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Landscape Pattern Evolution and Optimization Strategy in Wuhan Urban Development Zone, China

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***Abstract*—**With the rapid development of urbanization process in China, its environmental protection pressure is severely tested. So, analyzing and optimizing the landscape pattern is an important measure to ease the pressure on the ecological environment. This paper takes Wuhan Urban Development Zone as the research object, and studies its landscape pattern evolution and quantitative optimization strategy. First, remote sensing image data from 1990 to 2015 were interpreted by using Erdas software. Next, the landscape pattern index of landscape level, class level, and patch level was studied based on Fragstats. Then five indicators of ecological environment based on National Environmental Protection Standard of China were selected to evaluate the impact of landscape pattern evolution on the ecological environment. Besides, the cost distance analysis of ArcGIS was applied to simulate wildlife migration thus indirectly measuring the improvement of ecological environment quality. The result shows that the area of land for construction increased 491%. But the bare land, sparse grassland, forest, farmland, water decreased 82%, 47%, 36%, 25% and 11% respectively. They were mainly converted into construction land. On landscape level, the change of landscape index all showed a downward trend. Number of patches (NP), Landscape shape index (LSI), Connection index (CONNECT), Shannon's diversity index (SHDI), Aggregation index (AI) separately decreased by 2778, 25.7, 0.042, 0.6, 29.2%, all of which indicated that the NP, the degree of aggregation and the landscape connectivity declined. On class level, the construction land and forest, CPLAND, TCA, AI and LSI ascended, but the Distribution Statistics Core Area (CORE_AM) decreased. As for farmland, water, sparse grassland, bare land, CPLAND, TCA and DIVISION, the Patch Density (PD) and LSI descended, yet the patch fragmentation and CORE_AM increased. On patch level, patch area, Patch perimeter, Shape index of water, farmland and bare land continued to decline. The three indexes of forest patches increased overall, sparse grassland decreased as a whole, and construction land increased. It is obvious that the urbanization greatly influenced the landscape evolution. Ecological diversity and landscape heterogeneity of ecological patches clearly dropped. The Habitat Quality Index continuously declined by 14%. Therefore, optimization strategy based on greenway network planning is raised for discussion. This paper contributes to the study of landscape pattern evolution in planning and design and to the research on spatial layout of urbanization.

***Keywords*—**Landscape pattern, optimization strategy, ArcGIS, Erdas, landscape metrics, landscape architecture.

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I. Introduction

In 2011, the rate of urbanization in China has been in line with that of the world. In 2016, the urbanization rate of China's resident population reached 57.35% and 41.2% in household population, exceeding the average world level [1]. Rapid urbanization has a negative effect on landscape pattern. Therefore, it is of great significance to analyze the evolution of landscape pattern and put forward the optimization strategies to protect the ecological environment and optimize the pattern of urbanization.

Through literature review, it is found that there are few studies on the optimization strategies of Chinese landscapes in metropolitan areas with rapid urbanization from the perspective of planning and design by Chinese scholars. Jing studied the evolutionary characteristics and laws of land use pattern in the downtown area of Shanghai from 1947 to 2012, and then analyzed the landscape pattern [2]. Chen Shuang and other scholars studied the changes of urban ecological space in Nanjing City and proposed the countermeasures of ecological space protection [3]. Qiao-zhen et al. took Haidian District of Beijing as the research object. They analyzed the evolution of the urban landscape pattern and its driving factors from 1985 to 2006 according to the composition of urban landscape and index of degree of separation [4]. Other scholars [5]-[7] did similar studies. Gang et al. analyzed the changes of land use and landscape pattern in Wuhan in 1991 and in 2009 [8]. Hong-tao explored and analyzed the changes of land use and landscape pattern from the perspective of Wuhan metropolitan area [9]. It was found that most of the studies on the landscape pattern of large cities in China only analyze the evolution of temporal and spatial patterns, but seldom discuss the optimization strategies from the perspective of landscape planning and design. Few studies have used quantitative methods to verify the optimization of landscape pattern through wildlife migration simulations. Therefore, this paper takes Wuhan, the central city of China as the research object, and studies the landscape pattern evolution and its quantitative optimization strategy from the perspective of landscape planning and design to provide reference to the study of landscape pattern evolution and urbanization spatial layout.

II. Methodology

A. Study Areas

Wuhan Urban Development Zone is delineated according to the "Wuhan City Master Plan (2010-2020)". Basically, it includes the outer ring high-speed and nearby villages, rivers and roads with Yangluo to the east, Muling Ridge to the west, Tianhe the north and yarn hat the south. Its total land area is about 3261 square kilometers.

Wuhan is a national central city and the capital of Hubei Province. It is located in the east of Jiang-han Plain. Its terrain mainly consists of plains and a small amount of hilly areas and posts. The area of low mountains, hills, ridges and plain areas accounts for 5.8%, 12.3% 42.6% and 39.3% respectively. The Yangtze River and Han River pass through the city which have in total 166 lakes in the urban area [9]. The wetland is rich in resources with an area of 37,224.21 square kilometers [9]. The natural vegetation is mainly dominated by evergreen broad-leaved and deciduous broad-leaved mixed forest, and masson pine, fir, oak trees are widespread. The climate is cold in winter and hot in summer. It is a typical subtropical monsoon climate. The lowest average temperature in January is 4.1℃, and winter lasts for 110 days. The highest average in July is 29.2 ℃, and summer lasts for 135 days. Spring and autumn are about 60 days each. The annual precipitation is 1050 ~ 1200 mm and air humidity is relatively high along with a 240-day frost-free period. There are abundant biological resources, including 240, 50, 88 and 45 species of food crops, cash crops, fish resources and aquatic animals respectively [8]. Statistics of China's National Bureau of Statistics show that, in 2014, Wuhan's GDP has entered the "Trillion GDP Club" of Chinese cities, ranking first in the Central China region, third in 15 sub-provincial cities, and its GDP in 2015 reached 1.1 trillion yuan, ranking eighth in Chinese cities for two consecutive years [10].

B. Data Descriptions and Pre-Processing

1. Remote Sensing Image Interpretation

According to the principles of landscape ecology and land use classification in similar research in China [8]-[10], the types of land use were divided into six categories: farmland, forest, sparse grassland, water, construction land and bare land. Remote sensing data were collected from six Landsat remote sensing images with a resolution of 30 meters in September 1990, June 1995, September 2000, September 2005, May 2010 and April 2015 with a time span of 25 years. Next, Erdas Imagine 2010 software was used to interpret the images in supervised classification and unsupervised classification. Then the interpretation results were corrected and verified. The kappa coefficient ranged from 85.3% to 91.5%. The interpretation of the images met the research requirements. Thus, the basic data of the study were obtained (Fig. 1, Table I).

TABLE I
DIFFERENT PERIODS OF THE LANDSCAPE ELEMENTS OF AREA (AREA UNIT: KM²)

year	1990	1995	2000	2005	2010	2015
Construction land	160.8	300.9	331.1	411.8	725.1	950.9
Bare land	101.8	87.9	95.7	81.3	25.6	18.5
Sparse forest grassland	191.1	181.4	162.8	149.1	145.5	101.7
Forest (km²)	80.5	70.6	60.9	62.7	57.7	51.5
Farmland	1978.9	1898.7	1898.7	1852.5	1628.7	1475.3
Water	747.9	721.5	711.8	703.6	678.4	663.1
Total area	3261	3261	3261	3261	3261	3261

2. Landscape Pattern Index Selection

According to the interpretation results of remote sensing images, the landscape pattern index of landscape level as well as the class and patch level were analyzed using the popular landscape pattern software Fragstats to further analyze the landscape pattern evolution from 1990 to 2015.

First of all, this study analyzed the landscape level index and five representative landscape indexes was selected, such as NP, LSI, CONNECT, SHDI, AI. Through the study of landscape index changes, the whole landscape pattern evolution was explored.

On the basis of the landscape level, the class level pattern analysis of land use types, especially in forest, wetland and grassland, can further grasp the characteristics of landscape pattern change. In this study, eight of the landscape indices which can comprehensively reflect the evolution of the landscape pattern was analyzed [9]. They were Percentage of landscape (PLAND), PD, LSI, Total core area (TCA), Core area percent of landscape (CPLAND), Distribution statistics core area (CORE_AM) Landscape division index (DIVISION), AI, which can more fully describe the characteristics of different types of landscape elements.

In order to make a deep study of the landscape pattern index and to support the later selection of typical patches, this study selected and analyzed the patch level index combined with the above two types of landscape pattern analysis. Since the trend of the maximum patch can reflect the change of the overall patch level to a certain extent, this study took the largest area of patch as the research object and chose Patch area, Patch perimeter, Shape index to do patch-level index analysis of construction land, farmland, water, forest, sparse grassland and bare land.

3. Eco-Environmental Quality Evaluation

Habitat Quality Index including both ecological support and ecological constraints is a comprehensive indicator of the state of the environment. Habitat quality assessment is based on the Technical Regulations of the People's Republic of China on National Environmental Protection Standard (HJ192-2015) on Eco-environmental Quality Assessment issued by the Ministry of Environmental Protection of China in March 2015. A total of five indicators of ecological environment were selected to measure the quality of the habitat and to evaluate the impact of landscape pattern evolution on the ecological environment.

According to the calculation results, the Habitat Quality Index is divided into five grades namely excellent, good, general, poor and very poor (Table II). The quality of the ecological environment is analyzed according to different grades. The formula is as follows:

Habitat Quality Index = Abio × (0.35 × woodland + 0.21 × grassland + 0.28 × water wetland + 0.11 × cultivated land + 0.04 × construction land + 0.01 × unused land) / total study area. Note that the normalized coefficient of Abio Habitat Quality Index is 511.3, derived from the HJ192-2015 Habitat Assessment Specification.

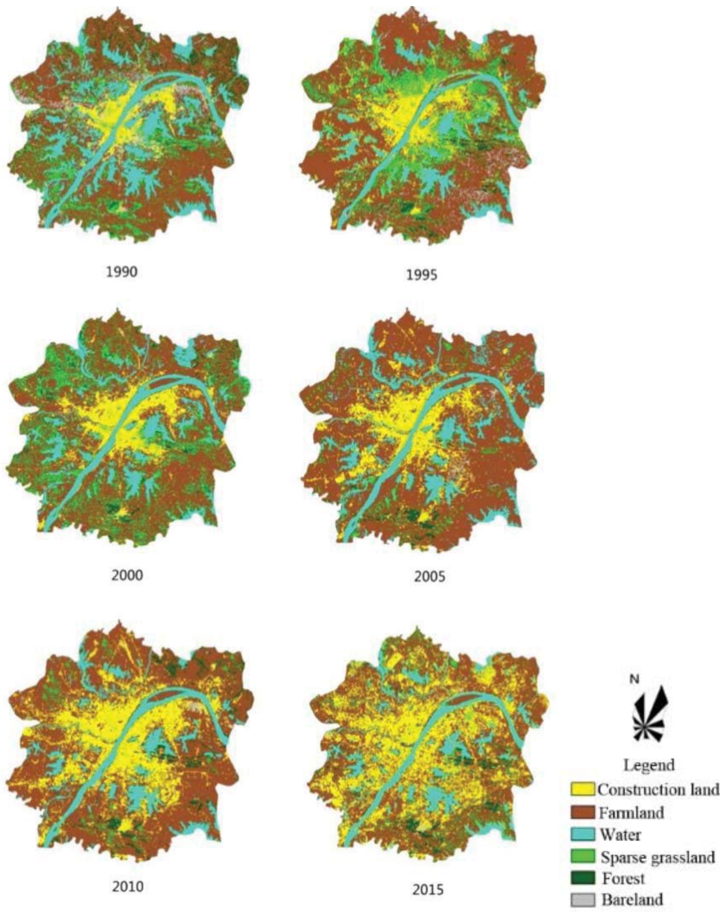

Fig. 1 Interpretation map of remote sensing images in different historical periods

TABLE II
HABITAT QUALITY INDEX LEVEL

level	Excellent	Good	General	Poor	Very poor
index	$EI \geq 75$	$55 \leq EI < 75$	$35 \leq EI < 55$	$20 \leq EI < 35$	$EI < 20$
description	The coverage of surface vegetation is high, Higher species richness, Resilience of the ecosystem after destruction is relatively strong, More suitable for human life.	The coverage of surface vegetation is relatively high, The degree of species richness is relatively high, Generally suitable for human life.	General level of vegetation, Moderate species richness, General level of ecosystem stability, Suitable for human life, but the comfort of life is not high.	Surface vegetation coverage is poor, Low species richness, Ecosystem stability is poor, Not suitable for human survival.	Surface vegetation coverage is particularly poor, Very low species richness, Ecosystems are extremely vulnerable, Obviously not suitable for human survival.

4. Evaluation of Landscape Pattern Index

First of all, the typical ecological patches are picked based on the above assessment criteria for eco-environmental quality in China and the type of land used for interpretation by remote sensing. In this study, the principle of minimum area frequency of sparse forest, forest and water body in unit grid was taken into account. Finally, a grid of 3000m × 3000m was finally selected considering factors such as the study area, the accuracy of terrain data and the combination of geomorphology. Then the patches are chosen according to the area covered by the grid. If the area of the patches exceeds the coverage of the grid, the patches in the area are regarded as typical plaques.

Then the planned greenway network, overlaying land types of patches, was converted into raster format in ArcGIS and was imported to Fragstats4.0 to calculate landscape index. After that, eight indexes which can completely analysis the pattern changes were picked to compare with the landscape pattern index before the optimization of greenway network in order to quantitatively analyze the optimization of landscape pattern.

5. Migration Simulation of Wildlife

The degree of migration of wild animals can reflect the level of patch connectivity and indirectly measure the improvement of ecological environment quality. Therefore, this study quantitatively researched the optimization of landscape pattern after overlaying of greenway network based on migration simulation of wildlife. In this study, the cost distance analysis of ArcGIS was applied, and this study took the compared cost distance of wild birds flying before and after the superimposition of greenway network as evaluation criteria. The cost distance formula is: $C1+2=a1*C1+b1*C2$, $C1 + 2$ represents the total cost required; C1 represents the cost of wild birds flying over different types of land; C2 represents the need for wild birds to overcome human interference costs which was represent by the distance from the construction buffer zone. And a1, b1 are resistance coefficients, which indicate the willingness of species to pass through the special landscape units or the suitability of the landscape units. They are given values of 0.4 and 0.6 respectively [11]. The cost of the overlay network is calculated as C1+3=a2*C1+b2*C3, C1+3 represents the total cost of overcoming the various factors and C1 represents the cost of overcoming the different land types. C3 represents the cost of passing greenways and buffers of different lengths. a2 and b2 respectively valued 0.35 and 0.65.

III. Results

A. Remote Sensing Image Classification and Interpretation

During the study period, the area of land for construction increased 491%; the bare land showed a rapid downward trend, with a decrease of 82% from 1990 to 2015; the area of sparse grassland, a 47% decrease; and forest area decreased by 29 square kilometers in total, presenting a drop of 36%. Similarly, farmland reduced 25%; water area decreased 11%. During the study period, bare land, sparse grassland, forest, farmland, and water body were mainly converted into construction land.

B. Landscape Pattern Index Analysis

1. Landscape Level

The change of landscape index all went down (as shown in Table III). NP decreased by 2778, LSI drop by 25.7, CONNECT,0.042; SHDI, 0.6; AI fell 29.2%. It showed that the NP, the degree of aggregation and the landscape connectivity descend. Also, the ecosystem stability got worse.

TABLE III
Landscape Level Index

Year	NP	LSI	CONNECT	SHDI	AI
1990	9787	93.8	0.083	1.33	87.9
1995	8844	90.3	0.068	1.28	78.4
2000	7604	87.8	0.067	1.25	71.7
2005	7987	77.7	0.056	0.98	63.6
2010	7318	65.6	0.047	0.87	52.8
2015	7009	68.1	0.041	0.73	58.7

2. Class Level

The construction land and forest, the Core area percent of landscape (CPLAND) and Total Core area (TCA) increased. But the Distribution statistics Core area (CORE_AM) decreased. AI and LSI went up. As for farmland, water, sparse grassland, bare land, Core Area Percent of Landscape (CPLAND), Total Core Area (TCA) and landscape division index (DIVISION), all of them reduced, yet the patch fragmentation increased. Moreover, the Distribution Statistics Core Area (CORE_AM) ascended; the PD and the LSI descended. It can be seen that the urbanization has a great impact on the landscape evolution.

3. Patch Level

Patch area, Patch perimeter, Shape index of water area, farmland and bare land continued to decline, indicating an increase in the degree of fragmentation of farmland and a decrease in the complexity of the shape of the patch. Correspondingly, landscape heterogeneity would also drop.

The three indexes of forest patches first increased and then decreased with an overall trend of increase, demonstrating that the shape complexity of forest patches rose. Year 2000 was the inflection point of sparse grassland whose three indexes decreased in 2000 and then went up with a decreasing trend as a whole, showing that the ecological diversity of sparse grassland decreased, construction land and the heterogeneity of landscape increased on the contrary.

C. The impact of Landscape Pattern Evolution on Ecological Environment Quality

During the study period, the Habitat Quality Index in the study area was between 55 and 75, and the ecological quality evaluation was always good. However, from a specific numerical point of view, the Habitat Quality Index continued to decline from 70.3 to 60.4 and the environmental quality also present a continuous downward trend (as shown in Table IV).

TABLE IV
Habitat Quality Index of Different Land Types

Year	Wood land (km²)	Grass land (km²)	Construction land (km²)	Cultivated land (km²)	Water wetland (km²)	Unused land (km²)	Habitat Quality Index	Quality level
1990	270.69	0.91	160.8	1242	747.9	101.8	70.3	good
1995	251.17	0.83	300.9	1191	721.5	87.9	68.1	good
2000	245.9	0.8	331.1	1157	717.8	90.7	67.2	good
2005	211.03	0.77	411.8	1082	703.6	81.3	63.9	good
2010	202.46	0.74	725.1	1007	678.4	25.6	62.9	good
2015	152.49	0.71	950.9	978	663.1	18.5	60.4	good

IV. Discussion

As an ecological green corridor, the greenway helps to improve the connectivity between the patches and provides a movable channel for migration of wild animals and it is also an ecological carrier for pedestrians and non-motor vehicles, bringing great benefits to ecology, society and economy. As the birthplace of greenway theory, the United States has planned to construct a greenway network on the mainland and the east coast of the United States. Singapore's greenway in the Island Park connect leisure parks, open green spaces and wetlands in different regions to form a healthy green corridor around the island. At present, many urban cities in China had planned and constructed greenways, for example, the Pearl River Delta region set the precedent in constructing greenway, connecting over 200 parks, historical and cultural scenic areas, wetlands and country parks, which played an important role in improving the region's ecological environment. According to "Planning for Green Space in Wuhan Urban Development Zones (2011-2020)" and "Planning for Green Space in Main Urban Areas of Wuhan (2011-2020)", the average green space per capita in urban parks in the main district of Wuhan will reach 16.8 m^2 per capita at the end of the planning period, higher than the national standard 10 m^2 per capita for the national ecological garden city. In terms of narrow greenway construction, at present, Wuhan has built greenway such as Dongsha greenway, Ink Lake greenway and Lion's Mountain greenway. However, the urban greenway and community greenway underperform, and the construction of greenway still lags behind. These all need to be planned and constructed.

A. Optimization Strategy Based on Greenway Planning

1. Optimization Strategy Based on Greenway Types

The width of the greenway determines the size of its ecological efficiency [12] Normally, the wider the greenway is, the better its ecological efficiency will be. However, the actual greenway width is often restricted by many factors. The types and widths of greenways in this study are based on the "Guidelines for greenway Planning and Design" promulgated by the Ministry of Housing and Urban-Rural Development in 2016 and combined with the actual situation of Wuhan. Thus, the greenways in Wuhan are divided into country greenways, urban greenways and community greenways. The country greenways are arranged outside the main urban district, whose green corridor width is not less than 110m; main walkways width is above 4.2m and secondary walkways, over 2.5m. The urban greenway is set in the main urban district. The green corridor is based on the ring expressway and the riverside greenway. The width of the green corridor is not less than 35m and walkway width is above 6.5m, which can be used as a bicycle track. The width of other greenway walkways is not less than 3m; community green corridor, over 18m; and walkway, more than 2.5m.

2. Optimization Strategy Based on Greenway Density

At present, the ecological rating of greenway in Wuhan is Grade II, and the low density of greenways explains partly its low rating [13]. In recent years, great changes have taken place in the landscape pattern of Wuhan City, worsening the connectivity of ecological patches. According to the "Wuhan Urban Green Space System Planning (2003-2020)", the coverage of greening in the main urban area will reach 45% by 2020 and the greening rate will reach over 35%. 32 urban parks and 50 regional parks will be planned and constructed. According to the plan, Wuhan greenway density can reach 0.81km / km², but the greenway density is still low. Therefore, it is necessary to improve the density of greenways for a better degree of patch connections and for the purpose of optimizing the landscape pattern.

B. Landscape Pattern Optimization Based on Greenway Network

1. Evaluation of Landscape Pattern Index After Overlaying Greenway Network

According to the interpretation of Wuhan's landscape pattern and the greenway planning strategy, the greenway planning structure of this study is determined as "one heart, six wedges and ten belts." "One heart" refers to the core area of the greenway in the main urban area, which mainly connects the green infrastructure elements of the main urban area. "Six-wedge" is mainly located in the transitional area from the main urban area to other new urban areas. It takes Wuhan's six green eco-wedges as its base and connects natural resources in series. "Ten Belt" mainly connects Wuhan New City, country parks and so on (as shown in Fig. 2 and Table V).

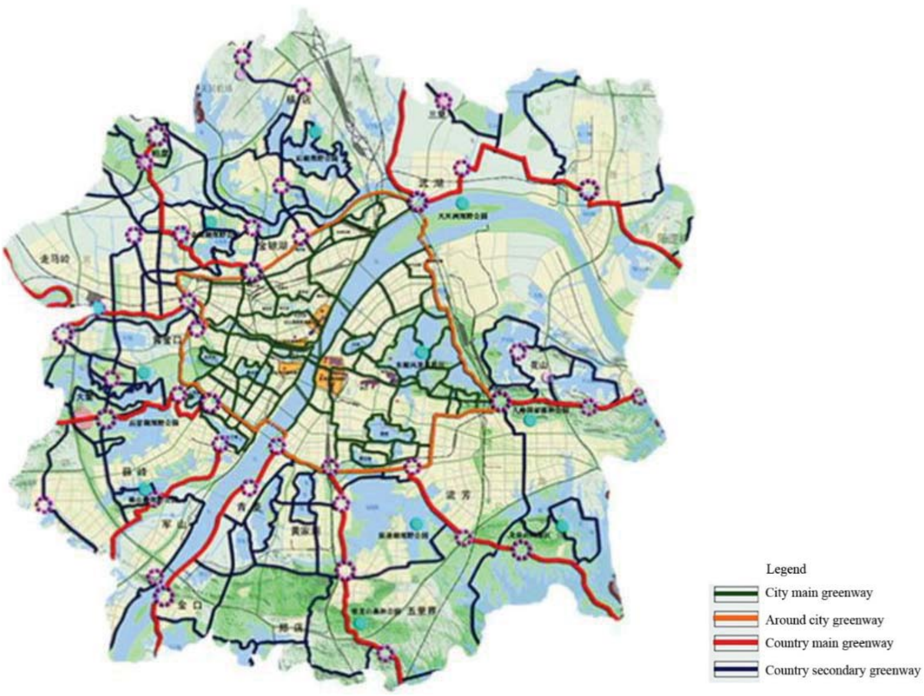

Fig. 2 Landscape pattern optimization

Given that LSI, Shape Index(SHAPE_AM) are the calculation of the number and shape of single or multiple patches, they are not analyzed due to few influences on the position and shape of the patches before and after overlaying the greenway network. The comparative analysis shows that Landscape Division Index(DIVISION) reduced by 0.11; Contiguity Index(CONTIG_AM) increased by 0.07; AI increased by 7.74%; SHDI and Shannon's Even-ness Index (SHEI) increased by 0.03 and Connectance Index (CONNECT) increased by 0.04 (as shown in Table VI). It indicates that after the greenway network was overlaid, the degree of patches segmentation went up, but the degree of aggregation went down. What's more, the degree of proximity and connectivity of patches, the type and NP as well as the uniformity of patches area increased.

TABLE V
GREENWAY TRACE AND BRANCH LINES OF "TEN BELT"

Ten belt	The main greenway connecting area	length (km)	Secondary greenway connecting area	length (km)
Line 1	East lake, yan-xi lake, yan -dong lake, Jiu-feng forest park	16.7	Around Yan-xi lake and Yan-dong lake	50.5
Line 2	Tang-xun lake, Long-quan Mountain	27	Around Liang-zi lake	70.5
Line 3	Qing-long mountain,Liang-zi lake	38.5	Around Liang-zi lake	118.5
Line 4	Qing-ling lake, Sun Yat-sen ship、Lu lake	31.5	Around Qing-ling lake, Huang-jia lake,Lu lake	137
Line 5	South taizi lake,chen Lake	59	Around Zhu-shan Lake	93.5
Line 6	Zhiyin lake,Suo river	40	Around Hou guan-hu	158.5
Line 7	Han River urban agriculture sightseeing area	33.9	Around Wu jia-shan New City, Zou ma-ling	38.5
Line 8	Jinyin lake,bai-quan	23.8	Around Jinyin lake and Fu he	127
Line 9	Mulan	68.9	In Mulan scenic area	333.5
Line 10	Wu lake, Daoguan river	91	Around Zhang-duriver	169.5

TABLE VI
COMPARISON OF LANDSCAPE PATTERN INDEX BEFORE AND AFTER GREENWAY NETWORK OVERLAID

Index	LSI	SHAPE_AM	CONTIG_AM	CONNECT	DIVISION	SHDI	SHEI	AI (%)
before	73.55	23.7	0.63	0.014	0.81	0.64	0.57	76.31
after	73.55	23.7	0.70	0.054	0.70	0.67	0.60	84.05

2. Landscape Pattern Optimization Based on Migration Simulation of Wildlife

As can be clearly seen (as shown in Figs. 3 (a) and (b)), the lower cost areas are forests and sparse grassland areas, and the higher cost areas are construction areas. By comparing the presence or absence of overlaid greenways, it is clear that after the addition of greenways, network-like low cost appears in developing urban areas with the increasing degree of connectivity, although the lower-cost areas are still concentrated in forests and sparse grasslands. After superimposing the greenway network, the maximum cost of wild birds flying over different factors reduced by about 39% and the average value dropped by about 21% (as shown in Tables VII and VIII). Therefore, the greenway network can significantly improve the connectivity of the landscape pattern.

V. CONCLUSION

Through the interpretations of the remote sensing images of urban development zones in Wuhan during 25 years from 1990 to 2015, this paper analyzed the changes of landscape pattern indices through three levels: landscape level, class level and patch level. It is found that the stability of the ecosystem in the study area get worse, the impact of urbanization on the evolution of landscape pattern is huge, and the ecological diversity and landscape heterogeneity of ecological patches obviously declined. Habitat quality index are between 55 and 75. Although the ecological quality evaluation is good, the Habitat Quality Index decreased from 70.3 to 60.4 with a continuous downward trend from the specific numerical point of view.

TABLE VII
THE COST OF OVERLAY PLANNING GREENWAY NETWORK

	Classification	Land type	Overcome different types of land costs		Classification	distance from the construction site (m)	overcome human interference costs
Land type	1	Construction land	2000	Distance factor	1	0-100	1000
	2	Water	200		2	101-500	700
	3	Farmland	100		3	501-1500	500
	4	Bare ground	50		4	1501-2500	200
	5	Sparse forest grassland	20		5	2501-3000	50
	6	forest	10		6	more than 3001	10

TABLE VIII
THE COST OF NON-OVERLAY PLANNING GREENWAY NETWORK

	Classification	Land type	Overcome different types of land costs		Classification	greenway length and buffer zone (m)	Cost
Land type	1	Construction land	1200	greenway factor	1	0-500	1500
	2	Water	10		2	501-1500	900
	3	Farmland	60		3	1501-2000	300
	4	Bare ground	30		4	2001-3000	150
	5	Sparse forest grassland	12		5	3001-4500	50
	6	forest	12		6	More than 4501	10

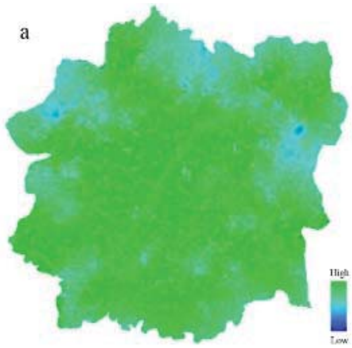

Fig. 3 (a) Cost before calculation

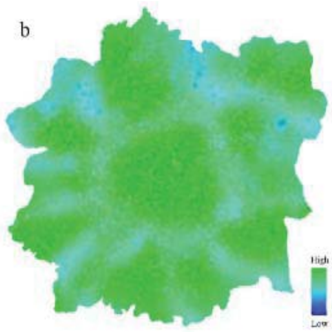

Fig. 3 (b) Cost after calculation

Then the greenway network is optimized through strategy discussion about the greenway type and greenway density from the perspective of landscape planning and design, followed by landscape pattern indexes which are evaluated by optimized greenway network. Then based on ArcGIS, the cost of wildlife migration is used to verify the optimized landscape pattern in this paper in the hope of providing a reference to the study of landscape pattern evolution in planning and design and research on spatial layout of urbanization.

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