Construction and Optimisation of Ecological Networks in Changchun City Centre

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Abstract. The acceleration of urbanisation has led to the aggravation of the problem of fragmentation of urban ecological space, and the construction and optimisation of ecological networks play an important role in alleviating urban ecological problems. Based on the problems of ecological fragmentation and lack of wetlands and greenery in Changchun City, this paper constructs an ecological corridor network in Changchun City through the methods of Morphological Spatial Pattern Analysis (MSPA), Minimum Accumulation Model (MCR) and Circuit Theory, conducts a quantitative analysis of ecosystem services and ecological restoration of the central urban area from the whole network to the macro to micro level, and proposes the optimisation strategy of ecological network. The study shows that: (1) the optimisation of the ecological network from the whole to the region is more objective; (2) the Changchun ecological network consists of 40 ecological sources and 82 potential ecological corridors;(3) In various development scenarios, incorporating the peripheral ecological source areas from the edge of Changchun's central urban district into the spatial layout of the city center yields the greatest ecological improvement for the urban.

Keywords: Ecological network; Circuit theory; Changchun City; Downtown area

1 INTRODUCTION

High-intensity and irrational land development and utilisation have led to the encroachment of large ecological patches in cities and the blocking of ecological corridors between patches, thus destroying the original ecological connectivity and deteriorating the originally fragile natural ecological environment [1,2]. This situation threatens the stability of urban ecosystems and is not conducive to the sustainable development of ecosystems. The construction of ecological networks is of great significance in mitigating urban habitat degradation and protecting the natural environment. Therefore, it is particularly important to establish an ecological network centred on landscape connectivity, which can effectively connect various ecological patches and construct an or-

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ganic whole that is structurally and functionally interconnected [3]. Furthermore, optimizing the landscape pattern to facilitate species migration and alleviate the impacts of ecological fragmentation is also a crucial step in the contemporary construction of ecological civilization [4].

After years of research, the development of regional ecological security patterns includes a gradual evolution from qualitative planning and quantitative pattern analysis to spatial data algorithms, static pattern optimisation, dynamic pattern simulation and state trend analysis [2]. Interdisciplinary use of disciplines such as ecology, geography and planning has led to a richer and clearer understanding of ecological networks [5]. Domestic research began in the 1990s [6], and initially the least resistance model was mainly used to extract ecological corridors, but the operation was cumbersome [7]. In recent years, the identification process of ecological corridors was simplified with the help of morphological spatial pattern analysis methods and circuit theory tools [8]. Ecology is iterative in its approach to the study of ecological corridors and ecological networks, being more a complement and optimisation of the latter approach to the former, rather than a shift in research paradigm. While there has been notable progress in recent years regarding the construction and optimization of urban ecological networks, certain limitations persist. According to previous studies, At present, the construction of regional ecological network mainly adopts the basic model of "ecological source identification - comprehensive resistance surface construction - ecological network generation" based on the principles of landscape ecology [9,10]. Scholars have used specific tools such as the least cumulative resistance model [11], circuit theory [12], and graph theory [13] for ecological network construction Construction. This paper combines the existing research basis on ecological network construction. However, from the research perspective, the existing ecological network research is mostly for large-scale areas, and there are fewer studies on the optimisation of ecological network construction in urban high-density areas from the overall to regional and macro to micro perspectives. From the overall to regional, macro to micro research perspective, can be more comprehensive understanding of the complexity and dynamics of the ecosystem, for the construction and management of the ecological network to provide a scientific basis. The green space area in Changchun is still insufficient compared to the size of the urban population, especially in some dense residential and commercial areas, there are problems such as low green space coverage and declining urban air quality. Optimising the green space system in Changchun's downtown area will help to improve green space coverage and quality improve air quality, make the main urban area of Changchun more ecologically efficient and create a more livable urban environment for the citizens of the city's practical significance.

In this study, the central urban area of Changchun City is taken as the research object, the core area patches are identified and extracted by morphological pattern analysis method, the ecological source sites are screened by combining with satellite maps, the potential ecological corridors are identified by using Linkage Mapper tool based on the principle of circuit theory, and the ecological pinch points and obstacle points are extracted. And the ecosystem of Changchun City is examined from a holistic to a regional perspective, and the ecological network of the central city of Changchun City is constructed.

2 MATERIALS AND METHODS

2.1 Overview of the Study Area

Changchun is located in Northeast China, is the capital of Jilin Province, is located in the geographical centre of Northeast China (latitude 43°05′~45°15′ north; longitude 124°18′~127°05 east), belongs to the temperate continental semi-humid monsoon climate type. It has a total area of 24,592km² (as shown in Fig. 1). The central area of Changchun City is a significant urban center in the northeastern region of China, covering approximately 394.3 km². It serves as a concentrated zone for urban development, characterized by relatively flat terrain and abundant blue and green resources. However, according to relevant studies, there has been a drastic decline in ecological quality in the research area in recent years, with a sharp decrease in urban water and green resources. Therefore, focusing on the central urban area of Changchun City and constructing an integrated ecological corridor holds significant practical significance.

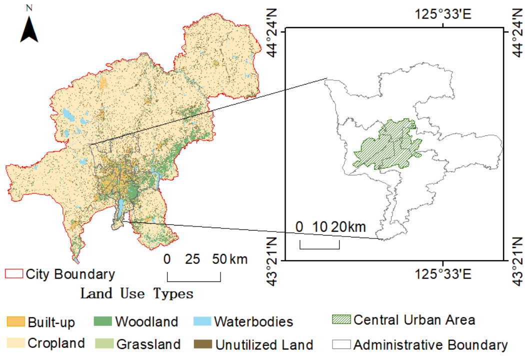

Fig. 1. Extent of the study area.

2.2 Data Sources and Pre-processing

The data of this study mainly consist of multiview Landsat8OLI multispectral remote sensing images on 16th and 25th October 2022 (data source: https://search.earthdata.nasa.gov); ASTERGDEM digital elevation data at 30m resolution (data source: https://www. gscloud.cn/home); and road vector data mainly from OpenStreeMap.

(1) Pre-processing of remote sensing images using ENVI5.3. Firstly, the Changchun landsat8 multi-scene image data radiometric calibration, respectively; secondly, atmospheric correction using Flaash atmospheric correction function; after that, fusion of multispectral map images and panchromatic images; finally the photomontages were cropped based on the administrative boundaries of the study area and the impacts were combined by false colour bands. (2) Using supervised classification, land use types were classified into watershed, cropland, forest, according to the purpose of the study and the needs of the study area six types of land, grassland, building land and unused

land. (3) Randomly generated points by ARCGIS, combined with high-resolution Google the map images were examined, and the results of the 2022 monitoring classification were examined for accuracy, and the results met the accuracy requirements. (4) Use of the digital elevation data was subjected to the spatial analysis tool of arcgis software to generate slope data. Euclidean distances were used to calculate the distance to the road, constructing distance from the building. The above data were set to a resolution of 30 M, and the data were standardised to projected coordinates.

2.3 Research Methodology

The downtown area of Changchun City was selected as the study area, and the research process was as follows: (1) The ecological source sites in Changchun City were extracted using the MSPA method and satellite maps. (2) Drawing from the study area's actual conditions and the identified ecological sources, we integrate factors such as land use types, MSPA landscape classifications, road proximity, slope, NDVI vegetation indices, among others, to establish Changchun City's landscape resistance surface. (3) The ecological network of Changchun City is then constructed utilizing the MCR model. (4) Subsequently, ecological network priorities are determined, and using circuit theory, ecological pinch points and obstacles within Changchun City's center are identified. (5) Explore the optimisation of overall landscape connectivity in Changchun from different regional perspectives.

The ecological network of green space in the central urban area is a continuation of the ecological network of the city and the metropolitan area, but also has the characteristics of humanisation, compared with the purely natural ecological network, the ecological network of green space in the central urban area mainly serves the human city [14]. By constructing the ecological network of Changchun City, the ecological network of Changchun City is delineated from the central urban area's ecological network. Through macroscopic analysis of the overall ecological network of Changchun City and microscopic analysis of the ecological network of the central urban area, the optimization of the overall ecological space is achieved.

Analysis of Morpho-spatial Patterns.

The identification of ecological source sites is an important step in the construction of ecological networks. Currently, there are many different methods for source site screening, the are mainly MSPA, ecosystem service importance, habitat quality, ecologically important areas (nature reserves, water conservation areas, etc.) and other methods for source identification[15].The MSPA technique is to segment and corrode the pixel elements of a binary raster image in the Tiff format, delineating it into a raster image format of seven different landscape types that do not intersect with each other[16]. Based on the connection of ecological sources to the surrounding environment in the whole landscape pattern space, the MSPA method can better provide a basis for the subsequent identification of ecological corridors and nodes.

According to the land use data map of Changchun City obtained from the processing, through the use of Geographic Information System (GIS) technology, the woodland

and grassland with strong ecological benefits and good biodiversity were set as foreground data, and other types of land use data were set as background data. Guidos Toolbox2.8 analysis software was used to generate seven landscape element types (core area, patch, bridging area, edge, pore, ring road and spur) for the raster image of MSPA. Among them, the core area is the main potential ecological source area. The accurate identification of ecological source areas lays the foundation for the construction of an ecological network with strong connectivity and high stability.

Key Ecological Source Extraction.

The selection of source patches is the basis of ecological network construction. Given the complexity of urban landscapes, the selection of ecological source patches must prioritize those with favorable ecological conditions and sufficient size, while also considering their connectivity. The data of seven landscape element types generated from MSPA raster images were converted into binary raster files in TIFF format, in which the core area was larger habitat patches, and when extracting ecological sources, the size, shape and location of the patches were considered, and the patches with an area larger than 1 km^2 were selected as the important ecological sources, and the habitat quality of the large patches and the wider corridors were better, which would greatly reduce the landscape resistance to species migration and dispersal and increase the survival rate during species migration [17,18]. These larger source areas have good ecological benefits and can provide good migration and habitat for wildlife.

Resistance Surface Construction.

Building ecological networks based on source sites requires relying on resistance surfaces to identify and address challenges and barriers. In the actual process of ecological network construction, through the use of Geographic Information System (GIS) technology and simulation models, resistance surfaces can be quantitatively assessed and spatially analyzed to determine the optimal ecological connectivity pathways and biological corridor locations. The selection of resistance factors is generally based on anthropogenic and natural factors. According to the needs of this study, for most species in Changchun City, construction land and roads have a greater resistance to animal migration. In this study, combining the results of previous research and synthesizing the actual situation in Changchun City, we selected selecting land-use type, MSPA landscape type, distance from the road, slope, and NDVI vegetation index as the main resistance factors, and utilized the raster weighted superposition of the ARCgis10.5 software to construct a ARCgis10.5 software raster weighted superposition was utilized to construct the comprehensive resistance surface and carry out hierarchical assignment. The specific resistance assignment and weighting of each factor are shown in Table 1.

Table 1. Grading values and weights of resistance factors for the construction of an ecological resistance surface.

Resistace factor	Classification index	Resistance value	Weight
Land use type	Woodland	1	0.259
	Grassland	3	

	Cropland	6	
	Unutilized Land	8	
	Built-up	9	
	Waterbodies	9	
NDVI	0.7-1	1	0.1673
	0.5-0.7	3	
	0.3-0.5	5	
	0.1-0.3	7	
	0-0.1	9	
MSPA	Core	1	0.3946
	Bridge	2	
	Loop	3	
	Branch	4	
	Islet	5	
	Edge	6	
	Perforation Background	7	
	Background	9	
Road distance (m)	<300	9	0.1077
	300-600	8	
	600-1200	6	
	1200-2400	3	
	>2400	1	
Slope (°)	0-3	1	0.0714
	3-8	3	
	8-15	5	
	15-25	7	
	>25	9	

Urban Ecological Network Identification Based on the MCR Model.

The primary conduits for material and energy exchange among various ecological sources within urban areas are known as urban ecological corridors. One common method for constructing ecological networks is the utilization of the Minimum Cumulative Resistance (MCR) model. Based on the integrated resistance surface constructed above, the minimum cost of moving between ecological sources is calculated and the path with the lowest risk and cost is mapped. The formula for the MCR model is as follows:

$$\mathrm{MCR} = f_{min} \sum_{j=m}^{i=m} \left(D_{ij} \times R_i \right) \quad (1)$$

where MCR is the minimum cumulative resistance, f is the positive correlation between the minimum cumulative resistance and ecological processes, Dij is the spatial distance from patch i to j, and Ri is the resistance coefficient for the spatial extension of patch i. In this study, we used the Linkage Mapper toolkit developed by McRae to perform calculations to determine the spatial layout of the ecological network [19].

Optimisation of Urban Ecological Networks Based on Circuit Theory.

Ecological corridors are connecting ecological source areas to improve ecological efficiency and provide effective pathways for species migration. Circuit theory identifies multiple ecological pathways based on electron random wandering to simulate species migration and diffusion within the landscape surface [20] Linkage Mapper completes the identification of ecological corridors in the study area through the steps of identifying neighbouring ecological sources, constructing a network of ecological sources, calculating the cost-weighted distances and least-cost pathways, and calculating standardised low resistance pathways [21]. Using the linkage mapper pathways tool in the linkage mapper toolbox, combined with the integrated resistance surface data, ecological circulation pathways with width information can be identified, which provides an important reference for subsequent ecological corridor planning.

Ecological nodes play a key role in the construction of ecological networks, and they are key locations with important facilitating or inhibiting effects in regional ecological processes. The Pinchpoint Mapper tool was used to identify areas of high current density as ecological pinchpoints. These areas represent key points that species may pass through during migration or are difficult to replace in biological activities, are critical to ecosystem integrity and stability, and deserve special protection.

Ecological barrier points are identified using the Barrier Mapper tool, which calculates the magnitude of the cumulative current recovery value to reflect the degree to which species are hindered from migrating between source sites. Areas with higher values indicate greater impediments to species migration, which may be due to factors such as anthropogenic activities or natural geographic conditions. The presence of ecological barrier sites may lead to loss of biodiversity and disruption of ecosystem function.

Accurate positioning and protection of ecological nodes is crucial to the construction of an ecological network with strong connectivity and complete functions. By identifying ecological pinch points and ecological obstacle points, biological migration and species exchange can be better guided to promote the healthy development of ecosystems and achieve the goals of biodiversity conservation and ecological balance.

3 RESULTS AND ANALYSES

3.1 MSPA Analysis Results

Using the MSPA analysis method, the proportions of various landscape types in Changchun were determined (as shown in Fig. 2), with a total area of 2968.04km², accounting for 50% of the city area. The core area accounts for the largest proportion, 1649.79km², or 76% of the area of the foreground elements, and these core areas are mainly distributed in the southeast of the study area along the Daxi Mountain Range, while less distributed in the north and west.

The landscape type of Changchun city centre is fragmented with core landscape. It is mainly concentrated in the Yitong River basin and South Lake Park area. It can be seen through the area of each type of landscape type that the core area is the largest, and the proportion of other landscape types is low, indicating that the degree of patch-breaking fragmentation in the study area is high and connectivity is poor.

3.2 Ecological Source Area Analysis

The overall distribution of ecological source sites in Changchun City is uneven, and a total of 40 ecological source sites were screened out (as shown in Fig. 3), with a total area of 1248.84 km². The core source sites are located in the south, concentrated in the Dahei Mountain Range and Bayi Reservoir. Ecological source sites in the west and north are less distributed. Among them, ecological source area 24 (with an area of 330.01 km²) and ecological source area 27 (with an area of 137.32 km²) are the two source areas with the largest area, which together account for 37.4 %of the total ecological source area.

The distribution of source land in the downtown area of Changchun City is relatively uneven, mainly in the northern Yitong River basin, the western automobile park and the Nanxi Wetland Park, etc., and the ecological parks in the northwestern area are missing, with low ecological benefits.

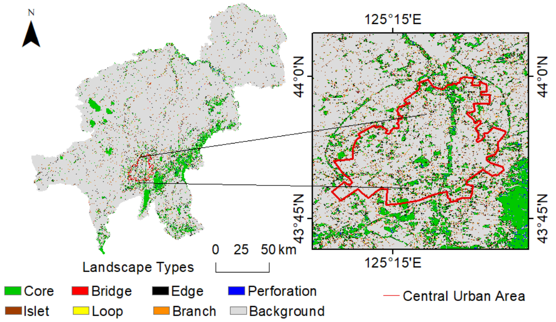

Fig. 2. Landscape type map of MSPA in Changchun City.

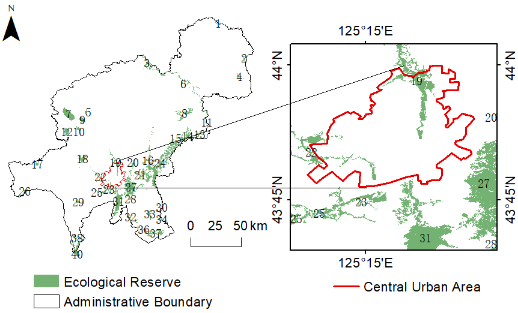

Fig. 3. Distribution of ecological sources in Changchun City.

Resistance Surface Analysis Results.

The comprehensive resistance surface analysis shows (as shown in Fig. 4) that the high resistance areas in Changchun are mainly located in the construction land use areas, especially in the areas where urban land use is more concentrated in the urban area. The areas with low resistance values are mainly located along the shores of water bodies such as the Dahei Mountain Range, Karun Lake and Bayi Reservoir, and around forested areas.

The urban centre of Changchun City has a high density of buildings, low vegetation cover, and high loads from roads and railways, reflecting the high level of interference from human activities. In spatial terms, the regions of low resistance are primarily found within the green spaces along the riverbanks and in urban parks. Conversely, high resistance values are predominantly observed in the central portion of the study area, primarily due to the elevated building density and reduced ecological quality in this zone.

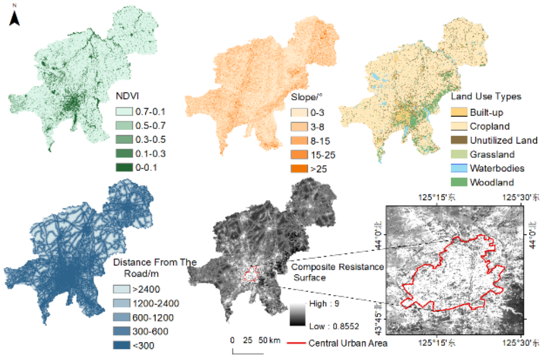

Fig. 4. Ecological resistance surface in Changchun City.

3.3 Ecological Network Construction in Changchun City Centre

Based on the above results, the distribution map of ecological corridors in Changchun City is analyzed (as shown in Fig.5), with a total of 82 potential corridors. The ecological sources in the southern part of the city are well distributed, and the ecological network is highly connected, mainly the hilly greens of Dahei Mountain Range extends into the city, and plays a complementary role to the urban greens in the southeastern part of the city; longer corridors are distributed in the western part of the study area, connecting the ecological sources in the west and the east, and due to the complex distribution of the sources in the east, the length of the connected corridors is shorter, and the ecological corridors are in a northeast -Southwest direction. The ecological sources in the northwest and northeast directions are missing and lack connectivity with the whole.

Five corridors were extracted from the central part of Changchun City, and these corridors were mainly located in the southern part of the study area because the ecological benefits in the southern part were better, and the lack of ecological sources in the northwest resulted in poor connectivity with the overall network.

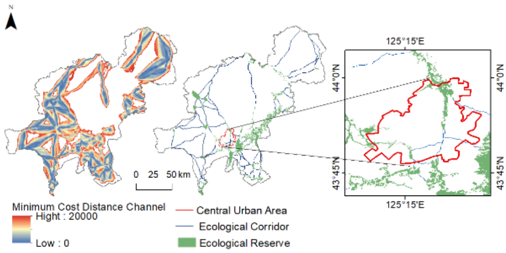

Fig. 5. Linkage Mapper identifies ecological corridor analysis.

3.4 Identification of Ecological Network Pinch Points and Obstacle Points

The result of ecological node identification was the extraction of 85 ecological pinch points (all-to-one and Pairwise modes) (as shown in Fig. 6), the high density area of pinch points is located in the southern part of Changchun City, and the land types in the identified pinch point areas are mainly farmland and construction land. There were 143 obstacle points (unselected improvement scores relative to LCD (leasl-cost distance) percentage and selected improvement scores relative to LCD percentage) between the source sites (as shown in Fig. 7), which were mostly located in farmland and water areas.

The pinch points in downtown Changchun are mainly located near the Beihu Wetland Park in the northern region, and the ecological obstacle points are mainly located at the ecological corridors in the southern region. The land types in the area where the ecological pinch points and obstacle points are located are forested land and construction land, with forested land contributing more to the overall ecological network, and construction land is the obstacle point in the ecological network that needs to be improved.

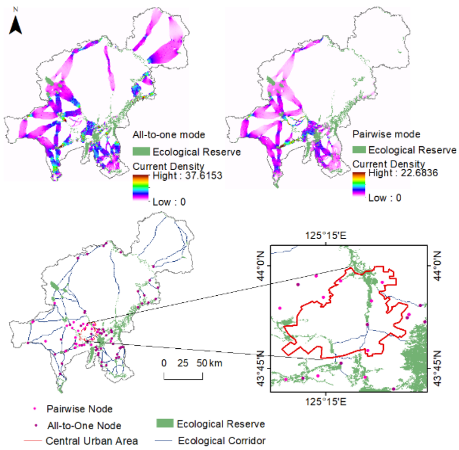

Fig. 6. Analysis of ecological nodes based on Pinchpoint Mapper.

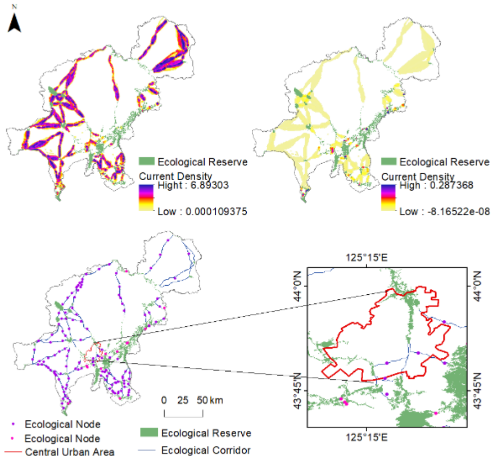

Fig. 7. Barrier Mapper based ecological node analysis.

Optimisation of Ecological Networks at the Municipal Scale.

The existing ecological source sites in Changchun City are unevenly distributed, mostly concentrated in the southeastern part of the study area, resulting in an incomplete ecological network pattern in the study area. Therefore, for the optimisation of the ecological network in Changchun, the focus should be on increasing the ecological source sites in the north and west. The extracted areas of ecological corridors that are easy to break are protected, such as the intersection of roads, railways and ecological corridors [22]. Nature reserves should be set up for the pinch point areas in the study area to ensure that the area will not easily disappear. Ecological obstacle points are mostly distributed at the edges of farmland and building land. Under the premise of ensuring basic farmland, moderate measures such as returning farmland to forests and wetland restoration should be adopted [23]. Blind restoration is not recommended for barrier points and pinch points that are far away from the ecological source and large in scope, as these areas have high ecological restoration costs and low vegetation survival rates after restoration [24].

Optimisation of the ecological network under the central city limits.

The optimisation of the ecological network in the central city is a complex and comprehensive task, which needs to take into account various factors such as ecological environment, land use and urban planning. The ecological network of the central urban area is missing source sites in the northwestern region, which needs to be increased at the tributaries of the Yitong River in the northwestern region. In the study area, high-density buildings and roads are an important barrier to animal migration, but improvements to street greening can provide habitats for small animals and insects. For ecological pinch point locations, natural conservation measures should be taken and combined with artificial interventions, such as increasing the area of green cover to expand the pinch points. Removing or repairing ecological pinch points through rational planning of the amount of land to be built on is aimed at maintaining the integrity of ecological processes.

4 CONCLUSIONS AND DISCUSSIONS

4.1 Conclusions

In this paper, Morphological Spatial Pattern Analysis (MSPA), Minimum Cumulative Model (MCR) and Circuit Theory are comprehensively applied to identify the important landscape elements and "pinch point" areas of the green infrastructure network by using Circuit Theory, in accordance with the basic model of "ecological source identification - comprehensive resistance surface construction - ecological network generation". Based on this model, we use circuit theory to identify important landscape elements and "pinch point" areas, and provide a scientific basis for the protection planning of the green infrastructure network in Changchun city centre from a new perspective of the whole to the region. The primary conclusions can be summarized as follows:

(1) The optimisation of ecological networks from the whole to the region is more objective;

(2) Changchun City screened 40 ecological source sites, a total of 82 potential ecological corridors, ecological node identification results for the mention of the

Eighty-five ecological pinch points and 143 obstacles between sources were removed.

(3) The overall green space distribution in Changchun city is closely linked to the natural environment, and the ecological resources outside the central city can well complement and optimise the inner city. Biological migration corridors should be considered in the construction of urban grey infrastructure to minimise landscape resistance.

4.2 Discussions

The construction of ecological networks is of great practical significance for improving urban ecological efficiency. It can guide urban ecological optimisation based on scientific methods. The main countermeasures are as follows:

(1) Focusing on the protection and restoration of existing ecological sources, including forests and grasslands, and strengthening ecological restoration, ecological corridors should be rationally set up and preserved in urban planning to connect different ecological sources and important ecological nodes, and their integrity and connectivity should be ensured through the establishment of green corridors and other means, in order to provide a good habitat for the migration of species.

(2) The construction and management of urban green space systems should be strengthened, the connectivity and coverage of green spaces should be increased, and urban ecological networks should be formed through the continuous layout and rational design of green spaces, so as to improve the ecological quality and living environment of cities. In urban planning and land use control, the need for ecological protection should be fully taken into account, and important areas such as ecological protection zones and water conservation zones should be reasonably delineated, so as to restrict

unsuitable development and construction activities and protect the ecological environment and biodiversity.

(3) Cross-sectoral cooperation will be strengthened, relevant policies and regulations will be formulated and improved, and scientific and technological means will be used to monitor the ecological environment and provide support for the optimisation of ecological networks. Public participation will be strengthened to promote the smooth implementation of ecological protection. These initiatives will gradually improve and optimise the ecological network in Changchun, achieving the harmonious development of the city and the natural ecosystem and creating a better living environment.

This study takes Changchun City as an example, and constructs and optimises the urban ecological network from Changchun City as a whole to the region, but there are still deficiencies. For example, for the selection of ecological sources, the area combined with the real satellite map is used as the criterion for selecting ecological sources. For the selection of ecological resistance factors, it is necessary to further explore the rationality of the different weights and tendencies of the resistance factors in each region and the whole. In future research, more detailed assessments should be conducted on the construction of small-scale ecological networks. Integrating urban ecological networks with urban planning, optimizing urban ecological networks on limited land resources can enhance the city's sustainable development.

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