of the habitat. The simplified formula is (HEINEN and CROSS, 1983):

$$SD_A = \alpha_A I_S + \beta_A J_S$$

where A indicates a particular species, SD_A indicates the Spatial Diversity for a particular species A, α_A means the relative weight of Interspersion, β_A means that of Juxtaposition. The range of both α_A and β_A is between 0 and 1 and their sum must be 1.

The indicator species, red-crowned crane, has a high requirement for habitat with large area of reed and *Suaeda* bottomland. Thus Juxtaposition was considered to be more important than Interspersion in composition of Spatial Diversity. After comparison and adjustment, α_A was assigned 0.3 and β_A was 0.7. Then the Spatial Diversity index of the center cell in Fig. 2 is:

$$SD_A = 0.3 \times 0.75 + 0.7 \times 0.23 = 0.386$$

All above three index values of each cell could be calculated with GIS and the distribution maps could also be generated. But the values were so numerous and various that they were difficult to be expressed and analyzed. Therefore, the values were grouped into four grades representing the habitat suitability. They were areas of low (0–0.25), mid-low (0.25–0.50), mid-high (0.50–0.65) and high (0.65–1) values for Interspersion, Juxtaposition, and Spatial Diversity. The four grades were assigned class 1 (low), 2 (mid-low), 3 (mid-high), and 4 (high) respectively. The higher the value was, the more suitable the habitat was.

By comparing and analyzing the spatial distribution maps of Interspersion, Juxtaposition, and Spatial Diversity values, it was found that Spatial Diversity (Fig. 3) could best represent the habitat suitability and the spatial distribution of red-crowned cranes. Finally Spatial Diversity was selected to describe the habitat pattern and changes between 1988 and 1998 in the Liaohe Delta.

4 RESULTS AND DISCUSSIONS

4.1 Changes of Land Cover Types

Table 3 presents the statistical results of the characteristics of land cover in the Liaohe Delta, which were derived from the maps of land cover type (Fig. 1).

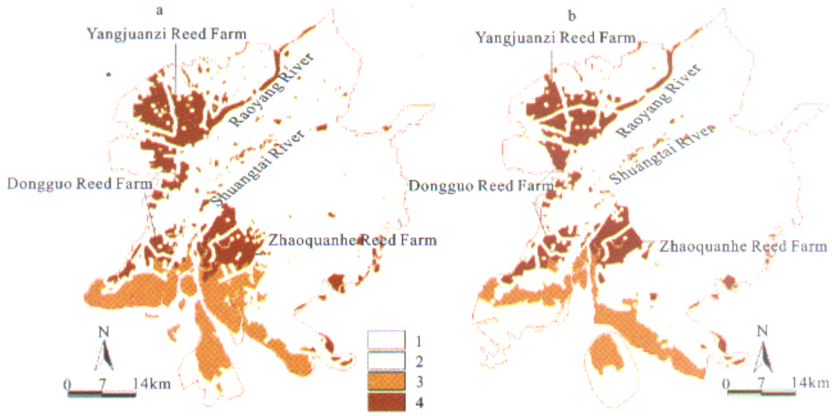

Fig. 3 Distribution of Spatial Diversity of the habitat of red-crowned cranes in the Liaohe Delta (a. 1988; b. 1998)

Table 3 Statistics of land cover types in the Liaohe Delta

Land cover type	1988		1998	
	Number of patches	Percentage of area(%)	Number of patches	Percentage of area(%)
Built-up area	255	41.07	249	42.54
Reservori-lake	62	0.78	41	0.75
Prawn-crab-ponds	41	0.91	48	1.45
Dry land	74	3.07	105	3.36
Paddy field	286	23.51	270	24.55
Reed	232	13.36	141	10.34
Forest	23	0.67	24	0.51
Suaeda community	37	12.06	21	7.64
Typha community	8	0.07	18	0.12
Tamarix community	1	0.01	1	0.04
River	41	2.06	30	1.60
Beach	2	2.39	9	6.96
Salt field	5	0.05	3	0.14

The built-up area (including buffer zones of roads and oil wells) occupied more than 40% of the delta, which was the highest among the 13 land cover types. The increasing trend indicated that human activities were becoming more intensive in this region. The area of paddy fields had a little increase while that of reed fields had decreased. But the number of patches of the two land cover types had both decreased. Though the percentage of the beach was very small, the area had a remarkable increase, one due to the delta expansion caused by sedimentation, and another due to the tidal level difference between the two images, from which the land cover maps were derived. *Suaeda* community loss was more than 1/3 of the area, which was the highest among all types. But the number of patches increased. This was mainly due to land occupation by breeding ponds and other land use types. The agricultural exploitation in the early 1990s and the development of oil industry had resulted in the decrease of natural land cover types, such as *Suaeda* community, reed fields and rivers, and the increase of artificial ones, such as paddy fields, prawn-crab ponds, and built-up area.

4.2 Basic Characteristics of Habitat Pattern

Fig. 3 indicated that the proportion of suitable habitats for red-crowned cranes (area of high and mid-high values) was quite small. They were mostly distributed in the reed fields and *Sueada* communities in the western and southern parts of the delta. The fragmentation pattern was highly associated with roads and oil wells. Some small patches with high values did exist in the scattered reed fields in the east of the delta, but the connectivity between them was low and the area of most of them was smaller than the territory needs of red-crowned cranes (the minimum area was 186ha during breeding) (HU, 2001). Therefore the value of these patches had been lost as habitats for red-crowned cranes.

The area with high Spatial Diversity index value was the extensive reed field with little human disturbance, mainly located at Yangjuanzi Reed Farm and Zhaoquanhe Reed Farm. But Yangjuanzi Reed Farm was not suitable for the cranes and other water birds, according to the field observation. The reason might be that this area was separated from the southern part by a large area of intensive oil fields. Another reason was that this area was mainly irrigated with polluted water from the Raoyang River, which has big paper factories upstream. The quality of food, water and smell was poor for the birds. Also, the reed farm was bisected by the new highway.

The distribution area of mid-high Spatial Diversity value was consistent with that of *Suaeda* community along the beach, besides a very small fraction linearly stretched along the border of high value area. The latter was caused by high Juxtaposition value, and did not mean high habitat suitability. Large areas influenced by intensive human activities, such as paddy fields and built-up area, namely, the area of low value and mid-low value in Fig. 3a and Fig. 3b, had lost the advantage to be used as habitats for red-crowned cranes.

In short, the most suitable habitat of red-crowned cranes was the extensive reed fields with less human disturbance near the river mouth and the *Suaeda* community near the beach. This agreed with the real distribution of red-crowned cranes in the Liaohe Delta.

4.3 Reduction of Habitat Suitability

Table 4 shows the changes of Spatial Diversity index for red-crowned crane's habitat in the Liaohe Delta from 1988 to 1998. The area with *SD* value of lower than 0.5 was obviously increased from 75.3% to 82.4%, while the area with high value was decreased to 9232ha, and that with mid-high value was decreased to 15 584ha. The decrease proportion was from 24.8% to 17.6%.

Table 4 The change of Spatial Diversity index for *red-crowned cranes'* habitat in the Liaohe Delta

Value grade of *SD*	1988		1998	
	Area(ha)	Percentage(%)	Area(ha)	Percentage(%)
1 (0 – 0.25)	283410	71.16	311069	74.42
2 (0.25 – 0.50)	16306	4.09	33190	7.94
3 (0.50 – 0.65)	51505	12.93	35921	8.59
4 (0.65 – 1.00)	47070	11.82	37838	9.05
Sum	398291	100.00	418018	100.00

The highest value of Spatial Diversity index also declined from 0.892 in 1988 to 0.881 in 1998. This change indicated that habitat spatial diversity, habitat suitability and the area of suitable habitat for red-crowned cranes were all decreased, and the quality of habitat was also degraded.

4.4 Change of Suitable Habitat Pattern for Red-crowned Cranes

By comparing the spatial pattern characteristic of red-crowned cranes in Fig. 3, it could be concluded that the spatial pattern of suitable habitat had been obviously changed in the ten studied years.

Firstly, in Yangjuanzi Reed Farm, Dongguo Reed Farm and the Raoyang River sides, there were some large patches with high values. It was three in 1988. But they were incised into 5 smaller ones after ten years, and 3600ha of the area were decreased. The change was related to the reclamation of paddy fields in reed farm. Furthermore, the newly built highway went through the reed fields, which cut apart the natural reed landscape as potential habitat for the cranes.

Secondly, the suitable habitat for red-crowned cranes was only 130ha and 100ha in 1988 and 1998, respectively, among 410ha of reed marsh in the reserve. The reason was that the area was rich in oil resource, with oil wells and related facilities all over the delta, which had a strong influence on wild animal habitats. In addition, the agricultural development occupied part of reed marsh in the nature reserve, and the protection levee along the seaside and tide locks on the tideway interrupted the natural succession of coastal wetlands (XIAO *et al.*, 2001), resulting in soil desalinization and reed degradation. The area of suitable habitat for red-crowned cranes of the reserve was getting smaller obviously.

Thirdly, some patches with mid-high values in the south, near the coast, which represented medium-suitable habitats, were only used in migrating season by red-crowned cranes. Fig. 3 showed that the area and the distribution of medium-suitable habitats were all different. They were in a serious tendency of habitat loss, because of agricultural reclamation, exploitation of prawn-crab ponds and the sedimentation from rivers. On the eastern bank of the Liaohe River, the agricultural reclamation in the early 1990s occupied large area of wetlands. The reservoir built lately occupied 1350ha of *Suaeda* community. In addition, with the improvement of irrigation through canals, about 5000ha of *Suaeda* community had been turned into paddy fields. On the western bank, the exploitation of 2800ha of prawn-crab ponds also caused the reduction of *Suaeda* community.

The paddy fields near the river mouth on the east bank were directly reclaimed from *Suaeda* bottomlands without the natural succession period of reed. The productivity of such paddy fields is very low. Now many farmers prefer to return these paddy fields to reed, or to fishponds. Then the economical and ecological situation will be both improved.

5 CONCLUSIONS

The economy of the Liaohe Delta had been developed rapidly with oil and agricultural exploitation. Therefore it is prominent for the influence from human activities on the wetland habitat of red-crowned cranes.

(1) The habitat of red-crowned cranes was distributed as following pattern: suitable habitat ($SD > 0.65$) in the reed fields with little disturbance, medium-suitable

($0.5 < SD < 0.65$) habitat in the *Suaeda* bottomland, and unsuitable habitat ($SD < 0.5$) in other areas.

(2) The habitat pattern of red-crowned cranes had been obviously changed from 1988 to 1998. The area of suitable habitat was getting more and more smaller and fragmented, and the connectivity of habitat was reduced.

(3) Human disturbance was the dominant driving force for the change of habitat pattern. It is necessary to seek appropriate methods for harmonizing the habitat conservation of wild animals with the development of regional economy.

(4) The study shows that Spatial Diversity index can describe the spatial pattern of habitats explicitly. If the relative weight values assigned to Interspersion, Juxtaposition, and the edge types are reasonable, Spatial Diversity index can be used to delineate suitable habitat for wild animals. This provides a sound approach for studying the spatial pattern of habitats and a scientific basis for protecting red-crowned cranes and their habitats.

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