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Optimization of Landscape Ecological Security Patterns and Planning in Low Hilly Areas

—A Case Study of Beigong Town, Fengtai District, Beijing City, China

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Abstract

With the continuous expansion of mega-cities in China, the landscape pattern of the original urban-rural area is broken, resulting in serious fragmentation of landscape patches in the fringe area of the urban center and threatening urban ecological security. Therefore, how to consider the needs for construction and development based on securing ecological security patterns is a key consideration for the fringe areas of megacities. The study takes Beigong Town as the research object and uses the MSPA model analysis method to extract nine ecological source sites that are important for ecological network construction. Then, the study constructs a comprehensive ecological resistance surface based on the MCR minimum cumulative resistance model, generates minimum cost paths to simulate regional potential corridors, and constructs the ecological security pattern in Beigong Town. The study further combines the current situation of land use in Beigong Town to optimize the ecological safety pattern and proposes the planning control systems, which provides the basis for the next planning and construction.

Keywords

Morphological Spatial Pattern, Ecological Network, Landscape Connectivity, Low Mountain Hilly Areas

1. Introduction

The fringe area of the urban center is also known as the combination of urban and rural areas, and its specific geographical location makes it a sensitive area for the continuous expansion of mega-cities. Although megacities in China today are entering the era of stock development, the partial urban expansion still leads to the gradual encroachment of urban center fringe areas, which makes the ecological security of urban-rural combination areas threatened (Wang & Li, 2015).

Warntz and Woldenberg (1967) proposed the construction of ecological security patterns based on resistance surfaces in the 1960s. Vimal et al. (2012) discussed the construction of regional ecological security patterns from the perspectives of regional landscape diversity, ecological integrity, and rare animal conservation. The construction of an ecological safety pattern is one of the effective methods to increase the connectivity of large ecological patches in the region. The methodological framework of "ecological source identification—resistance surface construction—corridor extraction" is widely used in ecological security pattern construction studies. Among them, the identification of the ecological source and potential corridors is the focus (Chen et al., 2017).

With the adjustment of Beijing's territorial spatial planning, the western region of Fengtai will be included in the construction scope of the central city of Beijing. This poses a major challenge for Beigong Town, located in the shallow mountainous area of Beijing, to build and develop a new urban area based on ensuring ecological security. The project takes Beigong Town as the study area, and constructs an ecological security pattern by analyzing its landscape pattern, promoting the exchange of resources, energy, materials, and information among patches, enhancing the functional-type connection of habitat patches, and thus improving the livability of urban ecological environment, continuously restoring the natural urban ecological environment.

In most of the existing studies, researchers selected source sites based on ecological indicators such as ecological service value (Huang et al., 2019), which is somewhat subjective. In this study, we used morphological spatial pattern analysis and cone for software to calculate the landscape connectivity index to determine the ecological source sites, which is more scientific. Based on the MSPA morphological spatial pattern analysis method, six types of landscape elements that are ecologically important were identified and extracted, and the IIC, PC, and DPC core indices were used to evaluate the landscape connectivity to select ecological source sites in the study area. Then, the minimum resistance model and gravity model were used to identify potential corridors. The corridors were classified into three classes according to the interaction strength between source patches, to construct a landscape ecological security pattern in the study area. Combined with the existing zoning plan and the present situation of land use in the study area, the analysis proposes the optimization strategy and planning control of the landscape ecological safety pattern to optimize the urban landscape pattern of Beigong town.

2. Research Background and Methods

2.1. Overview of the Study Area

Beigong Town, a town under the jurisdiction of Fengtai District, Beijing (**Figure**

1), is in the Pluvial impact zone of Yanshan Mountain Range, with the terrain sloping from northwest to southeast, and belongs to the shallow mountainous area of Beijing. The topography is divided into low mountainous hilly areas in the west and plain areas in the east. The climate type is a warm-temperate continental monsoon climate, characterized by hot and rainy summers, cold and dry winters, and windy springs.

Beigong Town, at the edge of the urban center, is rich in ecological resources, but the ecological space is unevenly distributed, mostly gathered in the western part of the study area, and a small part in the eastern part. The eastern part of the planning is mainly construction land, and the shantytowns within the area are in the process of urbanization. Most of the ecological patches here are small in area, and the fragmentation of patches is more serious. How to build a resilient spatial pattern based on ecological security is the main problem that needs to be solved at present. The town needs to optimize the ecological security pattern, connect the isolated ecological patches, form a complete ecological network, and provide a safe landscape pattern for the next urban development and construction.

2.2. Research Method

In recent years, a morphological spatial pattern analysis method (MSPA) focuses on the structural correlation of ecological sources, emphasizes the relationship between structures, and is more objective in the selection of ecological sources (Ye et al., 2020). Through the MSPA method, the spatial connection characteristics of different patches can be distinguished, and the patches with large contribution to the landscape ecological connection can be identified. According to the spatial pattern, topography and the impact on the ecological connection, the landscape can be divided into different types, including the core area, connecting

Figure 1. Location of study area. Source: Self-drawn by the author.

bridge, marginal zone, branch line, circle island, isolated island, porosity, and background. Then through the evaluation of landscape connectivity, select the important large patches as the ecological source.

Minimum cumulative resistance model (MCR) can comprehensively consider the topography, geomorphology, environment, human disturbance, and other factors in the study area. MCR is a spatial analysis method based on GIS technology, which simulates the resistance path by calculating the minimum cost generated by the flow of ecological flow between different landscapes and land use types, to identify potential ecological corridors (Chen et al., 2017).

3. Analysis of Research Process and Results

Based on the relevant data of Beigong Town, the method framework of "source identification—resistance surface construction—corridor extraction—ecological security pattern construction" is used in the research.

3.1. Data Sources

The data used in this study are the 2019 Beigong Town Land Use Vector Data and Dem Data, as well as the related Territorial Spatial Zoning Plan (2017-2035) and Block Guidelines Plan (2019-2035) of Fengtai District.

3.2. Identification and Analysis of Ecological Network Source Patches

Based on the current land use of the study area, forest and grassland were used as the green landscape element of the study area and as the main foreground for MSPA analysis (Chen et al., 2017), with the rest of the land use types as background. The total study area of Beigong town is 4443.80 hm^2. Due to the woodland landscape of the town is relatively fragmented, a raster cell size of 5 m × 5 m is used to retain the small and important landscape elements and ensure that the research accuracy meets the requirements. Next, the data were analyzed by Guido's Toolbox software for MSPA analysis. The final seven landscapes that did not overlap with each other (**Figure 2**) were derived and the results of their analysis were tallied (**Table 1**).

According to the analysis results, the seven types of landscapes that play an important role in ecological protection are 1985.75 hm^2, accounting for 44.69% of the total area, and their ecological substrate is better. The core landscape area is about 1723.23 hm^2, accounting for 38.78% of the total area, mainly concentrated in the western region of the study area, and the connectivity is preferable. The eastern side is planned to be mainly concentrated construction area, the core landscape is sparse and poorly connected, and there are highways, railroads, and other barriers to biological exchange between the core areas. The internal pore area of ecological patches that can reduce external interference is 13.33 hm^2, accounting for 0.30% of the total area. The isolated patches exist independently in the ecological network, accounting for about 0.08% of the total area,

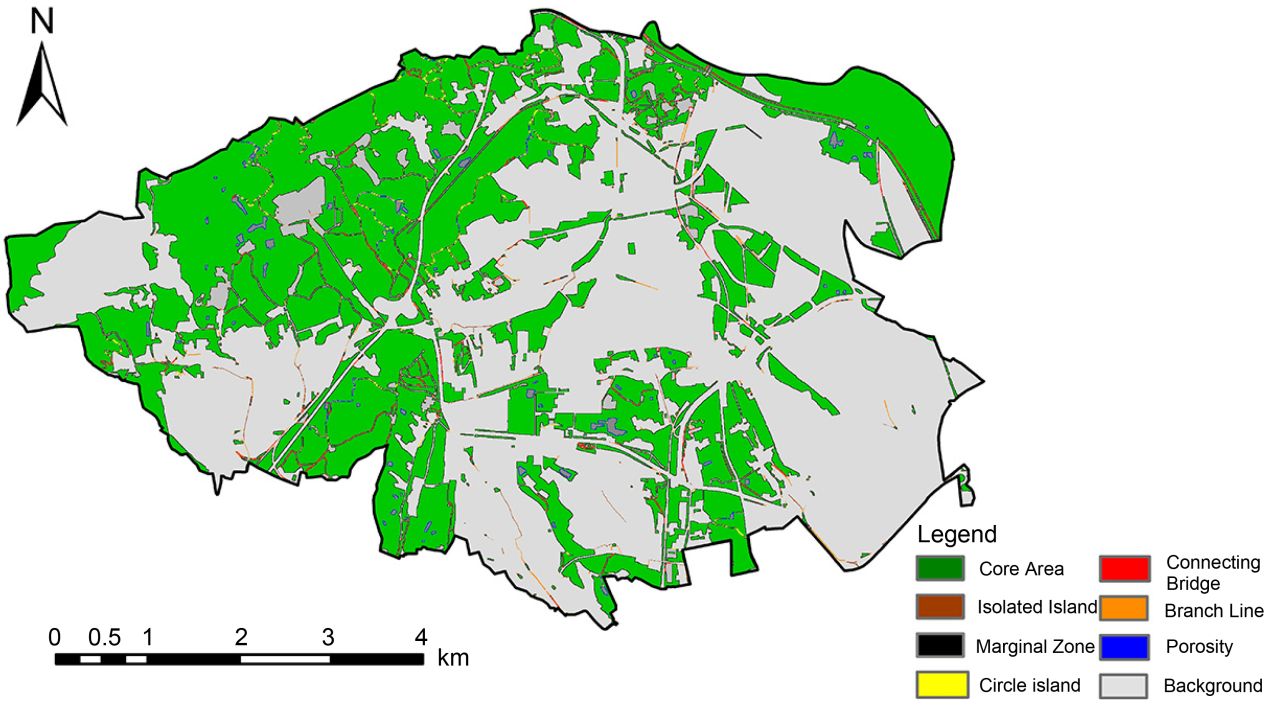

Figure 2. Analysis results of MSPA. Source: Self-drawn by the author.

Table 1. MSPA classification statistics. Source: Self-drawn by the author.

Landscape Type	Area (hm^2)	Of the total area (%)
Core Area	1723.23	38.78
ConnectingBridge	6.22	0.14
Marginal Zone	221.29	4.98
Branch Line	16.89	0.38
Circle island	1.33	0.03
Isolated Island	3.55	0.08
Porosity	13.33	0.30
Background	2457.75	55.31

mainly scattered in the eastern location of Beigong town, which can be used as steppingstones for the construction area of the town.

The overall east-west connectivity of the study area is poor, which is not conducive to biological exchange and energy exchange. The area of the connecting bridge is about 6.22 hm^2, accounting for 0.14% of the total area, which is too small and concentrated in the west. The lack of connection channels between patches leads to more serious fragmentation of the overall landscape. The Circle Island is the internal communication channel of the green patches, while the Circle Island area within Beigong town is 1.33 hm^2 in total, accounting for about 0.03% of the total area of the woodland. The area is so small that biological migration is not unobstructed in the patches. The branch line indicates the continuity of the corridor, and the branch line area of Beigong town is 16.89 hm^2, accounting for 0.38% of the total area so the connection is weak.

3.3. Landscape Connectivity Analysis

Through Cone for software, IIC, PC, and DPC landscape indices were calculated to evaluate the landscape connectivity of the core area patches in the study area, and the nine core area patches with DPC values greater than 1.5 and areas greater than 1 hm^2 obtained were used as ecological source sites for the reproduction of biological species (Table 2).

As shown in Table 2, the ecological patches with better connectivity in the study area are mainly large woodlands and scenic spots, which are mainly distributed in the west (patch 4, Beigong Forest Park; patch 2, Xinzhuang Village woodland; patch 8, Lijiayu Village woodland and farmland) and northeast (patch 1, Park Expo Park scenic spot) of the study area. Thus, the western region, due to its better overall connectivity, has habitat patches that enable the migration and material-energy exchange of biological species and thus provide species habitats. The eastern area is flatter and planned to be mainly a construction area with serious anthropogenic disturbance, with only one higher scoring greenfield patch. The east and west sides are very polarized and poorly connected, and corridors need to be built in the central and southern areas to maintain a good development of ecological service functions and a balanced ecosystem.

3.4. Potential Corridor Analysis

This paper combines the results of MSPA and landscape connectivity analysis, selects ecological source sites according to the size of the DPC value of core area patches, and selects four ecological resistance factors of land use, elevation, slope, and vegetation coverage to build an ecological comprehensive resistance surface by "aggregative weighted index method" (Figure 3 and Figure 4). With reference to relevant research results, the resistance scores and weights of each

Table 2. Connectivity index of 9 source patches in the core region. Source: Self-drawn by the author.

Number	Region	dIIC	dPC
1	Beijing Garden Expo Park	3.23	9.12
2	Xinzhuang Village Woodland	15.36	16.70
3	Thousand Forest Hill Woodland	3.65	3.02
4	Beigong National Forest Park	63.59	61.16
5	Sophora Ridge Park	4.70	3.08
6	Chinese Famous Jujube Expo	5.02	3.76
7	Lijiayu Woodland	3.31	3.21
8	Lijiayu Forest Land, Farmland Garden Land	16.04	16.21
9	Zhangguozhuang Green Park	1.61	1.59

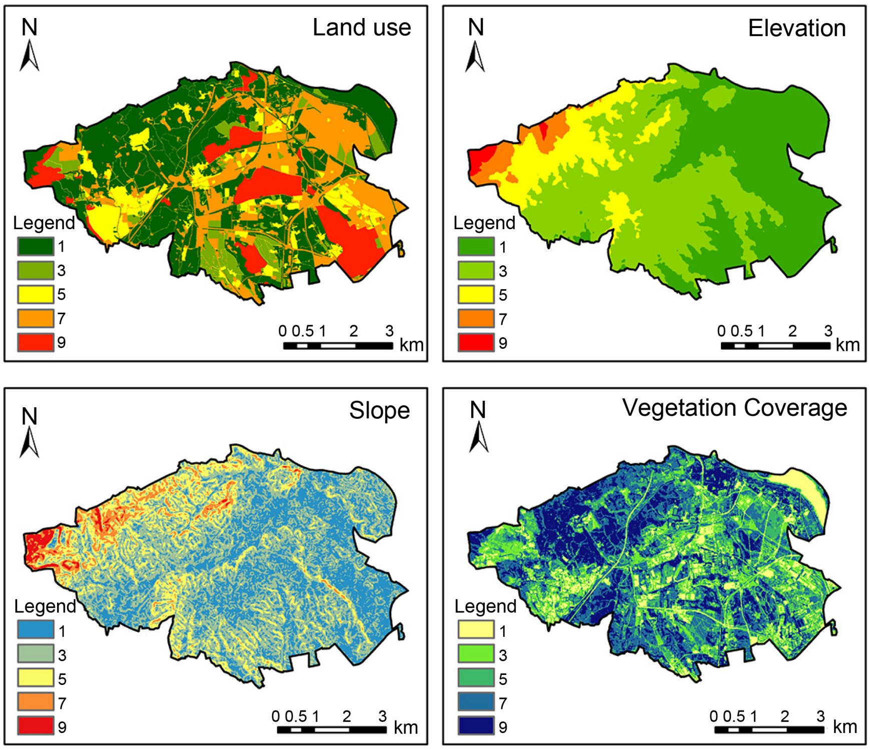

Figure 3. Classification resistance surface. Source: Self-drawn by the author.

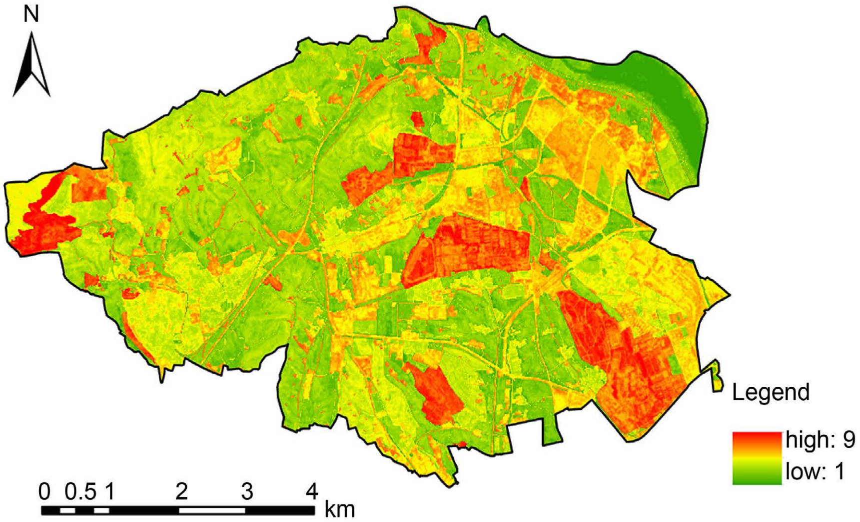

Figure 4. Comprehensive resistance surface. Source: Self-drawn by the author.

factor were determined by the expert scoring method to build a resistance system with five levels of resistance scores, with higher scores indicating greater resistance to the dispersal of biological species (**Table 3**). A raster cell size of 5 m × 5 m was used to derive the integrated ecological resistance surface using a raster calculator as the cost data of the MCR model. Then, potential corridors in the study area were generated based on the ArcGIS software platform (Yuan & Xu, 2015).

Table 3. Score and weight of resistance factors. Source: Self-drawn by the author.

Resistance Factor	Classification index	Resistance value	Weights
Elevation	<85	1	0.1
	85 - 135	3	
	135 - 200	5	
	200 - 335	7	
	335 - 540	9	
Slope	0 - 0.2	1	0.15
	0.2 - 0.4	3	
	0.4 - 0.6	5	
	0.6 - 0.8	7	
	0.8 - 1.0	9	
Vegetation coverage	0 - 8	1	0.45
	8 - 15	3	
	15 - 25	5	
	25 - 35	7	
	>35	9	
Land Use	Woodland,garden land, parkland Water surface and water use	1	0.3
	Recreation and Sports Land Land for cultural facilities	3	
	Residential land Educational Land	5	
	Commercial Land Business Land	7	
	Military land Industrial Land	9	

The gravity model can quantify the interaction strength between different ecological source patches and generate the interaction matrix (Table 4) between ecological source patches to scientifically determine the relative importance of potential ecological corridors (Yin et al., 2011). The interaction forces of nine source patches were calculated, and there were 36 corridors in total. According to the actual situation of the study area based on the matrix results, the corridors with interaction strength greater than 30 were extracted as primary corridors, 5 - 30 as secondary corridors, and less than 5 as tertiary corridors, and finally the landscape security pattern of the study area was obtained (Figure 5).

3.5. Ecological Security Pattern Construction

The classification and evaluation of potential corridors based on the MSPA model, ecological source determined by landscape connectivity, MCR model, and gravity model can construct the overall ecological security pattern (Figure 6). Overall, the ecological security pattern of the study area is generally good, but there are still deficiencies that need to strengthen, as shown by:

1) There are many ecological source sites, and most of them have large areas and high levels, accounting for 44.69% of the overall area. However, the spatial distribution is not uniform: high-quality ecological safety zones are mainly concentrated in the western region of the study area, where forest parks and mountain ecological protection areas with better connectivity are mainly located. In the eastern part of the study area, there are more barriers, forming an ecological pattern system of "strong in the east and weak in the west, strong in the north and weak in the middle" and "unbalanced spatial distribution, low network closure, and weak connectivity". The central construction area relied too much on the utilization of mineral resources in the early town development, which caused a certain degree of ecological damage, and the ecological resistance was larger. It is necessary to strengthen the management and control of the ecological security pattern in the future, to control the overall socio-economic development of the

Table 4. Interaction matrix based on the gravity model. Source: Self-drawn by the author.

	1	2	3	4	5	6	7	8	9
1	0	9.80	38.73	26.15	15.82	16.21	40.18	25.55	14.24
2		0	4.38	1.62	1.42	3.76	3.70	1.65	5.68
3			0	0.98	6.00	7.56	6.07	2.45	10.10
4				0	3.32	5.28	3.94	1.17	7.68
5					0	1.01	2.29	1.31	2.36
6						0	2.15	1.77	0.23
7							0	0.54	3.97
8								0	3.17
9									0

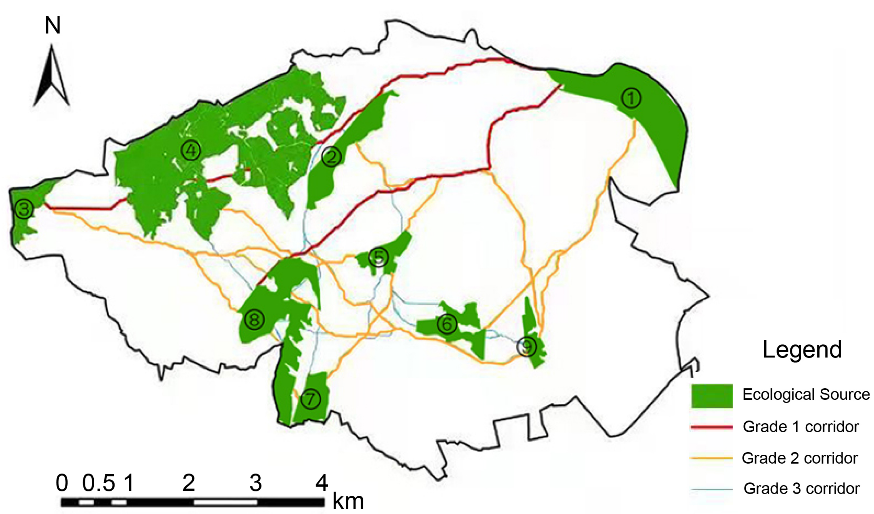

Figure 5. Ecological network planning. Source: Self-drawn by the author.

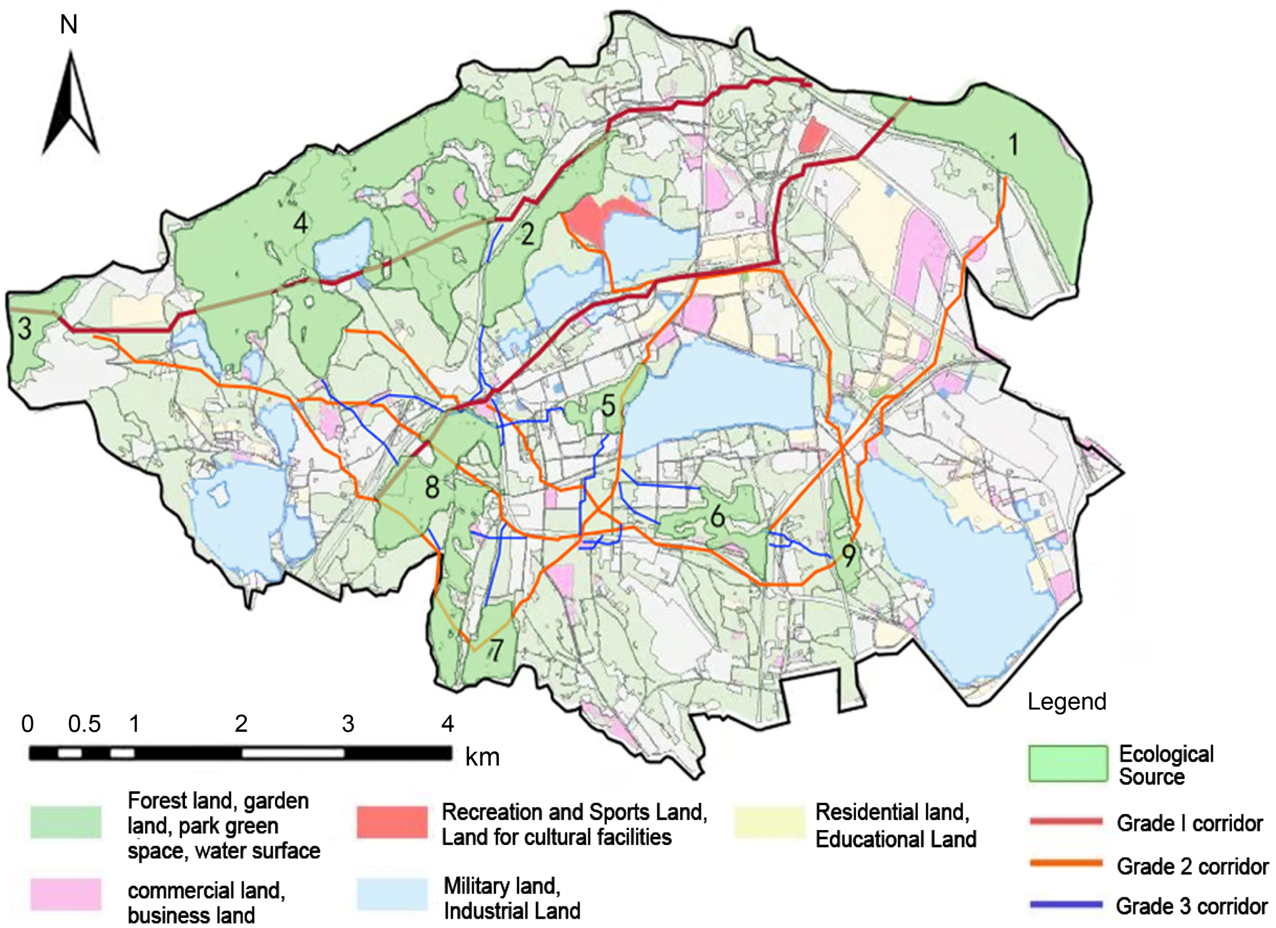

Figure 6. Landscape ecological security pattern construction. Source: Self-drawn by the author.

township, and ensure land resources at the same time. Make part of the land vacant to provide backup resources for the social economy and avoid dust pollution, ecological pollution, land subsidence, and other problems caused by industrial development.

2) The density of ecological corridors is not high. There are many ecological breakpoints, and ecological nodes need to be optimized. The level of potential corridors in the north is high, the overall quality and the connectivity is good as well, which is conducive to species migration, but the distribution of ecological source sites is small and the quality is low; the eastern corridors and ecological source sites are few, and the connectivity with the northern park needs to be strengthened. Overall, the number of corridors between ecological source sites in the non-construction area and the construction area is small, the quality is not high, and there are ecological fracture points that need to be repaired. In the later stage of ecological space construction, the ecological source sites in similar spatial geographic locations can be connected to the corridor routes according to the nature of the land. The construction of steppingstone patches can be strengthened to enhance the connectivity between different source sites and corridors.

4. Planning Controls

4.1. Comprehensive Balance between Ecological Protection and Socio-Economic Development

Spatial control based on ecological security pattern needs to focus on the integrity of ecological security pattern, balance ecological protection needs, and socio-economic development needs, and carry out different task-oriented control on different nature of the land.

1) In terms of spatial layout, the ecological source lands covering the important forest parks, woodland mountains, and other northern areas will be mainly protected, designated as ecological security protection zones. The ecological red line is kept, and the ecological conservation function and biodiversity are improved so that the ecological radiation effect is exerted. In the future construction, the area of ecological source areas is expanded, the ecological quality of source areas is improved, the destruction of natural resources by human activities is reduced, and some fragmented ecological source areas after mining are restored.

2) For the ecological source land around the central construction area can be designated as an ecological buffer zone. The planning can limit the urban development boundary to a certain extent and control urban expansion. To increase ecological steppingstones in combination with the greening project in Beigong Town and community renewal, it is necessary to improve the coverage of green vegetation, and jointly create a green space for residents' activities. The overall ecological optimization scheme of "controlling forest source in the north, optimizing cultivated land in the west and increasing green space in the middle" can be constructed.

4.2. Strengthen Corridor Planning and Control and Collaborate to Improve Ecological Network Structure

Based on the established ecological security pattern of Beigong Town, it is necessary to systematically control specific corridors. The network structure of the corridor system should be improved by considering the functions of the source sites connected by the corridors and the land use around the corridors. The study superimposed the ecological network planning map (**Figure 6**) with the elements of green areas, water systems, and railroads in the territorial spatial zoning plan of Beigong town to draw a comprehensive control map of ecological corridors (**Figure 7**) and give specific control opinions (**Table 5**).

The first-level corridor in Beigong Town is the most convenient and important corridor for material exchange, and it is also the ecological protection zone linking the northern source land (forest park, etc.) and the northern and western source land (woodland, farmland). It is necessary to strengthen the control of the corridor to avoid the destruction of its ecological space; the secondary corridor is an ecological network linking the central part (the park in the construction area) with the northern and western parts of the park, which improves the

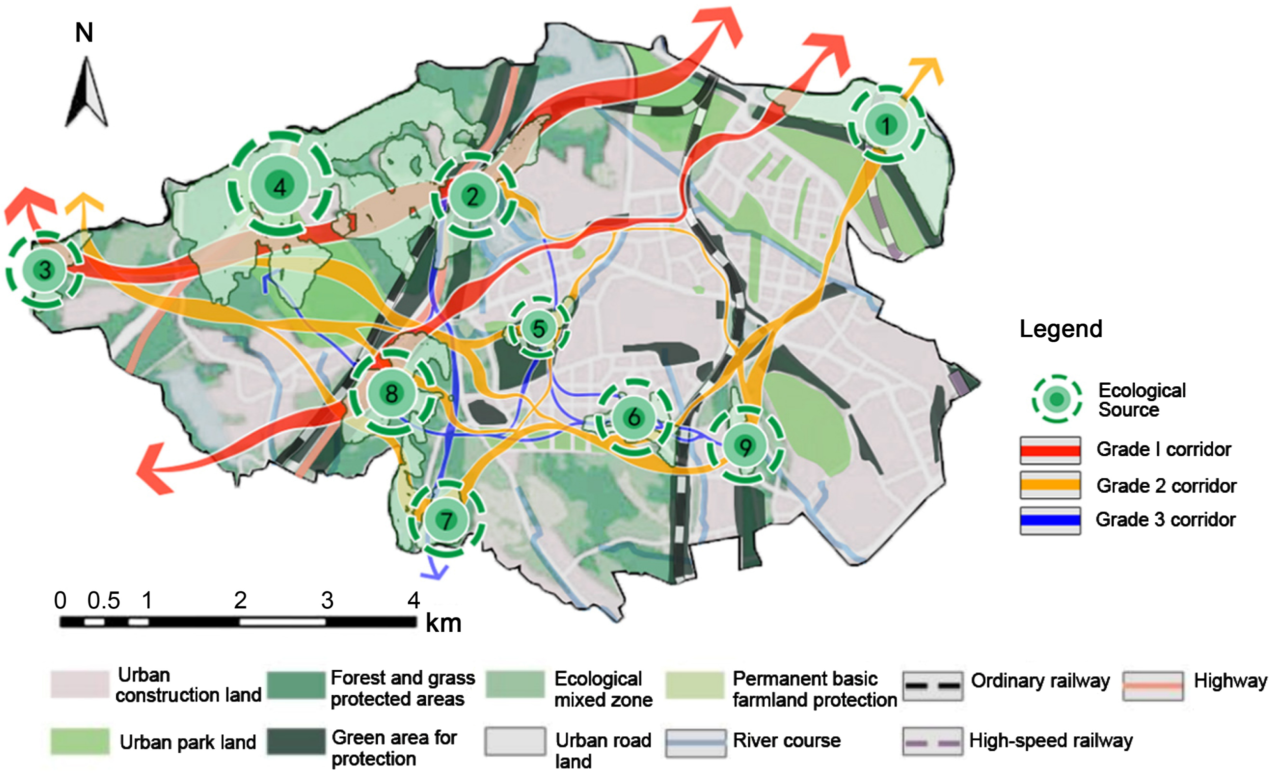

Figure 7. Integrated control map of ecological corridor. Source: Self-drawn by the author.

spatial connection between the source areas. It is necessary to optimize its ecology and control the scale of construction and development; the third-level corridor is the "capillary" of the central green space, which dredges the ecological space of the construction area and connects corridors of different levels. The minimum corridor width needs to be guaranteed to ensure the effectiveness of the corridor.

5. Summary and Conclusion

Taking Beigong town as the study area, this study identifies important ecological source sites from the perspective of ecological security pattern construction using the MSPA model and landscape connectivity evaluation; based on the study of ecological source site identification, potential corridors are identified using the MCR model, and the classification of corridors is determined using gravity model to construct an ecological security pattern. Finally, we propose planning and control opinions to achieve the protection of important ecological patches, the enhancement of corridor connectivity, and the improvement of species' survival environment.

1) In this paper, using the MSPA method, forested land as the green landscape element in the study area is used as the main prospect of MSPA analysis, and the ecologically important landscape types are identified through morphological principles. The core area patches in the study area are evaluated for landscape connectivity through IIC, PC, and DPC landscape indices, and the obtained 9

Table 5. Ecological corridor classification control measures. Source: Self-drawn by the author.

Types of land around the corridor	Management and Control Opinions	Proposed width of primary corridor	Proposed width of secondary corridor	Proposed width of tertiary corridor
Forestry and Grass Reserve	1) No additional construction land is created to maintain connectivity. 2) Restore animal diversity in the woodland, maintain the diversity of plant communities, and build water-conserving forests and riparian forests. 3) The connectivity between forest strips and the reasonableness of the width of forest strips need to be considered to ensure the important corridors for biological penetration.	12 or more.	8 m or more.	6 m or more.
Farmland and Garden	1) Set up protective forests in combination with roads to block the wind and sand, improve the soil, and improve the microclimate of farmland. 2) To build a higher-quality farmland garden based on ditches, rivers, roads and canals, and to increase its functions such as tourism and sightseeing.	12 m or more	6 m or more.	3 m or more.
Urban construction area	1) The primary and secondary ecological corridors along the road can be built as strip parks, and the tertiary corridors can be built as road green belts. 2) Corridors along highways and railroads can be built with highway green islands to meet the requirements of animal passage and habitat. 3) Corridor along the water system, which can be planted with corresponding riparian vegetation and create a riverfront landscape. 4) Corridor passing through the city park combines ecology, culture, and other themes to create an ecological park.	The corridor around railroads and highways can be 30 - 50 m or more than 50 m, and other types of ecological corridors are controlled at more than 12 m.	6 m or more.	3 m or more.

core area patches with DPC value greater than 1.5 and area greater than 1 hm^2 are used as the source place for biological species development and reproduction.

2) Using the MCR model, four resistance factors of land use, elevation, slope, and vegetation cover were selected to construct a comprehensive resistance surface by "comprehensive weighted index and method". Then, based on the ArcGIS software platform, 36 potential corridors in the study area were generated. Finally, the corridor importance was evaluated by the gravity model, and the corridor generation ecological network was planned.

3) The ecological security pattern constructed by the study will be carefully examined and controlled at different levels according to the ecological characteristics and spatial layout of the source area. The types of linkage patches and land use planning along the planned corridor will be analyzed, and specific opinions on the control of different levels of corridors will be put forward.

In the research process, although there is a quantitative analysis, the whole research process still has shortcomings: In the landscape resistance grading assignment, the study refers to expert opinion and related research but lacks the assignment analysis of specific species research. At the same time, due to the uncertainty of the direction of the next land type in Beigong Town, the planning control still needs to be combined with the next planning for precise control.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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