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Provincial-Scale Research on the Eco-Security Structure in the Form of an Ecological Network of the Upper Yellow River: A Case Study of the Ningxia Hui Autonomous Region

Zhonghua Yang [1], Caihong Ma [1,*], Yuanyuan Liu [1], Honghong Zhao [1], Yuqi Hua [1], Shengya Ou [2,3] and Xin Fan [4,5]

[1] School of Geography and Planning, Ningxia University, Yinchuan 750021, China; yzhzxrs@163.com (Z.Y.); 12022130985@stu.nxu.edu.cn (Y.L.); z3536414804@163.com (H.Z.); 12020130785@stu.nxu.edu.cn (Y.H.)
[2] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 101408, China; oushengya22@mails.ucas.ac.cn
[3] State Key Laboratory of Remote Sensing Science, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100094, China
[4] School of Public Administration, China University of Geosciences, Wuhan 430074, China; fanfx8@cug.edu.cn
[5] Center for Turkmenistan Studies, China University of Geosciences, Wuhan 430074, China
* Correspondence: mchyanni@nxu.edu.cn

Abstract: Important for promoting the integrated protection and systematic management of mountains, rivers, forests, farmlands, lakes, grasslands, and sandy areas, ecological networks form the backbone of the regional ecological security pattern. An improved morphological spatial pattern analysis coupled with a minimum cumulative resistance model (MSPA–MCR) based on multi-source data was used to study, on a provincial scale, the ecological security pattern of Ningxia, an ecologically fragile region in the upper reaches of the Yellow River in China. The results show the following: (1) A reasonable classification of ecological sources and ecological corridors is key to constructing hierarchical ecological networks. Classifying ecological sources by replacing patch areas with energy factors and identifying the importance of ecological corridors by modifying the gravity model with the energy factors proposed in this paper could improve the rationality of the hierarchical structure division of ecological networks. (2) Grassland as the substrate vegetation type is an important ecological source type in arid and semi-arid ecologically fragile areas, and forests and lake wetlands are the main ecological source types in mountainous areas and oasis areas, respectively. The study area was located in the arid–semi-arid transitional area, with a variety of ecological types, such as mountain, oasis, and desert. Therefore, the complex ecological source types of forest–grassland–wetland appear in some areas. (3) There are 45 ecological patch groups that can be classified as ecological sources in Ningxia, including 10 primary source groups. The number of primary source groups is small, and their spatial distribution is unbalanced. There are two categories of ecological corridors, the river corridor and the mountain corridor, and the network connectivity is poor. (4) The ecological network structure of Ningxia is presented as an ecological security structure consisting of one belt, three screens, three corridors, and five clusters, forming a hierarchical nested ecological network security structure system.

Keywords: ecological security; ecological network; ecological source; energy factor; ecological corridor

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1. Introduction

With rapid urbanization and economic growth, ecological land is gradually being fragmented and encroached upon, and ecological corridors are being occupied by artificial channels or urban construction land, resulting in problems such as landscape fragmentation and loss of biodiversity [1–3]. The mountain–river–forest–field–lake–grass–sand complex is a community of life that coordinates various elements of the natural ecosystem. Systematic management is the core of the ecological protection and restoration of this complex [4]. An

ecological network is a landscape structure system composed of an ecological source, an ecological corridor, and an ecological node with efficient self-maintenance and functional restoration [5,6]. It will effectively connect fragmented habitats to form a complete and continuous landscape and biological habitat network, which can realize the flow of ecosystem material and energy and promote gene exchange and species migration [7,8]. A scientific and reasonable ecological network is considered to be an important way of solving the fragmentation of habitat patches, reduce ecological resistance, enhance ecosystem diversity, and build a regional ecological security pattern [9–11]. The study of the ecological security pattern based on the ecological network perspective has become a focus among scholars in landscape ecology, geography, territorial spatial planning, and other fields [12].

To construct an ecological network, a model has been created in which the ecological source is identified, an ecological resistance surface is constructed, the ecological corridor is extracted, and an ecological node is identified [13,14]. However, there is no consensus on how to identify the ecological source and the corridor. For example, when selecting ecological source areas, some scholars identify the land types of key areas such as nature reserves, forest parks, and scenic spots as ecological source areas [15–17]; some scholars identify ecological sources on the basis of the importance and sensitivity of ecosystem services [18–20]; and some scholars use the landscape pattern index to screen the source area [21,22]. Among various methods, the morphological spatial pattern analysis method (MSPA), proposed by Vogt et al. [23] and more widely used in the literature, is biased toward measurement and landscape structure [24–26]. To extract the potential ecological corridor, there are methods based on the minimum cumulative resistance (MCR) model [27–29]. For example, Yao et al. [30] extracted watershed ecological corridors using the MCR model. Some scholars extract the potential ecological corridor on the basis of the current theory. For example, Mao et al. [31] simulated the current theory of species' ecological activities and proposed potential ecological corridors, and Ni et al. [32] identified potential corridors according to the charge travel path. Among these, the combination of the MSPA ecological source identification method and the MCR model ecological corridor extraction method has been widely used. For example, Lei et al. [33] constructed the ecological network of Heyuan City, and Dai et al. [34] explored the construction of the ecological network of Central city. Some scholars believe that important source areas and important corridors form the regional ecological security framework and that the lower-ranking source areas and corridors are attached to the basic framework. Accordingly, the construction of a ecological security pattern based on the hierarchical ecological network is proposed [35–37], and multi-scale correlation has gradually become the core content of ecological security pattern construction [38]. Scholars have explored ecological networks on different scales, such as urban agglomeration [39,40], river basin [41,42], county [43,44], city [45,46], and province [47]. For example, Ye et al. [48] adopted the minimum resistance model to construct the ecological network security pattern of ecological resettlement areas. Zhang et al. [49] explored the ecological network security pattern of the green space in Guyuan City, and Zhou et al. [50] constructed and evaluated the ecological network of the Guangdong–Hong Kong–Macao Greater Bay Area. In summary, at present, the MSPA–MCR model is an important method for constructing the ecological network to study the ecological security pattern, but some aspects need to be improved in the research methods. First, in the classification of hierarchical ecological source areas, there are many studies based on the area size of source areas. According to the authors, due to factors such as the composition and vegetation coverage of ecological source areas, patch area is not adequate as a method of classifying ecological source areas. In addition, in terms of the division of ecological corridors according to importance, the commonly used method of calculating the gravity magnitude on the basis of the ecological patch area is also inadequate.

The Yellow River Basin is an important ecological barrier and an economically significant region in China. The Central Committee of the Communist Party of China and the State Council have issued the "Outline of the Ecological Protection and High-quality Development Plan of the Yellow River Basin", which proposes to build a spatial layout

of "one belt and five zones with multiple points" for ecological protection in the Yellow River Basin [51]. Ningxia is located in the ecologically fragile area of the upper reaches of the Yellow River. It is the intersection area of the key ecological area of the Yellow River and the northern sand prevention belt in China's ecological security strategy pattern and an important ecological node of the country. It stabilizes the monsoon boundary, connects the national climate pattern, regulates water vapor exchange, improves the local climate in the northwest, and blocks the eastward movement of sand and dust. The construction of a multi-level spatial ecological network can effectively improve the stability of the ecological security structure in the semi-arid region of Northwest China [36]. However, there are few studies on the ecological security pattern from the perspective of ecological network in this region. Accordingly, this paper introduces an energy factor model to improve the classification method of ecological source areas and revises the gravity model to improve the method of identifying the importance of ecological corridors, carries out a case study on Ningxia, and explores the construction of Ningxia's provincial scale "network driving surface" ecological security structure model suitable for arid and semi-arid regions. It can effectively help in the systematic management and comprehensive protection of the mountains, rivers, forests, fields, lakes, grassland, and sandy areas in the Yellow River Basin.

2. Methods and Data

2.1. Study Area

Ningxia is located in the middle and upper reaches of the Yellow River Basin, with a geographical location ranging from 104°17′~107°39′ E to 36°06′~37°50′ N and a total area of 66,400 km^2 (Figure 1). It is situated in the temperate arid and semi-arid desert climate zone, with an average annual precipitation of 180–367 mm. From north to south, the region comprises the Tengger Desert, the Yellow River and its adjacent alluvial plain, the central low hills and mountains, and the southern Loess Plateau. The main types of ecosystems in the region are desert ecosystems, river and wetland ecosystems, farmland ecosystems, desert grassland ecosystems, forest ecosystems, and urban ecosystems. As an important part of the northern sand control belt and the ecological barrier belt of the Loess Plateau in China's ecological security pattern, Ningxia plays a crucial role in ensuring the food production and security of the water resources in the Hetao Plain, maintaining the water environment and the aquatic ecosystem health of the Yellow River, and consolidating the ecological barrier in northern China. The ecologically sensitive and fragile areas and the area of desertified land account for about half of the national territory. The central arid zone is severely affected by surrounding desertification and insufficient rainfall, resulting in serious land desertification. In the southern loess hills and gully region, soil erosion is severe. The distinct characteristics and interwoven structure of the three major geographical units make it challenging to enhance ecological space protection. Ningxia has always been at the forefront of ecological protection and restoration in the Yellow River Basin, achieving significant results in sand control, vegetation restoration, and soil and water conservation. However, it still faces ecological environmental problems, such as desert expansion, vegetation degradation, water shortage, soil erosion, source pollution in irrigated areas, fragile ecosystems, and poor stability.

2.2. Data Source and Processing

The data sources used in this study are as follows: (1) The remote sensing image spatial resolution is 30 m, from the China Scientific Resources and Environmental Science Data Center (http://www.resdc.cn, accessed on 5 September 2022); road network data are from Open Street Map (https://www.openstreetmap.org/, accessed on 5 September 2022); the digital elevation model (DEM), NDVI, and NDWI data were obtained from the Geospatial data cloud (https://www.gscloud.cn/, accessed on 5 September 2022) (accuracy: 30 m), NDVI and NDWI data were calculated by remote sensing images; and watershed data were obtained from the HydroSHEDS (https://www.hydrosheds.org/, accessed on 5 September 2022). (2) Social and economic data are from the Statistics Bureau of Ningxia Hui

Autonomous Region; nature reserves and ecological red lines data were obtained from the Ningxia Department of Natural Resources; and administrative division data were obtained from the National Center for Basic Geographic Information (www.ngcc.cn/ngcc, accessed on 5 September 2022). (3) The land use data used in MSPA analysis were supervised and classified via support vector machine method into six categories: forest land, water, grassland, construction land, arable land, and unused land. The overall accuracy was 86.30%, and the Kappa coefficient was 0.9530. (4) The distribution map of biodiversity in Ningxia was obtained by vectorization based on the literature data, and the spatial distribution characteristics of biodiversity were summarized.

The data in this paper were resampled to a uniform 30 m × 30 m resolution and projected using ArcGIS 10.6 with a uniform projection of WGS_1984_UTM_Zone_48N.

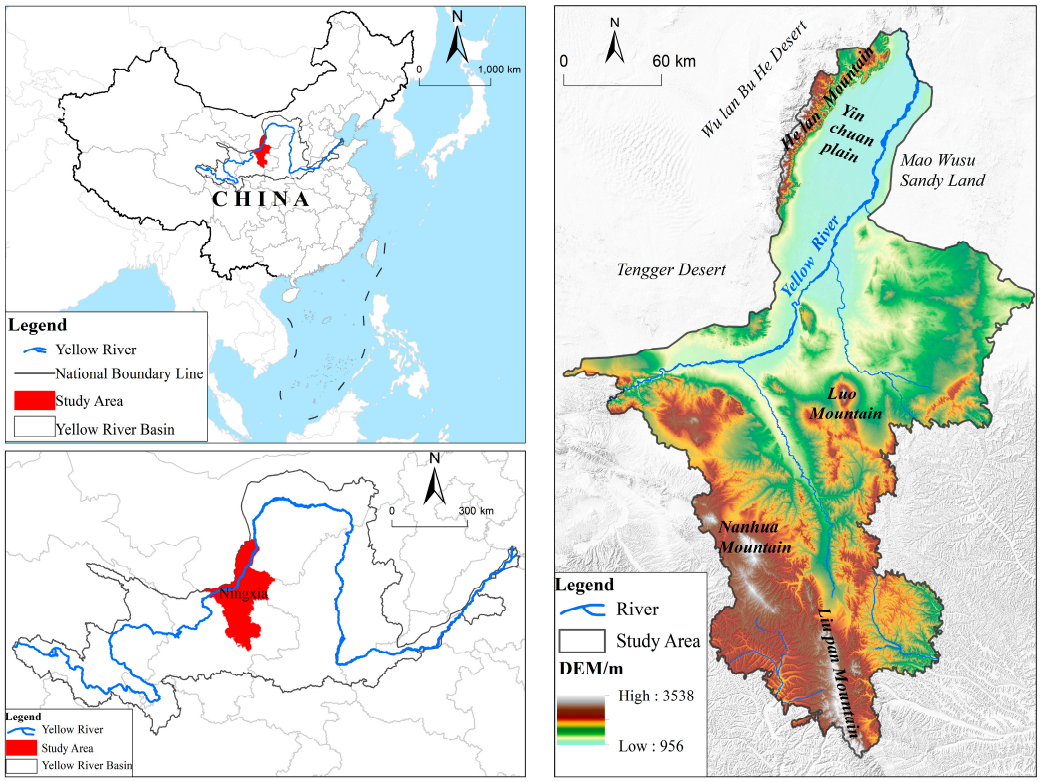


Figure 1. Scope of the study area (produced on the basis of the base map of the standard map with reference number GS (2019) 1822).

2.3. The MSPA–MCR Construction Method

The ecological network, based on the patch–corridor–matrix landscape ecology concept and with biodiversity conservation as its core goal, is a network structure composed of important points, lines, and landscape patches [52]. There are two types of ecological networks: species-oriented ecological networks and function-oriented networks. The former focuses on protecting target species, and the latter focuses on preserving or restoring natural and semi-natural habitats, connecting habitat fragments with large natural reserves and important natural patches to establish an organic and coherent ecological network pattern. In this study, the second type was adopted, and the ecological network construction and optimization were mainly based on the MSPA–MCR method (Figure 2).

This study is divided into three main steps: (1) identify ecological network elements, (2) construct a hierarchical ecological network, and (3) construct an ecological security pattern. To identify ecological network elements, the land use grid data is selected by MSPA, and then the landscape connectivity is evaluated according to the connectivity index to select the ecological source. Next, the multi-factor ecological resistance surface is constructed, and the potential ecological corridor is extracted using the minimum cumulative

resistance (MCR) model. To construct a hierarchical ecological network, the energy factor model and the modified gravity model are introduced to divide the source and corridor levels, respectively. To construct an ecological security pattern, the ecological network is optimized by constructing stepping stones and restoring ecological sources and fracture points. Finally, the ecological security spatial structure is proposed.

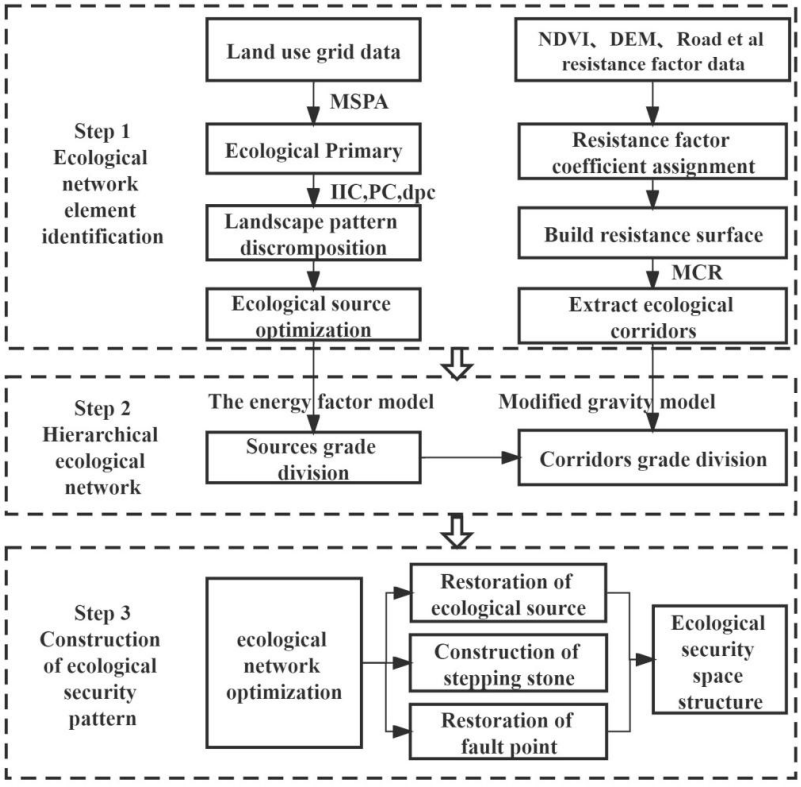


Figure 2. Flow chart of ecological network construction.

2.3.1. Optimization of Ecological Source Identification and Classification Method

The MSPA model [53] is based on principles of computer graphics and uses mathematical methods such as morphological opening and closing operations to recognize and segment raster images and calculate landscape patches at the pixel level [45], including the selection of core areas, connectivity analysis of potential source sites, and classification of ecological source site levels. With the support of Guidos ToolBox 2.8 software, potential ecological source sites are selected as foreground data and assigned a value of 2, while other land covers, as background data, are assigned a value of 1. Using an eight-neighborhood analysis method [54], the foreground land covers are divided into seven types of landscapes: core areas, isolated patches, gaps, edge areas, bridging areas, ring areas, and linear features [55]. According to the Guidos ToolBox [56] technical manual, core areas are a type of landscape associated with potential ecological source sites. The extraction of core areas is related to the selection of foreground land covers, which is closely related to biotic habitats. For Ningxia, located in the transition zone between desert and oasis, forests, grasslands, and water are the three major land covers that provide habitats suitable for forest biota, grassland biota, and aquatic biota and their transitional types. Therefore, forests, grasslands, and water are selected as foreground data and considered as optimal land covers for potential ecological source areas.

The landscape connectivity index is an important indicator for measuring the degree of regional-level connectivity between core patches [57,58]. It is of great significance in maintaining a regional ecosystem balance and can quantitatively characterize the ease of species migration or energy transfer for a certain landscape type. Commonly used

landscape connectivity indices include the patch importance index (*dPC*) and the overall connectivity index (*IIC*), and their formulas are as follows:

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij}^{*} a_i a_j}{A_L^2} \quad (1)$$

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

$$IIC = \left(\sum_{i=1}^{n}\sum_{j=1}^{n} \frac{a_i a_j}{1 + nl_{ij}}\right) / A_L^2 \quad (3)$$

where PC is the patch potential connectivity index; dPC is the patch importance index, with a larger value indicating stronger connectivity between patches; IIC is the integral connectivity index of the patch, with a value closer to 1 indicating better connectivity and a value closer to 0 indicating poorer connectivity; $i \neq j$; P_{ij}^{*} is the maximum product probability of the path between patches i and j; a_i and a_j are the areas of patches i and j, respectively; nl_{ij} is the number of connections between patches i and j; A_L is the total area of the foreground data; PC_{remove} is the connectivity index value of the remaining patches after removing patch i from the landscape; and n is the total number of foreground data patches.

Ecological sources have different ecological energies. The ecological energy mainly relates to the size and land cover type of the source area. This study used the normalized difference vegetation index (NDVI) and the normalized difference water index (NDWI) to calculate the energy value of ecological source sites [59]. To eliminate dimensional units, this study proposed the concept of standardized energy factors. The formula is as follows:

$$P_i = A_i N_{ir} \quad (4)$$

$$P_i' = \frac{P_i}{P_{\max}} \quad (5)$$

where P_i is the energy factor; P_i' is the standardized energy factor; A_i is the area of the i-th ecological source site patch; N_{ir} is the r-th normalized index of the i-th ecological source site patch; N_{i1} represents the vegetation index of the i-th patch; N_{i2} represents the water index of the i-th patch; the larger the value of P_i, the greater the ecological energy; and $P_{\max}$ is the maximum value in the energy factor.

2.3.2. Improvement of the Method of Extracting Potential Ecological Corridors

These tasks include calculating resistance surfaces, extracting potential ecological corridors, and identifying their importance.

The topography of Ningxia is mainly divided into mountains, plains, hills, and plateaus, with high elevations in the south and low in the north. Increasing slopes can affect surface runoff and greatly increase the possibility of soil erosion, causing changes in ecological suitability and ecosystem stability and increasing landscape resistance against species dispersal and energy flow. Though road construction contributes to socio-economic growth, it alters the distribution of natural landscapes, resulting in severe negative effects on natural landscapes and ecosystems. The normalized difference vegetation index (NDVI) reflects the degree of vegetation coverage, and MSPA landscape types with less human disturbance are closer to source characteristics. The result is less resistance to the movement and dispersal of species. Therefore, elevation, land use type, MSPA landscape pattern, road Euclidean distance, and NDVI were selected as resistance factors, and weight values were assigned on the basis of relevant studies [14,60]. The results are shown in Table 1.

Table 1. Resistance value system evaluation.

Resistance Factor	Classification Index	Resistance Value	Weight	Resistance Factor	Classification Index	Resistance Value	Weight
DEM (m)	<1200	10	0.1	NDVI	>0.6	10	0.1
	[1200, 1400)	30			[0.5, 0.6)	20	
	[1400, 1600)	50			[0.4, 0.5)	30	
	[1600, 1800)	80			[0.3, 0.4)	40	
	[1800, 2000)	100			[0.2, 0.3)	50	
	≥2000	150			<0.2	70	
Road distance (km)	<0.5	150	0.2	MSPA Landscape	Core	5	0.3
	[0.5, 1.5)	100			Bridge	10	
	[1.5, 3)	80			Loop	20	
	[3, 5)	50			Branch	30	
	[5, 7)	30			Islet	50	
	[7, 14)	20			Perforation	70	
	≥14	10			Edge	90	
					Background	200	
Land use	Forest land	10	0.3				
	Grass land	20					
	Water Area	30					
	Arable Land	60					
	Unused Land	80					
	Construction Land	150					

The minimal cumulative resistance (MCR) model is used to extract potential ecological corridors. The model represents the minimum cumulative distance that ecological flow needs to overcome from one ecological source to another [22]. Importance is calculated using an improved gravity model. The gravity model, also known as the attraction model, indicates that the larger the mutual attraction force, the higher the importance of the ecological corridor, and vice versa. The calculation [61–63] is usually based on the source patch area. However, due to the complexity of the source structure, the results based solely on the area calculation may be biased. Therefore, this study modified the gravity model [64] on the basis of the energy factor. The formulas are as follows:

$$V_{MCR} = f_{\min} \sum_{j=n}^{i=m} (D_{ij} \times R_i) \tag{6}$$

$$F = G_{ij} = \frac{P_i' P_j'}{{R_{ij}}^2} = \frac{\frac{P_i}{P_{\max}} \times \frac{P_j}{P_{\max}}}{\left(\frac{L_{ij}}{L_{\max}}\right)^2} \tag{7}$$

In the formulas, V_{MCR} is the minimal cumulative resistance; $f_{\min}$ is a function between MCR and D_{ij} and R_i; D_{ij} is the Manhattan distance from ecological source j to i; R_i represents the resistance value of species crossing the landscape surface i; G_{ij} represents the mutual interaction force between ecological source patches i and j; P_i, P_j represents the energy factor of the ecological source i, j; P_i and P_j are the energy factors of ecological source patches i and j; $P_{\max}$ is the maximum value of the energy factor; R_{ij} represents the resistance value of potential ecological corridors between patches i and j; L_{ij} represents the cumulative resistance value of potential ecological corridors between patches i and j; and $L_{\max}$ represents the maximum cumulative resistance value of potential corridors between source patches.

2.3.3. Evaluation of Ecological Network Connectivity

The network closure degree (α index), the line–node ratio (β index), and the connectivity index (γ index) are evaluation indicators [65,66]. The α index represents the ratio of the actual number of circuits to the maximum possible number of circuits in the ecological network, reflecting the degree of closure of the network. The β index represents the ratio of ecological corridor to ecological node, which reflects the nature of the ecological network structure. The value range is between 0 and 3, and the higher the value, the higher the degree of complex network in the region. The γ index is used to represent the ratio between the actual number of connected corridors and the maximum possible number of corridors in the network, reflecting the degree to which nodes in the network are connected. The formulas are as follows:

$$\alpha = (L - V + 1)/(2V - 5) \quad (8)$$

$$\beta = L/V \quad (9)$$

$$\gamma = L/3(V - 2) \quad (10)$$

In the formulas, L represents the number of corridors in the network and V represents the number of abstract ecological nodes in the network. A takes a value between 0 and 1, where α = 0 when there is no loop in the network, and α = 1 when the maximum number of loops is reached in the network. When β = 0, the network does not exist, and the greater the value of β above 1, the stronger the complexity of the network. When there are only isolated points in the network, γ is 0. Conversely, when nodes are fully interconnected in the network, γ is 1.

3. Results and Analysis

3.1. Identification Results and Distribution Characteristics of Ecological Source Areas

3.1.1. Landscape Pattern Characteristics and Structural Proportions

Landscapes of forests, water bodies, and grasslands were selected as foreground data for analysis, and landscape patterns were generated (Table 2): the core area covered an area of 145.03 $\times$ 10^4 hm^2, accounting for 21.83% of the total area of Ningxia; the islet covered an area of 13.79 $\times$ 10^4 hm^2, accounting for 2.07% of the total area; the perforation covered an area of 10.84 $\times$ 10^4 hm^2, accounting for 1.63% of the total area; the edge area was a buffer zone for landscape elements, covering an area of 41.05 $\times$ 10^4 hm^2, accounting for 6.18% of the total area; the bridging area was a structural corridor between source areas, covering an area of 52.14 $\times$ 10^4 hm^2, accounting for 7.85% of the total area; and the loop and the branch were conducive to species migration, energy exchange, and material flow, covering 1.89% and 0.05% of the total area, respectively.

Table 2. MSPA of different landscape types and their area distribution.

Landscape Type	Area/$\times 10^4$ hm^2	Percentage of Landscape Area/%	Percentage of Research Area/%
Core	145.03	35.58	21.83
Islet	13.79	3.38	2.07
Perforation	10.84	2.66	1.63
Edge	41.05	10.07	6.18
Bridge	52.14	12.79	7.85
Loop	12.62	3.10	1.89
Branch	0.34	0.08	0.05
Background	131.84	32.34	19.85
Total	407.64	100.00	61.35

Using Conefor 2.6 software [67], a distance threshold of 5000 m was set on the basis of multiple simulations, and the core area *dPC* and *IIC* were calculated according to a

connection probability of 0.5. The maximum value of *dPC* was 46.01, and the minimum value was 0.01. The cumulative contribution rate of the core patch importance (*dPC*) index was analyzed. The core patch with a cumulative contribution rate greater than 80%, that is, a *dPC* value greater than 0.3, was selected as the ecological source, some small fragmented patches were removed to eliminate the impact of fragmented patches on ecological network construction, and the ecological red line was superimposed. Finally, 45 patches with *dPC* > 0.3 were selected as ecological sources. In consideration of actual conditions, some fragmented patches were removed to eliminate their influence on ecological network construction. Finally, 45 patches with *dPC* > 0.3 were selected as source areas, with a total area of 1.00×10^6 hm^2, accounting for 15.06% of the total area of Ningxia. Grassland and forest land were the main land types in the source areas, followed by water areas. Grassland covered an area of 52.33×10^4 hm^2, accounting for 50.67% of the total source area, while the proportions of forest land and water bodies were relatively small, totaling 26.87% of the total source area (Figure 3).

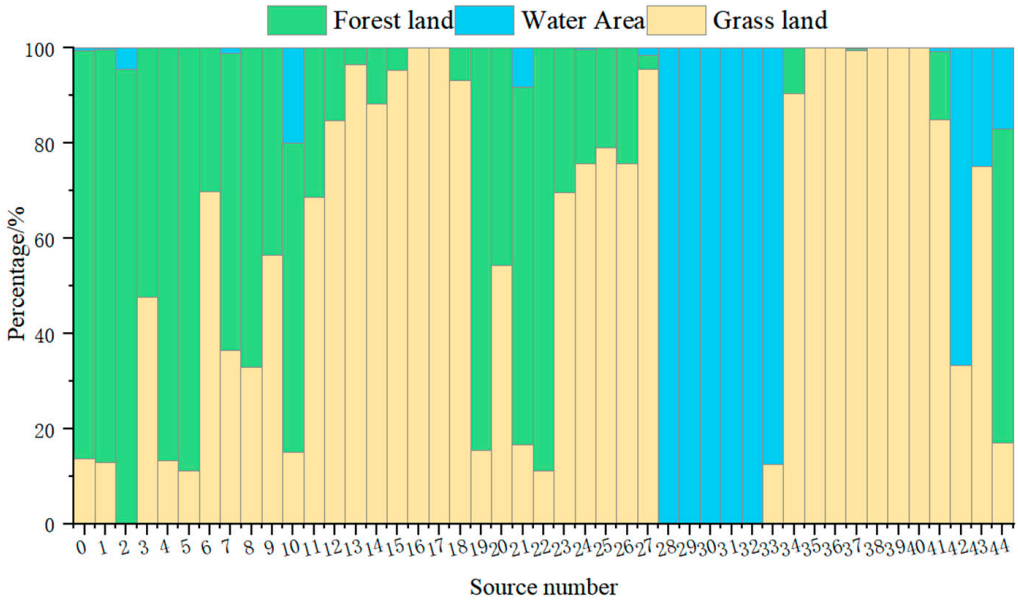


Figure 3. Proportions of ecological sources.

3.1.2. Spatial Pattern Characteristics of Ecological Source Areas

Because ecological source areas are different in terms of area and component structure, there are significant differences in energy values. Source areas 0 and 26 are, respectively, the Liupan Mountain and Helan Mountain national nature reserves, which are important ecological protection barriers and therefore have high energy factors. The energy factors of the remaining source areas are all below 0.6, with many important nature reserves located between 0.1 and 0.6 and river–lake wetlands below 0.1 (Table 3).

For a reasonable and comprehensive source area classification, the multi-factor effects were considered in the study area, and the source areas were classified according to the energy factor size. The MSPA and spatial distribution characteristics of ecological source areas are shown in Figure 4. (The 45 selected source areas are numbered, and the corresponding regional names and ecological group types of the source areas are shown in Appendix A).

Table 3. Area and proportion of landscape elements in important ecological sources.

Source Number	Area/ hm^2	Percentage/ %	Standard Energy	Number	Area/ hm^2	Percentage/ %	Standard Energy	Number	Area/ hm^2	Percentage/ %	Standard Energy
0	69,845.4	6.94	1	15	5706.39	0.57	0.02	30	3531.74	0.35	0.03
1	49,079.5	4.88	0.47	16	4755.7	0.47	0.02	31	1618.35	0.16	0.02
2	5474.71	0.54	0.07	17	6816.79	0.68	0.03	32	1430.94	0.14	0.01
3	13,945.1	1.39	0.09	18	18,369.3	1.83	0.07	33	1987.73	0.2	0
4	3759.48	0.37	0.03	19	2863.09	0.28	0.04	34	6764.97	0.67	0.02
5	1899.48	0.19	0.02	20	2396.59	0.24	0.02	35	16,051.2	1.6	0.05
6	22,054.7	2.19	0.09	21	2381.54	0.24	0.02	36	6249.35	0.62	0.02
7	24,646.3	2.45	0.19	22	2929.73	0.29	0.02	37	62,416.7	6.2	0.19
8	45,322.3	4.51	0.42	23	61,164.3	6.08	0.24	38	15,020.1	1.49	0.05
9	31,121.1	3.09	0.22	24	53,766.2	5.34	0.22	39	11,362.6	1.13	0.03
10	10,121.9	1.01	0.07	25	60,512.2	6.02	0.27	40	9568.94	0.95	0.03
11	7465.77	0.74	0.03	26	233,578	23.22	0.7	41	73,084.2	7.27	0.28
12	3986.6	0.4	0.01	27	132,25.4	1.31	0.05	42	1120.28	0.11	0.01
13	6616.75	0.66	0.03	28	3708.38	0.37	0.02	43	8847.84	0.88	0.05
14	4373.74	0.43	0.02	29	3300.15	0.33	0.03	44	11,703	1.16	0.2

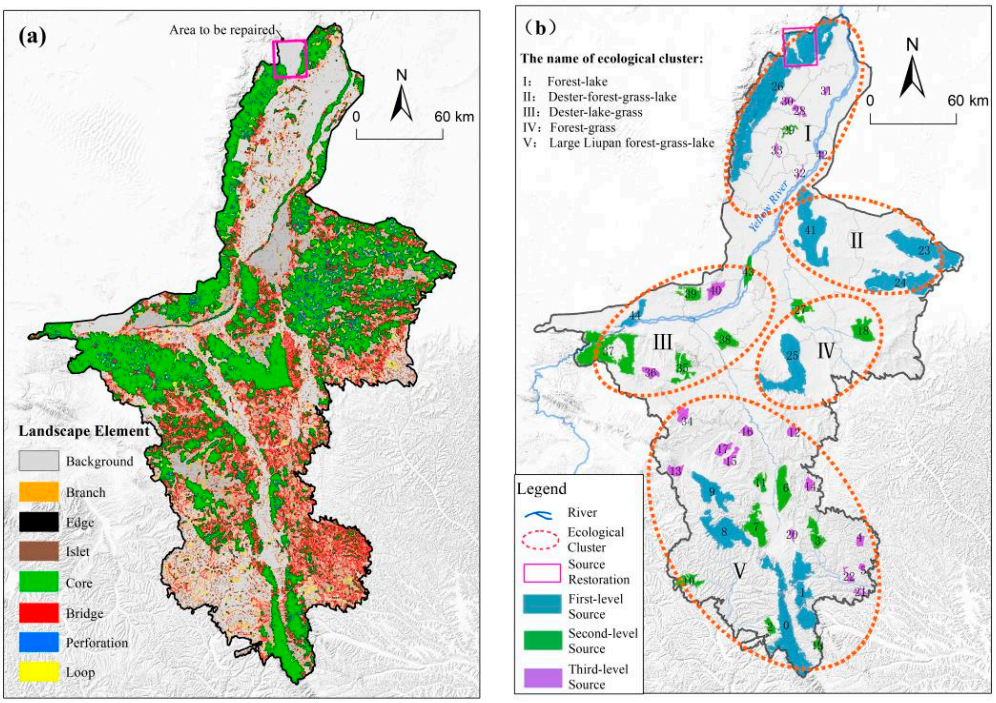


Figure 4. (**a**) MSPA landscape spatial pattern; (**b**) Ecological source space group in Ningxia Hui Autonomous Region.

The source areas were classified into three levels based on the standard energy value. Of these, 10 source areas with values between 0.20 and 1.0 were classified as first-level source areas (The Liupan Mountain and Haba Lake Nature reserves contain two first-level sources, respectively) that covered eight national nature reserves: the Liupan Mountains, Huoshizhai, the Luo Mountain, the Helan Mountains, Baijitan, the Nanhua Mountains, Shapotou, and Haba Lake. In addition, 15 source areas with values between 0.03 and 0.19 were classified as second-level source areas, covering four national nature reserves: the Dangjiacha Zhenhu Lake Nature Reserve, the Tianhu National Wetland Park, the Qingtongxia Reservoir Wetland, and the Yunwu Mountains National Nature Reserve. The remaining 20 source areas were classified as third-level source areas, including the Sha Lake, the Yuehai National Wetland Park, and the Xiangshan National Grassland Nature Park (ecological sources 30, 33, and 36, respectively). Among them, the Helan Mountains, The Luo Mountain, the Liupan Mountains, the Baijitan Nature Reserve, and the Shapotou Nature Reserve, which were all first-level ecological sources, constituted the key areas

of the ecological sources. Each first-level ecological source formed an ecological source cluster with surrounding second-level and third-level ecological sources. In northern Ningxia, the Helan Mountain Nature Reserve and many lake–wetland ecological sources in the Yinchuan Plain formed a forest–lake-type ecological cluster. In central Ningxia, a forest–grass-type ecological cluster was formed with theLuo Mountain as the core. In southern Ningxia, a large Liupan forest–grass–lake ecological cluster was formed with the Liupan Mountain Nature Reserve as the axis. In the western wing, a desert system–lake–grass-type ecological cluster was formed with Shapotou National Nature Reserve as the core. In the eastern wing, a desert ecological system–forest–grass–lake ecological cluster was formed with the coupling of the Baijitan National Nature Reserve and the Haba Lake Nature Reserve. Overall, the ecological sources in Ningxia present a spatial distribution pattern where forest ecosystems dominate in the northern and southern mountainous areas, desert and grassland ecosystems dominate in the eastern and western wings, and plain and lake–wetland systems dominate in between. This has formed a complex ecological cluster source area system with a forest ecosystem as the main body, coupled with grassland and lake–wetland ecosystems.

3.1.3. Analysis of Spatial Matching between Ecological Source Areas and Key Biodiversity Areas

Key biodiversity areas are the priority areas for ecological conservation proposed by the IUCN and widely recognized by the international community [68]. On the basis of our literature review, the distribution of biodiversity in Ningxia is summarized as follows (Figure 5): In the northern region, the main habitats are the Helan Mountains and river–lake wetlands, with a dominant animal population of temperate semi-desert animals and lake–beach–desert–residential animals, while the distribution of fish in the surrounding river–lake wetlands forms a composite aquatic–terrestrial–air biological community, which is consistent with the characteristics of surrounding ecological sources. In the central and eastern and western wings, the main habitats are the Baijitan National Nature Reserve, the Luo Mountain, and the Shapotou National Natural Reserve, which are characterized by temperate semi-desert animals and bird populations such as swans and geese, forming a biodiversity distribution pattern dominated by desert system grassland ecological clusters. In the southern water conservation area, the distribution of temperate mountainous forest–forest grassland animal populations is mainly concentrated in the Liupan Mountains and surrounding wetlands, where large raptors, such as golden eagles and eagles, and important fish populations are widely and densely distributed, and the biological composition is diverse, forming a large Liupan forest–grass–lake ecological cluster. The Yellow River and Qingshui River Basins in Ningxia have a wide variety and dense distribution of fish species, forming a river system dominated by the Yellow River. They have both corridor functions and aquatic biological source functions in the ecological space of Ningxia, effectively improving regional connectivity. In this article, they are classified as water corridors. Overall, the biological communities in Ningxia mainly inhabit ecological sources and the differences in environmental characteristics have created diverse and localized biodiversity communities that are characteristic of the region. The selected ecological sources cover important ecosystems, such as forests, grasslands, deserts, and wetlands, and cover key areas of biodiversity distribution in the region. Building an ecological network based on these areas will protect the vast majority of rare and endangered species and their habitats, effectively promoting regional biological exchange and biodiversity conservation and thus promoting sustainable development. The spatial distribution structure is characterized by "multi-type, high-aggregation and wide distribution".

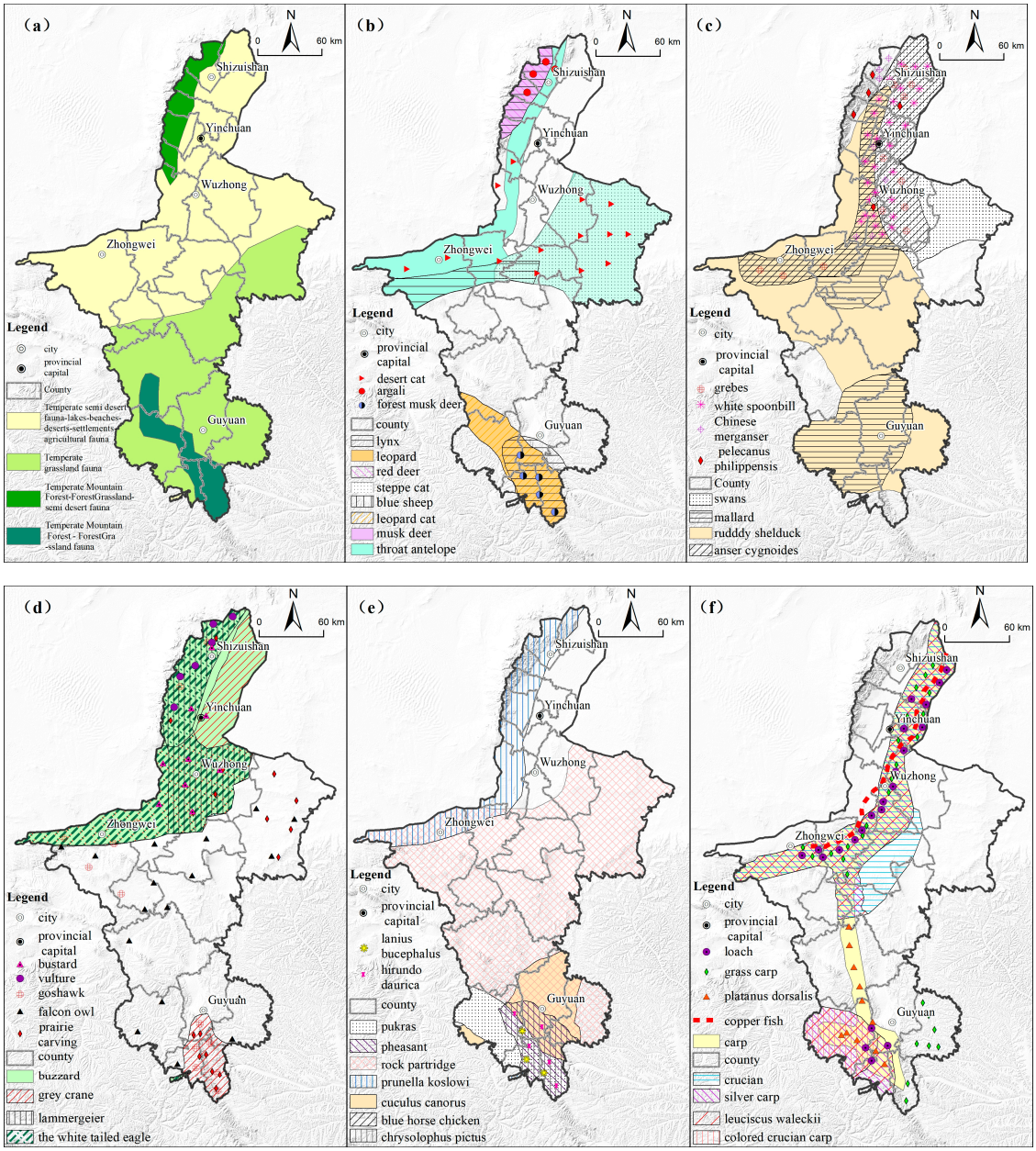


Figure 5. The biodiversity distribution map of Ningxia Hui Autonomous Region: (**a**) zoo geographical division; (**b**) beasts; (**c**) birds (1); (**d**) birds (2); (**e**) birds (3); (**f**) fish.

3.2. Identification Results and Characteristics Analysis of Potential Ecological Corridors

3.2.1. Characteristics of Resistance Surfaces

There is significant spatial differentiation in resistance surfaces in Ningxia (Figure 6). Spatial distribution according to the elevation resistance surface mainly shows a south–north direction and the resistance value gradually decreases from the southern mountainous area to the north. The low-value areas are mainly located in the Yinchuan Plain. The ecological resistance values based on the land-use-type resistance surface are generally low in most forest, grassland, and water distribution areas, while the central urban area and the desert area have higher resistance values. The median values are mainly distributed in the surrounding areas of arable land and the Yellow River Economic Belt. As per the morphological spatial pattern analysis (MSPA) landscape pattern resistance surface, the core area and the bridging area extracted with forests, grasslands, and water areas as the background values are potential sources and ecological corridors with low resistance.

Conversely, urbanized areas and desert regions have relatively less forest, grassland, and water content and higher resistance values. As per the NDVI resistance surface, the low-value area is mainly distributed in the southern mountainous areas of Ningxia and the surrounding areas along the Yellow River Economic Belt, while the medium–high-value area is mainly distributed in the western and eastern regions with sparse vegetation coverage. The roads are arranged in a dense and staggered network. As per the road resistance surface, the high-value area is mainly distributed in the areas where the road network is dense along the Yellow River Economic Belt and in the southern mountainous areas. In the central region, the important ecological functional areas are located far away from the roads, and the main distribution is in the medium–low-value area. As per the comprehensive resistance surface of Ningxia, the ecological resistance value increases from the central region to the north and south. The low-value area is mainly distributed in the central region and the important ecological functional areas, while the areas around the Yellow River Economic Belt are mainly in the medium-value area. The high-value area is mainly distributed in the central urban area and the desert region.

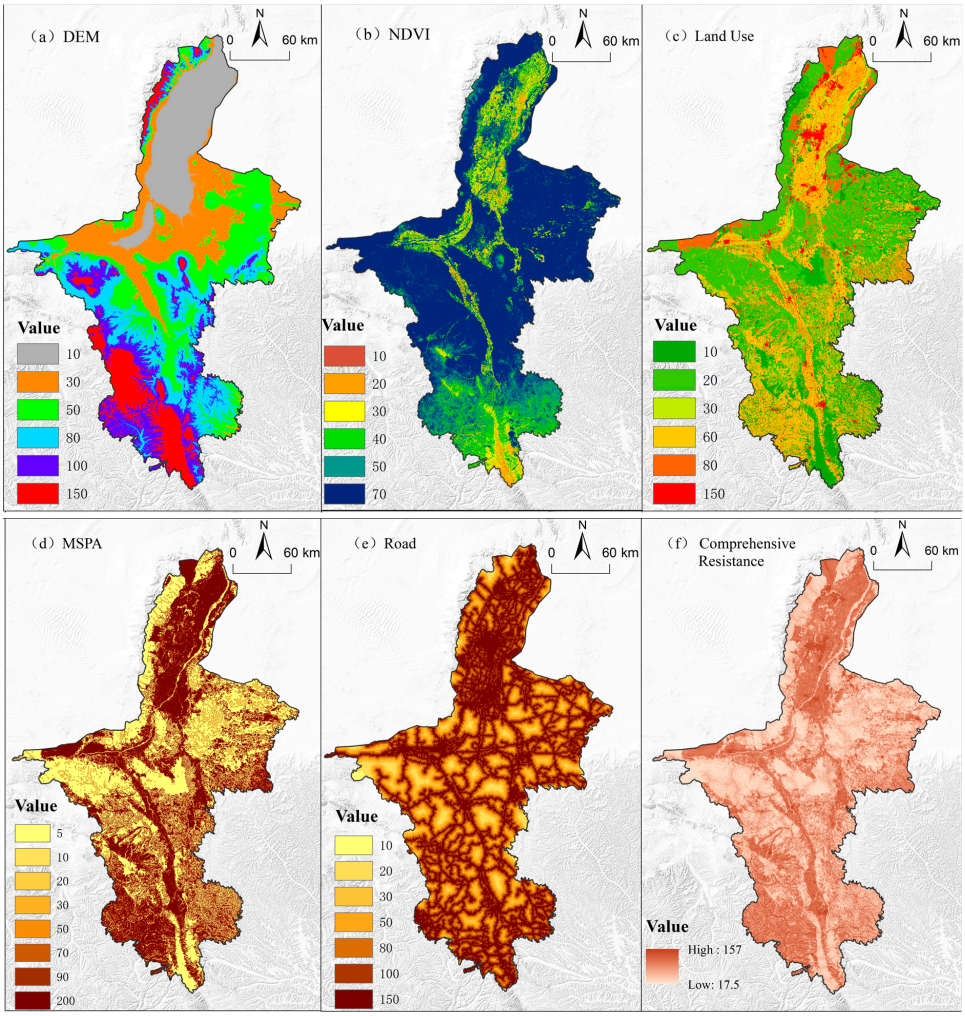


Figure 6. Resistance surface.

3.2.2. Extraction and Grading of Potential Ecological Corridors

A total of 990 potential ecological corridors were generated by MCR calculation. Due to the large north–south span, complex source types, and a large range of gravitational values in Ningxia, the redundant interleaved corridors between adjacent source areas were removed from north to south, and 101 corridors were finally selected according to the principle of priority of gravitational values and priority of species migration to adjacent

source areas. The ecological corridors were graded using an improved gravity model, with the maximum gravity value being 127.07 and the minimum value being 0.01. Due to the large range, a cumulative contribution rate analysis was conducted on 88 corridors with gravity values less than 2 to divide them into second-level and third-level ecological corridors. The analysis results set 60% as the boundary value. Since corridors in the top 60% in terms of the cumulative contribution rate were more important than others, they were classified as second-level corridors, while the rest were third-level corridors. Finally, corridors with gravity values $F > 2$ (13 in all) were selected as first-level corridors; corridors with $0.8 < F < 2$ (18 in all) were classified as second-level corridors; and corridors with $F < 0.8$ (70 in all) were classified as third-level corridors. To ensure a clear display, only corridors with cumulative contribution rates of less than 85% of gravity were plotted (Figure 7).

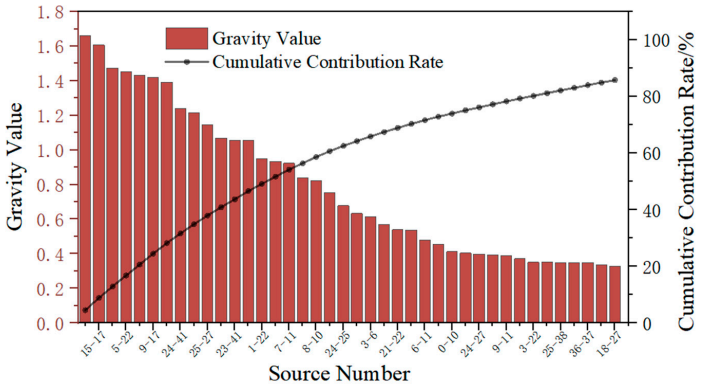


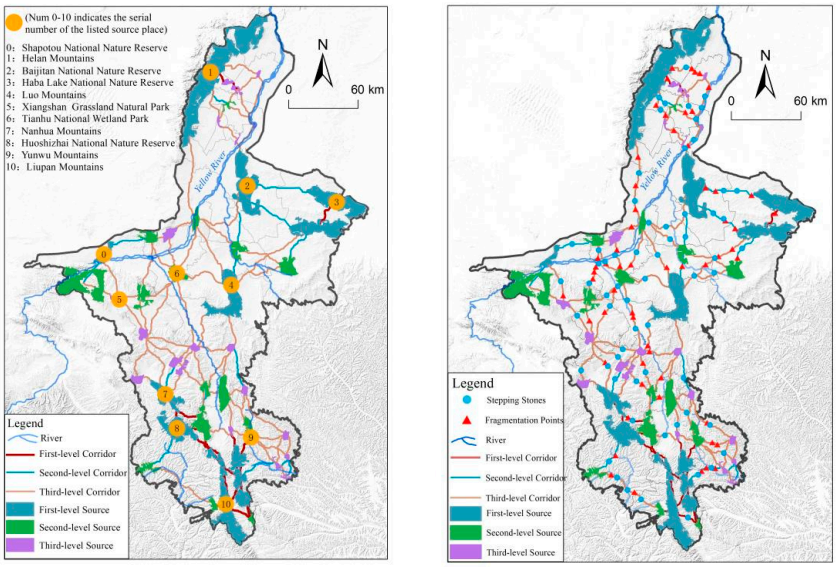
Figure 7. Magnitude of gravity values and cumulative contribution rates between source areas.

3.3. Characteristics of the Ecological Security Pattern in Ningxia

It can be seen that the southern region of Ningxia is mainly composed of first-level corridors, which are densely distributed. The northern region along the Yellow River Economic Belt is mainly composed of third-level corridors, and ecologically suitable construction should be strengthened in this area. The central and eastern regions are mainly composed of second- and third-level corridors, mostly in natural protected areas and long-distance corridors, which correspond to the important and general corridors classified by the gravity model on the basis of the magnitude of gravity. Overall, source 0 is connected to source areas 1, 19, 3, 7, and 8, all of which are important corridors within the Liupan Mountain National Nature Reserve. Source 26 is highly connected to surrounding river and lake wetlands within the Helan Mountain National Nature Reserve. Source 25 is mainly connected to source areas 23, 24, and 41, all second-level corridors, within the Luo Mountain National Nature Reserve, indicating strong stability and good biological migration effects. The river system in Ningxia is mainly composed of the Yellow River and Qingshui River watersheds. It serves both as a corridor function and as a water-borne biological source area in the ecological space of Ningxia. It enhances connectivity between the northern–central–southern regions, serving as an important channel for maintaining ecological security and promoting species exchange among organisms. It effectively promotes the protection of biodiversity and regional sustainable development and has an extremely important ecological status. Overall, the important corridors are more concentrated in the southern and eastern regions, and efforts should be made to strengthen the construction and protection between ecological sources. In the Yellow River Economic Belt, biologically suitable construction should be strengthened between source areas, and protection measures for source areas should be improved to facilitate species migration and exchange.

Human activities significantly impact ecological processes, and corridors are prone to fragmentation. To increase the stability of the ecological network between source areas, the top 100 larger patches ranked by area were selected for overlay analysis with the ecological red lines to establish ecological stepping stones. The intersection between ecological

corridors and the ridge line derived from the digital elevation model (DEM) is the most important and vulnerable point in the ecological network and is also selected as a stepping stone. A total of 62 locations requiring the establishment of ecological stepping stones were identified. The intersections between highways and ecological corridors were identified as ecological fragmentation points, with a total of 58 fragmentation points requiring restoration (Figure 8). After the stepping stones were established and fragmentation points restored, the α index increased by 0.13, the β index increased by 0.25, and the γ index increased by 0.09. The optimized index values all showed a significant increase, indicating the enhanced stability of the ecological network.



(**a**) (**b**)

Figure 8. (**a**) Ecological network pattern; (**b**) Its optimization.

The 14th Five-Year Plan [69] identifies the "One River and Three Mountains" region of Ningxia as a key area for promoting ecological system construction and ecological protection and restoration projects within important ecological functional zones. The plan aims to establish a natural protected area system primarily consisting of national parks that include nature reserves and are supplemented by various types of natural parks. In addition, the biodiversity protection network will be improved around the ecological red lines. In the northern green development zone, the Helan Mountains are identified as a priority area for the protection of endangered animals and plants and their habitats, including the arid natural ecosystem, rare tree species, and blue sheep. The protection of wetlands along the Yellow River and urban lakes and wetlands will also be strengthened. The Central Enclosed Protection Area, with priority areas at Baiji Beach and Haba Lake, focuses on the protection of desert ecosystems, rare wildlife and plant species, and inland arid wetland ecosystems of the Maowusu Sandyland and Ordos Plateau, as well as high-quality wild forage germplasm resources. The southern water source conservation area, with the Liupan Mountains as the priority area, focuses on the protection of water source conservation forests, typical grassland ecosystems, rare wildlife and plant species, and forage germplasm resources.

Based on this, this study proposes that Ningxia adopt the one-belt, three-screen, three-corridor, and five-cluster structural model (Figure 9) for the ecological security pattern of the network driving surface. One belt refers to the ecological belt of the Yellow River mainstem-centered plain river–lake wetland system in Yinchuan; the three screens refer to the ecological barriers of the Helan Mountains, the Luo Mountain, and the Liupan Mountains. The Helan Mountains play ecological functions such as maintaining biodiversity, controlling the expansion of Tengger and Wulanbuhe deserts and Maowusu Sandyland,

and protecting the ecology of Ningxia plain oasis. The Luo Mountain serves as an ecological barrier to ensure desertification control and sand fixation in the middle arid zone, blocking the southward expansion of Maowusu Sandyland and maintaining the ecological balance of the surrounding area. The Liupan Mountains provide ecological functions such as water source conservation and biodiversity conservation. The three corridors refer to the Qingshui River system corridor, the west–southeast-oriented Daliupan corridor, and the two mountainous ecological corridors in the southwest–northeast direction of the middle arid zone. They play ecological functions such as reducing pollution and providing biological migration channels. Five clusters are the combination of the Helan Mountain Nature Reserve in the north and many lakes and wetlands in Yinchuan Plain to form a forest–lake ecological cluster, including the capital–city–park system group. In central Ningxia, a forest–grass-type ecological cluster is formed with Luo Mountain as the core. In southern Ningxia, a large Liupan forest–grass–lake ecological cluster is formed with the Liupan Mountain Nature Reserve as the axis. In the western wing, a desert system–lake–grass-type ecological cluster is formed with the Shapotou National Nature Reserve as the core. In the eastern wing, a desert ecological system–forest–grass–lake ecological cluster is formed with the coupling of the Baijitan National Nature Reserve and the Haba Lake Nature Reserve. The north, central, and south sources form key ecological clusters around the ecological barrier of the Helan Mountains, the Luo Mountain, and the Liupan Mountains, respectively, which has important ecological value. On the whole, on the basis of the differences in environmental characteristics, five biological diversity ecological groups reflecting regional ecological characteristics are formed and include a large number of national and provincial nature reserves and wetland parks. Ecological communication among species is realized by dense ecological corridors.

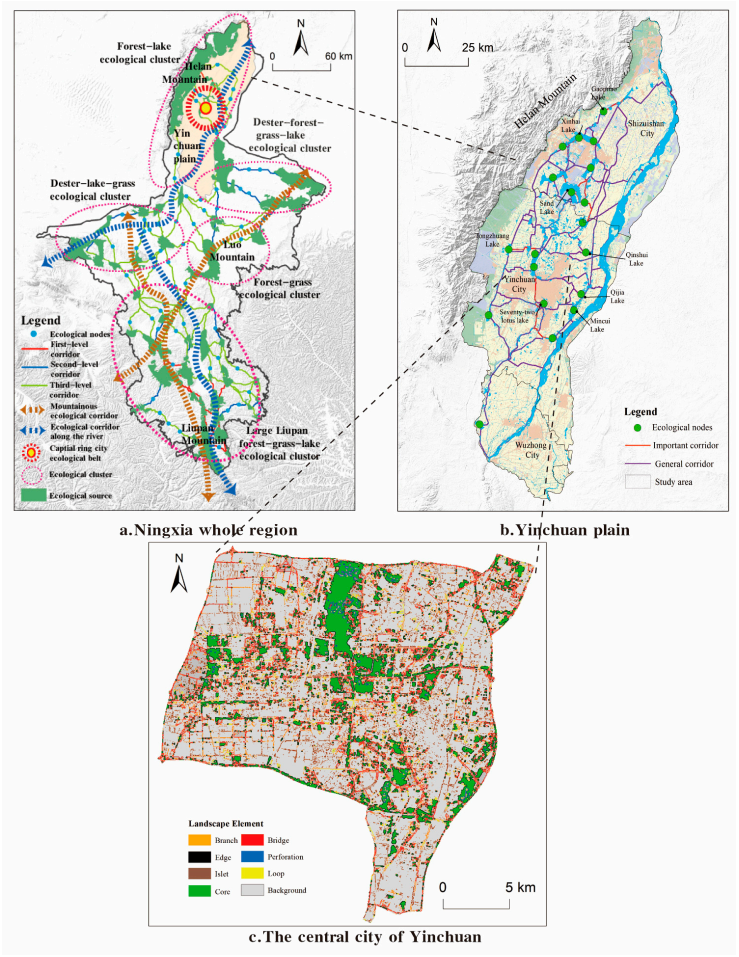


Figure 9. The spatial structure pattern of ecological security in Ningxia Hui Autonomous Region.

4. Discussion and Conclusions

4.1. Discussion

(1) Optimization of the classification of ecological source areas and the extraction method of key ecological corridors. The construction of a hierarchical ecological network mainly involves the classification of ecological sources and the classification of potential ecological corridors in terms of importance. Arid and semi-arid areas tend to have a fragile ecological environment, ecological networks are prone to fracture, and high- and low-level network structures restrict and influence each other. At present, there are few studies on arid and semi-arid areas, and there are ecological networks built around natural protection areas in Qinghai Province [25], while there are many related studies on humid areas [67,70]. Two different types of areas are mostly divided into corridor grades by area. In the classification of ecological sources where forest ecosystems are the main focus, quantifying the source area level on the basis of area units is relatively objective. However, in arid and semi-arid ecologically fragile areas, the ecological source areas are often composed of forests and grasslands or a combination of forests, grasslands, and water. Since source areas differ in size and component structure, relying solely on area measurement to determine the importance of ecological source areas is clearly lacking in scientific rigor. Therefore, on the basis of energy factors, this study proposes a classification of ecological sources that is more objective and accurate than one simply based on area. Since the importance of ecological source areas measured by energy factors is more objective, in the calculation of the gravity model of the ecological source area formula, the gravity factor of ecological source areas is expressed on the basis of the size of the energy factor, which is more scientifically rigorous than calculating gravity on the basis of area size.

(2) The impact of road construction on the connectivity of ecological networks. In previous studies, scholars have been more concerned about the impact of human activities and the expansion of construction land on animal habitats [71,72], with more attention paid to the increase in the size and number of construction land patches. This study found that the rapid expansion of the transportation network system in recent years has blocked ecological patches. This blocking effect on ecological corridors needs further attention. Calculations have shown that there are numerous ecological rupture points where ecological corridors intersect with roads above the general highway level, not to mention the even more numerous impacts of township and village roads, which are even more complex. At present, the development of green infrastructure network protection strategies [73] and plantation of grass and trees on both sides of traffic arteries have led to the development of ecological corridors connecting ecological sources and fragmentary patches to improve the circulation of ecological networks [74]. In the future, to maintain the connectivity of ecological networks, it is necessary to pay attention to the restoration of such ecological rupture points. When new roads are being constructed, it is important to pay attention to the placement of facilities such as culverts and diversion areas that facilitate animal migration.

(3) Enhancing the connectivity of ecological elements through the "network driving surface". Species find it difficult to survive in fragmented landscapes, and conflicts between nature and society hinder conservation efforts. Movement is a product of species evolution and has significant impacts on the survival and reproduction of animal species in various forms. Animals migrate within their nest ranges, but they may also move to places far from their birthplaces, where their relatives still remain. As an ecological strategy, ecological networks embody the concept of ecological civilization and connect humans and nature in space, balancing economy and ecology. They play an important role in improving the material cycle, energy exchange, and information transmission of regional ecosystems. The ecological security pattern of a network driving surface connects important ecological sources in space and is important in establishing an ecological security pattern that facilitates the flow of ecological elements.

(4) Restoration of an ecological source area. Ningxia is located in an ecologically fragile area; some important areas or areas to be restored have less woodland, grassland, and water coverage; and MSPA often fails to identify such areas, thus adversely affecting the maintenance of regional ecological security. The ecological red line includes important ecological functional areas and ecologically fragile and sensitive areas and is the bottom line of national and regional ecological security [75]. A superposition analysis of the ecological red line and the core patch is helpful in identifying and restoring relevant ecological sources. As shown in Figure 4, the patch of the core area is superimposed with the ecological red line to identify the source area of the Helan Mountain Nature Reserve to be repaired, and the source area restoration of the relevant ecologically fragile areas can effectively improve the quality of the source area and the stability of the ecological network.

4.2. Conclusions

Important for promoting the integrated protection and systematic governance of mountains, waters, forests, farmlands, lakes grasslands, sandy areas, and other natural resources, ecological networks form the backbone of the regional ecological security pattern. On the basis of MSPA and landscape connectivity analysis, this paper introduced the ecological protection red lines to determine the ecological sources and the energy factor and modified gravity models to study the ecological security mode of the Upper Yellow River Basin on the provincial scale on the basis of the network driving surface. The conclusions are as follows:

(1) The ecological source areas in Ningxia exhibit a distribution pattern characterized by forests dominating in mountainous areas, desert grassland ecosystems dominating in the eastern and western wings, and plain lake wetland systems dominating the plain systems. This has formed a composite ecological cluster source system with mountainous forest ecosystems as the main body, coupled with grassland and lake wetland ecosystems.

(2) A composite ecological corridor structure system, Ningxia is composed of a water system ecological corridor system and a land ecological corridor system. The northern region is dominated by the Yellow River water system network system. The Helan Mountain National Nature Reserve has a high degree of connection with the surrounding river and lake wetlands. The Liupan Mountain National Nature Reserve is connected to source areas 1, 19, 3, 7, and 8, all of which are important corridors. The Luo Mountain National Nature Reserve is mainly connected to ecological sources 23, 24, and 41 through secondary corridors.

(3) There are many ecological breakpoints in the ecological network, resulting in poor connectivity. To enhance network connectivity, it is necessary to add 62 ecological stepping stones and repair 58 ecological breakpoints. After optimization, the α, β, and γ indices can be increased by 0.13, 0.25, and 0.09, respectively.

(4) The ecological security structure of Ningxia is proposed to be a one-belt, three-screen, three-corridor, five-cluster structure based on the network driving surface. The belt is an ecological zone of rivers, lakes, and wetlands, mainly along the main axis of the Yellow River. The three screens refer to the ecological barriers of the Helan, Luo, and Liupan Mountains. The three corridors are the Qingshui River water system corridor, the large Liupan corridor, and the southwest–northeast ecological corridor in the central arid zone. The five clusters, which are desert–forest–grass–lake type, desert–lake–grass type, Daliupan forest–grass–lake type, forest–lake type, and forest–grass type, reflect the characteristics of biodiversity in the east, west, south, north, and central regions of Ningxia around the key source areas, respectively.

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Conflicts of Interest: The authors declare that there are no conflicts of interest.

Appendix A

Source Number	Source Name	Cluster	Source Number	Source Name	Cluster	Source Number	Source Name	Cluster
0	Liupan Mountain Nature Reserve	**V**	15	-	**V**	30	Sand Lake	**I**
1	Liupan Mountain Nature Reserve	**V**	16	-	**V**	31	-	**I**
2	-	**V**	17	-	**V**	32	-	**I**
3	Yunwu Mountain Nature Reserve	**V**	18	-	**IV**	33	-	**I**
4	-	**V**	19	-	**V**	34	-	**V**
5	-	**V**	20	-	**V**	35	-	**III**
6	-	**V**	21	-	**V**	36	Xiangshan National Grassland Park	**III**
7	-	**V**	22	-	**V**	37	-	**III**
8	Huoshizhai Nature Reserve	**V**	23	Haba Lake Nature Reserve	**II**	38	Tian hu National Wetland park	**III**
9	Nanhua Mountain Nature Reserve	**V**	24	Haba Lake Nature Reserve	**II**	39	-	**III**
10	Zhenhu wetland Reserve	**V**	25	Luo Mountain Nature Reserve	**IV**	40	-	**III**
11	-	**V**	26	-	**I**	41	Baijitan Nature Reserve	**II**
12	-	**V**	27	-	**IV**	42	-	**I**
13	-	**V**	28	-	**I**	43	Qingtongxia Reservoir Area Wetland	**III**
14	-	**V**	29	-	**I**	44	Shapotou Nature Reserve	**III**

Note: Names of the ecological Cluster: **I**: forest–lake ecological cluster; **II**: desert–forest–grass–lake ecological cluster; **III**: desert–lake–grass ecological cluster; **IV**: forest–grass ecological cluster; **V**: large Liupan forest–grass–lake ecological cluster.

References

1. Chen, X.Q.; Kang, B.Y.; Li, M.Y.; Du, Z.B.; Zhang, L.; Li, H.Y. Identification of priority areas for territorial ecological conservation and restoration based on ecological networks: A case study of Tianjin City, China. *Ecol. Indic.* **2023**, *146*, 109809. [CrossRef]
2. Peng, J.; Pan, Y.J.; Liu, Y.X.; Zhao, H.J.; Wang, Y.L. Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape. *Habitat Int.* **2018**, *71*, 110–124. [CrossRef]
3. Dang, X.W.; Zhou, L.; Hu, F.N.; Yuan, B.; Tang, J.J. Multi-scale influence of urban agglomeration expansion on ecological land in Guanzhong Plain. *J. Ecol.* **2022**, *42*, 3020–3032.
4. Peng, J.; Lu, D.N.; Zhang, T.; Liu, Q.Y.; Lin, J. Systematic cognition of the ecological protection and restoration of mountains, rivers, forests, fields, lakes and grasslands. *J. Ecol.* **2019**, *39*, 8755–8762.
5. Yao, C.Y.; An, R.; Dou, C.; Liu, Y.L. Construction and evaluation of woodland ecological network in the Three Gorges Reservoir Area based on MSPA and MCR model. *Resour. Environ. Yangtze River Basin* **2022**, *31*, 1953–1962.
6. Zhang, Y.; Xu, D.Y.; Li, X.; Zhang, X.Y.; Wang, X.B.; Wang, S.Q. Construction of ecological corridor and identification of key nodes in the core area of the middle-old traffic corridor. *J. Ecol.* **2020**, *40*, 1933–1943.
7. Liu, J.J.; Chen, J.R.; Lai, Y.N.; Luo, B.Y.; Zhao, F.; Du, Q. Optimization and application of Ecological Network Methods based on Landscape Pattern and Connectivity Evaluation. *J. Appl. Ecol.* **2019**, *30*, 3108–3118.

8. Liu, X.Y.; Wei, M.; Zeng, J.; Zhang, S. Analysis and construction of ecological network in Fujian Triangle urban agglomeration. *Resour. Sci.* **2021**, *43*, 357–367.
9. Chen, H.B. Promoting ecological priority and green development in the Yangtze River Economic Belt—Based on the perspective of biodiversity. *Res. Social. Chin. Charact.* **2020**, *2*, 79–87.
10. Dai, L.; Liu, Y.B.; Luo, X.Y. Integrating the MCR and DOI models to construct an ecological security network for the urban agglomeration around Poyang Lake, China. *Sci. Total Environ.* **2021**, *754*, 141868. [CrossRef] [PubMed]
11. Jiang, H.; Zhang, Z.M.; Xu, Z.H.; Dan, Y.Z.; Ye, Y.Y.; Li, J.Z.; Peng, J. Construction of ecological security pattern in Guangdong Province by integrating multiple ecological protection objectives. *J. Ecol.* **2022**, *42*, 1981–1992.
12. Huang, X.Y.; Zhao, X.M.; Guo, X.; Ding, H.; Chen, L.; Zhang, J.J. Simulation analysis of the influence of land use change on the stability of ecological network in Poyang Lake Plain. *J. Agric. Eng.* **2022**, *38*, 277–287.
13. Su, C.; Dong, J.Q.; Ma, Z.G.; Qiao, N.; Peng, J. Identification of priority areas for ecological protection and restoration of mountains, rivers, forests, farmland, lakes and grass based on ecological security pattern—Take Huaying Mountain area of Sichuan Province as an example. *J. Ecol.* **2019**, *39*, 8948–8956.
14. Li, Z.Y.; Li, Y.Y.; Li, W.X.; Xue, M.K. Research on the construction of ecological security pattern in Kunming city based on the analysis of morphological spatial pattern and the minimum cumulative resistance model. *J. Ecol. Rural. Environ.* **2023**, *39*, 69–79.
15. Li, Q.P.; Zhang, Z.D.; Wan, L.W.; Yang, C.X.; Zhang, J.; Ye, C.; Chen, Y.C. Optimization of Landscape Pattern in the Ningjiang River Basin Based on Landscape Ecological Risk Assessment. *J. Geogr.* **2019**, *74*, 1420–1437.
16. Vergnes, A.; Kerbiriou, C.; Clergeau, P. Ecological corridors also operate in an urban matrix: A test case with garden shrews. *Urban Ecosyst.* **2013**, *16*, 511–525. [CrossRef]
17. Shi, F.N.; Liu, S.L.; An, Y.; Sun, Y.X. Research on biodiversity conservation of mountains, rivers, forests, fields, lakes and grasses based on ecological network—Take Zuo River in Guangxi as an example. *J. Ecol.* **2019**, *39*, 8930–8938.
18. Wu, M.Q.; Hu, M.M.; Wang, T.; Fan, C.; Xia, B.C. Identification of urban ecological sources based on ecological security pattern and multi-scale landscape connectivity. *J. Ecol.* **2019**, *39*, 4720–4731.
19. Chen, X.; Peng, J.; Liu, Y.X. Construction of ecological security pattern in Yunfu city based on the framework of "importance-sensitivity-Connectivity". *Geogr. Res.* **2017**, *36*, 471–484.
20. Gao, M.W.; Hu, Y.C.; Li, X.; Song, R. Construction of ecological security pattern in karst mountainous areas based on the importance of ecosystem services and environmental sensitivity—Take Hechi in Guangxi as an example. *J. Ecol.* **2021**, *41*, 2596–2608.
21. Zheng, Q.M.; Hu, J.H.; Shen, M.Z. Construction of Hunan Province ecological network based on MSPA and MCR models. *J. Nat. Sci. Hunan Norm. Univ.* **2021**, *44*, 1–10.
22. Chen, Q.; Liu, P.H.; Zhu, C.M. Construction of Ecological Security Pattern in Fuzhou City, Jiangxi Province based on MCR model. *Notif. Soil Water Conserv.* **2022**, *42*, 210–218.
23. Vogt, P.; Ferrari, J.R.; Lookingbill, T.R.; Gardner, R.H.; Riitters, K.H.; Ostapowicz, K. Mapping functional connectivity. *Ecol. Indic.* **2009**, *9*, 64–71. [CrossRef]
24. Chen, Z.A.; Ma, B.B.; Wei, X.J.; Zeng, L.Q.; Jiang, X.H. Construction and optimization of ecological network in Nanchang city based on MSPA and MCR models. *Soil Water Conserv. Bull.* **2021**, *41*, 139–147.
25. Shi, N.N.; Han, Y.; Wang, Q.; Quan, Z.J.; Luo, Z.L.; Ge, J.S.; Han, R.Y.; Xiao, N.W. Construction and optimization of ecological network in protected areas in Qinghai Province. *J. Ecol.* **2018**, *37*, 1910–1916.
26. Zhang, Q.S.; Li, F.X.; Wang, D.W.; Li, M.C.; Chen, D. Study on ecological spatial connectivity changes in Jiangsu Province based on ecological network. *J. Ecol.* **2021**, *41*, 3007–3020.
27. Chen, N.N.; Kang, S.Z.; Zhao, Y.H.; Zhou, Y.J.; Yan, J.; Lu, Y.R. Construction of mountain ecological network in Qinling Mountains (Shaanxi section) based on MSPA and MCR models. *J. Appl. Ecol.* **2021**, *32*, 1545–1553.
28. Xu, F.; Yin, H.W.; Kong, F.H.; Xu, J.G. Construction of ecological network based on MSPA and minimum path method. *J. Ecol.* **2015**, *35*, 6425–6434.
29. Zhang, L.L.; Zhang, H. Study on the evolution of landscape pattern in ecological sources based on grain size inversion method and MCR model—Take Fengdu County, Chongqing city as an example. *Resour. Dev. Mark.* **2020**, *36*, 1320–1325+1333.
30. Yao, C.; He, Y.; Cheng, J.; Zhang, T.; Pan, H.; Ma, H. Research on evaluation and optimization of ecological security pattern in Minjiang River Basin based on MCR model and gravity model. *J. Ecol.* **2023**, *43*, 1–14.
31. Mao, C.R.; Dai, L.M.; Qi, L.; Wang, Y.; Zhou, W.M.; Zhou, L.; Yu, D.P.; Zhao, F.Q. Construction of watershed Ecological security Pattern based on ecosystem services—Take the Liaohe River Basin of Liaoning Province as an example. *J. Ecol.* **2020**, *40*, 6486–6494.
32. Ni, Q.L.; Ding, Z.Y.; Hou, H.P.; Jia, N.F.; Wang, H. Research on ecological pattern identification and protection based on circuit theory—Take Ningwu County as an example. *Resour. Environ. Arid. Zone* **2019**, *33*, 67–73.
33. Lei, S.; Li, Z.B.; Xiao, L.; Wu, L.; Chen, S.Y.; Wei, L.; Yin, Z.Y. Construction and optimization of the ecological network in Heyuan City based on the MSPA-MCR model. *For. Environ. Sci.* **2023**, *39*, 1–11.
34. Dai, J.P.; Zhu, K.; Zhou, T.Y.; Long, F.; Huang, L.; Peng, J.S. Urban ecological network optimization in Qujing Center based on MSPA and MCR models. *J. Northwest Coll. For.* **2022**, *37*, 250–257.
35. Liu, J.H. *Study on the Structure and Pattern Evolution of Ecological Network in Baotou Based on Hierarchical Analysis*; Beijing Forestry University: Beijing, China, 2019.

36. Wang, G.; Yu, Q.; Yang, D.; Zhang, Q.B.; Yue, D.P.; Liu, J.H. Research on the hierarchical ecological network structure based on the complex network analysis method. *J. Agric. Mach.* **2019**, *50*, 258–266+312.
37. Yao, X.J.; Hu, Y.; Li, J.L.; Jiang, D. Construction of ecological security pattern in Linquan County, Anhui Province based on "pressure-state-response mode". *J. Anhui Agric. Univ.* **2020**, *47*, 538–546.
38. Peng, J.; Zhao, H.J.; Liu, Y.X.; Wu, J.S. Research progress and prospect of the construction of regional ecological security pattern. *Geogr. Res.* **2017**, *36*, 407–419.
39. Yang, Z.G.; Jiang, Z.Y.; Guo, C.X.; Yang, X.J.; Xu, X.J.; Li, X.; Hu, Z.M.; Zhou, H.Y. Construction of ecological network in Guangzhou based on morphological spatial pattern analysis and minimum cumulative resistance model. *J. Appl. Ecol.* **2018**, *29*, 3367–3376.
40. Feng, S.; Tang, Z.Y.; Yu, L.; Guo, C.; Tang, M.X.; Yang, Z.P. Take the Guangdong-Hong Kong-Macao Greater Bay Area as an example. *J. Ecol.* **2022**, *42*, 8223–8237.
41. Wei, Q.Q.; Halike, A.; Yao, K.X.; Chen, L.M.; Balati, M. Construction and optimization of ecological security pattern in Ebinur Lake Basin based on MSPA-MCR models. *Ecol. Indic.* **2022**, *138*, 108857. [CrossRef]
42. Jin, Y.L.; Zhou, D.M.; Zhou, F.; Yang, J.; Zhu, X.Y.; Ma, J.; Zhang, J. Construction and optimization of the ecological security network in the Shule River Basin. *J. Appl. Ecol.* **2023**, *34*, 1063–1072.
43. Tang, F.; Wang, L.; Zhang, P.T.; Fu, M.C. Construction of county ecological security pattern based on ecological protection red line and ecological network. *J. Agric. Eng.* **2020**, *36*, 263–272.
44. Yu, Y.; Meng, J.H.; Song, Z.M.; Xu, L. Construction of county ecological network based on MCR model and landscape connectivity. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2023**, 1–9. Available online: http://kns.cnki.net/kcms/detail/61.1202.S.20230403.1314.006.html (accessed on 12 May 2023).
45. Guo, J.X.; Hu, Z.Q.; Li, H.X.; Liu, J.L.; Zhang, X.; Lai, X.J. Construction of the municipal ecological space network based on the MCR model. *J. Agric. Mach.* **2021**, *52*, 275–284.
46. Shen, Q.W.; Lin, M.L.; Mo, H.P.; Huang, Y.B.; Hu, X.Y.; Wei, L.W.; Zheng, Y.S.; Lu, D.F. Construction and optimization of ecological network in Foshan city. *J. Appl. Ecol.* **2021**, *32*, 3288–3298.
47. Gu, F.; Huang, Y.X.; Chen, C.M.; Cheng, D.L.; Guo, J.L. Construction and optimization of the ecological network of nature reserves in Fujian Province. *J. Appl. Ecol.* **2017**, *28*, 1013–1020.
48. Ye, J.Y. Research on Ecological Landscape Pattern and Ecological Network Construction in Ecological Resettlement Area in South Ningxia. Master's Thesis, Ningxia University, Yinchuan, China, 2018.
49. Zhang, L. *Research on the Construction of Green Land Ecological Network in Guyuan City*; Suzhou University of Science and Technology: Suzhou, China, 2016.
50. Zhou, Y.S.; Zheng, Z.H.; Wu, Z.F.; Guo, C.; Chen, Y.B. Construction and evaluation of ecological networks in highly urbanised regions: A case study of the Guangdong-Hong Kong-Macao greater Bay Area, China. *Ecol. Indic.* **2023**, *152*, 110336. [CrossRef]
51. The CPC Central Committee and The State Council. The Outline of the Plan for Ecological Protection and High-quality Development of the Yellow River Basin. Available online: https://www.gov.cn/zhengce/2021-10/08/content_5641438.htm (accessed on 12 May 2023).
52. Zhu, J.; Su, J.; Yin, H.W.; Kong, H.H. Construction of Xuzhou ecological network based on source comprehensive identification and multi-scale nested. *J. Nat. Resour.* **2020**, *35*, 1986–2001.
53. He, J.H.; Guo, X. Construction of Datong County ecological network based on MSPA and MCR models. *Spec. Econ. Zone Econ.* **2022**, 104–109.
54. Xu, W.Z.; Huang, S.Y.; Geng, J.W.; Wang, X.Y.; Fu, W.C.; Lin, S.Y.; Dong, J.W. Construction of Xiamen Ecospace network based on the MCR and gravity model. *J. Northwest Coll. For.* **2022**, *37*, 264–272.
55. Wang, Q.; Wang, C.; Zhang, L.G.; Guo, H. Construction and analysis of urban woodland ecological network in the lower reaches of the Yellow River-Taking Jinan as an example. *J. Shandong Jianzhu Univ.* **2022**, *37*, 101–107.
56. Vogt, P.; Riitters, K. GuidosToolbox: Universal digital image object analysis. *Eur. J. Remote Sens.* **2017**, *50*, 352–361. [CrossRef]
57. Wu, C.G.; Zhou, Z.X.; Wang, P.C.; Xiao, W.F.; Teng, M.J. Concept, measure of landscape connectivity and its application. *J. Ecol.* **2010**, *30*, 1903–1910.
58. Mitchell, M.G.E.; Bennett, E.M.; Gonzalez, A. Linking Landscape Connectivity and Ecosystem Service Provision: Current Knowledge and Research Gaps. *Ecosystems* **2013**, *16*, 894–908. [CrossRef]
59. Wang, G.; Yu, Q.; Yang, D.; Zhang, Q.B.; Yue, D.P.; Liu, J.H. Research on the construction method of hierarchical ecological network in Baotou city. *J. Agric. Mach.* **2019**, *50*, 235–242+207.
60. Zeng, Z.; Ai, J.W.; Wang, Z.L.; He, T.Y.; Zheng, Y.S. Research on the spatial and temporal evolution of landscape pattern and ecological network construction in Sanming city. *J. Ecol. Rural. Environ.* **2023**, *39*, 1–13.
61. Qin, Z.B.; Xuan, J.; Huang, L.J.; Liu, X.Z. Construction of sea-island urban ecological network based on MSPA and MCR models—Take Pingtan Island in Fujian Province as an example. *Res. Soil Water Conserv.* **2023**, *30*, 303–311.
62. Liu, J.; Chen, J.J.; Yang, Y.P.; You, H.T.; Han, X.W. Construction and Optimization of an Ecological Network in the Yellow River Source Region Based on MSPA and MCR Modelling. *Int. J. Environ. Res. Public Health* **2023**, *20*, 3724. [CrossRef]
63. Yu, C.; Wang, L.Z.; Zhao, S.; Gui, F. Construction and optimization of Zhoushan Island based on MSPA and MCR models. *Ocean. Bull.* **2023**, *42*, 102–111.

64. Wei, B.J.; Su, J.; Hu, X.J.; Xu, K.H.; Zhu, M.L.; Liu, L.Y. Study on the comprehensive identification of Ecological corridors and ecological nodes based on "HY-LM". *J. Ecol.* **2022**, *42*, 2995–3009.
65. Urban, D.L.; Minor, E.S.; Treml, E.A.; Schick, R.S. Graph models of habitat mosaics. *Ecol. Lett.* **2009**, *12*, 260–273. [CrossRef]
66. Kong, Y.; Wang, S.Y. Construction of urban and rural ecological network in Yanqing District of Beijing based on the MSPA model. *J. Beijing For. Univ.* **2020**, *42*, 113–121.
67. Wang, Y.; Zhao, W.L.; Liu, C.Q. Ecological network optimization and its construction based on MSPA-Conefor-MCR pathway—Takes Pengze County as an example. *J. Jiangxi Agric. Univ.* **2022**, *44*, 504–518.
68. Wang, B.Y.; Yan, H.M.; Feng, Z.H.; Yang, Y.Z. Changes in the Ecological Characteristics of Key Biodiversity Areas in the BRI Region. *J. Resour. Ecol.* **2022**, *13*, 328–337.
69. The General Office of the People's Government of Ningxia Hui Autonomous Region. The 14th Five-Year Plan for the Protection and Utilization of Natural Resources in Ningxia Hui Autonomous Region. Available online: https://www.nx.gov.cn/zwgk/qzfwj/202109/t20210924_3045970.html (accessed on 12 May 2023).
70. Shao, R.Y.; Luo, Z.W.; Hu, X.J.; Wang, Y.Z.; Zhang, J.Y. Construction and optimization of Zhuzhou ecological network based on MSPA and MCR models. *J. Northwest Univ. For.* **2023**, 1–15. Available online: http://kns.cnki.net/kcms/detail/32.1161.S20230327.0921.002.html (accessed on 12 May 2023).
71. Zhang, J. *Study on Ecological and Economy Coupling in Wanzhou District Based on InVEST and Landscape Pattern Index*; Southwest University: Chongqing, China, 2017.
72. Yang, J. Influence Mechanism and Optimization Path of the Spatial Development Intensity of Construction Land under the Constraint of Ecological Network. Master's Thesis, Huazhong Agricultural University, Wuhan, China, 2021.
73. Shi, S.M.; Qin, M.Z.; Li, B.; Li, C.Y.; Song, L.L. Research on green infrastructure network in Zhengbian Metropolitan based on MSPA and circuit theory. *J. Henan Univ. (Nat. Sci. Ed.)* **2018**, *48*, 631–638.
74. Pan, J.H.; Liu, X. Evaluation and pattern optimization of inland river landscape ecological safety based on spatial principal component and minimum cumulative resistance model—Take Ganzhou District of Zhangye City as an example. *J. Appl. Ecol.* **2015**, *26*, 3126–3136.
75. Wu, Z.Q.; Wang, Z.Z. Red line of ecological protection, ecological compensation and farmers' livelihood dilemma based on the perspective of governance. *J. Chongqing Univ. (Soc. Sci. Ed.)* **2020**, *26*, 230–243.

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