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Analysis of patterns and ecological security trend of modern oasis landscapes in Xinjiang, China

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Abstract Ecological security has become so important that it will affect the national security and social sustainable development. In this paper, a case study on the ecological security indexes of modern oasis landscapes in Beitun Oasis, Xinjiang, was carried out. The spatial neighbouring parameters, such as the contiguous length, measure of area and patch quantity of oasis landscape patches, affected by desert landscape patches were calculated by using GIS-based buffer analysis, the method of calculating ecological security indexes of oasis landscape was developed, and the dynamic changes of patterns and ecological security indexes of the oasis landscapes since recent 30 years were analyzed. The results showed that soil salinization or alkalization and paludification were major factors affecting the ecological security in Beitun Oasis. Therefore, measures should be taken actively to prevent and control secondary salinization and paludification. The ecological security indexes of the oasis landscape in 1972, 1990 and 2005 were 78.91, 82.28 and 83.86, respectively, which showed the degree of security is improving, and the environment was developing harmoniously between human and nature. The methods of evaluating ecological security based on the spatial neighbouring relations between landscape patches can be used to reflect preliminarily the ecological security patterns of landscapes.

Keywords Oasis landscapes · Ecological security · Patch · Secondary salinization · Paludification · Beitun Oasis · China

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Introduction

Land, a kind of non-substitutable and non-renewable resources, is indispensable to all human beings. With the development of economy, expansion of population and increase in industrialization and civilization, human beings demand more land resources than ever. At the same time, technological progress has greatly increased the "human landscape" at the expense of the genuine nature. As a result, the structure and functions of global ecosystems are substantively affected and the landscape is losing its biological and cultural richness. (Niroula and Thapa 2005; Vitousek et al. 1997). These changes in land use and land cover are recognized as major components of the large-scale perturbations known as global change (Vitousek 1994). Various disasters occurring across the global scales in recent years have proved that ecological destruction will lead to heavy losses of human's living space and influence the sustainable development of human society seriously. The issue of ecological security has attracted extensive attention from experts and scholars all over the world. Ecological security was proposed by IIASA (International Institute for Application System Analysis) in 1989, where its definition is elaborated from two aspects, namely, in a narrow sense and in a broad sense (Xiao et al. 2002). In a narrow sense, it refers to the security of nature and semi-nature ecosystem, that is, the reflection of the ecosystem integrity and health. In a broad sense, it is a kind of state reflecting that no threat will be posed to human living, health, basic right, living guarantee, necessary resources, social orders and the abilities to adapt to environmental changes. Besides, it also includes nature, economy and society ecological security (Ma et al. 2004). Both senses focus on interactions between economic development and environmental conditions, and both base ecological security on the presence of a sound ecosystem, sustainable exploitation of natural resources, and harmony between human and nature. And the study on ecological security at landscape scale emphasizes the biodiversity conservation, regeneration of degenerated ecosystems, rational spatial collocation of resources, maintenance of healthy ecosystems, optimization of landscape patterns, and satisfaction to the requirements of social and economic development. Moreover, it also stresses the security of patterns, that is, the positions, portions and spatial relationships of parts compose certain patterns. And the security patterns have, or potentially have, critical significance in safeguarding ecological processes. Based on the study on security patterns, the measures of ecosystem management will be applied to the specific regions so as to achieve the intuitional effects.

Having profound significance to the structure and functions of modern landscapes, Land Use and Cover Change (LUCC) will produce two kinds of opposite processes, namely, the enhancement of urbanization & agricultural development, and land abandonment. Consequently, it is urgent to find out a suitable method to correctly monitor and evaluate the change process of landscape patterns (Herzog et al. 2001), and to arrange and manage the land use, making land cover develop harmoniously between human and nature. The landscape pattern of having both deserts and oases in arid areas in China attracts many geoscientists in the world to study them in these regions. Currently, however, more attention is paid to landscape patterns and their dynamic changes in the study of oases at landscape scale in China (Xiao et al. 2003). On the other hand, the analysis, evaluation and study on the ecological security of oasis landscapes are still at the theoretical level (Guan et al. 2003; Xiao et al. 2004; Yu 1999; Yu and Gao 1999). Nor have the integrated quantitative methods formed yet (Jiao and Xiao 2004). In this paper, a case study is carried out on the patterns and ecological security index of modern oasis landscape in Beitun Oasis located on the riverside of the Ertix River. To begin with, a method of GIS-based buffer analysis is put forward to calculate the ecological security indexes of oasis landscapes with the support of GIS spatial analysis. Calculations are also done to the spatial neighbouring parameters between the oasis landscapes and the desert ones. Then, a preliminary study is conducted on features of changes in ecological security of Beitun Oasis since China's implementation of reform and opening up to the outside world. The results of this case study will surely help decision makers know better the status of ecological security in making policies to achieve sustainability.

The study area

Beitun Oasis is in a mountain–oasis–desert coupling system (MODS), that is, the Altay Mountains-Beitun Oasis-Gurbantonggut Desert system (Fig. 1). It is located in the piedmont plain of the Altay Mountains, along the riverside of the Ertix River (47°00′–47°30′ N, 87°32′–88°25′ E) and encompasses a total area of 2,284 km^2. The northern part of the oasis is at the central section of the Altay geosynclinal fold system. The desert region is part of the north Junggar depression of the Junggar geosynclinal fold system, and the terrain slopes northward step by step. Beitun Oasis belongs to the temperate desert climate with a mean annual temperature of 4.1°C, the extreme minimum being −46.7°C (January 27th, 1969) and the extreme maximum being 40.1°C (July 27th, 1989). The annual accumulated temperature of the region (≥10°C) reaches 3,101.8°C. And the annual daily mean sun duration gets to 2,884.4 h with the frost-free period averaging 160 days. Mean annual precipitation reaches 101.4 mm, and evaporation capacity 1,922.0 mm. eight-scale gale and above it amount to 29.8 times, the northwest being the most disastrous one. The

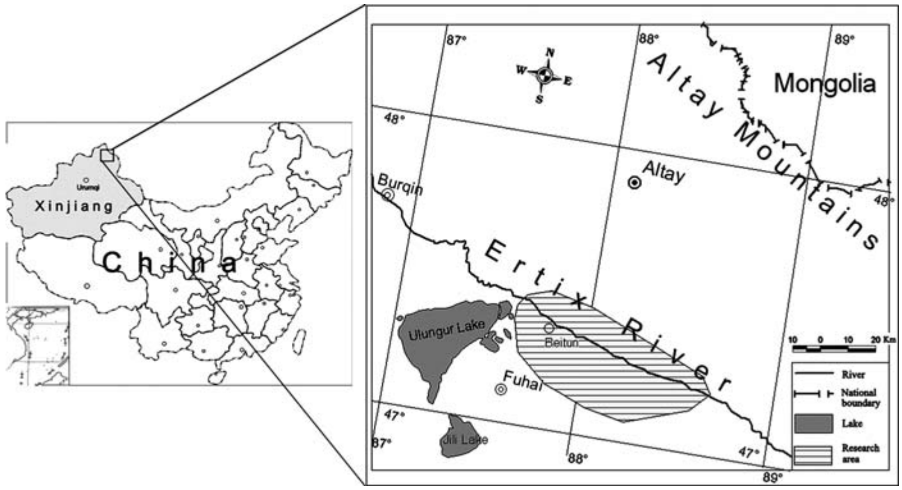

Fig. 1 Geographical location of Beitun Oasis

Ulungur Lake, one of the 10 largest freshwater lakes in China, is located at southwest of Beitun Town, covering an area of 1,000 km^2 with fine water quality. The Ertix River, the main stream system, flows through the area. The oasis abounds with wild animals, plants and mineral resources.

In recent 50 years, large-scale reclamation plays a key part in increasing the productivity of the modern oases in Xinjiang. The oases similar to Beitun Oasis are universally distributed in Xinjiang. As one of the most important reclamation areas, Beitun brings its role into full play. Moreover, because its natural environmental factors are changed so greatly that it is typical and representative in MODS development and evolution. Accordingly, it is selected as the study area.

Study methods and approaches

The raw data in this study include the landsat MSS image data in September 1972, TM image data in September 1990 and CBERS-02 CCD data in September 2005. Based on the topographic map in scale of 1:10,000, the geometry of the image was first corrected by the RS image processing system, ERDAS 8.7. After verification and matching, the RS images in different periods were classified by visual-interpretation based on the method of direct spectrum classifications. Ultimately the map of land use was charted. Polygons in the form of vector versions were used in this study. All the spatial and temporal analysis and data development were performed by using ArcView 3.2 and ArcInfo 8.0.1. By examining the classified results of RS images in three periods, the Kappa indexes were in the minimum precision of 0.8. According to the characteristics of land cover, the original land use types are integrated into eight landscape types, including farmland, woodland, grassland, urban and rural residential area, water area, sandland, salina-marsh, and Gobi. The distribution of oasis landscape patterns in each period was shown in Fig. 2.

These landscape types consist of three kinds of patches: oasis landscapes' patches, desert landscapes' patches and others. The detailed description of each landscape type is listed in Table 1.

Since contiguous patches affect each other significantly, three parameters can be used to describe the spatial neighbouring relationships between patches of oasis landscapes and desert landscapes. They are neighbouring length, affected area and number of adjacent patches, which are of great use to the detection of spatial processes in landscape transformation (Bogaert et al. 2004). This information may then be used to evaluate alternative land management and environmental conservation strategies. Generally, the longer the neighbouring length, the more affected area, and the larger adjacent patches' number are, the greater the threat made by desert landscapes will be, and the less secure of the oasis landscapes will be. The threatening index of the desert landscape patch j on the oasis landscape patch i can be expressed as

$$C_{ij} = L_{ij} + M_{ij} + A_{ij} \quad (1)$$

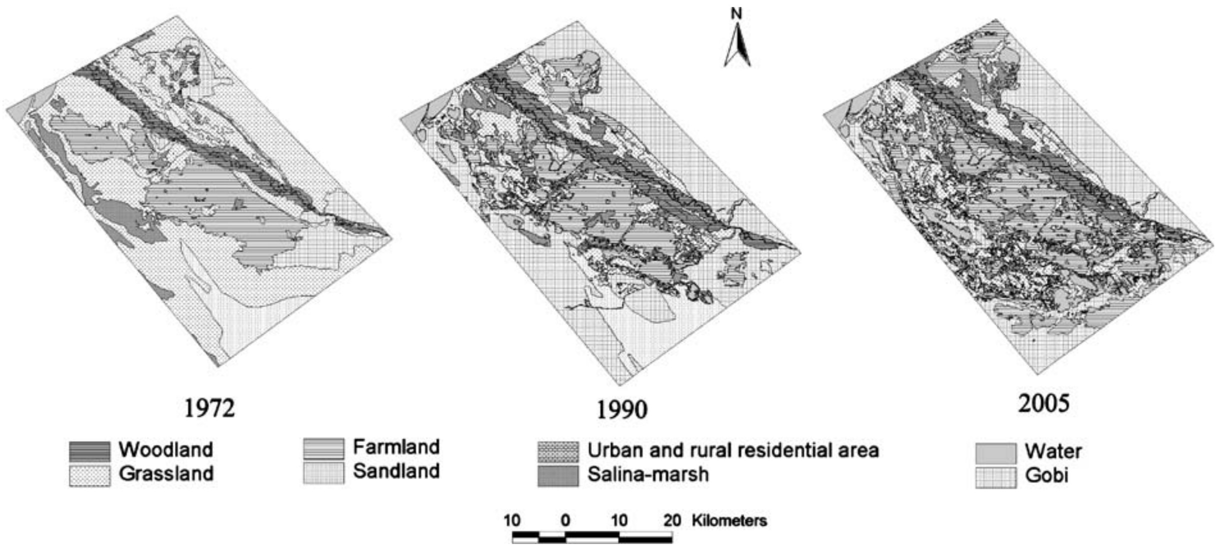

Fig. 2 Landscape pattern in each period of Beitun Oasis

Where, L_{ij} is defined as the percentage of neighbouring length (between patches of oasis landscape i and desert landscape j) in the total perimeter of oasis landscape i; M_{ij} is the percentage of adjacent patch number (between patches of oasis landscape i and desert landscape j) in the total patch number of oasis landscape i; A_{ij} is the percentage of the area of oasis landscape patch affected by desert ones in the total area of oasis landscape i. The holistic threatening index of oasis landscape patch i can be expressed as

$$C_i = \frac{1}{3}\sum_{j=1}^{n} C_{ij} \quad (2)$$

Table 1 Landscape classification system in Beitun Oasis

Landscape type I	Landscape type II	Description
Oasis landscapes	Farmland	Various crops farmland including paddy fields and irrigated dry fields.
	Woodland	Including forest lands, sparse wood lands and shrub lands, and mainly concentrating in the Ertix River coast. The canopy density or coverage ≥40%.
	Grassland	Including the natural meadows, improved artificial meadows and meadows for storage.
	Urban and rural residential area	Referring to the building sites of cities, towns and counties as well as rural residential areas.
Desert landscapes	Sandland	Covered by sand on the top layer, basically with no or extremely low vegetation coverage.
	Salina-marsh	Smooth low-lying terrain with poor drainage and seasonal or long-term water accumulation. Marshes covered by reeds, or the severe saline or alkali land covered by salt or alkaloid, with sparse vegetation, only alkali proof plants can survive.
	Gobi	Covered by soil but no vegetation on the top layer basically. Surface area ≥70% covered by gravel. Farmland discarded from cultivation for many years.
Others	Water area	Referring to the rivers, lakes, fishponds, reservoirs, pit ponds and so on.

Where, n is the total number of desert landscape types (here, n is 3). Thus, the ecological security index of the oasis landscape patch i (ESI_i) can be expressed as

$$ESI_i = 100 - C_i \tag{3}$$

The holistic ecological security index of the oasis landscape can be expressed as

$$ESI = \sum_{i=1}^{m} \left(ESI_i \times \frac{A_i}{\sum_{i=1}^{m} A_i} \right) \tag{4}$$

Where, A_i is the total area of oasis landscape patch i, m is the total number of oasis landscape types (here, m is 4).

The equations above show that the span of ESI is [0, 100]. The closer the value to 100 is, the more secure of the landscape ecology will be.

If so, in order to analyze the ecological security in the study area, the buffer analysis function of Spatial Analysis module in ArcView was first employed to establish the buffer zone. And the width of the buffer zone for sandland and salina-marsh was defined as 20 and 10 m, respectively, (for details, see "Discussions"). Then, ArcInfo is used to intersect the buffer zone on the original oasis landscapes' patches in order to achieve the three parameters L_{ij}, M_{ij} and A_{ij}. And only then can the threatening index (C) and ecological security index (ESI) be calculated. Because the landscape metrics are highly sensitive to the scale, the resolution of RS images will strongly affect the indices performance and interpretations. In this study, the ratio (such as L_{ij}, M_{ij} and A_{ij}) is employed instead of the original data derived from RS images directly to minimize the negative impact of resolution. In addition, the buffer zone for Gobi was omitted because this kind of landscape type might be much more easily influenced by other kinds of landscape types than it does on others. The direct intimidations of Beitun Oasis landscape are the land desertification, soil salinization or alkalization and paludification. Through investigations into these intimidations, the ecological fragility of oasis will be revealed. And by analyzing and evaluating the ecological fragility, the ecology security will be improved and the ecological risk will be reduced.

Table 2 Land use statistics in Beitun Oasis in 1972, 1990 and 2005 (km^2)

Year	1972	1990	2005
Farmland	404.955	390.800	569.808
Woodland	128.238	222.479	192.210
Grassland	1,168.687	370.262	516.144
Urban and rural residential area	2.376	10.165	14.710
Water area	52.861	98.236	157.490
Sandland	155.489	179.416	11.075
Salina-march	150.943	113.846	139.539
Gobi	220.444	898.794	683.065

Results and analysis

Features of landscape patterns changes

The changes of farmland

Beitun Oasis is a modern artificial oasis. The natural grassland in large area has been reclaimed as farmland thanks to the reclamation made by The Corps of Production and Construction in Xinjiang. The area of farmland is continuously enlarged (Table 2). In the tectonic movement of the region, however, the Tertiary sandy mudstone and muddy sandstone were interbeded with sandstone, which are in semi-agglutination with impervious stratum. The deposit (1~2 m in thickness) is mainly composed of unconsolidated and un-agglutinated coarse gravels (Team of Synthesize Examination in Xinjiang 1965). So, the region is characterized by thin soil and crude texture. All this leads to frequent occurrence of secondary salinization and paludification after the reclamation of the land. Meanwhile, due to the high groundwater level (0.6~1.2 m) (Xinjiang Institute of Biology, Soil & Desert, Chinese Academy of Sciences 1991), poor drainage conditions and violent evaporation, salt accumulation takes place in topsoil. Consequently, soil salinization or alkalization, land degradation and crop yield reduction also occur. Sometimes, the farmland is even discarded from cultivation. All these are factors seriously restricting agricultural production in the region.

The changes of woodland

The Ertix River is the only river flowing into the Arctic Ocean in China. Forests are distributed in most of the valleys. The river replenishment is plenitudinous so the natural valley forests are extensively distributed in the artificial oasis. And the oasis is obviously characteristic of intrazonal vegetation, affecting significantly the near-by environment. Along the riverbanks is distributed the largest gene bank of *Populus* spp. in China as well as many species of rare animals and plants. Along the river reaches in Beitun Oasis, the valley forests grow luxuriantly of *Populus* spp. (Bai et al. 2004). The areas of valley forests in 1972, 1990 and 2005 were 128, 222 and 192 km^2, respectively, (Table 2), having reduced in a fluctuation way owing to the artificial disturbance, such as the deforestation for reclamation, excessive pasturage and reservoir construction. Moreover, the structure of standing forests is irrational. According to the investigated data in 1998, the proportions of areas of mature and over-mature forests, approximate-mature forests, mid-aged forests and young growths in Beitun Forestry Centre were 57.3, 38.3, 4.4 and 0%, respectively, (Bai et al. 2004), which shows that the forests are degenerating, and that is also one of the reasons why the forest area is reducing.

The change of grassland

The history of animal husbandry development in the study area is centuries old. The area of grassland in Altay Prefecture ranks first in Xinjiang (Han 1991), and the prefecture has become an important production base of animal husbandry in Xinjiang. Some pieces of grassland, however, are degenerating due to the irrational utilization by people such as excessive pasturage. The total area of grassland in Beitun Oasis was dramatically reduced from 1,168.69 km^2 in 1972 to 370.26 km^2 in 1990 (Table 2). Both the vegetation coverage and biomass of the grassland are seriously decreased. The grass height in most grassland was only 5~10 cm in 2000, while the overloading rate of the grassland was as high as 39% (Wu et al. 2003). Because the edible grasses are pastured again and again, their proliferous capability is decreased, whereas, the poisonous weeds and non-edible grasses can grow. The composition of grass species is changed, and the quality of grassland is reduced. However, the area of grassland was enlarged to 516 km^2 in 2005, which should owe much to the project of returning land from farming to afforesting and grass planting and the climate change, especially the obvious increase of precipitation in north Xinjiang (Jiang et al. 2004).

The changes of urban and rural residential area and other landscape types

The area of urban and rural residential is continuously enlarged due to rapid population growth. Population growth results undoubtedly in the increase in natural resources consumption and affects the change process of oasis landscapes. Meanwhile, according to the statistical data, soil salinization occurred in one fourth farmland in Altay Prefecture in 1990, and the area of farmland discarded from cultivation because of salinization or paludification in the prefecture in 2000 was as large as 240 km^2 (Yang et al. 2000). Moreover, land desertification becomes more and more serious. The area of desert is enlarged with a speed of 16 km^2/a in the prefecture. The area of sandland in the delta of the Ulungur River was 140 km^2 when an aerial survey was carried out in 1950s, but it was extended to 166 km^2 at the end of 1970s (Kang et al. 2004). Table 2 shows that in Beitun Oasis the areas of sandland and salina-marsh were expanded significantly during the period of 1972~1990, but reduced to some extent in 2005. On the other hand, water area is enlarging all along. These changes are affected by both artificial and natural factors. The change in factors related to water resources affects the structure and functions of the whole ecosystems. The hydrological factors, especially in arid areas, are the main factors affecting the economic development and changing of environment in oases, and their slight change could influence the security of the whole ecosystems.

Spatial neighbouring relations between oasis landscape types and desert ones

Using GIS Spatial Analysis module of buffer, the parameters of L, M and A in Eq. 1 are derived (Table 3).

Table 3 reveals the changes of spatial neighbouring relations of oasis landscape types and desert landscape types in three periods. In 1972, the influence of the desert landscape patches on the oasis ones was mild, among which the greatest is that of salina-marsh on the grassland (L=18.63, M=37.5, A=0.28) but with small affected areas. In 1990, the influences of deserts on farmland and grassland were in an increasing trend. And the greatest is that of salina-marsh on the farmland (L=16.31, M=40.00, A=0.38) due to irrational irrigation, and soil salinization. Soil salinization is induced by natural factors, such as the

Table 3 Spatial neighbouring relations between the oasis landscapes and the sandland, salina-marsh (%)

Year		1972		1990		2005	
Landscape type		Sand-land	Salina-marsh	Sand-land	Salina-marsh	Sand-land	Salina-marsh
Farmland	L	\	9.72	1.47	16.31	1.34	15.86
	M	\	21.43	10.77	40.00	4.17	32.29
	A	\	0.08	0.07	0.38	0.07	0.44
Woodland	L	0.86	3.34	0.82	1.33	0.71	5.00
	M	3.03	21.21	3.28	10.17	7.35	11.76
	A	0.06	0.12	0.06	0.05	0.06	0.21
Grassland	L	9.19	18.63	1.68	14.88	1.82	13.64
	M	12.50	37.50	2.99	39.80	5.04	29.97
	A	0.23	0.28	0.17	0.74	0.24	0.90
Urban and rural residential area	L	\	1.94	\	0.57	\	3.92
	M	\	6.25	\	4.00	\	12.90
	A	\	0.19	\	0.04	\	0.24

L means the percentage of neighbouring length between patches of its row and its column in the total perimeter length of its row; M means the percentage of adjacent patches number between its row and its column in the total patches number of its row; A means the percentage of patches area of its row affected by patches of its column in the total patches area of its row.

regional tectonic movement and soil properties. Therefore, some rational irrigation and drainage measures are needed so as to use lands reasonably, to protect the integrality of the landscape structure, and to keep the sustainability of the landscape functions. In 2005, the three parameters of L, M and A were decreased to some extent overall. And the threatening situation of desert landscapes on those of the oasis was in a trend of alleviation. All this results from the fact that the ecological issue has been paid more attention and a series of measures have been taken to improve the environment in the headwaters areas of the Ertix River and Ulungur River since the late-1990s. On all accounts, the threatening fact of salina-marsh on oasis is much more severe than that of desertification, so measures should be taken to prevent soil salinization or alkalization and paludification.

Changes of the oasis landscape ecological security

The threatening indexes (C_i), the ecological security indexes (ESI_i) and the holistic ecological security index (ESI) of the oasis landscape can be calculated based on Table 3 using the Eqs. 1, 2, 3, and 4. The outcome is listed in Table 4.

What reveals from Table 4 is that, from spatial aspect, the threatening predicaments of farmland and grassland were the most severe in the oasis landscapes (their C_i values were higher than those of other two types) in three periods. In the first period the threat of

Table 4 Threatening indexes and ecological security indexes of oasis landscape in Beitun Oasis

Year	1972			1990			2005		
Item	C_i	ESI_I	ESI	C_i	ESI_i	ESI	C_i	ESI_i	ESI
Farmland	10.41	89.59	78.91	23.00	77.00	82.28	18.06	81.94	83.86
Woodland	9.54	90.46		5.24	94.76		8.37	91.63	
Grassland	26.09	73.91		20.08	79.92		17.21	82.79	
Urban and rural residential area	2.79	97.21		1.54	98.46		5.69	94.31	

C_i means the threatening index of i; ESI_i means the ecological security index of i; ESI means the holistic ecological security index of the oasis landscape.

grassland was the greatest while in the third period the greatest one was that of farmland. From temporal aspect, the integrated *ESI* of Beitun Oasis was gradually increased from 1972 to 2005, which indicates that the landscape structure is improving. Two factors contributed to this improvement. One is nature, such as the climatic changes, and the other is human. And the two should be integrated to implement a series of ecological conservation projects to maintain sustainability, such as water-saving irrigation, moderate pasturage, returning land from farming to afforesting or grass planting, and demarcating nature reserves as well. In addition, it is suggested enhancing the effectiveness of conservation projects so as to keep ecosystem improving, and extend this improvement from one oasis to the whole Altay Prefecture and even to other arid areas. Only by relying on increasing the ecological security can the sustainable development be reliably ensured.

Discussions

Ecological security has become the cornerstone of national security. The current research domain of ecological security includes: agriculture ecological security, water security, resource security, relations between land utility and ecological security and relations between nature protection and ecological security, and so on (Cheng and Chen 1995). The condition of ecological security influences directly the service functions of ecosystems (Wang and Ye 2001). Ecological security relates to such critical issues as population, water, food, energy, climate change, deforestation, biodiversity, etc. And the analysis of ecological security is evolved from the study on ecological risk and ecological fragility, which have been developed all over the world (Forman and Godron 1986; Kong et al. 2002; Rapport 1993; Ryan 1998). Due to its complexity, researchers find it difficult to agree on the concept of ecological security, which influences the resolution of ecological security problems. Establishing scientific evaluation standards and a reliable indicator system remains a key aspect in this field. The landscape ecology method is relatively new, and has gradually been employed in the study of ecological security as a basilic one. In this paper, the ecological security of oasis landscapes is studied based on landscape patterns and the spatial neighbouring relations between landscape patches. The method proposed is flexible and practical, which could help the government to know whether the decision-making is secure for both human and physical environment, so as to achieve the sustainable development.

This paper also finds difficulty in ascertaining the width of the buffer zone. One patch buffer zone could be determined by a series of factors, such as topography, water, soil, climate and human activities. Moreover, in modern oasis land use and land cover change is much more easily enslaved to governments' decisions. In order to simplify the complexity, the same standards are applied to define the same kind of buffer. The movement of Sandland is most closely related to wind speed. Northwest wind occurs frequently in the study area. Normally, the wind is blowing at 3.0~4.8 m/s. Crops are often lodged by mountain-valley gust in summer, and sandstorm disasters occur frequently. According to the experience summed up by predecessors, it is assumed that the width of sandland buffer zone concerned is 20 m (Zhou 2002). Similarly, the assumption of the width of salina-marsh buffer zone will be made. The study area is rich in precipitation relatively, and with strong evaporation, where the soil is characterized by high clay content and cohesion, easy hardening and poor aeration, as well as human's flooding irrigation except drainage. So the groundwater level is easily risen up. Salt accumulation in topsoil is as a consequence of being frequent and commonplace when groundwater depth is risen to 1.5~2.5 m due to evaporation. And land becomes marshland when groundwater depth is risen to 0.1~0.3 m (Sarah and O'Hara 1997). Therefore, the assumed width of salina-marsh buffer zone is 10 m. All of these assumptions are ideal, whereas the actual conditions are much more complicated. When a high accuracy during the study of ecological security is needed, a special functional equation should be established to show the possible change of each patch. And in this equation, the initial conditions and the terminal conditions of all the variable parameters should be preset. Accordingly, the accuracy in defining the width of buffer zone in each patch will be achieved. The more accurate it is, the more exact the ecological security indexes will be, which in turn will reflect the ecological status. All this provides more worthwhile topics in further research in the future.

References

Bai, Z. Q., Zhang, Y. T., Guo, Z. J., & Du, S. J. (2004). The present state and ecosystem protecting measure of Xinjiang Ergis River watershed. *Journal of Fujian College of Forestry, 24*, 188–192.

Bogaert, J., Ceulemans, R., Salvador, D., & Eysenrode, V. (2004). Decision tree algorithm for detection of spatial processes in landscape transformation. *Environmental Management, 33*, 62–73.

Cheng, S. L., & Chen, Y. (1995). Paying great attention to national ecological security strategy. *Ecological Economy, 5*, 9–11.

Forman, R. T. T., & Godron, M. (1986). *Landscape ecology* (pp. 166). New York: Wiley.

Guan, W. B., Xie, C. H., Ma, K. M., Niu, J. Z., Zhao, Y. T., & Wang, X. L. (2003). A vital method for constructing regional ecological security pattern: Landscape ecological restoration and rehabilitation. *Acta Ecologica Sinica, 23*, 64–73.

Han, D. L. (1991). Some problems of land use in Altay. In: CAS thematic group in using water resource of Ergis River, *Scientific exploration analectsin Altay prefecture* (pp. 118–124). Beijing: Science.

Herzog, F., Lansch, A., Muller, E., Thulke, H. H., Steinhardt, U., & Lehmann, S. (2001). Landscape metrics for assessment of landscape destruction and rehabilitation. *Environmental Management, 27*, 91–107.

Jiang, F. Q., Hu, R. J., & Yang, Y. H. (2004). Abrupt change in the time sequences of flood disasters in Xinjiang and its possible climatic reasons. *Journal of Glaciology and Geocryology, 26*, 674–681.

Jiao, Y. M., & Xiao, D. N. (2004). Spatial neighbouring characteristics among patch types in oasis and its ecological security. *Chinese Journal of Applied Ecology, 15*, 31–35.

Kang, X. W., Wu, S. H., Yang, Q. Y., Yang, P. G., Ma, X., & Liu, Z. Q. (2004). Ecological environment problems and sustainable development strategy in Altay prefecture, *XinJiang*. *Press in Geography, 23*, 19–27.

Kong, H. M., Zhao, J. Z., Ji, L. Z., Lu, Z. H., Deng, H. B., Ma, K. P., et al. (2002). Assessment method of ecosystem health. *Chinese Journal of Applied Ecology, 13*, 486–490.

Ma, K. M., Fu, B. J., Li, X. Y., & Guan, W. B. (2004). The regional pattern for ecological security (RPES): The concept and theoretical basis. *Acta Ecologica Sinica, 24*, 761–768.

Niroula, G. S., & Thapa, G. B. (2005). Impacts and causes of land fragmentation, and lessons learned from land consolidation in South Asia. *Land Use Policy, 22*, 358–372.

Rapport, D. J. (1993). Ecosystems not optimized: A reply. *Journal of Aquatic Ecosystem Health, 2*, 57.

Ryan, P. B. (1998). *Historical perspective on the role of exposure assessment in human risk assessment* (pp. 23–24). Michgan: Ann Arbor.

Sarah, L., & O'Hara (1997). Irrigation and land degradation. *Journal of Arid Environments, 37*, 165–179.

Team of Synthesize Examination in Xinjiang (1965). *Groundwater of Xinjiang* (pp. 78–80). Beijing: Science.

Vitousek, P. M. (1994). Beyond global warming: Ecology and global change. *Ecology, 75*, 1861–1876.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of earth's ecosystems. *Science, 277*, 494–499.

Wang, R. H., & Ye, X. (2001). Strategy of Ecological environment construction during the development of west arid zone in China. *Arid Land Geography, 24*, 152–156.

Wu, S. L., Hai, Y., & Ba, T. (2003). Research on issues of ecological environment in the source region of two rivers in Altai Mountain. *Environmental Protection of Xinjiang, 25*, 5–8.

Xiao, D. N., Chen, W. B., & Guo, F. L. (2002). On the basic concepts and contents of ecological security. *Chinese Journal of Applied Ecology, 13*, 354–358.

Xiao, D. N., Wang, G. X., & Wang, R. H. (2003). *Perspective of landscape ecology in Chinese arid zone* (pp. 88). Urumqi: Xinjiang People's Press.

Xiao, D. N., Xie, F. J., & Wei, J. B. (2004). Regional ecological construction and mission of landscape ecology. *Chinese Journal of Applied Ecology, 15*, 1731–1736.

Xinjiang Institute of Biology, Soil & Desert, Chinese Academy of Sciences (1991). *Research of Xinjiang soil and land resource* (pp. 94–102). Beijing: Science Press.

Yang, F. X., Li, G. Z., Zuo, H. Z., Shen, Y. L., Qiao, M., Li, W. P., et al. (2000). Formation causes and the transformation measures of the meso-low yield land in Altay Prefecture, Xinjiang. *Arid Land Geography, 23*, 239–243.

Yu, K. J. (1999). Landscape ecological security patterns in biological conservation. *Acta Ecologica Sinica, 19*, 8–15.

Yu, K. J., & Gao, Z. C. (1999). Eogical security format approaching landscape ecology and environmental protection program. *Shaanxi Environment, 6*, 4–45.

Zhou, H. R. (2002). On test of wind erosion for soil in Yanji Basin of Xinjiang, China. *Journal of Soil and Water Conservation, 16*, 26–27.