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Original Research

Construction of Green Space Ecological Network in Jinan City Based on MSPA and MCR Model

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Abstract

This study takes Jinan City as the research area, the landscape elements of the core area which are most suitable for the survival of species are extracted by the method of morphological spatial pattern analysis (MSPA); Through the analysis of landscape connectivity, the importance of the extracted patches in the core area to the overall connectivity is evaluated, and 19 patches in the core area with the greatest effect on the connectivity are selected as the ecological source areas; Based on the minimum resistance model (MCR), 171 potential ecological corridors are calculated; Based on the gravity model, the importance of corridors is quantitatively evaluated, and 51 important corridors and 120 general corridors are classified. Removing redundant parts, the ecological network of Jinan is constructed, and the characteristics and landscape composition of the network are analyzed. The results show that the green space in Jinan City is relatively concentrated and seriously broken, with obvious characteristics of distribution along the ridge and except for some source patches, the overall connectivity of its ecological network is in sound condition, so it is necessary to build stepping stone patches for protection. The results of this study can provide basis for the protection and improvement of ecological environment in Jinan City, and also have some reference significance for the construction of ecological network in other areas.

Keywords: morphological spatial pattern analysis, landscape connectivity, minimal cumulative resistance model, ecological network, Jinan

Introduction

The rapid development of social economy inevitably leads to the expansion of the city, as well as the destruction of a large number of woodland and grassland, resulting in a significant reduction of habitat patches and a significant increase in fragmentation in the region [1-2]. This not only causes the deterioration of the urban ecological environment, but also hinders the migration and diffusion of species, aggravates the "island" phenomenon, causes the imbalance of the ecosystem, and leads to the decline of species and even regional extinction [3-4]. Ecological network is a collection of the same type of ecosystem in a region. It connects habitat patches through potential corridors and stepping stones, forms a highly connected ecosystem, and strengthens the communication of species in each patch, so as to improve the adverse

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impact of habitat patch fragmentation on the ecological environment and biodiversity, strengthen the ecosystem service function [5-6].

Whether the ecological network is reasonable or not depends on the selection of ecological source areas and ecological corridors in the network. Domestic and foreign scholars have proposed many methods and models around ecological networks. Hofman et al. constructed low-cost corridors through habitat suitability analysis and graph theory method [7]. Pierik et al. modeled ecological corridors based on current theory [8]. Wang Fei constructed an ecological network of greenways in Jinan through the Telfer expert evaluation method and gravitational model [9]. In recent years, morphological analysis methods are often introduced in the selection of ecological sources [10-13]. Vogt et al. proposed Morphological Spatial Pattern Analysis (MSPA) [14], which emphasizes structural connections and can more accurately distinguish core areas, bridge areas, and other areas that play an important role in landscape connectivity [15]. The minimum cumulative resistance model (MCR) constructs a cumulative resistance surface by setting different resistance values and weights to scientifically extract the best path to connect ecological sources [16-17]. Chen Zhu'an et al. constructed an ecological corridor in Yujiang County by MSPA and MCR models [18], and Cao Yikun et al. studied the green landscape connectivity in Shenzhen based on LSMM and MSPA [19].

In this paper, Jinan City, the capital city of Shandong Province, was taken as the research area, and the core area of the landscape types with the best ecological function in the study area were obtained by MSPA method. Then the importance of the core area was quantified by three indicators: global connectivity (IIC), possible connectivity (PC) and plaque importance (DPC). According to the quantitative results, the ecological source areas were extracted. Then the MCR model was constructed to obtain the potential ecological corridor, and the importance of the potential ecological corridor was graded based on the gravity model, so as to complete the construction and evaluation of the ecological network of Jinan City, in order to provide a scientific basis for the construction of the ecosystem and the protection of biodiversity in Jinan City.

Material and Methods

Data Sources

The main data used in this paper include 10 meters resolution land use grid data provided by Tsinghua University data center, 90 meters resolution DEM data provided by geospatial data cloud platform and administrative boundary data of Jinan City. The coordinates were WGS-84 coordinate system and UTM projection. After cutting the land use data and DEM data, the remaining 8 types of land use data in Jinan City were crop land, forest land, grassland, shrub, wetland, water area, impervious surface and bare land (Fig. 1). After verification, the accuracy of land use data was ideal, which can be used as the data of this study.

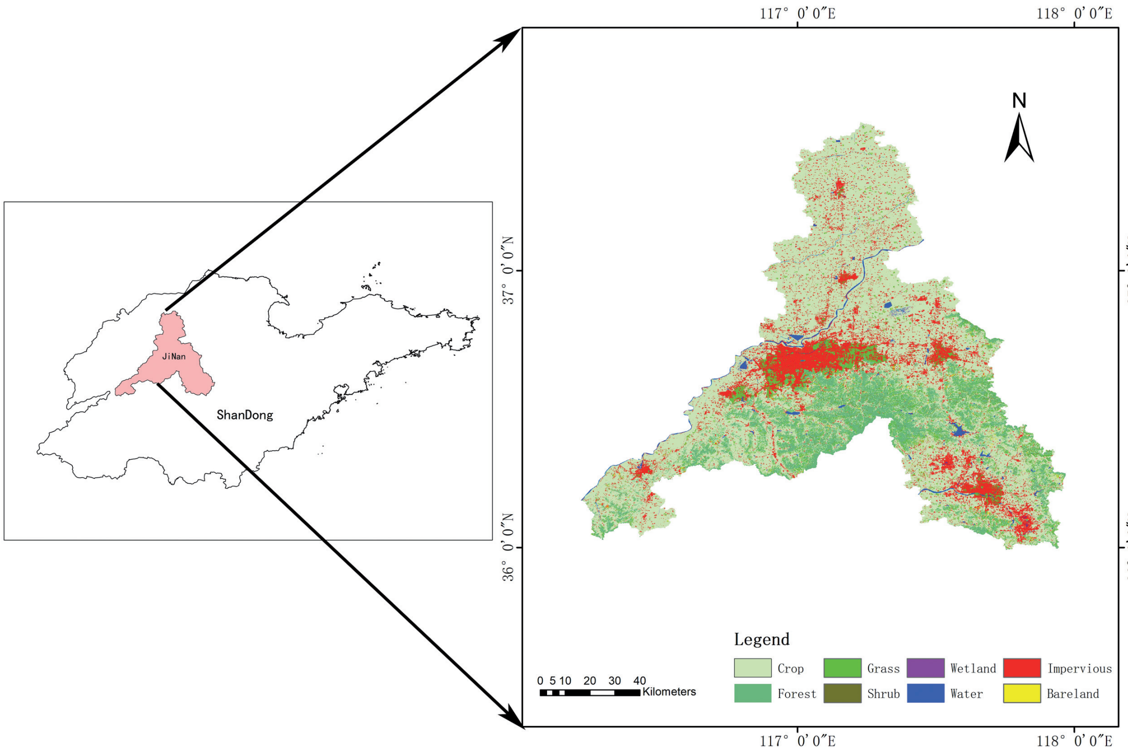

Fig. 1. Study area and land utilization distribution map.

Research Methods

Landscape Pattern Analysis Based on MSPA

According to the obtained land use data of Jinan City, the forest land, grassland and shrub land were used as the foreground data of MSPA analysis, and other land types were used as the background data, which were exported to the binary grid image in TIFF format. Using Guidos Toolbox analysis software, MSPA analysis was performed on the binary raster map using the 8-neighborhood analysis method.

Landscape Connectivity Evaluation

Landscape connectivity can effectively judge the connectivity between landscape patches, scientifically characterize the difficulty of migration and diffusion of a certain element between habitat patches, and identify important ecological sources, which is of great significance for ecological function and species diversity protection [20,21]. Integral Index of Connectivity index (IIC), probability of connectivity index (PC) and patch importance index (DPC) were widely used in landscape connectivity evaluation.

$$\text{IIC}=\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i a_j}{1+nl_{ij}}}{A_L^2}$$

In the formula, n is the total number of patches; a_i and a_j are the area of patch i and j respectively; l_{ij} is the shortest path from patch i to patch j, A_L^2 is the total landscape area of the study area.

$$\text{PC}=\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j p_{ij}^*}{A_L^2}$$

In the formula, n is the number of patches; a_i and a_j are the area of patch i and j respectively; A_L is the total landscape area; p_{ij}* is the maximum probability of species spreading in patches i and j. The value of PC is between 0 and 1. The larger the value is, the higher the connectivity of regional landscape is.

$$\text{d}I=\frac{I-I_{remove}}{I}\times 100\%$$

In the formula, dI represents the importance of the removed elements; I is the result of connectivity calculation; I_{remove} is the result of connectivity calculation after removing a certain element. The greater the dI value, the greater the importance of the elements.

$$\text{d}PC=\frac{PC-PC_{remove}}{pc}\times 100\%$$

By substituting PC value into dI formula, we can get DPC, which indicates the importance of the plaque. Conefor software was used for analysis, the distance threshold was set at 2500 meters, the connectivity threshold was 0.5928 [22-24], calculated the landscape indexes of PC and DPC.

Construction of Ecological Network Based on MCR Model

When species spread and migrate, they will inevitably be affected by different degrees of resistance brought by the environment. This paper analyzed the environmental impact of human activities and biological habitat characteristics according to the relevant research at home and abroad. Based on the four factors of land use type, MSPA landscape factor, elevation and slope, the resistance values of each factor were assigned by expert scoring method (Table 1). The weights of the above four factors were set as 0.2, 0.3, 0.15, 0.35 [25]. After the above resistance grids were reclassified in Arc GIS, the weighted sum tool was used to construct the comprehensive resistance surface as the cost data of MCR model.

The factors affecting the difficulty of species migration are not only the distance, but also the resistance in the migration path. The greater the landscape resistance is, the less conducive to the migration and diffusion of species. The minimum cumulative resistance model (MCR) is used to calculate the minimum cumulative resistance surface of the ecological source area to expand around [26]. It has the characteristics of simplicity, scalability and wide application. It can determine the best path from the initial source to the target source, which can effectively reduce the interference of the external environment and minimize the difficulty of biological flow and reflect the possibility and tendency of biological flow path [27].

$$\text{MCR}=f_{min}\sum_{j=n}^{i=m}(D_{ij}\times R_i)$$

In the formula, MCR refers to the minimum cumulative resistance value from ecological source to other sources; f is a function reflecting the proportional relationship between MCR and variables D_{ij} and R_i; D_{ij} is the distance from ecological source j to other landscape unit i; R_i is the resistance value of species crossing a landscape surface i.

Then, based on Arc GIS software, the cost distance tool was used to calculate the minimum cumulative cost distance and cost backtracking connection of the nearest unit of each ecological source on the comprehensive resistance surface, and the cost path tool was used to calculate the minimum cost path from each ecological source to the remaining target source to ensure that a minimum cost path was generated between each two ecological sources.

Table 1. Score of Resistance Factors.

Resistance factor	Classification index	Resistance value
Land use type	Forest	5
	Shrub	10
	Grass	20
	Wetland	20
	Crop	100
	Bareland	100
	Water	200
	Impervious	500
Landscape type	Core	5
	Bridge	10
	Loop	30
	Branch	40
	Islet	50
	Edge	60
	Perforation	70
	Background	100
Altitude	h<200	5
	200≤h<400	10
	400≤h<600	20
	600≤h<800	30
	800≤h	50
Slope	<5	5
	6~15	10
	16~25	20
	26~35	40
	36~45	80
	>45	100

Extraction of Important Ecological Corridors Based on Gravity Model

The gravity model was used to evaluate the force strength between patches. The gravity model was introduced into the identification of important ecological corridors to calculate the ecological force between ecological source. The higher the value was, the more frequent species exchange and migration were, and the closer the relationship between ecological sources was, so as to scientifically determine the relative importance of ecological corridors [28-29].

$$F=G_{ij}=\frac{N_i N_j}{D_{ij}^2}=\frac{\ln(a_i)\ln(a_j)}{P_i P_j}\Big/\left(\frac{L_{ij}}{L_{max}}\right)^2=\frac{L_{max}^2\ln(a_i)\ln(a_j)}{L_{ij}^2 P_i P_j}$$

In the formula: F is the ecological gravity model, which is equal to the interaction strength G_{ij} between patch i and patch j; N_i and N_j are the weight coefficients of patch i and patch j respectively; D_{ij} is the normalized resistance value of potential corridor between patch i and patch j; a_i and a_j are the area of patch i and j respectively, and P_i is the overall average resistance value of patch i; L_{ij} is the cumulative resistance value of potential corridor between patch i and patch j; L_{max} is the maximum resistance value of all corridors in the study area.

Results and Discussion

Evaluation of the Landscape Pattern Analysis

Analyzed by MSPA, the foreground was divided into 7 disjoint landscape types, namely core area, bridge area, island patch, branch line, edge area, loop area and perforation (Fig. 2), and the analysis results were statistically analyzed (Table 2). The core area of grid format was transformed into vector format, and 38 patches with an area of more than 5 square kilometers were extracted as landscape elements for connectivity analysis.

As shown in Fig. 1 and Table 1, The green area of Jinan City was about 19.78% of the total area of Jinan City. It was mainly large patches, relatively concentrated, mainly distributed in the southern part of Jinan, while the central and northern parts were mainly cities and cultivated land, with only sporadic distribution of green space. The core area of the study area was the

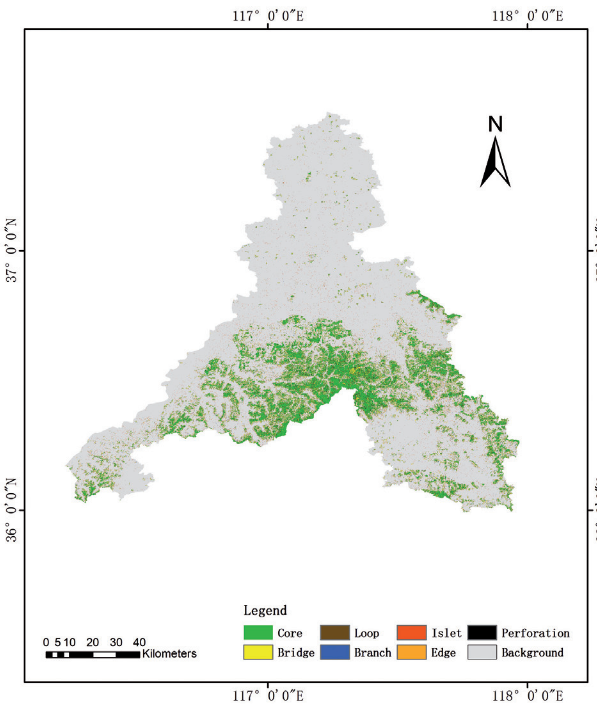

Fig. 2. Landscape pattern map of Jinan City Based on MSPA.

Table 2. Classification Statistics Table of MSPA.

Landscape type	Area (km^2)	Landscape proportion of green area (%)	Proportion of total landscape (%)
Core	1359.45	66.59	13.17
Islet	109.42	5.35	1.06
Perforation	71.22	3.48	0.69
Edge	336.51	16.50	3.26
Loop	23.74	1.14	0.23
Bridge	44.39	2.20	0.43
Branch	97.03	4.74	0.94
Total	2041.76	100	19.78

largest, about 1359.45 km^2, accounting for 66.59% of the total green area. The core area was relatively dense in the southern mountainous area, which was obviously distributed along the mountains. Their connectivity and stability were relatively good, which was conducive to the diffusion and exchange of organisms in the core area. However, the southwest and Southeast core areas were relatively rare and seriously fragmented, which was not conducive to the connectivity between patches, and the ecological exchange was more difficult. The edge area was the transition area between the core area and the non-green landscape area, covering an area of 336.51 km^2, accounting for 16.5% of the green space area. The edge effect was significant, which can reduce the negative impact of external environmental interference on the interior of the core area. However, the more the edge area was, the smaller the core area was and the more fragmented it was. The isolated island area was 109.42 km^2, accounting for 5.35% of the foreground area. The island area was 109.42 km^2, accounting for 5.35% of the landscape types in the future. Each patch of the island was small

Table 3. Ranking of the Importance of Core Area Based on Landscape Connectivity.

Rank	Number	dPC	dIIC	Area (km^2)
1	15	92.55298	93.20607	313.84
2	18	11.00489	6.805891	21.10
3	6	10.64599	8.370521	16.69
4	16	6.869377	3.379957	20.40
5	13	6.636636	3.704035	13.36
6	17	6.365642	3.289935	11.59
7	7	5.915187	3.850341	5.60
8	2	5.286356	4.316637	16.88
9	10	5.087424	2.922921	7.55
10	14	4.693276	1.640503	6.02
11	9	3.992664	3.798422	14.13
12	12	3.077723	1.378748	6.34
13	5	2.962608	1.966059	7.34
14	4	2.347353	1.423588	7.60
15	8	2.238401	1.100487	5.88
16	11	2.017301	0.973402	5.27
17	19	1.649498	0.927963	5.93
18	1	1.548072	1.121169	7.36
19	3	1.483662	1.350052	23.00

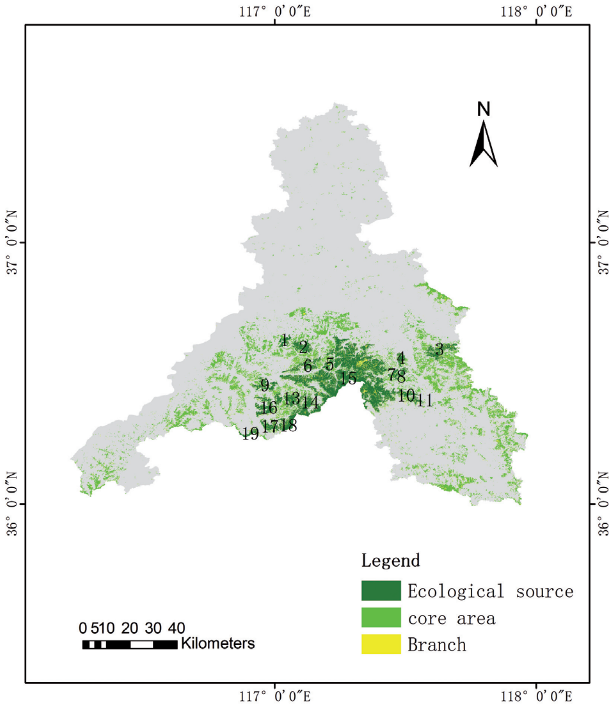

Fig. 3. Distribution map of source area, core area and bridge area.

and scattered around the core area. It can be used as a stepping stone in species exchange and indirectly improve the connectivity between patches. Bridging area was a long and narrow area connecting the core area, which was an important landscape element of material flow, and was of great significance to biological migration and landscape connection. However, the area of bridging area is only 44.39 km^2, accounting for 2.2% of the prospect, indicating that the connecting conditions between the core areas were not ideal. The branch was a patch with only one end connected to the green space in the non-core area, which had a certain connectivity, accounting for 4.74%. In addition, the loop connecting the same core area and the perforation representing the inner edge of the patch accounted for 1.14% and 3.48% respectively.

Based on the above data, the core area of Jinan City accounted for the majority of green space, and there were relatively more edge areas, islands and branches and less area of bridges. These show that the core area of Jinan City was dominated by large patches, and the edge was relatively broken, which was easy to cause interference by external environment. In addition, the edge core area was not easy to connect, and there were many interrupted corridors.

Identification and Evaluation of Ecological Sources

The landscape connectivity of extracted patches in the core area was evaluated (Table 3). The 19 core patches with D*PC* value greater than 1 were used as ecological sources for biological species development and reproduction (Fig. 3).

The key node of the ecological network was the ecological source. The better the landscape connectivity and the larger the area of the ecological source, the more abundant the resources and species will be, and the more conducive to maintaining the ecological function of the landscape. As shown in Fig. 2 and Table 2, the ecological source areas were completely concentrated in the only ecological function area in the 13th five years plan of ecological environmental protection in Jinan - the ecological function area in the southern mountainous area, which was also the main concentration area of the provincial ecological protection red line in Jinan. No. 15 was the largest and most important ecological source, with an area of 313.84 km^2 and dPC of 92.55. It was the main body and core of Jinan ecological source, and was located in Liubu Town, Xiying Town, Qixingtai Forest Park and Duozhuang town. There are many scenic spots and sites in the patch. No. 18, with an area of 21.10 km^2 and dpc11.00, was located in the northwest of Mount Tai, Changqing changchengling scenic area; No. 6 source area was 16.69 km^2, dPC 10.65, located in Qingtongshan Grand Canyon; No. 3 source area had the smallest dPC value, covering an area of 23 km^2. It was located near yanjiayu Township and Wenzu Forest Park in Zhangqiu, and its location was relatively isolated. The dPC of other sources was lower than 7, which made a relatively common contribution to the connectivity of the whole study area.

In general, except source No. 15, other source areas were small, and all of them had the characteristics of edge breakage and many internal pores. These patches not only played the role of providing habitat for species, but also played the role of connectivity to a certain extent. Therefore, it was necessary to strengthen the protection and construction of the edge broken zone and internal gap of the source area.

Analysis of Ecological Network Results

According to the land utilization type, elevation, slope and landscape type, the comprehensive resistance surface of Jinan City is constructed (Fig. 4). It can be found from Fig. 3 that high resistance areas were mainly concentrated in construction land. Obvious high resistance strips were formed from the central main urban area of Jinan City to Zhangqiu district and Laiwu district to Gangcheng district. There were also obvious high resistance patches in the urban centers of Shanghe County, Jiyang district and Pingyin County. There were many villages in the north, southwest and southeast of Jinan City, producing a large number of high resistance spots, and most of them were covered by cultivated land, forming ecological barriers, causing high ecological resistance. In addition, the high resistance patches had the characteristics of forming a line along the road, especially on the Beijing-Shanghai corridor in the west of Jinan. The southern mountainous area

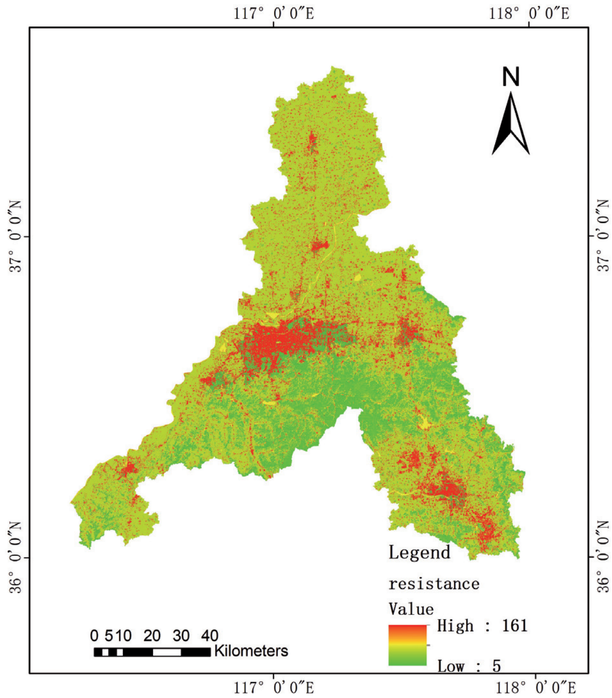

Fig. 4. Jinan comprehensive resistance surface.

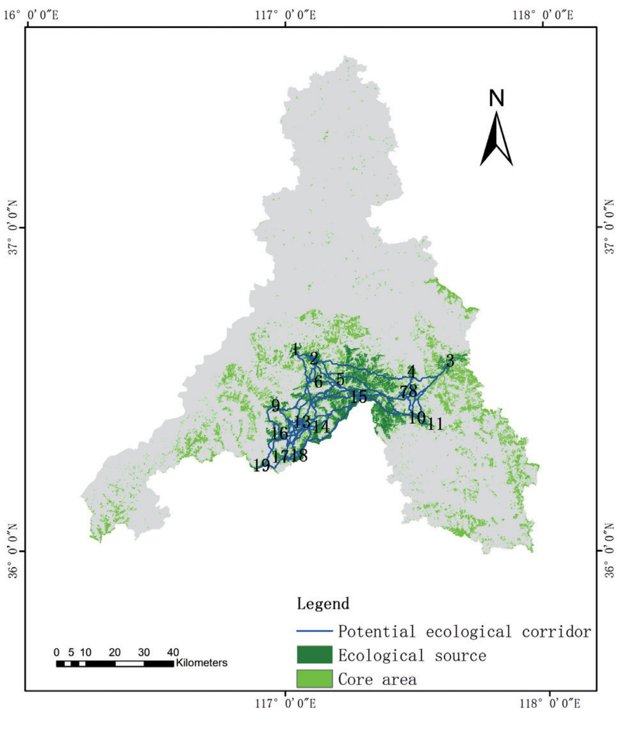

Fig. 5. Potential ecological corridor in Jinan City.

of Jinan City was mainly composed of woodland and grassland, which was rich in ecological resources and well protected, with less ecological resistance.

After the MCR analysis, 171 potential ecological corridors were obtained (Fig. 5), and their land use types were analyzed (Table 4).

Table 4. Land use composition of potential corridors.

Land Use Type	Area in the corridor (km^2)	Proportion of total corridor area (%)
Crop	2.35	11.34
Forest	15.65	75.42
Grass	1.66	7.99
Shrub	0.94	4.54
Wetland	0	0.00
Water	0.02	0.07
Impervious	0.07	0.34
Bareland	0.06	0.30
Total	20.75	100

The total length of potential ecological corridors was 679.92 km. The corridor width was set as 30 m, and the total area of potential corridors was 20.75 km^2, accounting for 0.2% of the total area of the study area; The area of green space in the corridor was about 18.25 km^2, accounting for 87.95% of the total area of the corridor, of which the source land accounted for the majority. In the ecological network, the cultivated land area was 2.35 km^2, accounting for 11.34%, which was relatively large in the network and had a certain hindrance to species migration, in the ecological network planning, we should pay attention to the protection when the corridor passed through the cultivated land; Impervious surfaces and bare land did not account for a large proportion of the network, about 0.74%. Impervious surfaces were mainly villages and roads, which would have a greater obstructive effect in the migration of species, and when planning corridors, villages and traffic corridors should be avoided as far as possible; The water area was relatively small, only 0.02 km^2, accounting for the 0.07% of the whole ecological network. Although a large area of water would play a hindering role in species migration, an appropriate water body could provide water for organisms and serve as a temporary habitat during migration. The network had too few water bodies, and attention should be paid to the protection of water sources near the corridor. Ecological corridors were distributed like a network between ecological sources, which not only greened the ecological gaps, but also made the scattered ecological patches form an organic and unified whole, laying the foundation for building an ecological network in Jinan.

According to the calculated results of gravity model (Table 5), 51 corridors with ecological force greater than 15 were taken as important corridors, and the remaining 120 corridors were taken as general corridors. Then, the redundant corridors with the same path were removed, and the stepping stone patches were planned at the important nodes, then we got the ecological network map of the study area (Fig. 6).

Table 5. Interaction Matrix Based on the Gravity Model.

Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		263.3	2.0	4.4	21.7	38.0	5.5	4.5	5.0	3.1	2.6	6.7	7.7	8.1	14.3	5.5	4.5	5.0	2.7
2			2.7	6.4	48.8	91.2	8.4	6.7	6.9	4.4	3.7	9.5	10.9	11.8	25.4	7.6	5.9	6.7	3.4
3				17.8	3.6	2.3	13.0	16.5	1.3	7.3	6.0	1.6	1.9	2.0	6.7	1.5	1.5	1.7	1.1
4					9.7	5.1	125.9	196.4	2.3	21.3	14.4	3.0	3.9	4.2	23.3	2.8	2.8	3.3	1.9
5						67.4	17.4	12.5	8.4	7.2	5.6	13.9	16.4	20.7	129.5	10.2	7.4	9.1	3.8
6							7.7	6.1	9.1	3.9	3.3	14.1	15.8	18.7	27.3	10.1	7.2	8.4	3.7
7								606.3	3.1	40.2	23.7	4.1	5.4	6.0	54.9	3.8	3.7	4.5	2.3
8									2.6	45.4	25.9	3.4	4.4	4.8	33.9	3.2	3.1	3.7	2.0
9										1.9	1.6	48.3	30.2	19.6	7.1	23.7	11.6	12.9	5.0
10											390.0	2.5	3.2	3.4	17.6	2.3	2.3	2.7	1.5
11												2.1	2.7	2.8	12.6	2.0	2.0	2.3	1.4
12													360.1	131.3	10.8	150.0	38.2	46.5	9.9
13														301.7	14.5	190.1	73.6	106.1	14.6
14															18.5	62.2	31.2	57.5	8.9
15																9.1	8.6	11.1	4.5
16																	75.1	73.9	16.3
17																		314.0	41.1
18																			22.9
19																			

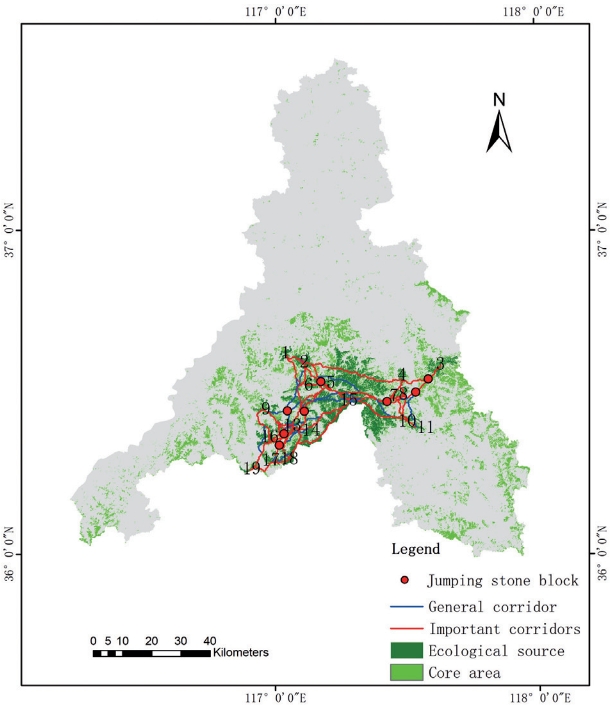

Fig. 6. Jinan ecological network.

As could be seen from Table 5, the values between source areas 7 and 8, 10 and 11, 12 and 13, 13 and 14, and 17 and 18 were the largest, all greater than 300, indicating that these source sites had strong interactions between the two, with frequent species exchange and material exchange, and the most important ecological corridors between them. The smaller values between some source sites, in addition to the large resistance surface between the two patches, were mostly caused by the distance between the source areas, for example, the G value between source sites 3 and 19 was only 1.10, and the distance between the two areas was so far that the possibility of organisms migrating to each other between source areas 3 and 19 was extremely low. Potential ecological corridors were graded according to the gravitational force value calculated by the gravity model, and corridors with gravitational force values greater than 15 were classified as important corridors, while others were classified as general corridors. Important corridors were the basis of interconnection between source patches and were the backbone of the whole network, which needed to be focused on. To the north of Mount Tai, there were many patches near the scenic spot of Lingyan Temple in Changqing and they were close to each other, with frequent biological exchanges. The important corridors here were as dense as a net. The important corridors in the northwest as well as in the northeast of the southern mountain area served as a pivotal function to connect source sites 1, 2 and 3 with source site 15, avoiding the isolation of the three ecological source sites outside the ecological network. The central part was the core ecological source site, and the edge of the source site had formed a good connection with other source sites, and the important corridors within the patch were relatively sparse. In addition, due to the large area and extremely irregular shape of source site 15 in the central core, there were many branches, for example, some source site 2, 4 and 18 were close to the branch part of source site 15, which could be used as both a corridor and a migration destination for source site 15. Although the G value between source site 2 and 4 and between source site 18 and 15 was small, they still had good connectivity and were set as important corridors and needed to be protected. General corridors mainly enhanced the connectivity between smaller patches and were an effective complement to the main corridors, which were more sparsely distributed between source sites.

In addition, some of the source sites were relatively isolated, and for some species with weak migration ability or long migration distance, they needed temporary habitats during migration, so stepping stone patches could be built in the non-source areas of the ecological corridor to reduce the spacing of temporary habitats and improve the migration success rate of organisms. According to the distribution of ecological source sites and green areas, eight stepping stone patches were planned at the intersection of the ecological corridor.

Limitations and Uncertainties

In the MSPA analysis, the image scale would have a large impact on the analysis results, and a larger scale would not only lead to the loss of small green space elements, which would have an impact on the division of the core area and other landscape land types, but also lead to the separation of green spaces that belong to the same patch or make the patches that were not connected stick together, which would seriously change the spatial location relationship and size of the core area, and then had an impact on the spatial structure of the ecological network [30]. In this study, the green space was severely fragmented, and considering that a larger scale would result in larger changes in green space landscape morphology and the loss of some small patches that play an important role in connectivity, a study scale of 10×10 was selected, and the scale issue of MSPA analysis needs to be further explored.

The width of the edge landscape needed to be set in the MSPA analysis, and the edge width not only represented the magnitude of the edge effect in the study area, but also had an impact on the core area, which may result in a series of changes in the landscape form such as core separation [31]. Edge effect was an important ecological concept, which was a buffer zone between the core area and the external environment and was important for ecological conservation [32]. However, the width of the edge effect varied depending on the topography of the study area, the magnitude of the vulnerability of green spaces to human disturbance, and the biological species. In this study, the edge width was set to one raster cell which is 10 m, which is not applicable for some specific populations.

When performing landscape connectivity analysis, a distance threshold and a connectivity probability needed to be set, and when the distance was greater than the threshold, it was considered that two patches were not connected to each other [33]. The distance threshold was related to the migratory capacity of organisms, however, different species tend to vary widely in their migratory capacity. In this study, the distance threshold was set at 2500 m and the connectivity probability was set at 0.5928 in infiltration theory, which was not set according to the specific conditions of the study area.

The construction of resistance surface was the key to calculating ecological corridors, but there was no unified standard for the selection of resistance elements and the size of resistance values, and the resistance surface in this paper incorporated the results of MSPA and considered the influence of landscape type on bio-migration, which had some scientific validity. In addition, the ecological network in this study was not specific to a particular species due to the lack of biological information.

Finally, when using the MCR model, it was necessary to convert the surface patches of the source area into points, which resulted in some large and irregularly shaped patches that could not better represent the original patch shape after the point was converted. Deviations in the spatial structure and relationship of, affected the construction of ecological corridors and the calculation of gravitational values in the gravity model. This issue needs further study.

Conclusions

Ecological networks can protect species habitats, improve the fragmentation of habitat patches and the difficulty of species migration, improve the connectivity between biological habitats, and protect ecological service functions. The coverage rate of green land in Jinan area was average and too concentrated. It was mainly distributed in the southern mountainous area, southern Changqing District and eastern Laiwu District. The fragmentation was severe, and the migration environment between some source areas was poor. This study could improve the above problems by constructing ecological sources and ecological corridors.

In this study, woodland, grassland, and shrubland were combined into greenfield as the research prospect, and the core landscape areas suitable for biological survival were extracted in the greenfield using the MSPA method, and the landscape connectivity analysis was used to analyze the importance of each extracted core area to maintain the overall connectivity based on three landscape indices, IIC, PC, and dPC, and to identify the patches that contribute significantly to the connectivity of the entire ecological network as ecological source sites. This method not only analyzed the structural characteristics of the green landscape, but also considered the connectivity role of ecological source sites in the whole ecological network, avoiding the artificial subjectivity of direct selection of forest parks or nature reserves in the previous ecological source site selection, making the selection of source sites more scientifically based and with certain research significance. In addition, based on the MCR model, the slope, MSPA landscape type, land use type and elevation factors were considered comprehensively, and the integrated resistance surface was constructed according to their degree of influence on bio-migration, and the path of least resistance for bio-migration was calculated to construct potential ecological corridors. Finally, based on the gravity model, the magnitude of mutual gravitational force between individual patches was calculated to evaluate the mutual importance of patches and distinguish important corridors from general corridors. This study organically combined MSPA, MCR model and gravity model, which could provide reference for the construction of ecological network in green-land fragmentation areas.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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