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Original Research

Construction and Analysis of Ecological Security Pattern of Qingdao Based on MSPA and MCR Models

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Abstract

Building an ecological security pattern is an important way to relieve ecological pressure and promote the harmonious development of human and ecosystem in the context of rapid urbanization. The article takes Qingdao, Shandong Province as the study area, and firstly identifies ecological sources by the Morphological Spatial Pattern Analysis (MSPA) method combined with the ecological red line of Qingdao City. Secondly, the potential ecological corridors are identified based on the Minimum Cumulative Resistance model (MCR) method, and the potential corridors are classified by gravity model. According to the research paradigm of "point- line- area", the ecological security pattern of "Four Zones, One Axis and One Belt" in Qingdao is constructed. The results show that the ecological security pattern of Qingdao consists of 22 ecological source areas, 128 ecological corridors and 16 stepping stones, with a total area of ecological source areas is 753.28 km^2, mainly forest land and water, showing a spatial distribution pattern of "clustering from north to South and East and connecting in the middle"; the overall ecological network is well connected, but the spatial span between the north and south ecological source areas is large, and the construction cost of the ecological network is high; forest land and water are the main landscape types of the ecological corridor, and forest land has the largest area, accounting for 34.02% of the total area of the ecological corridor; in addition, arable land, as the main land for living and production, is seriously disturbed by man, accounting for 27.30% of the total area of the ecological corridor. Therefore, we should strengthen the ecological corridor protection and avoid excessive human interference with ecological sources, ecological corridors and stepping stones. As an important ecological barrier along the southeast coast of Shandong Peninsula, Qingdao takes its whole elements of ecological land as the life community, fully considers the ecological functions of ecological source areas and the spatial structure of ecological networks, and constructs the

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ecological security pattern of Qingdao, in order to provide a scientific basis for ecological protection and high-quality development in Qingdao.

Keywords: morphological spatial pattern analysis, minimum cumulative resistance model, ecological network, ecological security pattern, Qingdao

Introduction

Rapid urbanization has promoted and enhanced the socio-economic level, while resulting in ecological problems of reduced regional ecological quality and increased habitat fragmentation. How to resolve the conflict between rapid urban development and ecological environmental protection has become a key issue. Ecological safety pattern aims to maintain ecological networks consisting of certain key ecological elements in ecological processes, and to explore the relationship between ecological processes and components of landscape structure from an ecological global perspective, which is significant for biodiversity conservation and ecosystem restoration [1]. The 18th National Congress of the Communist Party of China clearly pointed out that the construction of ecological security pattern as an important measure to maintain ecological civilization, and thus the ecological security pattern has been elevated to a national strategic height.

There are two different understandings of the concept of ecological security, one is broad and the other is narrow. The former is based on the definition proposed by the International Institute for Applied Systems Analysis (IASA) in 1989: ecological security refers to a state in which human life, health, well-being, basic rights, sources of life security, necessary resources, social order and human ability to adapt to environmental changes are not threatened, including natural ecological security, economic ecological security and social ecological security. It is a composite artificial ecological security system. Ecological security in a narrow sense refers to the security of natural and semi-natural ecosystems. That is, the overall level of ecosystem integrity and health is reflected in the security of the conditions (or ecological environment) on which human beings depend. In a certain sense, ecological security in a narrow sense refers to the state of environmental security and sustainability on which human beings depend [2]. The ecological safety pattern is based on the study of the entire ecological environment rather than individual elements, which is in line with the current general international perception of ecological safety in a broad sense. Thus, the study of ecological security patterns satisfies the theoretical discourse of ecological security research and ecological process development [3]. With the deepening of the research on the ecological security pattern by scholars at home and abroad, the research on the ecological security pattern is carried out from different angles, such as biodiversity [4], ecological protection red line [5], ecological service function [6], land use mode [7]. Among them, the construction mode of point (ecological source) - line (ecological corridor) - area (ecological network) has become a typical paradigm for the study of ecological security pattern [8]. Whether the ecological security pattern is reasonable or not based on ecological sources and building resistance surfaces. After years of continuous exploration by domestic and foreign researchers, in the pattern of ecological security, the identification of ecological source areas is mainly divided into the qualitative selection of natural places with better habitat quality and more suitable landscape, such as nature reserves and scenic spots, and the construction of comprehensive evaluation system, combined with the quantitative selection of ecological service value [9-11]. However, in the selecting process of traditional ecological source areas, the results are highly subjective, and the selection of indicators and the setting of weights vary from region to region, which is less adaptable. Therefore, some scholars have introduced the Morphological Spatial Pattern Analysis (MSPA), which takes landscape connectivity into account, to identify ecological source areas more scientifically. In terms of research methods for identifying ecological corridors, the minimum cumulative resistance model (MCR) is widely used because it can better respond to the effects of changes in landscape patterns on the evolution of ecological processes [12]. At present, the research on ecological safety pattern based on "point-line -area" theory mainly focuses on watershed, mountain range and other regional landscapes, for example, Wang Xueran [4] used "point-line-surface" research model based on MSPA and MCR model to construct the ecological safety pattern of Taihu Lake watershed. Zhu Zhenxiao [13] et al. used the Huanggang Mountain area in Wuyishan as the research object, extracted ecological source areas using a combination of qualitative and quantitative methods, identified ecological corridors using the minimum cumulative resistance model, and constructed a point-line-surface regional ecological security pattern. This paper breaks the regional research barriers and takes Qingdao, Shandong Province as the research object to provide theoretical supports for the analysis of urban ecological security pattern.

Located in the southeastern coast of Shandong Peninsula, Qingdao is not only the first national coastal open city, but also the national "Belt and Road Initiative" strategic pivot city. The superior geographical advantages and strong historical heritage not only bring many development opportunities to Qingdao, but also improve the requirements of Qingdao's infrastructure construction. In recent years, with the rapid expansion of the city and the continuous rise of urban building density, the degree of ecological fragmentation in Qingdao has gradually intensified, and the urban environment lacks systematic protection. In April 2018, the Qingdao Municipal Government released the Qingdao Urban Environment Master Plan (2016-2030), which aims to protect the living community of "mountains, rivers, forests, farmlands, seas, islands and bays" and improve the ecological environment, putting forward guiding and binding requirements for the long-term development and spatial pattern of Qingdao. The plan proposes to select ecological sources based on nature reserves, scenic spots, wetland parks and other natural places, and identify ecological corridors through landscape pattern analysis, which effectively promotes the construction of ecological civilization in Qingdao. The ecological sources selected by the plan can meet the basic requirements of ecological functions, but there is room for further improvement of their objectivity and scientificity. Therefore, this paper uses the MSPA analysis method considering landscape connectivity to identify the ecological source, uses the MCR model to identify the ecological corridor through the weight of the resistance surface, and constructs the ecological security pattern of Qingdao, so as to promote the high-quality development of social economy with the high-level ecological environment protection.

Material and Methods

Data Sources

The data of this study includes the Landsat Image of Qingdao in 2020 provided by the Geospatial Data Cloud (HTTPS: www.gscloud. CN), with a spatial resolution of 30m. In order to improve the reliability of image classification results, the time range is selected in August and September 2020 with good vegetation coverage, and the land use data of Qingdao in 2020 is extracted by using the classification method of random forest through eCognition software, After classification, the overall accuracy and kappa coefficient are more than 85% (Fig. 1); 30 m resolution digital elevation model (DEM) data and generate slope direction data through ArcGIS software. The ecological protection red line of Shandong province comes from the ecological protection department of Shandong Province from the ecological protection department of Shandong Province.

Research Methods

MSPA Analysis

Ecological source areas are relatively safe, stable or radiating habitat patches in the ecosystem, which are not only habitats for native species, but also source areas for ecological energy flow and provision of ecosystem services, as well as the basis for building ecological security patterns [14-15]. Combining with the current biodiversity situation in Qingdao, selecting national-level protected animals of Qingdao, namely the Oriental White Stork and the *Grus japonensis*, as indicator species. After considering their survival habits and habitats, three types of natural areas with higher ecological value and less effects by human activities, namely forest land, grassland and water area, are selected as the foreground for MSPA calculation, while the rest of the land types are the background. Using GuidosToolbox analysis software, the eight-

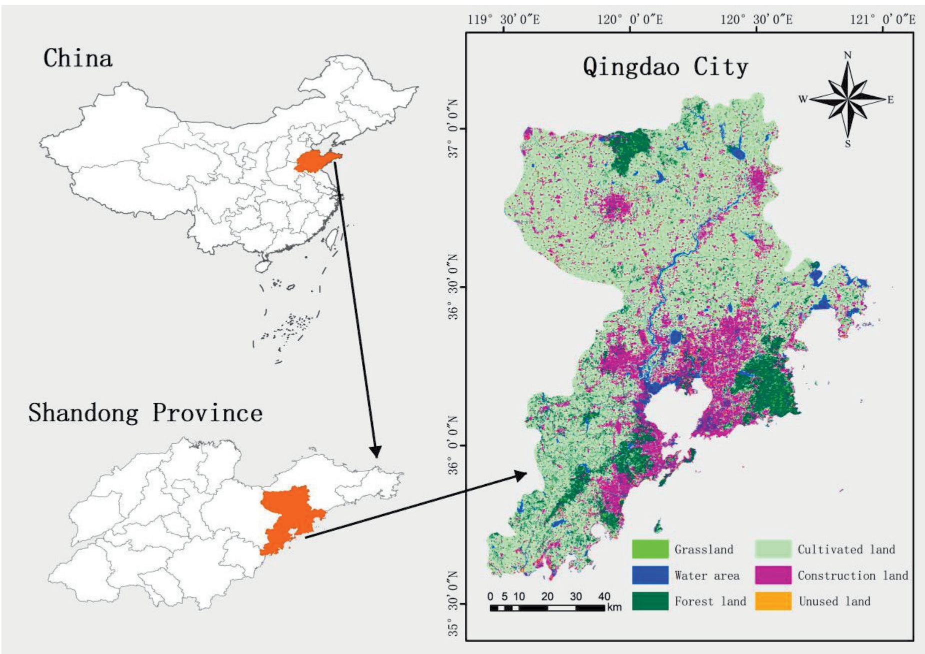

Fig.1. Location and land use of the study area.

Table 1. MSPA landscape types and their meanings.

Class	Meaning	Value [byte]
Core	Habitat patches with larger area, higher vegetation cover, higher ecological service value and perfect ecological function are generally used as ecological source areas in the ecological safety pattern.	17/117
Bridge	The ribbon area connecting the core areas plays a corridor role in the ecological security pattern and is an important landscape type for enhancing landscape connectivity.	33/133
Loop	The ecological corridor connecting the same core areas also serves as a channel for energy exchange within the core areas.	65/165
Branch	A linear landscape with only one end connected to bridging, loops, edges, and perforation.	1/101
Edge	The external boundary of the core areas protects the internal core areas from external interference and ensures normal energy flow and material exchange in the core areas.	3/103
Perforation	Marginal zones of inner core patches with edge effects.	5/105
Island	Small core areas with small patch size and poor connectivity.	9/109

neighborhood analysis method was used to convert the binary raster data of landuse type in Qingdao into seven landscape types with independent ecological values and no duplication of each other: core, bridge, loop, branch, edge, perforation and island (Table 1), and the core area with larger area was selected as the alternative patch of ecological source areas.

Landscape Connectivity Analysis

Landscape connectivity is a measure that describes how corridors or matrices in a landscape are connected or continued on the landscape [16]. It reflects the organic connection of landscape elements in spatial patterns or ecological processes [17]. As one of the main research elements in landscape ecology, landscape connectivity is important for species exchange between biological groups, material and energy exchange and migration between species elements [18-19]. The probability of connectivity (PC) is based on the probability model, which can fully consider the influencing factors between the probability of connectivity and the location of patches, and is widely used in the evaluation of landscape connectivity indexes. The patch importance index (dPC) is the index value of possible connectivity remaining after removing individual patches, and can be a good indicator of how much the landscape type facilitates or hinders the spread of ecological flows [20]. In this study, the probability of connectivity (PC) and the patch importance index (dPC) were selected as the landscape connectivity evaluation indexes, and their calculation formulae and meanings are as follows:

$$PC = \left(\sum_{x=1}^{n}\sum_{y=1}^{n} P_{xy} a_x a_y\right)/a_L^2 \qquad (1)$$

$$dPC = \frac{PC - PC_{remove}}{PC} \times 100\% \qquad (2)$$

Where: n represents the total number of core areas of forest lands, grasslands, and waters; a_x, a_y represent the area of core area x, core area y respectively, and a_L^2 represents the total area of core areas of forest lands, grasslands, and waters. (Equation 1) The probability of connectivity (PC) values between 0 and 1. The larger the *PC* value is, the better the landscape connectivity of the core area and the greater the connectivity potential becomes. The smaller the *PC* value is, the worse the landscape connectivity of the core area becomes; PC_{remove} indicates the landscape connectivity after removing a certain element in the study area, in which case a larger value shows a more important ecological source, and vice versa.

Resistance Surface Construction

Species need to overcome a certain resistance when flowing through different landscape units, and the higher the patch habitat suitability, the lower the landscape resistance [21]. Rational construction of integrated resistance surface is the basis for judging the reasonableness of ecological corridors generated according to ecological source areas [22]. The traditional landscape resistance surface construction only considers the land use type and the index level is single, so the constructed resistance surface is not enough to complete the accurate simulation of ecological resistance in the study area. This paper combines the natural geographic pattern and ecological environment elements of Qingdao city, and constructs a comprehensive resistance surface from three perspectives: natural environment, topography and landscape structure, based on land use type data, superimposed on MSPA landscape types, slope and DEM data. Referring to the existing research results and literature [23-25], weights were set and assigned to each resistance factor separately (Table 2).

Potential Corridor Extraction Based on MCR Model

Corridors in landscapes are zonal landscape elements distinct from both sides of the matrix [26].

Table 2. Resistance factor assignment.

Resistance Factor	Weight	Grading Index	Resistance Value
Land use types	0.2	Forest land	5
		Grassland	20
		Water area	20
		Cultivated land	100
		Construction land	100
		Unused land	500
MSPA landscape type	0.3	Core	5
		Bridge	10
		Loop	30
		Branch	40
		Island	50
		Edge	60
		Perforation	70
		Background	100
DEM	0.15	$h<200$	5
		$200\leq h<400$	10
		$400\leq h<600$	20
		$600\leq h<800$	30
		$800\leq h<1000$	50
Slope	0.35	$\alpha<5^{\circ}$	5
		$6^{\circ}\leq\alpha<15^{\circ}$	10
		$16^{\circ}\leq\alpha<25^{\circ}$	20
		$26^{\circ}\leq\alpha<35^{\circ}$	40
		$36^{\circ}\leq\alpha<45^{\circ}$	80
		$\alpha\leq45^{\circ}$	100

The ecological corridor in the ecological security pattern is the channel connecting the minimum resistance in the ecological source areas and the easiest passway for species exchange and energy flow, which can provide a channel for the activities of organisms in different habitats [27]. The minimum cumulative resistance (MCR) model can comprehensively consider the topography, geomorphology, environment and other influencing factors in the study area. It was first introduced by Yu Kongjian in China, and has been widely used in ecological corridor extraction by scholars at home and abroad in recent years [28–29]. The key to the application of the minimum cumulative resistance model is to set the landscape resistance surface. The smaller the resistance value is, the easier the ecological flow is, and the larger the resistance value is, the more difficult the ecological flow is, so as to determine the strength of connectivity [30]. MCR formula is as follows:

$$MCR = f_{min}\sum_{j=n}^{i=m}\left(D_{ij}\times R_i\right) \tag{3}$$

Where: *MCR* is the minimum cumulative resistance value from ecological source to other points; D_{ij} is the spatial distance from source j to space i; R_i is the resistance coefficient of spatial unit i.

The Cost-Distance tool in ArcGIS software is used to generate cost distance grid and cost back link grid based on ecological source areas and MCR model, and Cost-Path tool is used to generate the minimum cost path between each source areas.

Important Ecological Corridor Extraction Based on Gravity Model

Gravity Model is a mathematical formula used to quantify the degree of interaction between different elements in space. In the study of ecological network, gravity model is widely used to evaluate the importance of ecological sources by introducing the cumulative resistance value and migration distance to express the degree of habitat patches [30]. The stronger the interactive gravity is, the more important the potential ecological corridor is. The formula is as follows:

$$G_{\mathrm{ab}} = \frac{N_a N_b}{D_{ab}^2} = \frac{L_{max}^{2\,ln(S_a)\,ln(S_b)}}{L_{ab}^2 P_a P_b} \quad (4)$$

In the formula, G_{ab} is interactive gravity, N_a and N_b are quantitative weight values, D_{ab} is ecological corridor resistance value, L_{max} is the maximum cumulative resistance value, S_a and S_b are patch area, L_{ab} is patch cumulative resistance value, P_a and P_b are single patch resistance value.

Ecological Network Evaluation

Network circuitry (α), line point rate (β), network connectivity (γ) and cost ratio (c) are used to evaluate the connectivity of ecological networks based on graph theory and network analysis, and the complexity of ecological networks is interpreted from the structure, with the following equation:

$$\alpha = \frac{l-v+1}{2v-5} \quad (5)$$

$$\beta = \frac{l}{v} \quad (6)$$

$$\gamma = \frac{l}{l_{max}} = \frac{l}{3v-2} \quad (7)$$

$$c = 1 - \frac{l}{d} \quad (8)$$

In the formula: l is the number of ecological corridors; v is the number of ecological nodes; d is the total length of ecological corridor;

Between [0,1], value α is used to describe the maximum number of loops in an ecological network. The larger the value and the more loops are, the more frequent the material circulation and energy flow are; β is used to describe the degree of connection between ecological corridors and ecological nodes; β<1 indicates that the network is a tree-like structure, β = 1 indicates that it is a single-loop structure, and β>1 indicates that it is a complex network. γ is the ratio of the number of corridors in the ecological network to the maximum number of possible loops, used to describe the degree of connectivity between ecological nodes. c represents the income-expenditure relationship of ecological network construction. The smaller the value is, the smaller the cost of ecological network construction is.

Results and Discussion

Landscape Pattern Analysis Based on MSPA

MSPA analysis was conducted with Qingdao's forest land, grassland and water area as foreground and its other land types as background, then seven landscape types with different ecological significance were obtained. The area and proportion of each landscape type are counted. The total area of landscape elements based on MSPA is 1921.499 km^2, among which the core area is 1349.026 km^2, accounting for 70.05% of the total area. The landscape type is mainly forest land and water, followed by grassland. The core area is mainly located in the southern coastal area of Qingdao, with large habitat patches including Laoshan Mountain in Laoshan District and Chengyang District, Dazhu Mountain and Xiaozhu Mountain in Huangdao District, and the Tiejue Mountain; the northern core area is mainly located in Daze Mountain in Pingdu City, Yinfu Reservoir, Huangtong Reservoir, and Chanzhi Reservoir and Beishu Reservoir in Laixi City. The eastern core area is dominated by the Dingzi Bay wetland. Secondly, the central Dagu River important water connotation area becomes a strip running through the north and south sides of Qingdao city, radiating the ecological condition of Jiaozhou, Chengyang, Jimo, Pingdu and Laixi. The overall layout of the core area of Qingdao is concentrated on the north, south and east sides, and the central part is striped through. The eastern core area has very few and severely fragmented patches, reflecting the poor landscape connectivity and high resistance to species exchange and energy flow in the eastern part of Qingdao. The edge area is the outer edge landscape of the core area, which can protect the inner core area from external disturbance. In addition to the core area, the edge is the second largest landscape type in the MSPA results, with an area of 369.305 km^2, accounting for 19.22% of the total landscape area, indicating that the core area of Qingdao is relatively scattered and irregular in shape, mainly due to the central and southwestern parts of Qingdao are mostly small core patches and high fragmentation. As the channel connecting the core area, bridge area is an important landscape of ecological network, accounting for 2.30% of the total landscape area. Isolated islands are independent landscape patches, which are far away from other sources or landscapes with low connectivity, accounting for 0.79 % of the total landscape area. Perforation is other landscape types inside the core area that are different from the core landscape, In this study, they are mainly degraded green landscapes, accounting for 1.02% of the total landscape area. The larger the areas of perforation are, the more serious the core area is damaged by human; branch is the transition area between the core area and non-green landscape. The total landscape area is 114.982 km^2, accounting for 5.98% of the foreground

Table 3. Area and proportion of different landscape elements in Qingdao.

Landscape type	Area (km^2)	Percentage of foregrounds
Core	1346.026	70.05%
Island	15.228	0.79%
Perforation	19.697	1.02%
Edge	369.305	19.22%
Loop	11.973	0.62%
Bridge	44.288	2.30%
Branch	114.982	5.98%
Total	1921.499	100.00%

ratio. Large branch area indicates that the core areas are less connected to each other. Branch areas mainly concentrated in the coastal area of Jiaozhou Bay in the south of Qingdao. The excessive urbanization of the southern coast has hindered the urban ecological development process to a certain extent. Loop is channels for species to exchange energy and information within the core, accounting for 0.62% of the foreground.

Extraction and Analysis of Important Ecological Sources

Based on the "Red Line Atlas of Ecological Protection in Shandong Province" released by Shandong Ecological Protection Department in March 2021, the adjacent core area patches in the MSPA classification results were integrated and small broken patches were removed. On the basis of the formulas (1)-(2), Conefor 2.6 software was used to evaluate the landscape connectivity of the core area patches after organizing and integrating. In the results of the landscape connectivity evaluation, we found that the core area patches with dPC value below 0.8 are small in area and have poor landscape connectivity, most of which are close to the construction areas and are easily disturbed by human factors. Therefore, 22 core area patches with dPC values greater than 0.8 were selected as ecological source areas. As shown in Fig. 2, there

Table 4. Statistical table of important ecological source area.

Number	Name of ecological sources	dPC	Ecological source area/(km^2)
2	Laoshan Mountain (Laoshan District)	62.93934	259.8406
14	Laoshan Mountain (Jimo City)	15.83861	22.841
1	Xiaozhu Mountain	13.54098	87.697184
6	Daze Mountain	12.07374	120.459971
20	Tiejue Mountain	12.05093	61.1048
3	Sisheshan Mountain	7.512449	3.074
12	Dingzi Bay Wetland No.3	7.345552	16.4088
17	Wu Mountain	3.52005	8.68
11	Dingzi Bay Wetland No.2	3.063965	17.8868
18	Caochengshan Mountain	2.582893	4.512
22	Dazhu Mountain	2.481783	22.016
9	Dagu River	2.054415	32.108769
7	Huangtong Reservoir	1.908385	5.7148
5	Chanzhi Reservoir	1.479737	24.233597
4	Beishu Reservoir	1.451131	3.2828
10	Dingzi Bay Wetland No.1	1.365731	10.320056
21	Douyazi Reservoir	1.256145	6.7984
16	Jiaozhou Bay Wetland	1.201679	15.9788
19	Yumingzui Area	1.159591	3.9108
15	Jihongtan Reservoir	0.881611	14.1364
13	Dingzi Bay Wetland No.4	0.855191	5.594
8	Yinfu Reservoir	0.803724	6.6844

are important ecological source areas distributed in all districts and cities, except for Shinan District and Shibei District, which are major urban agglomerations with almost no important ecological source areas. The ecological source areas with better connectivity are mainly concentrated in Laoshan District and Huangdao District in the south of Qingdao, and in Pingdu City and Laixi City in the north. The Laoshan Mountain Group, mainly in Laoshan District, and the Tiejue Mountain, Dazhu Mountain and Xiaozhu Mountain Group in Huangdao District are important ecological greenland landscapes in Qingdao, with large patch areas and more concentrated distribution, which can meet the needs of species migration and energy exchange. At the same time, these sources are close to construction areas, which are severely disturbed by human activities and have a high degree of edge fragmentation, so it requires urgent protection. The central Dagu River basin and the Jihongtan Reservoir are important water connotation areas in Qingdao. The Dagu River basin has a strip-like structure and runs from north to south through almost the whole Qingdao city, which not only serves as an important ecological source, but also plays an important role as a corridor connection. The ecological source area in northern Qingdao is relatively far away. There are not only Daze Mountain as biodiversity conservation areas, but also Yinfu Reservoir and Chanzhi Reservoir as important water conservation areas, which greatly increase the types of biological habitats in northern Qingdao. In addition, the Dingzi Bay Wetland in eastern Qingdao has a wide water area, abundant wild endangered species and high plaque importance [31], which is an important ecological source areas in eastern Qingdao.

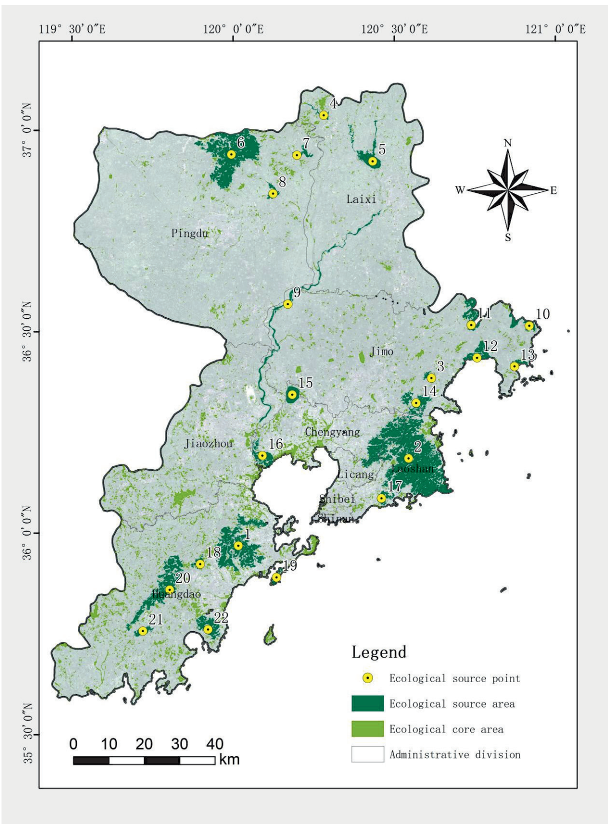

Fig. 2. Distribution of ecological sources in Qingdao.

Ecological Resistance Analysis

The reclassification tool in ArcGIS 10.5 software was used to obtain four single-factor resistance surfaces of land use type, MSPA landscape type, DEM, and slope, and the comprehensive weight overlay was calculated based on the coefficients of each resistance layer and the corresponding resistance values to obtain the comprehensive resistance surface of Qingdao city (Fig. 3). The integrated resistance value of the land area around Jiaozhou Bay is high, and the area with low resistance value is mainly concentrated in the southern part of Qingdao City, the northern part and the mudflat waters around and Dingzi Bay in the eastern part of Qingdao. Among them, Laoshan District and Huangdao District in the south of Qingdao are rich in forest lands and wetlands and have low overall resistance, but they are close to the central city of Qingdao and are strongly disturbed by human factors, showing a cliff-like decline from high to low along the perimeter of Jiaozhou Bay. In addition, the land type in central Qingdao is mainly cropland and construction land as the main land for living and production, the overall resistance is high.

Analysis of Ecological Network Construction in Qingdao

Based on ArcGIS 10.2, using the cost distance tool and the MCR model to generate cost distance and cost back links, the minimum cumulative resistance path between 22 ecological source areas was generated using cost path simulation. The generated corridors were combined and de-duplicated to obtain 128 potential ecological corridors with a total length of 841.63 km, and a total of 53 ecological nodes were selected as ecological corridor intersections. The interaction matrix between ecological sources was generated based on the gravity model, with higher values indicating stronger species linkages and more frequent energy flow between the two source areas [32]. As shown in Table 5, it can be seen that the strongest interactions between ecological source areas 18 and 20 and 1 and 18 are as high as 3362.2 and 923.5, respectively indicating that the ecological resistance between this patch is low and suitable for species migration, and the ecological source areas distributed along this corridor have a positive effect on species habitat. Therefore, sources above can be considered to have the key protection to maintain the stability and integrity of the ecological spatial pattern of Qingdao. The gravity value between No. 2 and No. 4, No. 2 and No. 6 of the ecological sources is only 0.8, which is small, indicating that the landscape resistance of this ecological source is large, which is

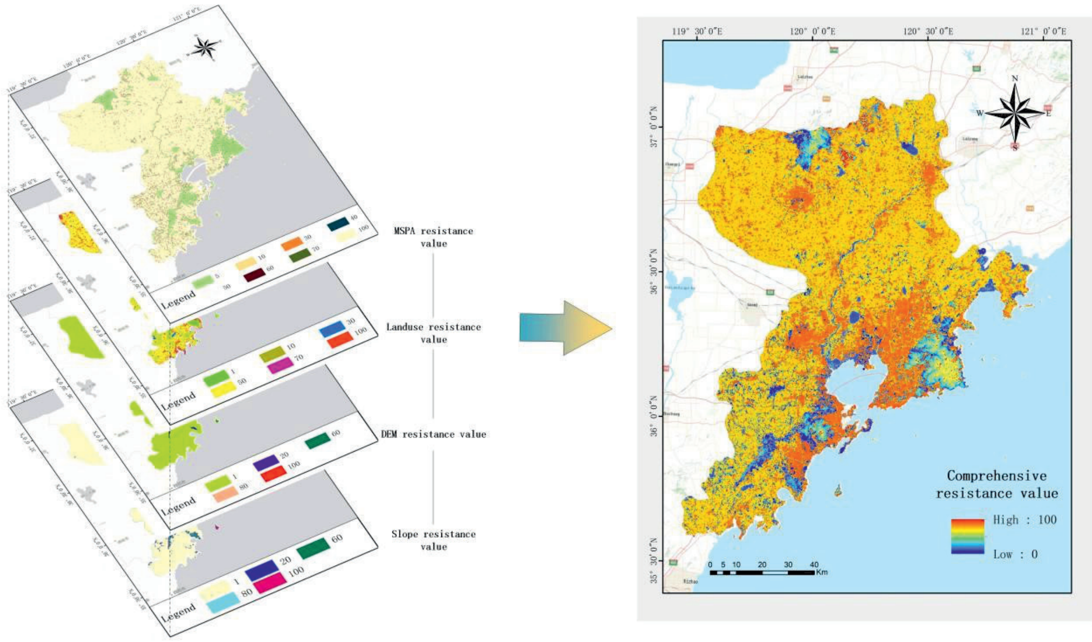

Fig. 3. Comprehensive ecological resistance surface of the study area.

not conducive to the information exchange and energy flow between the two sources. It is necessary to further strengthen the ecological construction between the two sources. In addition, the overall interaction between source 8, source 13, source 17 and other ecological sources is not strong. Therefore, in the construction of ecological security pattern, consideration should be given to strengthen the channel connection between this source and other sources by adding “stepping stones”, thus increasing the suitability of species habitat. According to the interactions between patches, those with gravitational values >150 are classified as primary ecological corridor, with a total of 42 corridors of 208.78km in length; those with 50<gravitational values <150 are classified as secondary ecological corridor, with a total of 32 corridors of 231.47km in length, and the rest are classified as tertiary ecological corridors (Figure 4).

The ecological corridor calculated by cost path tool and MCR model is a linear ecological corridor without width, but in fact, the width of the corridor has an important impact on the full play of ecological functions. Based on the research results of previous scholars, the currently recognized width of ecological corridor is between 10 and 1200 meters. This paper selects nine scales of 10 m, 30 m, 60 m, 100 m, 200 m, 400 m, 600 m, 900 m and 1200 m to calculate the proportion of each land use type in the ecological corridors. Table 6 shows that with the increase of corridor width, the proportion of forest land, grassland and water area, which are the main landscape types of ecological sources, increases first and then decreases, while the proportion of cultivated land and construction land decreases first and then increases. The proportion of forest land, grassland and water area reaches the highest when the width of the corridor is 100 m. In order to avoid excessive human interference with the ecological corridor as much as possible, the proportion of cultivated land, construction land and unused land, which are mainly used as production and living land, should be controlled to the lowest, so within 100 meters is the suitable width of the ecological corridor in Qingdao. Summarizing the threshold selection of corridor width by previous scholars and combining with the habitat types of native organisms in Qingdao, the widths of primary, secondary and tertiary ecological corridor were set to 80m, 70m and 60m in order [33-34]. Primary and secondary ecological corridors have strong interactions and are important channels for species migration and energy circulation, which are valuable for maintaining the stability of urban ecosystems. Figure 4 shows that the primary ecological corridors are mainly distributed in the south, southeast and east of Qingdao, but due to the uneven distribution of landscape resistance, the connectivity of the primary ecological corridor is poor, so the primary ecological corridor and the ecological sources of coastal distribution should be protected. The secondary ecological corridors are mainly distributed in the northern, eastern and central regions of Qingdao. The secondary corridor is concentrated in Pingdu City and Laixi City, connecting Daze Mountain Group, Yinfu Reservoir, Huangtong Reservoir and Beishu Reservoir, which is an important part of the ecological barrier in northern Qingdao; the central part connects the Jihongtan Reservoir and Dagu River water conservation area, which is an important part of the north-south ecological protection axis in Qingdao; the eastern

Table 5. Interaction forces between ecological sources.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	-	5.9	3.8	1.7	4.5	1.9	3.0	4.0	15.6	2.9	4.7	5.3	3.4	9.2	31.3	105.3	6.1	923.5	122.0	365.1	98.5	77.3
2		-	21.9	0.8	1.9	0.8	1.3	1.7	4.7	5.5	11.4	17.0	7.5	123.3	15.2	14.9	68.7	7.2	6.8	6.1	4.7	3.9
3			-	0.9	2.2	0.9	1.4	1.8	4.1	9.6	25.2	51.4	15.2	148.2	8.9	8.1	15.9	4.7	4.9	4.1	3.3	2.8
4				-	76.4	11.2	70.6	17.1	5.5	1.1	1.9	1.5	1.1	1.4	3.7	2.8	0.9	2.2	2.7	2.0	1.8	1.5
5					-	12.3	58.0	19.9	19.6	2.6	4.7	3.7	2.6	3.5	10.3	7.8	2.1	5.7	6.6	5.1	4.4	3.7
6						-	49.8	62.3	6.0	1.1	1.9	1.5	1.1	1.5	4.0	3.0	1.0	2.4	2.9	2.2	1.9	1.6
7							-	95.0	10.7	1.7	3.0	2.4	1.7	2.3	6.5	4.9	1.5	3.8	4.6	3.4	3.0	2.5
8								-	18.2	2.1	3.8	3.0	2.1	3.0	9.3	7.0	1.9	5.1	5.9	4.6	3.9	3.3
9									-	3.7	8.1	6.0	3.9	7.5	59.9	45.4	5.0	18.7	16.3	15.6	11.5	9.5
10										-	62.7	61.3	91.0	14.1	5.8	4.9	5.4	3.7	4.5	3.4	2.9	2.5
11											-	418.4	76.5	33.9	9.7	8.4	10.5	5.9	6.8	5.3	4.5	3.8
12												-	172.8	56.5	10.0	8.3	11.2	4.8	5.1	3.9	3.1	2.4
13													-	21.1	6.9	5.9	7.1	4.3	5.0	3.8	3.3	2.8
14														-	23.1	22.2	64.9	11.3	10.9	9.7	7.5	6.3
15															-	122.0	15.1	36.6	28.5	29.7	20.5	17.0
16																-	14.4	106.7	49.7	74.4	39.2	31.8
17																	-	7.5	7.3	6.4	5.0	4.2
18																		-	123.7	3362.2	283.4	214.5
19																			-	91.7	53.6	43.8
20																				-	529.3	274.1
21																					-	89.1
22																						-

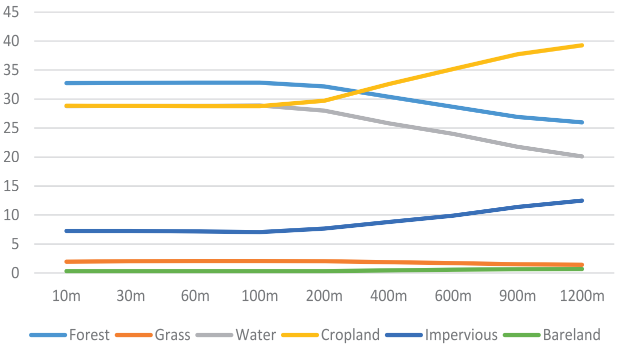

Fig. 4. Percentage of land-use types in different ecological corridor widths (%).

part connects four small isolated islands of Dingzi bay wetland to form the Dingzi bay wetland group, providing material carriers for aquatic birds to winter and migrate.

Forest land, grassland and water area can be used as buffer zones for ecological corridors. Rivers, waters and the surrounding green vegetation are the main components of ecological core areas and ecological corridor construction areas. Forest land is the largest landscape type in the ecological corridor, with a total area of 17.79 km^2, accounting for 34.02% of the total area; The area of grassland is 1.18 km^2, accounting for 2.03% of the total area of the corridor, and the total area of water area is 16.76 km^2, accounting for 28.80% of the total area of the corridor (Table 7). Planning ecological corridors with forest land, grassland and water area as the main landscape elements can greatly reduce construction costs. The cultivated land type, while satisfying the urban economic development, has a certain obstructive effect on the flow of ecological material and the exchange of species information. The total area of cultivated land in the ecological corridor is 15.89 km^2, accounting for 27.30% of the total area of the corridor. Therefore, adding stepping stones should be considered as a way to increase the overall connectivity of Qingdao's ecological network in the central-eastern part of the city, where cultivated lands are the main landscape type.

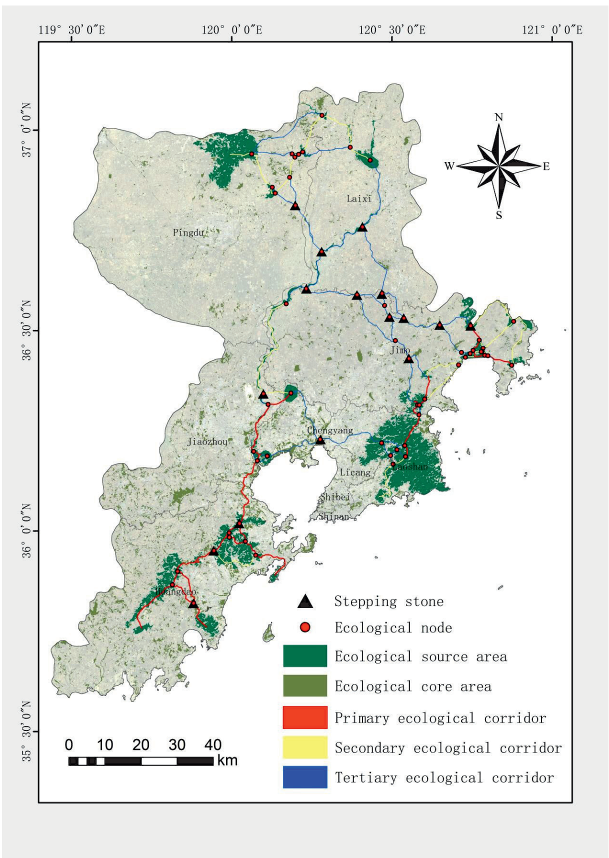

Fig. 5. Distribution of ecological corridors and nodes.

Stepping stones are temporary stopping stations for organisms during migration and movement. When the ecological corridor is too long, adding stepping stones can effectively promote the circulation rate of organisms in areas with high ecological resistance. Ecological nodes are "transfer stations" in the process of biological movement and are important for the integrity and connectivity of ecological networks. Combining the ecological red line and ecological core area distribution in Qingdao, 16 ecological nodes with high ecological value and less human interference were selected as stepping stones, 10 of which are located within the ecological red line of Qingdao and 4 in the ecological core area.

Ecological Network Evaluation

Based on network circuitry (α), line point rate (β), network connectivity (γ) and cost ratio (c), the rationality of ecological network is judged. α was 0.56, indicating that there are more circuits in the ecological network and a wider range of alternative channels for information exchange and energy exchange between species; β is 2.42, indicating that the ecological network in Qingdao is a complex network structure with good connectivity of ecological corridors; γ is 0.83, indicating that the ecological nodes are well connected. The value of c is 0.85, which indicates that the ecological network construction cost is high. In summary, the connectivity of ecological sources, ecological corridors and ecological nodes in Qingdao's ecological network is at a high level. However, due to the large spatial span of the study area, the central ecological corridor improves the landscape connectivity between the north and south ecological sources while also greatly increasing the construction cost of the ecological network. Therefore, in order to satisfy the ecological function and reduce the construction cost of ecological network at the same time, it is necessary to build the ecological security pattern of the city and plan its zoning according to the ecological condition of the city.

Table 6. Area and proportion of land use types in corridors at all levels
(A = area; P = proportion of area; PC = primary corridor; SC = secondary corridor; TC = tertiary corridor)

Corridor Type	Total/km²	Area Percentage	Forest		Grass		Water		Cropland		Impervious		Bareland	
			A (F)/km²	P (F/A)/%	A (G)/km²	P (G/A)/%	A (W)/km²	P W/A)/%	A (C)/km²	P (C/A)/%	A (I)/km²	P (I/A)/%	A (B)/km²	P (B/A)/%
PC	16.95	29.13	9.38	16.12	0.22	0.37	3.62	6.22	1.87	3.21	1.75	3.01	0.11	0.19
SC	16.33	28.07	4.28	7.36	0.48	0.83	6.10	10.49	4.40	7.56	1.03	1.78	0.03	0.06
TC	24.90	42.80	6.13	10.54	0.48	0.83	7.04	12.10	9.62	16.53	1.57	2.70	0.06	0.10
Total	58.18	100.00	19.79	34.02	1.18	2.03	16.76	28.80	15.89	27.30	4.36	7.49	0.20	0.35

Ecological Security Pattern Construction

By comparing the importance indices between ecological sources and the interaction forces between adjacent patches, we found that there are some differences in the overall ecological conditions in Qingdao. Among them, the southern and southeastern patches are larger in area and have stronger landscape connectivity, and the ecological sources are mostly mountain groups with biodiversity protection and reservoirs with important water conservation areas protection. In the meantime, as a national key seaside city, Qingdao's main urban area is distributed along Jiaozhou Bay, which has a great impact on the security and stability of the surrounding ecosystem. The northern part is dominated by mountains and reservoirs, giving full play to important ecological functions such as biodiversity protection, soil conservation and water containment. The eastern part is dominated by the Dingzi Bay wetland group, but the degree of fragmentation of the wetland landscape in Dingzi Bay has been exacerbated by the use of coastal polder farming and salt flats in recent years, and the ecological condition needs to be protected urgently [35]; The Dagu River, as the ecological corridor of the Jiaodong Peninsula, runs through the north and south, effectively driving the ecological construction of Qingdao's urban and rural integration and playing an important role in the overall ecological stability of Qingdao. In addition, in the territory of Laixi City and Jimo District, the tertiary ecological corridors are intertwined and nodes are dense, which is an important ecological corridor construction area.

On this basis, this paper proposes an ecological security construction strategy for Qingdao, in order to provide reference for its ecological pattern planning. Considering the location and ecological conditions, named Laoshan Ecological Control Area, Jiaonan Ecological Conservation Area, Dingzi Bay Ecological Restoration Area, The Northern Ecological Barrier Area, Dagu River Ecological Protection Axis, The Eastern Ecological Corridor Construction Belt "Four Zones, One Axis and One Belt" ecological protection pattern. (1) Laoshan Ecological Control Area. This zone has the highest important ecological sources in Qingdao, including the Laoshan Mountain Group, the Sishe Mountain, and the Wushan Mountain, with low ecological resistance and high habitat quality, mainly located in Laoshan District, Shinnan District, Shibei District, Licang District, and the southeastern part of Chengyang District. At the same time, these areas are also the intersection of densely populated areas and industrial influence in Qingdao. Therefore, we should adhere to the bottom line of ecological red line protection, strengthen the key control of this area, and repair damaged ecosystems such as broken mountains and soil erosion by combining natural restoration and artificial protection, avoid the erosion of ecological resistance and degradation of habitat quality due to the occupation of stepping stones and ecological corridors by urban construction. (2) Jiaonan Ecological Conservation Area. This area is mainly located in Huangdao District, and the ecological sources include Dazhu Mountain, Xiaozhu Mountain, Tiejue Mountain, Leichengshan Mountain, Yumingzui Area, and Douyazi Reservoir. These sources share the ecological functions of biodiversity, soil conservation and water conservation in the Jiaonan Ecological Conservation Area, and can effectively resolve the adverse effects of excessive development and industrial pollution on the ecosystem in the surrounding urban areas. Therefore, the ecological supervision should be increased to strictly prohibit excessive human interference with the ecosystem, to ensure the safety and stability of the biological living environment, and at the same time to open up the broken ecological patches in the urban area to form an ecological spatial pattern of urban-wild intermingling. (3) Dingzi Bay Ecological Restoration Zone. This zone is located in Dingzi Bay in the eastern part of Jimo District, which is defined as a gathering area of marine cultural tourism industry due to its unique geographical location and rich marine resources. Because of this, the original single wetland resources are gradually replaced by farming areas, tourist industrial parks, ditches and roads, resulting in higher ecological resistance in the area and increased fragmentation of the wetland landscape, which has a serious impact on the ecological function. Therefore, the development intensity of waterfront areas should be strictly controlled through measures such as returning ponds to beaches, demolishing ponds to the sea and river restoration, restoring isolated habitat patches, turning fragmentation into wholeness, and strengthening the spatial connectivity among ecological sources. (4) The Northern Ecological Barrier Area. This zone is mainly located in Pingdu City and the northern part of Laixi City. It includes Daze Mountain, Huangtong Reservoir, Yinfu Reservoir, Chanzhi Reservoir, Huangtong Reservoir and Beishu Reservoir, with rich landscape types and perfect ecological functions. Among them, the Daze Mountain Group is an important biodiversity reserve in the north of Qingdao and an important source of biological migration, but the peripheral forests of the Daze Mountain have less landscape and relatively poor connect with other sources, so the ecological landscape restoration project should be strengthened with the reconstruction of the surrounding green landscape mainly in the Daze Mountain and the restoration of cultured forests around the reservoirs. (5) Dagu River Ecological Protection Axis. Dagu River is the ecological axis and "green backbone" of Qingdao city, passing through five districts and cities of Laixi, Jimo, Pingdu, Jiaozhou and Chengyang, radiating and linking the ecological information exchange of other districts and cities. As the mother river of Qingdao city, Dagu River is also an important corridor for aquatic birds to migrate, while the green vegetation along the river provides a natural "shelter" for aquatic birds. Therefore,

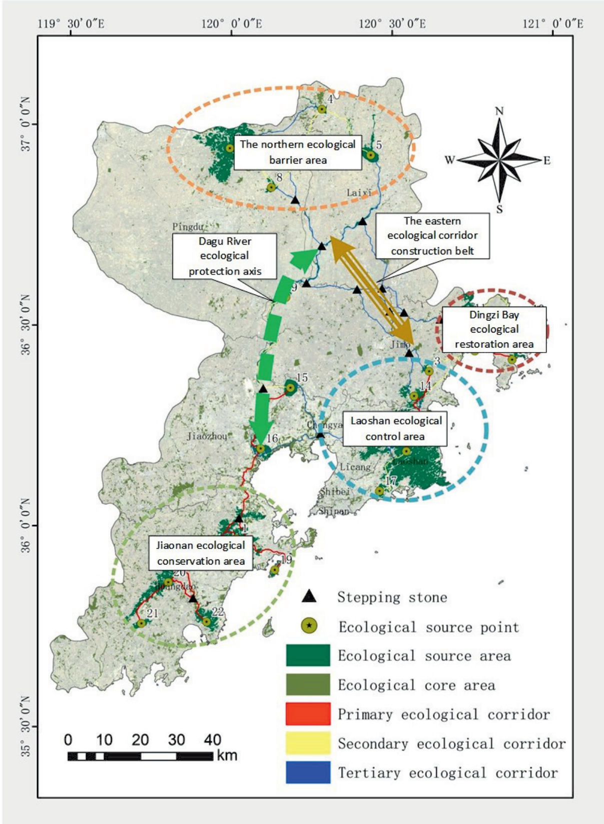

Fig. 6. Ecological security pattern of Qingdao.

based on the protection of the existing ecological red line, building ecological protection forests on both sides of the river should be strengthened. We should implement key protection to the Dagu River estuary, Jihongtan Reservoir and other coastal ecological sources, and give full play to biodiversity conservation and ecological services of important water-conservation areas. (6) The Eastern Ecological Corridor Construction Zone. Mainly located in the territory of Jimo and Laixi, the landscape type of this zone is mainly cropland with uniform ecological resistance, and it is also the high-density intersection area of the tertiary ecological corridor and stepping stones, the connection corridor between the northern ecological barrier area and the Laoshan ecological control area and the Dingzi Bay ecological restoration area. Therefore, without affecting the protection of permanent basic cropland, we should strengthen the construction of farmland forest network, broaden the area of forest and wetland landscape, strengthen the protection of ecological corridors, ensure the ecological stability of ecological corridors and stepping stones, and promote the exchange of information from north to south ecological sources.

Conclusions

This paper takes Qingdao, Shandong Province as the research object. From the perspective of landscape ecology, this paper aims to construct ecological security pattern and improve ecological suitability of Qingdao, so as to promote biodiversity conservation and stable development of the ecosystem in the study area, and provides scientific suggestions for ecological planning decisions and sustainable development of the city. The results of the study showed that:

(1) Eight-neighborhood analysis of forest land, grassland, and water area based on the MSPA method of morphospatial to obtain the ecological core area patches in Qingdao. And 22 ecological sources with high ecological value, including mountain groups, rivers, reservoirs, wetlands and other ecological landscape types, were identified based on the possibility of connectivity index PC and the patch importance index dPC, among which, Laoshan Biodiversity Reserve is the most important ecological source area. From the overall distribution, the ecological source areas with larger area and better connectivity are mainly concentrated in the north and south of the city. While the central Dagu River source area runs through from the north to the south, providing a central connecting corridor for biological migration.

(2) From 3 perspectives of natural environment, topography and geomorphology, and landscape structure, single factor assignment and comprehensive weight overlay calculation of MSPA landscape type, land use type, DEM and slope to obtain a comprehensive resistance surface that has a significant impact on biological migration. The area with higher ecological resistance in Qingdao is concentrated along the coast of Jiaozhou Bay, extending outward with higher habitat quality and less ecological resistance, which falls like a cliff.

(3) Based on the cost path and MCR model, 128 potential ecological corridors for biological migration are extracted, forest land and water are the main landscape types constituting ecological corridors. The area and proportion of land use types in corridors of different widths were analyzed, and the most suitable width of ecological corridors in Qingdao was finally determined within 100 m. Using the gravity model, the importance of potential ecological corridors was graded, and then the ecological network of Qingdao is constructed, and the connectivity and rationality of the ecological network are evaluated based on the network circuitry (α), line point rate (β), network connectivity (γ), and cost ratio (c). The results show that Qingdao has a good ecological network landscape connectivity but the construction cost is high, mainly due to the large spatial span of ecological sources in the north and south of Qingdao and the lack of large ecological source areas in the central of the city.

(4) Based on the spatial distribution characteristics of ecological sources and ecological corridors, the ecological security pattern of "Four Zones, One Axis and One Belt" in Qingdao is constructed, including Laoshan ecological control zone, Jiaonan ecological conservation zone, Dingzi Bay ecological restoration zone, northern ecological barrier zone, Dagu River ecological protection axis and eastern ecological corridor construction belt. On the basis of the ecological resistance distribution and ecological functions of each zone, the ecological security pattern control strategy is proposed.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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