Research Paper

Spatiotemporal responses of habitat quality to urban sprawl: A case of Harbin City

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Abstract

In recent years, urban expansion has greatly changed the distribution pattern and function of regional habitats. Under the background of new urbanization and ecological civilization construction, understanding the spatial-temporal response of habitat quality to urban expansion plays an important role in ensuring urban ecological security. In this paper, the urban and rural space of Harbin City was divided into 50 circles by using the concentric buffer zone as the partition method of spatial gradient. The habitat quality and landscape pattern index of the study area were analyzed by InVEST model and FRAGSTATS platform, and the influence of landscape pattern and habitat quality in different urban and rural gradient layers was summarized. The results showed that: (1) the habitat quality in Harbin was decreasing; (2) the habitat quality was the lowest in the main urban area; The habitat quality in urban fringe area decreased obviously; (3) patch density increased, fragmentation increased, and landscape diversity decreased; (4) the closer the distance from the city center, the greater the degree of fragmentation. Landscape fragmentation in urban fringe increased, which aggravated the degradation of habitat quality. The results of this study provide a theoretical basis for ecological protection in the context of Harbin's expansion.

Keywords

habitat quality, InVEST model, Urban expansion, Harbin.

1. Introduction

In recent years, China's urbanization has developed rapidly, with the urbanization rate increasing from 17.9% to 64.7% from 1978 to 2021. In particular, from 2000 to 2020, the urbanization rate increased rapidly from 36.2% to 63.9% (China, 2022). The rapid urbanization process promotes the rapid expansion of construction land and the continuous transformation and reconstruction of land use, which results in the change of ecosystem structure and function, and the decline of urban land carrying capacity, habitat degradation and other environmental problems. These problems lead to the decline of urban livable level. Therefore, understanding the evolution trend of habitat quality in the process of rapid urbanization is of great significance for regional urban and rural planning.

Habitat quality refers to the ability of the environment to provide appropriate resources for the sustainability of individuals and populations, including survival and reproduction (Hall, et al., 1997). Scholars at home and abroad have carried out a large number of studies on habitat quality, ranging from early field investigations of single species or communities to assessment of habitat quality at different scales. The evaluation approaches are divided into two categories, one is the construction of habitat quality indicator system, the other is model-based evaluation methods, such as ARIES (F. Villa, 2009), HIS (Jihyang Jung, 2016), SolVES (B.C. Sherrouse, 2014), InVEST (Sharp, et al., 2018) and other models. The Habitat quality module of InVEST model, developed in collaboration with Stanford University, WWF and TNC, assesses the distribution and degradation of habitat quality by analyzing the extent to which land use and different land groups pose threats to biodiversity (Terrado, et al., 2016). This model has obvious advantages in spatial visualization and management scenario decision-making, and has been widely used by scholars at home and abroad to study habitat quality at different scales such as region, watershed and city.

Landscape pattern is regarded as the key factor driving the evolution of habitat quality (Vögeli, et al., 2010), and landscape pattern index is the digital information expressing landscape pattern quantitatively. In recent years, exploring the coupling relationship between landscape pattern index and habitat quality has gradually become a research hotspot. Scholars have conducted empirical studies on river basins (Aneseyee A BT, 2020), cities (Yanan LiDuo, 2021) and urban agglomerations (Wang HL, 2020). However, all the above studies evaluated the study area as a whole, and the analysis of how the habitat quality and landscape pattern in the study area responded to the spatial characteristics of urban and rural areas in the process of rapid urbanization was insufficient.

The rural-urban gradient paradigm provides a new perspective for further study of the impact of urban expansion on the ecosystem. This analysis method decomposes the study area according to its horizontal or vertical spatial characteristics, and then makes an in-depth analysis of the interior of the study area (Zhang X S, 1997). At present, the study of urban-rural gradient, for domestic and foreign scholars mostly adopt the way of constructing concentric buffer, to explore human activities and ecological system on the space of the law of change of gradient (YE Y Q, 2018). However, urban development is a complicated process, habitat quality, and how to response to the spatial characteristics of urban and rural landscape pattern, and along the gradient between urban and rural areas show what kind of change, Further research is needed.

As the central city in northeast China, Harbin is of great significance to strengthen the construction of ecological civilization and protect the environment and resources in the process of urban expansion. Therefore, this paper takes Harbin City as an example to evaluate the habitat quality in 2000, 2010 and 2020. Based on the circle gradient division method, the urban expansion pattern of Harbin city in the past 20 years under the urban-rural gradient boundary is discussed. At the same time, the FRAGSTATS platform is used to analyze the landscape pattern index. The spatial and temporal responses of landscape pattern and habitat quality to urban expansion in different urban and rural gradients were summarized. The results of this study can provide reference for land use planning, urban spatial layout optimization and ecological environment protection and development in Harbin.

2. Methods and materials

2.1. Study area

Harbin, in the south of heilongjiang province, China, has a total area of 53100km2 and has jurisdiction over 18 county-level administrative units. From 2000 to 2020, Harbin's total population increased from 9.4 million to 1 million, and its GDP increased from 100.2 billion yuan to 518.38 billion yuan. With the expansion of urban scale, the rapid increase of construction land in Harbin has changed the original land use and landscape pattern, and environmental pollution, habitat quality decline and other problems have become increasingly serious, causing pressure on the ecosystem.

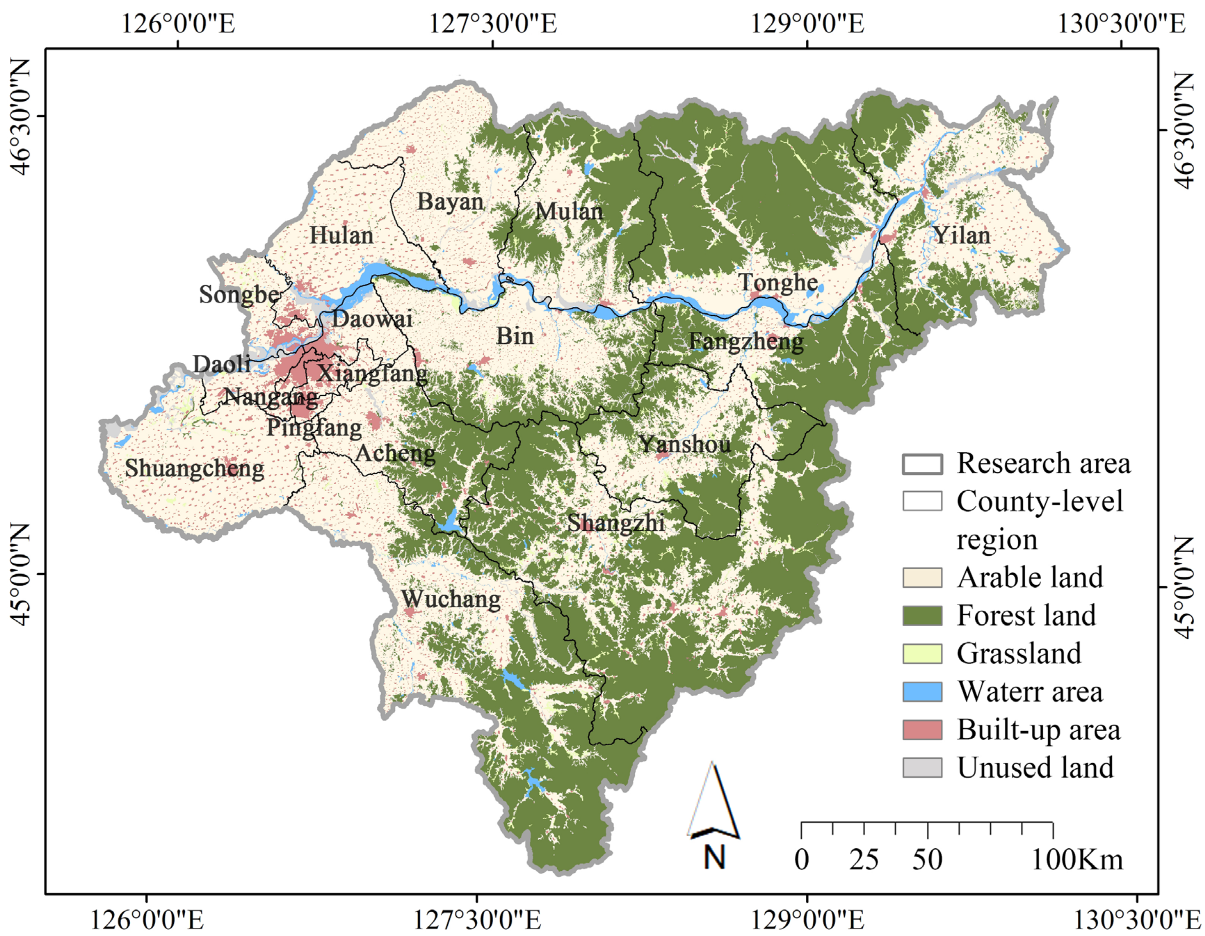


Figure 1. The study area. Source: Diagram by authors.

2.2. Data sources

This study selected the land use data and road data of Harbin City in 2000, 2010 and 2020. The land use data came from the Data Center for Resources and Environmental Sciences (http://www.resdc.cn), Chinese Academy of Sciences. According to the "China Land Use/land Cover Remote Sensing Monitoring Data Classification System", a total of 6 first-level land classes and 16 second-level land classes were divided (Table 1). The road data are obtained from the National Basic Geographic Information Center of China (http://nfgis.nsdi.gov.cn), including railway, expressway, national road, provincial road and county road data. The borough boundary data is derived from the Bigemap GIS Office map downloader.

Table 1. Land use classification. Source: Author.

Class1	Class2	Class1	Class2
Cropland	Paddy field	Water	River
	Dryland		Lake
Forest	Woodland		Reservoir
	Shrubwood		Marshland
	Sparse forest	Built-up land	Urban land use

	Other woodland		Rural residential areas
Grassland	High-coverage grassland		Other construction land
	Moderate-coverage grassland	Bare land	——
	Low-coverage grassland		

2.3. Methods

2.3.1 Habitat quality assessment based on InVEST model

This study calculates Habitat Quality index based on the Habitat Quality module in InVEST3.8.5, which mainly includes Habitat degradation degree and Habitat Quality assessment. The calculation formula of Habitat degradation degree is as follows:

$$i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{rmax}}\right) \text{ if linear}$$

$$i_{rxy} = exp\left(-\left(\frac{2.99}{d_{rmax}}\right)d_{xy}\right) \text{ if exponential}$$

$$D_{xj} = \sum_{r=1}^{R}\sum_{r=1}^{Y_r}\left(\frac{\omega_r}{\sum_{r=1}^{R}\omega_r}\right) r_y i_{rxy} \beta_x S_{jr}$$

Where, i_{rxy} is the influence of threat source r in grid y on grid x, d_{xy} is the linear distance between grid x and y, d_{rmax} is the maximum influence range of threat source r; D_{xj} is the habitat degradation degree of grid x in land use type j, R is the number of threat sources, Y_r is the total number of threat sources, ω_r is the weight, r_y is the number of threat sources on grid cells, β_x is the anti-interference level of grid x, S_{jr} is the sensitivity of land use type j to threat sources.

The habitat quality calculation formula is as follows:

$$Q_{xj} = H_j\left[1 - \left(\frac{D_{xj}^z}{D_{xj}^z - k^z}\right)\right]$$

Where, Q_{xj} is habitat quality of grid x in land use type j, H_j is habitat suitability of grid x in land use type j, z is scale constant, k is half-full and constant.

On the basis of the InVEST model (Sharp, et al., 2018) manual and related studies (He JJ, 2017) (Gao YL, 2017), this study sets arable land, urban land, rural settlements, other construction land and roads which are severely disturbed by human activities as threat sources. Combined with the maximum impact distance, weight, habitat suitability of each land use type and the sensitivity of habitat to various threat sources of the actual situation in the study area, the values were assigned (Table 2 and Table 3).

Table 2. The sensitivity of different landscapes to threatening factors. Source: Author.

Stress factors	Maximum impact distance /km	Weight	Decay type
Cropland	8	0.7	exponential
Urban land use	10	1.0	exponential
Rural residential areas	5	0.6	exponential
Other construction land	8	0.8	exponential
Road	3	0.5	linear

Table 3. The sensitivity of different landscapes to threatening factors. Source: Author.

Name	Habitat suitability	Cropland	Urban land use	Rural residential areas	Other construction land	Road
Paddy field	0.6	0.3	0.5	0.35	0.4	0.6
Dryland	0.4	0.3	0.5	0.35	0.4	0.2
Woodland	1	0.7	0.85	0.8	0.7	0.65
Shrubwood	0.9	0.6	0.7	0.6	0.6	0.4
Sparse forest	0.8	0.85	0.85	0.7	0.55	0.6
Other woodland	1	0.9	0.85	0.85	0.6	0.7
High-coverage grassland	0.8	0.5	0.6	0.45	0.5	0.3
Moderate-coverage grassland	0.7	0.5	0.65	0.5	0.55	0.35
Low-coverage grassland	0.6	0.5	0.7	0.55	0.55	0.3
River	0.9	0.65	0.9	0.7	0.8	0.45
Lake	1	0.7	0.9	0.75	0.8	0.5
Reservoir	1	0.7	0.9	0.75	0.8	0.5
Marshland	0.65	0.75	0.95	0.8	0.7	0.55
Urban land use	0	0	0	0	0	0
Rural residential areas	0	0	0	0	0	0
Other construction land	0	0	0	0	0	0
Bare land	0.1	0.1	0.2	0.2	0.2	0.15

2.3.2 Landscape pattern index method

Landscape pattern index is a common index for landscape pattern analysis. Based on relevant studies (YuanyuanYang, 2021) (Wang SR, 2021), from the two dimensions of type level and landscape level, Patch density (PD), COHESION index, CONTAG index and Shannon Diversity Index (SHDI) were selected to describe the degree of landscape fragmentation, aggregation, connectivity and diversity in the study area.

Based on FRAGSTATS 4.2 platform, firstly, the landscape pattern index is calculated at the overall level of the study area using standard method. Then, using the moving window method, the moving window with a radius of 1000m is selected to calculate the landscape pattern indexes (Tibebu KassawmarS. R. Murty, 2019).

2.3.3 Urban-rural gradient analysis

In order to explore the effect of urban expansion process on the spatial gradient of habitat quality and landscape pattern, considering the spatial morphology of Harbin city, this study used the circle method of urban-rural gradient analysis. Urban circle division generally starts from the center of the city and divides several equidistant buffer zones outwardly with a certain buffer distance (H, 2020). This study takes Harbin municipal government as the center and establishes a concentric buffer zone with an interval of 5km from inside to outside in the research area, forming 60 circles that can cover all areas of Harbin.

3. Results

3.1. Habitat quality changes and gradient characteristics

The spatial distribution of habitat quality in Harbin in 2000, 2010 and 2020 was calculated using InVEST model. Using the natural break point method, the results of habitat quality calculation in the three periods were divided into four intervals: 0-0.3, 0.3-0.6, 0.6-0.9 and 0.9-1. According to these four intervals, the habitat quality was divided into four grades: low quality zone (I), medium quality zone (II), high quality zone (III) and high quality zone (IV). The area proportion of each grade of habitat and the mean value of habitat quality index were calculated (Table 4).

Table 4. The level of habitat quality of Harbin City from 2000 to 2020. Source: Research findings.

Level	Value interval	2000		2010		2020	
		Area weight/%	Average value	Area weight/%	Average value	Area weight/%	Average value
I	0—0.3	4.70%	0.68	5.41%	0.66	5.95%	0.65
II	0.3—0.6	44.58%		45.54%		47.79%	
III	0.6—0.9	9.69%		13.95%		11.64%	
IV	0.9—1	41.04%		35.09%		34.61%	

From the time scale, the habitat quality index in Harbin city showed a decreasing trend. During the past 20 years, the total proportion of habitat quality area in high and high quality areas was 50.73%, 49.04% and 46.25%, respectively, which showed a significant decrease. At the same time node, the proportion of habitat quality grade area in medium quality area and high quality area was higher. These two areas also showed great changes, and the conversion from high quality to high and medium quality directly led to the decline of habitat quality conversion grade in Harbin in the past 20 years. From the perspective of spatial pattern, the overall habitat quality in Harbin was high in the middle, middle in the east, and low in the west. The high and high quality areas were mainly distributed in the woodland and grassland in the north, southeast and south, where the green vegetation coverage was high and the habitat quality was good. The middle quality area is mainly distributed in the cultivated land in the west, northeast and central of China. Affected by urban expansion, a large amount of cultivated land is occupied by construction land, and the habitat quality decreases. The low-quality area is mainly distributed in the western main urban area and its periphery, where the construction land is densely covered, the original ecological resources are heavily occupied, and the habitat quality is seriously degraded.

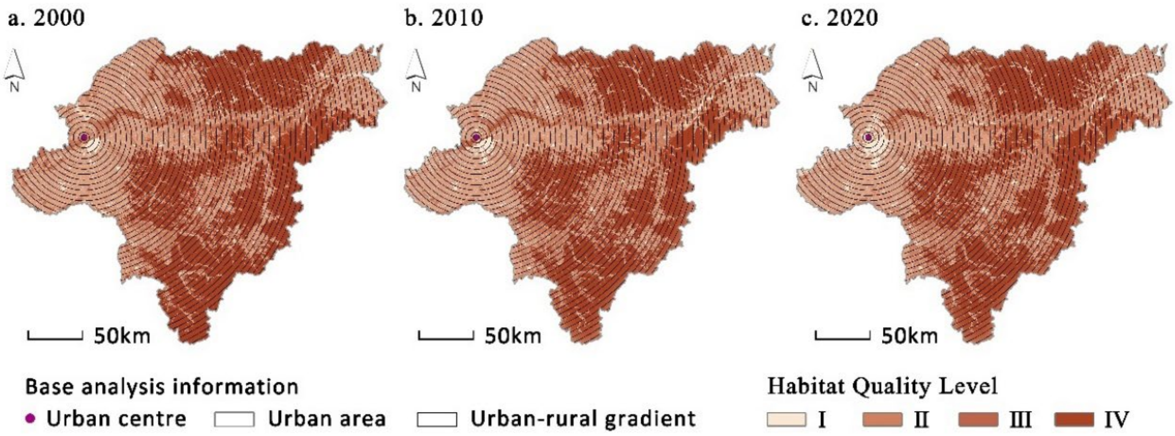


Figure 2.Spatial distribution of habitat quality in Harbin City from 2000 to 2020. Source: Research findings.

The circle differentiation curves of habitat quality showed that, on the whole, with the increase of the distance from the city center, the habitat quality gradually increased and then decreased. Among them, the 1-3 circles are in the main urban area, which is the area with the lowest habitat quality due to the densely covered construction land. In the urban fringe area about 15-20 km away from the city center, the habitat quality decreased significantly due to the influence of urban construction. The habitat quality of the 29-46 enclosures is high, mainly due to the fact that these enclosures have several forest parks and nature reserves, and the density of urban construction land is low. From the perspective of time longitudinal comparison, the ecological quality of a few circles decreased to different degrees from 2000 to 2010, except the habitat quality of a few circles increased. The ecological index of the 1-3, 40-46 and 55-60 circles decreased significantly. The construction land in the main urban area of No. 1-3 circle expanded rapidly, and the habitat quality declined seriously. Affected by the expansion of the surrounding towns, the area of woodland and grassland in the 40-46 circle contracted sharply, and the habitat degradation trend was obvious. Due to the large amount of arable land in Yilan County, the habitat quality of the 55-60 circle was also significantly degraded. From 2010 to 2020, the habitat quality of circles 1-6 decreased significantly, while the ecological quality of circles 32-38 and 46-59 increased. This indicated that the construction land in the main urban area and the near suburbs expanded outward during this period, which was the area with the most serious habitat quality degradation. With the construction of the project of returning farmland to forest and grassland, the ecological environment of Yilan County has been optimized.

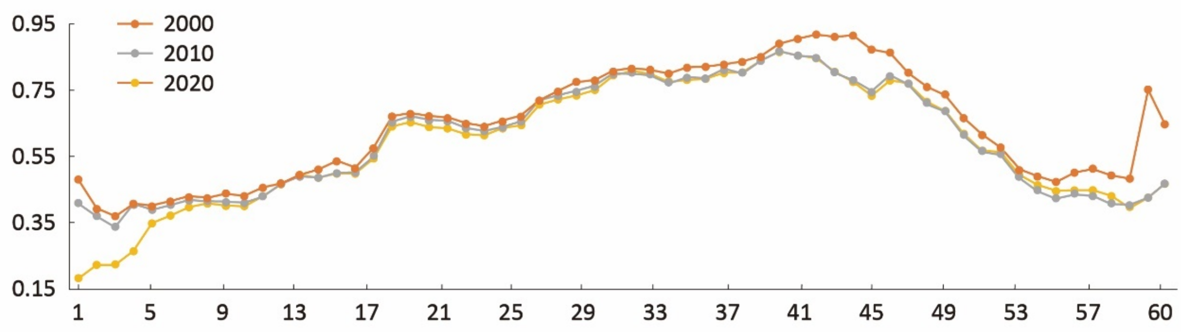


Figure 3. Quantitative changes of habitat quality on different concentric rings in Harbin City from 2000 to 2020. Source: Research findings.

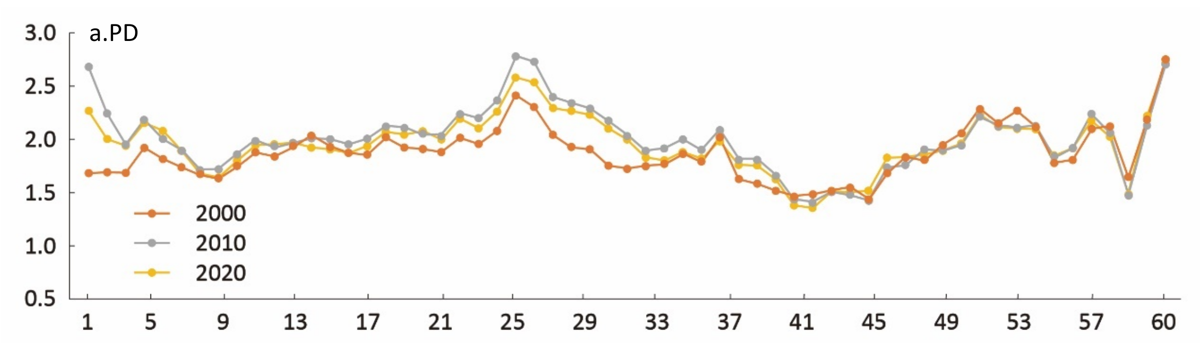
3.2 Landscape pattern index changes and gradient characteristics

From 2000 to 2020, the PD value increased in the first ten years and decreased slightly in the last ten years, with an overall increase of 16.6%, indicating that the study area was greatly influenced by the intervention and transformation of human activities, and the overall degree of fragmentation increased. The COHESION value increased slightly over the 20 years, and the COHESION of the study area slowly increased. CONTAG values decreased first and then increased, but the increase was small, which means that the dominant plaque types in the study area formed a good continuity. The SHDI value increased in the first decade and decreased in the last decade, with an overall decrease of 3.1%, indicating a decline in landscape diversity during the 20-year period. The above four landscape pattern indicators showed that in the process of urban expansion in the study area, large and concentrated patches were transformed into small and scattered patches, the degree of fragmentation increased, the landscape types tended to converge, and the landscape diversity decreased.

Table 5. Landscape patter index in Harbin City from 2000 to 2020. Source: Research findings.

Landscape patter index	2000	2010	2020
PD	0.2367	0.283	0.2761
COHESION	99.9058	99.9258	99.9391
CONTAG	65.2774	64.92	66.6639
SHDI	1.1112	1.1331	1.0766

The results of circle differentiation curves of each landscape pattern index are shown in FIG. 5. In circles 1-9, PD, CONTAG, and SHDI in different years varied with the distance from the city center, but they had the same variation trend, and showed a decreasing trend with the increase of circles. Especially in the urban fringe 20km away from the city center, there are obvious fluctuations. This is because the urban core area and the surrounding urban fringe area are significantly affected by the development and construction activities related to urban expansion, and numerous fragmented patches are formed in the periphery of the main urban area, with decreased connectivity and enhanced homogeneity. Circle 10-24 was mainly cultivated land. PD and SHDI gradually increased, while COHESION and CONTAG gradually decreased, indicating that the landscape away from the urban area became rich and diverse, while the degree of agglomeration and connectivity of patches decreased. Circles 25-27 and 58-60 cover the county seat areas of Yanshou, Shangzhi, Wuchang and Yilan counties, which are more disturbed by human activities and have increased the degree of plaque fragmentation. However, the indicators of circle 29-45 showed an opposite trend with the increase of distance, indicating that the outer suburban area was relatively less disturbed by human activities, and the woodland patch area was large and the connectivity was strong. The fragmentation degree of forestland decreased with time from 2010 to 2020, which reflected that Harbin paid attention to the conservation of nature reserves in the process of urban development.



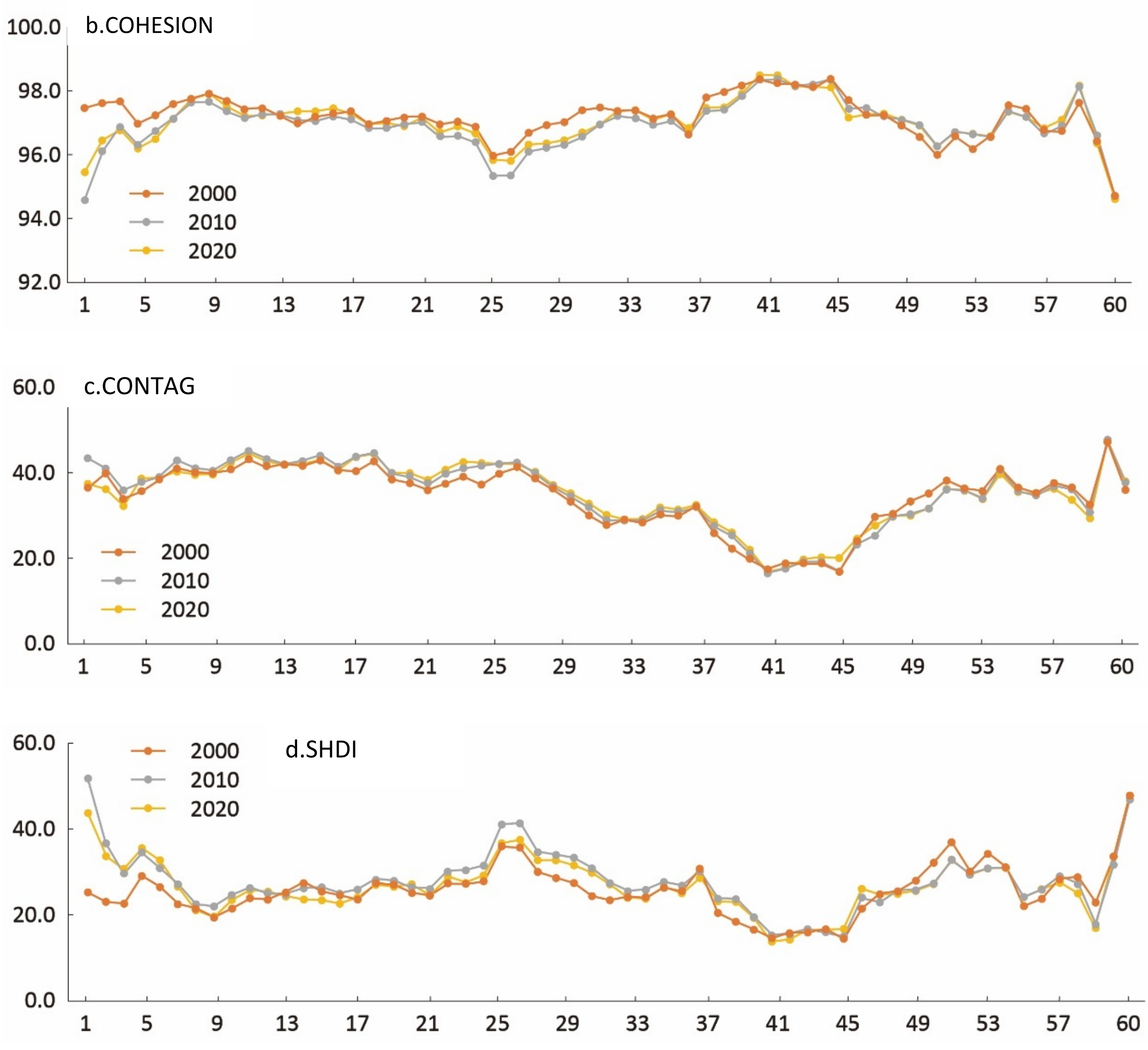


Figure 4. Quantitative changes of landscape patter index on different concentric rings in Harbin City from 2000 to 2020. Source: Research findings.

4. Discussion and conclusion

Based on InVEST model and landscape pattern index, the spatio-temporal evolution and gradient differentiation of habitat quality and landscape pattern in Harbin City from 2000 to 2020 were studied by establishing urban-rural gradient circle. The results showed that habitat quality and landscape pattern changed with the rapid expansion of Harbin from 2000 to 2020:

(1) The habitat quality index showed a decreasing trend in general, with the overall trend of high in the central region, middle in the eastern region and low in the western region.

(2) The main urban area is the area with the lowest habitat quality due to the densely covered construction land. In the urban fringe area about 15-20 km away from the city center, the habitat quality decreased significantly due to the influence of urban construction.

(3) Due to the urban expansion and the disturbance of human activities, the landscape pattern changes significantly, the patch density increases, the fragmentation intensifies, and the diversity of landscape types decreases.

(4) The landscape pattern showed obvious regional differentiation along the urban-rural gradient. The closer it was to the city center, the higher the proportion of construction land was, and the fragmentation of landscape pattern gradually increased. In the urban fringe area 20 km away from the city center, the construction intensity and human activities have a greater impact, and the fragmentation and diversity of the landscape are enhanced, while the degree of convergence and connectivity are reduced.

Through exploring the spatio-temporal response of habitat quality to urban expansion in Harbin, this paper proposes suggestions for the formulation of relevant urban planning and ecological control measures in Harbin: according to relevant national directives and policies, the cultivated land scope should be rigorously and scientifically defined to ensure the integrity and connectivity of regional cultivated land patches. It is necessary to reasonably demarcate the boundaries of urban growth, pay attention to intensive and compact development, and minimize the damage to the landscape that plays an important ecological function. Based on the holistic thinking of the ecosystem and the existing natural ecological resources, the scope of the ecological red line is divided. In addition to the large ecological patches, some small ecological patches with important connectivity also need to be included in the protection scope to ensure the ecological security of the region.

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