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Changes of Urban Wetland Landscape Pattern and Impacts of Urbanization on Wetland in Wuhan City

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Abstract: In this study, remote sensing data of Wuhan City, Hubei Province, China in 1996–2001 were selected to extract wetland landscape information. Several landscape indices were used to evaluate the changes of landscape pattern within the five years, including patch number, patch density, patch fractal dimension, landscape diversity, dominance, evenness, and fragmentation indexes. Then, transformation probabilities of wetland landscapes into non-wetland landscapes were calculated based on Markov Model, and on these grounds the relationship between changes of wetland landscape pattern and urban construction was analyzed. The results showed that fragmentation degree of all wetland types increased, lake area declined, and dominance of natural wetland decreased. The reasons for these results were mainly because of urban construction. According to the features of abundant wetland in Wuhan City, we suggested that protection of wetland landscape should cooperate with urban construction, which means wetland should become important part of urban landscape.
Keywords: wetland landscape; urban wetland; wetland protection; Wuhan City

1 Introduction

Urban wetland is an important part of urban landscape. Therefore, its ecological function plays a significant role in the development of urban eco-environment (Yang, 2002). Urban landscape results from the interactions between social and natural factors. As a part of natural ecological landscape, the form and changes of wetland landscape are thus highly associated with human activities. Urban wetlands, in the forms of artificial and semi-artificial wetlands or remnant natural wetlands in urban construction, are distinguished manifestly from natural wetlands in such aspects as ecological attribute, landscape pattern, and function service due to the influence of cities (Wu et al., 2007). It is known that the sustainability of urban development depends on forward-looking municipal infrastructure and ecological infrastructure. Urban wetland is an important ecological infrastructure of a city and provides multitudinous ecological and social services. Moreover, urban wetland (e.g. river system pattern) plays a decisive role in the form of a city and its pattern, and affects the sustainability of urban development directly (Yuan et al., 2001; Liu et al., 2005). Overall, it is meaningful to research the relationship between the dynamic change of urban wetland landscape pattern and landscape ecological planning (Sun and Wang, 2000; Weber and Puissant, 2003).

The elementary topic in landscape ecology is the connection and feedback among structure, pattern and progress of landscape (Bai et al., 2005). It is also the foundation of landscape ecological planning (Randolph, 2004). In recent years, the researches on the dynamics of wetland and urban wetland landscape pattern have already become a hot-spot area in wetland science and ecological studies. At present, the researches mainly concentrate on the dynamics of wetland landscape pattern and driving forces, landscape indices and dynamic models (Wang and Cao, 2005; Yue et al., 2005). As for the driving forces, natural wetland differs fairly from urban wetland. Almost all urban wetlands are driven by artificial factors, and evolve faster, out of any law and even irreversible (Lemly and Ohlendorf, 2002).

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The methods for the research of landscape dynamics mainly include the traditional qualitative description method, map overlay method and quantification method (Huang et al., 2005; Li and Xiao, 2001; Fu et al., 2001; Li and Zhu, 2003; Li et al., 2004). At present, the third one is usually used by many scholars to study the changes of landscape pattern. As to the study on wetland landscape dynamics, there is a newly developed method, which uses landscape dynamics model based on certain rules and tries to combine with artificial intelligence. The primary models employed by many scholars are dynamics degree model, relative change ratio model, patch connection degree model, etc. (Wang et al., 2003; Guo and He, 2005). Moreover, Markov model and cellular automata are used to simulate and predict the dynamic progress of wetland landscape.

Urban wetland landscape researches has drawn increasing attention and applied many landscape analysis methods. But most of them mainly focused on one wetland landscape type, lack of comprehensive study on the relationship between all wetland types and other urban landscapes. This paper conducted an overall study on the relationship, which will give more practical advices on the construction, conversation and exploitation of urban wetland landscape, and better service the sustainable urban development.

2 Study Area

We selected Wuhan City as study area. It is located in the hinterland of China, south of Hubei Province, and is the junction of the Changjiang (Yangtze) River and the Hanshui River (Fig. 1). Its geographical position is 113°41′–115°05′E and 29°58′–31°22′N. The physiognomy of the city belongs to the transitional belt from southeast highland to foothill in the south piedmont of Dabie Mountain. The middle part is low and flat, and the south part and north part are hills. The landform types of Wuhan City belong to alluvial plain of rivers and lakes, with many lakes and rivers. The climate of the region belongs to semitropical monsoon climate, with four clear seasons and abundant precipitation mostly concentrating in June–August. The soil types are various, of which paddy field soil has the biggest area, occupying about 45.5% of the total area. Wuhan City has 13 administrative districts of Jianghan, Jiang′an, Qiaokou, Hanyang, Wuchang, Qingshan, Hongshan, Caidian, Jiangxia, Huangpi, Xinzhou, Dongxihu and Hannan. Ten of them, excluding Jiangxia, Huangpi, and Xinzhou districts, were selected in this study for their more rapidly change in urban construction.

3 Data and Methods

3.1 Data

The original data used in this paper were remote sensing data and relative charts or maps of 1996 and 2001, which were rapid developing periods of Wuhan City. By applying GIS software ArcGIS, the spatial attribute in formation of wetland and non-wetland landscapes, such as patch size, patch number and patch perimeter, could be derived from interpretation and mapping of the remote sensing data. The attribute data were the foundation of spatial pattern analysis, which were processed

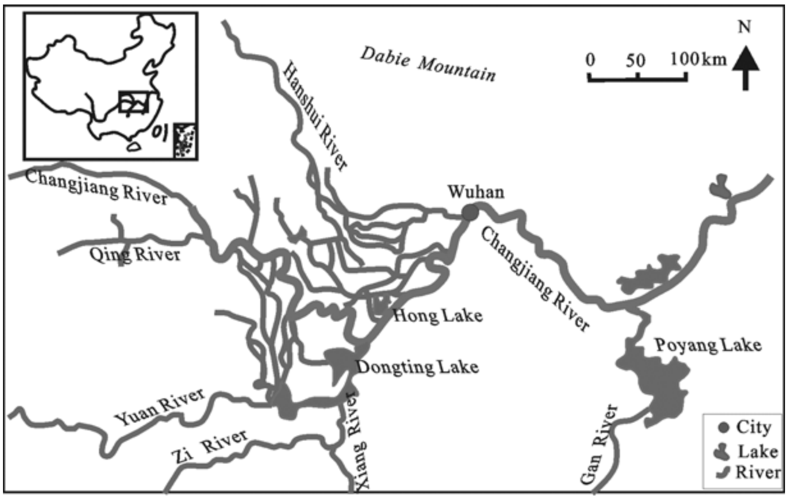

Fig. 1 Situation of Wuhan City

and calculated by using software of Excel and VC++.

3.2 Methods

3.2.1 Landscape type classification

In the study area there exist 13 landscape types, i.e., river, bottomland, lake, paddy field, pond, lotus pool, canal, road, residential area, industrial and mine land, meadow, woodland and dryland. In order to study the dynamics of wetland landscapes and their conversion into other urban landscapes in Wuhan City, these landscape types are divided into four landscape classes, that is, natural wetland (river, bottomland and lake), man-made wetland (paddy field, pond, lotus pool, canal), construction land (road, residential area, industrial and mine land), and other non-wetland (meadow, woodland, dryland). For convenience the landscape classes of construction land and other non-wetland are often used when discussing the dynamics of wetland landscape types. From 1996 to 2001, the spatial distribution of wetland landscape types changed obviously (Fig. 2).

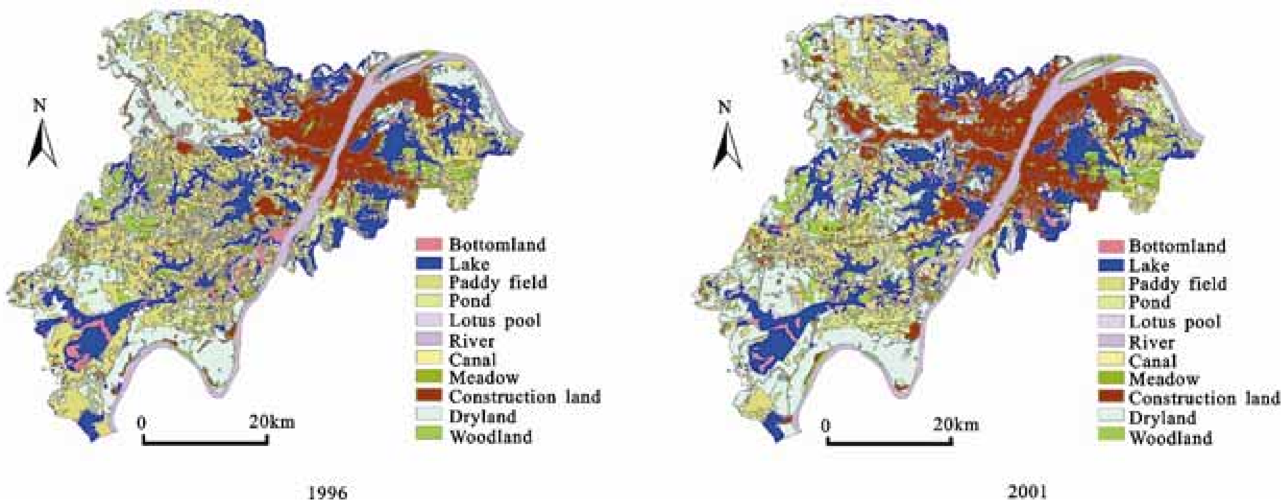

Fig. 2 Spatial distribution of wetland and non-wetland landscapes of Wuhan City in 1996 and 2001

3.2.2 Determination of landscape pattern indices

Landscape pattern indices are widely used in landscape ecology. With the spreading of GIS technology, it is very easy for us to process one or several landscape type maps and obtain a variety of pattern indices data. At present, the indices used in China are somewhat a lot. Some are relatively simple like area, patch shape and so on, most of which come directly from mathematical statistics. Besides, many complex landscape indices originate from information theory, such as diversity, dominance and contagion indices. Some new indices continue to come forward, e.g. lacunarity index and aggregation index. Because these indices are based on the geometry feature of spatial landscape structure, they can describe complicated phenomenon easily. Although some of them are a little abstract, they are still appreciated by many researchers. In recent years, as the rapid development of remote sensing and GIS technology, more and more studies have been conducted in this field (Li et al., 2004). Besides some simple indices, the main indices used in this paper are listed in Table 1.

4 Results and Discussion

4.1 Change of wetland landscape type

In this study, we selected the commonly used indices, such as area, area ratio, patch number, patch density, fractal dimension, fragmentation, diversity, dominance and evenness to study the dynamics of wetland landscapes. Their calculating methods can be seen in Table 1. The index values of landscape types are shown in Table 2.

Table 2 showed that patch number of wetland types in 2001 increased a bit than that in 1996, but patch number of non-wetland types, e.g. construction land, decreased by a considerable amount. On the one hand, the growing of wetland patch number indicates that human activities strengthened the disturbance on wetland; on the other hand, this suggests that fragmentation degree of wetland

Table 1 Description of landscape pattern indices

Index	Formula	Ecological significance
Patch Density (*PD*)	$PD=N_P/A$ $PD_i=N_{Pi}/A_i$	Fragmentation degree of a landscape type
Fractal Dimension Index (*FD*)	$FD=2\ln(\frac{l}{k})/\ln(s)$	Complexity or self-similarity of a patch
Fragmentation Degree Index (*FN*)	$FN=(N_P-1)/N_c$	Fragmentation degree of a landscape type
Dominance Index (*D*)	$D=\ln m+\sum_{i=1}^{m}P_i\times\ln P_i$	To what extent several principal landscape types control whole landscape
Evenness Index (*E*)	$E=\frac{-\sum_{i=1}^{m}P_i\times\ln P_i}{\ln m}$	Even degree of different landscape types
Diversity Index (*H*)	$H=-\sum_{i=1}^{m}(P_i)\log_2(P_i)$	Variation of landscape factors and their proportion

Notes: N_P is the total number of patches of whole landscape; *A* is the total area; N_{Pi} is patch number of landscape class *I*; A_i is the area of class *i; k* is a constant, as to grid map, *k* equals to 4; *l* and *s* are patch perimeter and area; N_c is total grid number of landscape map; P_i is area ratio of class *i; m* is total landscape class numbe

Table 2 Index of wetland landscape type and non-wetland landscape class in 1996 and 2001

	1996						2001					
	Area (ha)	Area radio (%)	Patch number	Patch density (/ha)	Fractal dimension	Fragmentation	Area (ha)	Area radio (%)	Patch number	Patch density (/ha)	Fractal dimension	Fragmentation
Bottomland	5456	1.95	129	0.0236	1.281	0.0193	6002	2.14	139	0.0232	1.319	0.0213
Lake	45602	16.29	254	0.0056	1.431	0.1623	45437	16.24	334	0.0074	1.372	0.1691
River	16822	6.01	15	0.0009	1.511	0.0001	17317	6.19	15	0.0009	1.473	0.0578
Paddy field	88565	31.64	287	0.0032	1.465	0.0502	53236	16.23	341	0.0064	1.439	0.1897
Pond	10685	3.82	264	0.0247	1.335	0.0424	14865	5.31	294	0.0198	1.339	0.0529
Lotus pool	3710	1.33	158	0.0426	1.366	0.0152	7837	2.80	367	0.0468	1.294	0.0279
Canal	155	0.06	5	0.0322	1.335	0.0000	1181	0.42	34	0.0288	1.582	0.0041
Construction land	37941	13.55	672	0.0177	1.369	0.2756	57753	20.64	311	0.0054	1.507	0.2057
Other non-wetland	70986	25.35	865	0.0122	1.355	0.2533	76220	27.24	447	0.0059	1.385	0.2718

landscape type was intensified to some degree. As to each wetland landscape type, patch densities of paddy field, lake and lotus pool showed an increasing tendency, which reflects that their porosity was much bigger and they dispersed more relatively. On the contrary, the density of canal and pond reduced slightly, it reflects lower lacunarity and more concentrated distribution. As for the whole landscape, path density dropped from 0.0095 in 1996 to 0.0082 in 2001, which indicates landscape mosaic degree decreased and heterogeneity of the landscape was enhanced.

With regard to patch dimension, the value of most wetland types except bottomland decreased to different degree and among them lotus pool decreased greatly, which means that the shape of wetland landscape tended toward simplifying and self-similarity was enhanced. The fractal dimension should be higher at a natural state comparing with the declined actuality. It could thus be merely explained that human activities interfered with the wetland types. Fractal dimension of construction land stepped up to very high, which means that construction land was irregular and not so self-similar.

We can also find that fragmentation degree of all types of wetland and the whole urban landscape became bigger with time, the value of construction land however diminished to a large extent. This resulted from road building and construction land connection in Wuhan in recent years. It was obvious that changes of wetland patterns were highly influenced by human activities, and the heterogeneity of wetland landscape was gradually increasing.

4.2 Changes of landscape classes and whole urban landscape

According to the calculation methods shown in Table 1, dominance, fragmentation, evenness and diversity indices of natural wetland, man-made wetland and non-wetland landscapes were calculated respectively (Table 3).

From Table 3, we can see that fragmentation of natural wetland increased while its dominance index declined. This phenomenon indicates that natural wetland was disturbed greatly. And because of heavy influence from human activities, the area of lake wetland was reduced by 0.36%, thus its dominance was therefore lowered. The area of bottomland increased by 10%, which strengthened the evenness of natural wetland landscape.

Table 3 Index of landscape class and whole urban landscape of Wuhan in 1996 and 2001

	1996				2001			
	Fragmentation	Dominance	Evenness	Diversity	Fragmentation	Dominance	Evenness	Diversity
Natural wetland landscape	0.2419	0.4083	0.5433	1.1767	0.2452	0.3819	0.5967	1.2031
Man-made wetland landscape	0.3679	1.2859	0.2078	0.7141	0.2753	0.7455	0.4659	0.2545
Non-wetland landscape	0.3889	0.8543	0.5400	1.4685	0.4781	0.5716	0.6298	1.4284
Whole landscape	0.0016	0.3754	0.6563	3.2095	0.0080	0.6156	0.7484	2.8438

Note: The non-wetland landscape includes construction land and other non-wetland

As to man-made wetland landscape, both of fragmentation and dominance indices decreased but evenness index increased. The reason was that paddy field used to prevail among man-made wetland types, while five years later, the proportion of each type of man-made wetland altered to a great extent and their areas turned to be more uniform. Non-wetland area was the place where human activities were the fiercest in the whole city, and thus its fragmentation index become greater.

The diversity index of whole urban landscape droped from 3.2095 in 1996 to 2.8438 in 2001. It denoted the proportion difference among landscapes was narrowed. In 1996 the dominance of urban landscape was low, only 0.3754 and the evenness index was 0.6563. Both of them reflect that the proportion difference among all landscape types was not so big. But in 2001 the dominance and evenness indices were 0.6165 and 0.7484, increased by 0.2411 and 0.0911 respectively. It was clear that whole urban landscape pattern more and more depended on few types of landscapes and landscape evenness degree was rising.

4.3 Transformation probability of wetland type

In order to find out the change trend of wetland landscape and investigate the relation between wetland types and non-wetland types especially construction landscape, the wetland distribution map in 1996 was overlaid by the one in 2001. Then the area data about transformation among wetland types could be extracted. Later Markov transformation matrix was used to clarify the condition of wetland in Wuhan City in recent years. Markov process is a random process, which shows that the moving status at one time (t+1) of a system is related to a former time (t) (Wang and Wu, 2002). The transformation probabilities among landscape types were confirmed based on the average annual conversion ratio of every landscape type. With transformation probabilities of bottomland turning into other types as the first line and the transformation probabilities of lake turning into other types as the second line, and the like, the shifting probability matrix was set up (Table 4).

As shown in Table 2, the urban wetland landscape of Wuhan changed greatly in the form of decreasing in natural wetland, especially lake wetland. From 1996 to 2001, the area of lakes in the study area dropped from 45,602ha to 45,437ha. But the patch number of lake landscape and its patch density both increased greatly and it was getting obvious that lakes were artificially divided into smaller ones. For the situation of lake wetland converting to other wetland types, the main reasons were as follows:

Firstly, filling out lakes for building houses was the primary reason for the loss of lake area. According to Table 4, the transformation probability from lake to construction land reached to 0.0030. In history, West Lake, Gedi Lake and Chang Lake in Wuchang District disappeared for being filled and builting house on them. And Hou Lake, lying north to Zhongshan Road in Hankou District, was also filled partly.

Secondly, enclosing lake for cultivating and fishing caused the area of lakes to reduce. In the exterior margin of central city zone in Wuhan, lakes were enclosed and

Table 4 Transformation probability matrix of wetland landscapes in Wuhan from 1996 to 2001

1996	2001										
	Bottomland	Lake	River	Paddy field	Pond	Lotus pool	Canal	Construction land	Meadow	Dryland	Woodland
Bottomland	0.9687	0.0101	0.0016	0.0046	0.0061	0.0014	0.0000	0.0058	0.0000	0.0017	0.0000
Lake	0.0038	0.9735	0.0000	0.0007	0.0093	0.0070	0.0000	0.0030	0.0000	0.0027	0.0000
River	0.0022	0.0000	0.9978	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Paddy field	0.0000	0.0000	0.0004	0.9717	0.0031	0.0016	0.0000	0.0092	0.0003	0.0006	0.0000
Pond	0.0000	0.0000	0.0000	0.0002	0.9928	0.0000	0.0000	0.0070	0.0000	0.0000	0.0000
Lotus pool	0.0000	0.0000	0.0000	0.0059	0.0000	0.9871	0.0000	0.0070	0.0000	0.0000	0.0000
Canal	0.0000	0.0000	0.0000	0.0000	0.0781	0.0000	0.8642	0.0497	0.0000	0.0000	0.0080
Construction land	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.9992	0.0000	0.0000	0.0008
Meadow	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0000	0.0057	0.9712	0.0000	0.0221
Dryland	0.0000	0.0000	0.0000	0.0050	0.0010	0.0000	0.0000	0.0202	0.0003	0.9707	0.0025
Woodland	0.0000	0.0000	0.0000	0.0012	0.0007	0.0000	0.0000	0.0073	0.0000	0.0080	0.9828

changed into paddy field or dry land with the transformation probabilities of 0.0007 and 0.0027 and some were transformed into pond and lotus pool with the probabilities of 0.0093 and 0.0070. It is conspicuous that economic benefit eventually stimulated the decline of lake size and fragmentation of lake wetland landscape.

Third was the deposition of lakes, mainly caused by human activities while the natural progress was fairly slow. From 1996 to 2001, transformation probability from lake to bottomland was 0.0038, ranked the third of all probabilities. As we know, the productive waste and domestic rubbish were abandoned in East Lake, Sha Lake, Yangchun Lake and Daijia Lake，therefore it brought about shrinking of water surface and caused the lakes to reduce more than half in depth compared with that in 1949 and the water bodies were also polluted seriously.

In addition, Table 4 shows the transformation probabilities of wetland landscapes turning into construction land were bigger than that into other landscapes, and the probabilities were all bigger than 0.005 except for river and lake wetlands. To study the level of wetland urbanization, we made use of urbanization index *E*. Here, *E* was calculated by the formula:

$$E=A_c/A_w$$

where A_c is the total area of construction land, A_w is total area of natural and man-made wetlands.

The results were 22.2% in 1996 and 39.6% in 2001, increasing as time went by. It reflects that urban construction brought about disappearing of wetland landscape to some extent, and also indicated that changes of construction land had very great influence on dynamics of wetland landscape.

4.4 Relation of wetland landscape dynamics and urban landscape construction

The expansion of urban construction land is usually regarded as one of urban development manifestations. If the urban landscape construction of Wuhan plans to gain a foothold as a city of one hundred lakes, then wetland size shrinking would turn to disadvantageous trend for Wuhan’s development. The expansion of urban construction landscape is to meet the need of urban economic development. Therefore no matter filling lakes for housing or enclosing lakes for planting, the motive is driven by economic interest. As urban population increases, the scarcity of urban land is getting really tense. In this circumstance, a number of wetlands were changed into other landscape types especially construction land so as to lower cost in short run and obtain remarkable profit. But as a kind of non-renewable resources for urban landscape, natural wetlands produce much higher potential value in ecology than in economy directly. Since Wuhan City possesses a large area of wetland, it is indispensable to maintain a certain amount of them for the health of urban ecosystem. The key whether we can protect wetland or not, lies in the city planning policy. Firstly, in order to prevent wetland from shrinking conscientiously, the government should forbid filling wetland with building rubbish or domestic rubbish and forbid enclosing the lakes for cultivating. Next, effort should be made to prevent wetland environment from deteriorating and keep wetland function from degenerating by administrating pollution and restoring the diversity of wetland ecosystem. Besides, artificial wetlands are supposed to add to the construction of urban landscape, which aims at enlarging wetland area and meeting residents' aesthetic request for the living environment.

5 Conclusions

Urban wetland is important to urban climate, pollution degradation and water permeation and impoundment. It is more influential by human factors, especially different from the natural evolution process under the urbanization development. Through analyzing the dynamics of wetland landscapes and transformation among all landscape types between 1996 and 2001, the following results are obtained.

(1) As for the changes of wetland landscape pattern in Wuhan, both patch number and fragmentation degree of all wetland types increased and lake wetland area declined, which attributed to intensive human activities. Urban construction in the past five years occupied large number of wetland, especially lakes. It results in the fragmentation and depressed dominance of natural wetland.

(2) As for the transformation situation, loss of wetland landscape related closely to the expansion of urban construction land and there existed the phenomenon that the former decreased while the latter increased. In order to deal with the disadvantage, protect wetland and benefit from the reparian urban development in the long run, we suggested government should improve wetland environment and constitute artificial wetland with the guarantee of a certain wetland area, and make wetland become the main body of urban landscape.

(3) Wuhan City has large amount of river and lake resources, playing a key role of ecological function, which is also a urban landscape characteristic. Changes of wetland are intimately connected with urban landscape construction. Therefore, it was proposed that protection and construction of wetland should be embodied in the development of urban landscape.

References

Bai Junhong, Ouyang Hua, Yang Zhifeng, 2005. Changes in wetland landscape patterns: A review. *Progress in Geography*, 24(4): 36–45. (in Chinese)

Fu Bojie, Chen Lixiang, Ma Keming, 2001. *Landscape Ecology Principle and Application.* Beijing: Science Press, 202–209. (in Chinese)

Guo Yuedong, He Yanfen, 2005. The dynamics of wetland landscape and its driving forces in Songnen Plain. *Wetland Science*, 3(1): 54–59. (in Chinese)

Huang Qunfang, Dong Yawen, Chen Weimin, 2005. Programming of Lake Tianmu Wetland Park based on landscape ecology. *Rural Eco-Environment*, 21(1): 12–16. (in Chinese)

Lemly D A, Ohlendorf H M, 2002. Regulatory implications of using constructed wetlands to treat selenium-laden wastewater. *Ecotoxicol. Environ. Saf.*, 52: 46–56.

Li Xiaowen, Xiao Duning, 2001. The landscape planning scenarios designing and the measures identification in the Liaohe River Delta wetland. *Acta Ecologica Sinica*, 21(3): 353–364. (in Chinese)

Li Xiuzhen, Bu Rencang, Chang Yu, 2004. The response of landscape metrics against pattern scenarios. *Acta Ecologica Sinica,* 24(1): 124–125. (in Chinese)

Li Yangfan, Zhu Xiaodong, 2003. Landscape eco-planning for Guan River estuary wetland in Jiangsu Province: Towards sustainable development. *Scientia Geographica Sinica*, 23(5): 635–640. (in Chinese)

Liu Hailong, Li Dihua, Han Xili, 2005. Review of ecological infrastructure: Concept and development. *City Planning Review*, 29(9): 70–75. (in Chinese)

Randolph J, 2004. *Environmental Land Use Planning and Management*. Washington, DC: Island Press, 95–105.

Sun Peng, Wang Zhifang, 2000. The natural landscape of the river and waterfront design in urban areas. *City Planning Review*, 24(9): 19–22. (in Chinese)

Wang Aihua, Zhang Shuqing, Zhang Bai, 2003. A study on the change of spatial pattern of wetland in the Sanjiang Plain. *Acta Ecologica Sinica*, 23(2): 237–243. (in Chinese)

Wang Xuelei, Wu Yijin, 2002. The application of the Markov model on the dynamic change of wetland landscape pattern in four-lake area. *Journal of Huazhong Agricultural University,* 21(3): 288–291. (in Chinese)

Wang Yawen, Cao Mingming, 2005. The history and the present of wetlands in Xi'an. *Wetland Science*, 3(2): 154–159. (in Chinese)

Weber C, Puissant A, 2003. Urbanization pressure and modeling of urban growth: Example of the Tunis metropolitan area. *Remote Sensing of Environment*, 86: 341–352.

Wu Fenglin, Zhou Demin, Hu Jinming, 2007. Approach on ecological planning of urban wetland on changes of landscape patterns. *Resources and Environment in the Yangtze Basin*, 16(3): 368–372. (in Chinese)

Yang Yongxing, 2002. The 21st century hot point and forward position field of international wetland research from Quebec 2000-millennium wetland event. *Scientia Geographica Sinica*, 22(2): 150–155. (in Chinese)

Yuan Xuying, Tao Yuxiang, 2001. Impacts of urbanization on lake and bay. *Volcanology and Mineral Resource*, 22(2): 102–114. (in Chinese)

Yue Xie, Wang Yiling, Peng Jian, 2005. A conceptual framework for the study of urban river based on landscape ecology. *Acta Ecologica Sinica*, 25(6): 1422–1429. (in Chinese)