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Construction of Ecological Security Pattern for Plateau Lake Based on MSPA–MCR Model: A Case Study of Dianchi Lake Area

Shaokun Zhou [1], Yuhong Song [1,2,*], Yijiao Li [1], Jing Wang [1] and Lan Zhang [1]

[1] College of Landscape Architecture and Horticulture Science, Southwest Forestry University, Kunming 650224, China
[2] Southwest Landscape Engineering Technology Research Center of National Forestry and Grassland Administration, Kunming 650224, China
* Correspondence: songyuhong@swfu.edu.cn

Abstract: The construction of ecological security patterns is an effective means to improve ecological environment quality, protect regional biodiversity, and alleviate the landscape fragmentation caused by urbanization in plateau lake cities. Taking the Dianchi Lake area as an example, we used the morphological spatial pattern analysis method (MSPA) and the minimum cumulative resistance model (MCR) to construct a comprehensive resistance surface, ecological corridor network, and ecological security pattern for the study area. Firstly, we selected 12 ecological sources with more than 1000 hm^2, PC, IIC index more than 1, and high habitat quality and connectivity from the study area, including the Dianchi lake body and the mountain forests in the south, north, and west. The overall habitat quality in the eastern region was poor. Secondly, the regional comprehensive resistance value was 1.0925–4.5395. The comprehensive resistance surface showed that the influence of human activities in the region was strong, and the connectivity between important sources was poor. Thirdly, we identified 26 important corridors with interaction force values higher than 50, mostly mountain corridors, between sources that were close to one another and over 40 general corridors with interaction force values lower than 50 in urban built-up areas, most of which were river corridors. Fourthly, by identifying five potential sources and 43 potential corridors in the eastern region, we improved the ecological network function and overall connectivity. The α index (loop pass degree), β index (line point rate), and γ index (connectivity degree) were 2.895, 5.5, and 2.2 before optimization and 3.206, 6.412, and 2.422 after optimization, respectively. Lastly, the "ridge lines" and "valley lines" were used to screen the ecological nodes in our ecological network model and construct a "one core, three regions, and one belt" ecological security pattern by combining the geographical characteristics of the research region and the local policy planning guidance. We also provided ecological control, restoration, and construction suggestions based on the corridor plans of other administrative regions and the different types of source area.

Keywords: ecological source area; comprehensive weight; resistance surface; ecological corridor; connectivity of network

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1. Introduction

Taking Dianchi Lake area as an example, this study explored the ecological corridor network and the construction of an ecological security pattern in the plateau lake area, in order to provide experience for the sustainable development of similar areas. As an important part of natural ecosystems, lakes conserve water, produce materials, control pollutants, protect biodiversity, encourage tourism, provide entertainment, and perform important economic, social, and ecological functions [1]. Human land-use change and infrastructure expansion have led to the loss of many habitats, the deterioration of the quality of the remaining habitats, and increased landscape fragmentation. The remaining

patches of many habitat types are often small and isolated from each other in an unsuitable landscape matrix. This further restricts animal movement and plant dispersal and reduces connectivity between habitat patches. According to the principles of landscape ecology, a green channel is a type of corridor, and according to the point–line–plane principle, ecological corridor networks are highly important for maintaining the integrity of ecosystems' structural processes, resisting habitat fragmentation, and promoting and protecting regional biodiversity [2].

In terms of research objects, early scholars focused on biodiversity and ecological protection of national parks [3,4], natural heritage sites [5], and nature reserves [6]. In recent years, the evaluation of urban landscape connectivity and the construction of ecological corridors have attracted widespread attention from scholars at home and abroad [7–9]. The common ecological network construction methods include circuit theory and the minimum cumulative resistance model (MCR). Circuit theory holds that the migration or diffusion of species is not based on knowledge of the surrounding environment and may not follow the optimal path [10]. Yu Kongjian optimized the minimum cumulative resistance model (MCR) created by Knaapen and applied it to the study of ecological corridors. The advantages of this method are its simplicity, efficiency, and suitability for studying large areas. It is one of the most important methods for studying ecological network construction, ecological security pattern construction, nature reserve planning, and other topics [11–14]. The morphological spatial pattern analysis method (MSPA) is based on the traditional green infrastructure theory and has been widely used in ecological network planning. In the early stages, the data volume is small, the data structure is simple, the calculation and operation are efficient, and no subjective bias is involved [15]. MCR and MSPA models have been widely used in various types of ecological governance. Yao Caiyun et al., taking the TGRA (Three Gorges Reservoir Area) as the study area, used MSPA to identify forest ecological source patches, and the importance of patches was evaluated using the landscape connectivity index. MCR was used to construct the ecological corridor, and the important ecological nodes were extracted to form the forest ecological safety network in the TGRA [16]. Ai et al. took the MSPA–MCR model to identify important ecological source sites and potential corridors. In addition, the impacts of wind power projects on the connectivity, pathways, and importance of ecological corridors were assessed [17]. Li et al. applied the morphological spatial pattern analysis (MSPA) method to identify ecological sources, used the minimum cumulative resistance model to evaluate the landscape connectivity of Guiyang in 2008, 2013, and 2017, and analyzed the temporal-spatial change features of landscape connectivity [18].

Dianchi Lake is the largest plateau freshwater lake in the Yungui Plateau, and Kunming is a plateau lake city with unique characteristics. The rapid urbanization in recent years has threatened and repeatedly damaged the ecological environment of the Dianchi Lake area, which has attracted the attention of many scholars and government departments. In 2021, the first phase of the 15th Meeting of the Conference of the Parties to the United Nations Convention on Biological Diversity (COP15) was successfully held in Kunming. In the meantime, the Kunming Municipal Government issued the Regulations on the Protection of Dianchi Lake in Yunnan Province, with the aim of "lake revolution", advocating for the standardization of the planning and construction of the Dianchi Lake watershed and the maintenance of its ecological environment. In 2022, Yunnan Province will vigorously implement the 3 year action plan for greening and beautifying urban and rural areas in Yunnan Province, aiming to improve the living environment in these locations, increase carbon sinks, and lay a solid foundation for becoming a leader in ecological progress. In recent years, scholars have paid more attention to research at the watershed scale, focusing on land-use change, habitat quality assessment, ecological security assessment, etc. [19,20]. Few studies have addressed the ecological security pattern for Dianchi Lake. We selected six administrative regions closely related to the Dianchi Lake body to construct an ecological security pattern covering the Dianchi lake watershed region and provide planning suggestions at the district and county scale. We specifically considered the

prominent contradiction between ecological construction and urban construction in the Dianchi Lake area. Our model provides a useful theoretical basis and reference point for regional development planning.

2. Materials and Methods

2.1. Study Area

Yunnan is rich in biodiversity resources, with a total of 25,434 species. Among them, there are 2729 species of macrofungi, accounting for 56.9% of the total in China, 1067 species of lichen, accounting for 60.4% of the national total, and 19,365 species of higher plants, accounting for 50.2% of the total, including 1906 species of mosses, 1363 species of ferns, 127 species of gymnosperms, and 15,969 species of angiosperms. Furthermore, there are 2273 species of vertebrates, accounting for 52.1% of the total, including 617 species of fish, 189 species of amphibians, 209 species of reptiles, 945 species of birds, and 313 species of mammals [21]. From the perspective of flora, Kunming area is a combination of tropical and temperate flora, with 46.5% belonging to tropical genera, 48.9% belonging to temperate genera, and 3.9% belonging to endemic genera in China. The vegetation types of plant resources include nine types, 20 subtypes, 11 groups, 56 groups, and 118 groups, including evergreen broad-leaved forest, hard-leaved broad-leaved forest, deciduous broad-leaved forest, warm coniferous forest, warm coniferous forest, shrub, meadow, and lake aquatic vegetation [22]. Dianchi Lake belongs to the Jinsha River system of the Yangtze River basin. It is located in the middle of the Yunnan–Guizhou Plateau, to the southwest of Kunming city. The climate, upper soil, landform, and vegetation of the study area are typical of the central Yunnan plateau. Its geographical coordinate range is 102°29′ E–103°01′ E, 24°29′ N–25°28′ N, and it has a total area of about 2920 km^2. The study area has a subtropical plateau monsoon climate with an annual precipitation of 1036.1 mm and an average annual temperature of about 14.4 ± 2.2 °C [23]. The terrain gradually descends in a ladder-like formation from the north to the southeast, with a low elevation in the middle and a high elevation from east to west. The main terrain is mountainous, with hills and basins interleaved [24]. Figure 1 showed the geographical location and land use status of the study area.

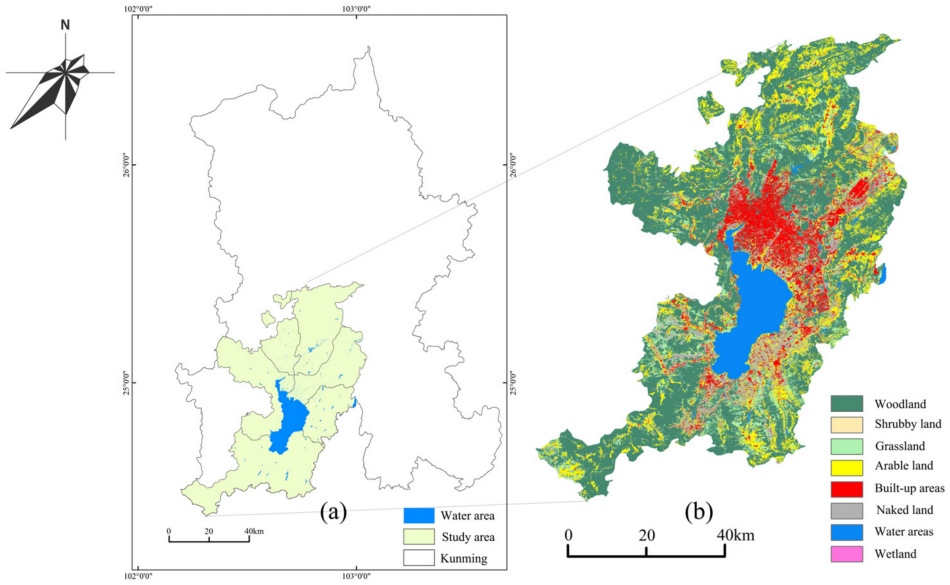


Figure 1. The geographical profile (**a**) and land use (**b**) of the study area.

The Dianchi area defined in this study comprised the six administrative regions of Kunming Wuhua, Panlong, Guandu, Xishan, Chenggong, and Jinning, with an area of about 4598.83 km^2. According to the seventh census, the population of the Dianchi area is 5,689,834, accounting for 67.26% of the total population of Kunming. The Dianchi Lake region is typical in that it shares many political, economic, ecological, historical, and

cultural characteristics with Kunming; however, it is typical in that it comprises both a vulnerable lake ecological environment and a rapidly developing city, making its regional characteristics distinct from the rest of the country [25].

2.2. Data Sources

We obtained the administrative boundary, residential, road, and water area data from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn/, accessed on 3 March 2022). We downloaded 30M 2020 DEM data points from the Earthdata website (https://earthdata.nasa.gov/, accessed on 3 March 2022).

We downloaded land-use data for Kunming in 2020 (resolution: 10 m) from the ESA WorldCover website (viewer.esa-worldcover.org, accessed on 11 March 2021) and classified them into eight categories: woodland, shrubby land, grassland, arable land, water areas, built-up areas, naked land, and wetland.

We obtained 2020 human settlement footprint data from the EOC Geoservice website (https://geoservice.dlr.de/, accessed on 6 March 2021) and night light data for 2020 from the Earth Observation Group (EOG) website (https://eogdata.mines.edu/, accessed on 6 March 2022).

We obtained remote-sensing image data from the geospatial data cloud site (http://www.gscloud.cn/, accessed on 13 March 2022) and used them to calculate the normalized vegetation index (NDVI) of the study area. Remote sensing images were acquired in June; vegetation growth was good, image cloud cover was less than 10%, and image quality was clear. ENVI5.3 images were used following atmospheric correction, radiometric calibration, geometric correction and other preprocessing.

Lastly, all the data were projected, trimmed, and corrected according to the administrative division to obtain the data needed for this research.

2.3. Methods

2.3.1. Identification of Main Ecological Sources

(1) Ecological source identification based on MSPA

Morphological spatial pattern analysis (MSPA) is an image processing method based on corrosion, expansion, and opening and closing operation, adjusting the overall spatial pattern through identification and segmentation, and effectively defining landscape types and structures. We combined the identification of important ecological sources with the geographical environment and biological characteristics of the area around Dianchi Lake and used the natural landscapes with high ecological service value and low human disturbance, including forests, shrubby land, grasslands, and bodies of water (including wetlands), as the prospective data for MSPA analysis. We included cultivated land, bare land, and construction land as background data, because human activities substantially affect these environments, and they lack suitable habitats for foraging [15]. Using GuidosToolBox, we identified seven landscape types in the study area, namely, core, islet, perforation, edge, bridge, loop, and branch. We selected the core areas, which were large and had high ecological value, as the ecological sources.

(2) Landscape connectivity evaluation based on Conefor

Figure 2 [26] shows the basic principles of landscape connectivity calculation. The probability of connectivity index (PC) [27,28] is defined as the probability that two animals randomly placed within the landscape fall into habitat areas that are reachable from each other (interconnected) given a set of n habitat patches and the connections (pij) among them. The integral index of connectivity (IIC) [27,28] is based on a binary connections model in which two patches are linked (directly connected) if the distance between them is below a certain threshold dispersal distance.

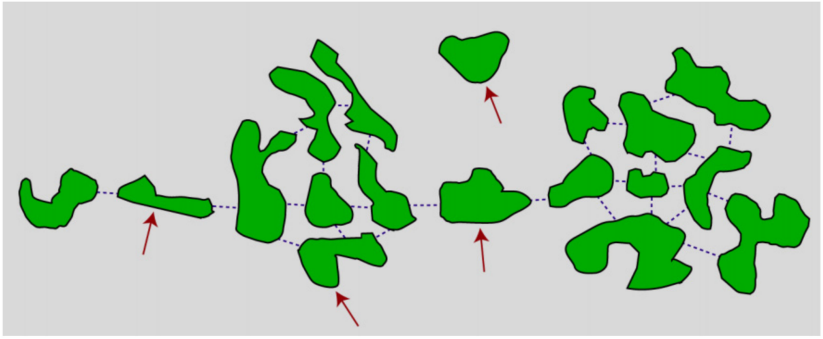


Figure 2. Schematic diagram of landscape connectivity calculation concept.

According to the relevant studies [29], combined with the seed dispersal path of wild plants in the study area and the migration distance of mammals and birds, the distance threshold and probability adopted in this experiment were 2500 m and 0.5. We used the graph theory connectivity index developed by Pascual-Hortal et al. to evaluate the landscape connectivity level of the extracted core areas. Using ConeforSensinode, we calculated the possible connectivity index (PC) and global connectivity index (IIC) of each patch in the extracted core areas to determine the landscape connectivity [29] and identified the ecological origin of the study area as a function of the patch importance index (dPC) and global connectivity index (dIIC). The formulas were as follows:

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

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

where n represents the number of plaques, a_i and a_j are the areas of patch i and patch j, A stands for total landscape area, and P^*_{ij} represents the maximum likelihood of diffusion between plaque i and j; higher PC and IIC values denote a higher degree of plaque connectivity.

2.3.2. Construction of Resistance Surface

(1) Comprehensive weight analysis of resistance factors based on AHP and entropy weight method

We evaluated the advantages and disadvantages of subjective and objective weighting methods and selected a comprehensive weighting method that combined the analytic hierarchy process [30] and the entropy weight method [31] to determine the weight of the indicators. The comprehensive weight calculation method implemented a mathematical programming model to find the optimal balance between the subjective and objective weights [32].

We determined the comprehensive weight of the indicators as follows:

$$W_{Ci} = kW_{Si} + (1-k)W_{Oi}, \quad (3)$$

where W_{Ci} is the comprehensive weight of the i-th index, W_{Si} is the weight of the i-th index obtained using the analytic hierarchy process, W_{Oi} is the weight of the i-th index obtained using the entropy method, and K is the coefficient of subjective preference. Aiming to minimize the sum of squared deviations of the subjective weight, objective weight, and combined weight, we established the following function:

$$Z_{min} = \sum_{i=1}^{n} (W_{Ci} - W_{Si})^2 + (W_{Ci} - W_{Oi})^2. \quad (4)$$

Substituting the formula into the above equation, we obtained k = 0.5.

(2) Construction of resistance surface

The scientific evaluation of ecological resistance factors is highly important for biodiversity conservation. We used natural resistance factors and human resistance factors to construct the comprehensive resistance surface of the ecological corridors.

(1) Construction of resistance surface based on natural factors

Natural factors, such as elevation, slope, and aspect, affect the range of species in an area. On the basis of selecting natural resistance factors, a higher altitude is correlated with a higher environmental adaptability of species. A plain or mountain with a small slope is the habitat of most species; a greater slope produces a less suitable area for species to survive. As slopes approach the south, more light can be obtained, which is conducive to the growth and foraging of species. A shorter distance to a water source is more conducive to biological activities. The normalized vegetation index accurately reflects the quantity of organisms and the habitat quality in a region. We used elevation, slope, aspect, distance from water source, and the normalized vegetation index as natural resistance factors. Combined with reference to the literature on the Yunnan region, we used the comprehensive weight method to determine the weight of each factor, so as to construct the natural comprehensive resistance surface. Table 1 shows the resistance score and weights of the factors.

Table 1. Scores and weights of natural factor resistance.

Type	Resistance Score					Weight		
Evaluation Factor	**1**	**2**	**3**	**4**	**5**	**Subjective Weight**	**Objective Weight**	**Comprehensive Weight**
Grade	<5°	5°–15°	15°–25°	25°–35°	>35°	0.1503	0.3358	0.243
Slope	Due south	Southeast, southwest	Due east, due west	Northeast, northwest	Due north	0.0884	0.1966	0.142
Elevation	<1800	1800–2000	2000–2200	2200–2400	>2400	0.1309	0.2394	0.185
Distance from water source	<100	100–300	300–800	800–1500	>1500	0.3152	0.0439	0.18
NDVI	0.8–1	0.6–0.8	0.4–0.6	0.2–0.4	0–0.2	0.3152	0.1843	0.25

(2) Construction of resistance surface based on human factors

Among the anthropogenic factors, the land-use type of an area determines whether it is conducive to the survival of certain species. A greater distance from roads and human footprints is more conducive to biological activities. We used land-use type and distance from road and human footprint as human resistance factors. Combined with reference to the literature on the Yunnan region, we used the comprehensive weight method to determine the weight of each factor, so as to construct the manmade comprehensive resistance surface. Table 2 shows the resistance score and weights of the factors.

Table 2. Human factor resistance scores and weights.

Type	Resistance Score					Weight		
Evaluation Factor	**1**	**2**	**3**	**4**	**5**	**Subjective Weight**	**Objective Weight**	**Comprehensive Weight**
Land-use type	Grass land	Water	Cultivated Land	Bare Land	Construction Land	0.5396	0.2989	0.419
Distance from road	>2000	2000–1500	1500–1000	1000–500	<500	0.2970	0.4286	0.363
Distance from footprint of human activity	>1000	1000–800	800–600	600–500	<500	0.1634	0.2725	0.218

(3) Construction of comprehensive resistance surface

Alongside the natural and manmade resistance surfaces, we constructed the minimum cumulative resistance surface around Dianchi Lake using a weighted grid calculation.

2.3.3. Ecological Corridor Extraction and Optimization

(1) Construction of ecological security network based on MCR model

Using the cost distance method in ArcGis, we calculated the ecological corridors between two sources according to the minimum cumulative resistance surface, which was

constructed by integrating the natural and manmade resistance surfaces. The formula was as follows:

$$MCR = f \times \min \sum_{j=n}^{i=m} (D_{ij} \times R_i), \quad (5)$$

where MCR represents the minimum cumulative resistance value of diffusion from ecological source patch j to a certain point in space, f is the function of the product $D_{ij} \times R_i$ between MCR and variables, D_{ij} represents the spatial distance between target patch source j and other patch sources i, and R_i represents the diffusion resistance coefficient of patch source i in a certain direction in space.

(2) Evaluation of ecological corridor importance based on gravity model

We introduced the gravity model [33] to calculate the interaction force between two ecological sources. A greater interaction force between sources suggests a higher importance of constructing corridors between them [34,35]. Therefore, we categorized the corridors into important and general ecological corridors according to the gravity value [36]. The formula was as follows:

$$G_{ab} = \frac{N_a N_b}{D_{ab}^2} = \frac{\left[\frac{1}{P_a} \times \ln(S_a)\right]\left[\frac{1}{P_b} \times \ln(S_b)\right]}{\left(\frac{L_{ab}}{L_{max}}\right)^2} = \frac{L_{max}^2 \ln(S_a) \ln(S_b)}{L_{ab}^2 P_b P_b}, \quad (6)$$

where G_{ab} is the interaction force between core patches a and b, N_a and N_b are the weight values of the two patches, D_{ab} is the standardized value of potential corridor resistance between patches a and b, P_a is the resistance value of patch a, S_a is the area of patch a, L_{ab} is the cumulative resistance value of corridor between patches a and b, and L_{max} is the maximum cumulative resistance of all corridors in the study area.

2.3.4. Ecological Corridor Network Optimization Based on Network Structure Index Evaluation

Network structure indexes are used to quantitatively analyze the connectivity and complexity of an ecological network [36], with the α, β, and γ indices being the most common [37]. The alpha index (also called the loop pass degree) refers to the number of nodes in the network that could be connected, describing the possible extent of connectivity [38]; the beta index (also called the line point rate) describes the average number of connections (corridors) belonging to each node in the network; the gamma index (also known as the connection degree) represents the rate of corridor saturation, reflecting the degree of network connection. The index computation formulas are as follows:

$$\alpha = \frac{l - v + 1}{2v - 5}, \quad (7)$$

$$\beta = \frac{l}{v}, \quad (8)$$

$$\gamma = \frac{l}{3(v - 2)}, \quad (9)$$

where l is the number of corridors, i.e., the number of ecological corridors in the ecological network, and v is the number of nodes, i.e., the number of ecological sources or stepping stones.

3. Results

3.1. Ecological Source Identification Results

Figure 3 shows the ecological sources identified around Dianchi Lake according to MSPA. After performing the calculations, we identified 8381 core areas, indicating that the habitat fragmentation in the study area was serious. A larger core area can provide a larger habitat for organisms, which is highly important for the survival and reproduction of species. We selected 17 core areas with an area larger than 1000 hm^2 as ecological foci. According to the possible connectivity index of the sources and the overall connectivity

index, we selected 12 sources with high connectivity. Table 3 shows the dIIC, dPC and Source Type of the source areas.

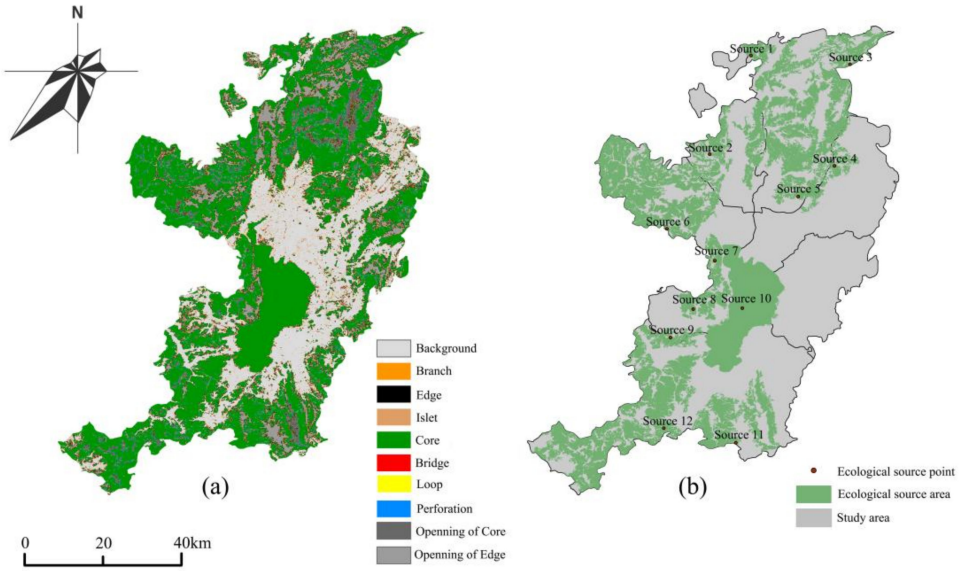


Figure 3. Identification of ecological sources: extraction result of ecological sources based on MSPA (**a**), and selection result ecological source based on Conefor (**b**).

Table 3. Importance index values for ecological source areas.

Number	Area (hm^2)	dIIC	dPC	Source Type
1	2401	1.570495	2.023994	Sheepfold Mountain Range
2	4013	14.44456	22.67083	Biandan Mountain—Black Mud Mountain Range
3	43,000	34.25792	38.17062	Changchong Mountain Range, Songhua Dam Reservoir, Luoshuidong Reservoir, Qinghua Reservoir, Panlong River
4	3597	2.418848	3.774734	Yeyahu Ecological Area, Tiansheng Dam Reservoir
5	4833	3.250011	4.735686	Pingding Mountain Range, Dongda Forest Park
6	35,786	24.157	28.58676	Qipan Mountain—Dayakou Mountain Range
7	3390	2.307571	3.57774	Xishan Mountain—Daqingshan Mountain Range
8	5167	3.582198	5.424817	Huosduo Mountain—Caifeng Mountain Range, Dianchi National Key Scenic Area, Shicheng Scenic Area
9	4132	3.394046	4.225554	Anshan Mountain—Heijian Mountain Range
10	30,364	25.49712	30.35946	Dianchi Lake and coastal wetlands (South Dianchi Lake National Wetlands, etc.)
11	15,119	11.09165	10.15178	Mada Mountain Range, Sanjian Mountain Range, Caihe Reservoir
12	37,898	36.04618	37.37583	Jiyao Mountain—Lvpao Mountain Range

Among them, Dianchi Lake, Changzi Mountain, Xishan Mountain, and Jiyaoshan demonstrated the highest comprehensive importance index values, while several other high-quality ecological source areas were located in the east and southeast. The human activities around Dianchi Lake have a great influence on the retention of ecological sources, and the core areas of Dianchi Lake are separated from other sources to varying degrees. Not only the area of a source but also its connectivity to other sources can affect the movement and survival of organisms and significantly improve its importance.

3.2. Construction of Comprehensive Resistance Surface

(1) Construction of natural factor resistance surfaces

Taking account of the resistance surfaces for elevation, slope, aspect, vegetation coverage rate, and distance from water source, we established a comprehensive natural factor resistance surface for the construction of ecological corridors around Dianchi Lake (Figure 4). The comprehensive natural factor resistance value ranged from 1 to 4.608. As evidenced in the natural factor resistance surface model, the geography of the Dianchi Lake region is relatively complex, with mountains surrounding a flat area in the middle. The altitude range is large, and the mountainous forests are richer in natural resources. The

overall model showed that the resistance to biological activities was lowest near the water sources, while the natural barriers in the mountainous areas with high altitude ranges, such as those containing ridges and cliffs, provided high resistance to biological activities.

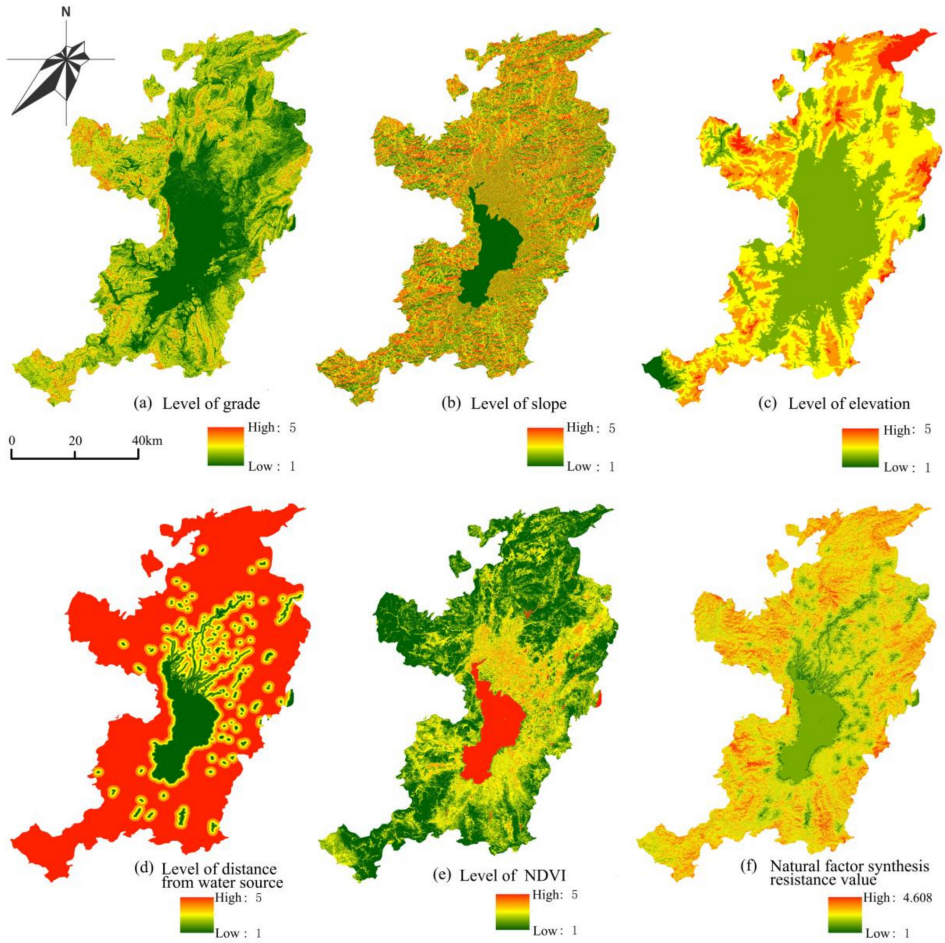


Figure 4. Natural factor resistance surfaces: grade resistance surface (**a**), slope resistance surface (**b**), elevation resistance surface (**c**), distance from water source resistance surface (**d**), NDVI resistance surface (**e**), and natural factor synthesis resistance surface (**f**).

(2) Construction of human factor resistance surfaces

Taking account of the resistance surfaces for land-use type and distance from road and human footprint, we established a comprehensive human factor resistance surface for ecological corridor construction around Dianchi Lake (Figure 5). The comprehensive resistance value ranged from 1 to 5. As shown in the model, human activities are very common in the study area, and the human factor resistance value was highest in the northern, eastern, and southern regions surrounding the Dianchi Lake. Infrastructure such as expressways and railways often broke up high-quality ecological sources in the surrounding areas to form several smaller patches.

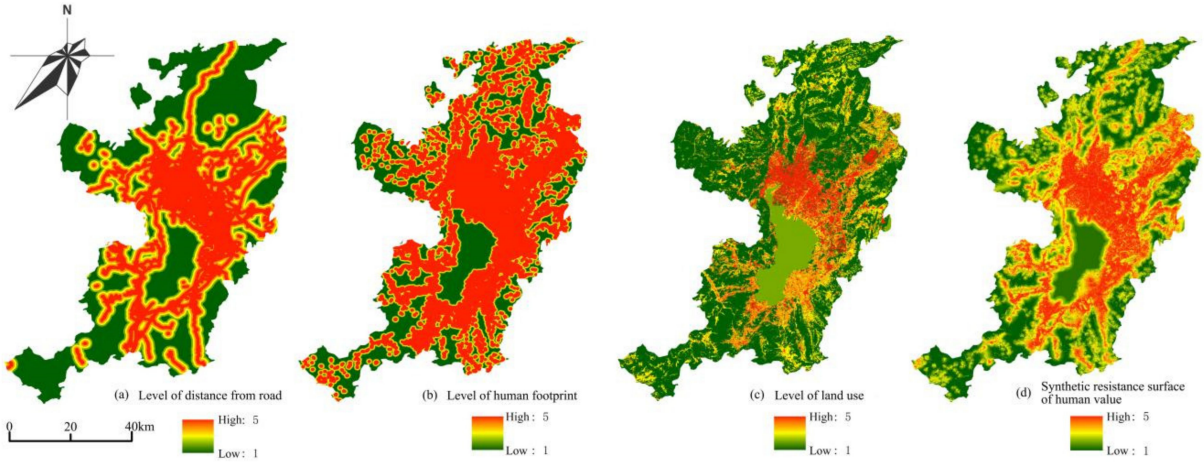


Figure 5. Human factor resistance surfaces: land-use type resistance surface (**a**), distance from road resistance surface (**b**), distance from footprint of human activity resistance surface (**c**), and human factor synthesis resistance surface (**d**).

(3) Construction of comprehensive resistance surface

We established a comprehensive resistance surface for the construction of ecological corridors around Dianchi Lake by calculating the weights of the comprehensive natural factor resistance surface and the comprehensive human factor resistance surface (Figure 6); the comprehensive resistance value ranged from 1.0925 to 4.5395. The human factors substantially influenced the resistance surface of the study area, with human production and living spaces presenting a considerable obstacle to the reproduction, survival, and migration of other species. However, the resistance surfaces varied widely between factors, and human activities and urban development mostly occupied the relatively flat areas close to water sources (with a higher habitat quality).

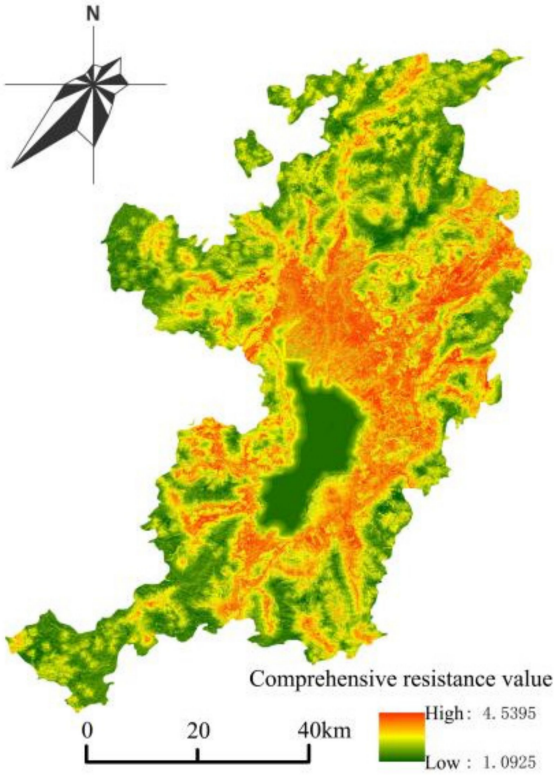


Figure 6. Comprehensive resistance surface.

3.3. Construction of Ecological Security Pattern

(1) Construction of ecological corridor network

On the basis of the comprehensive resistance surface, we used the ArcGis tool to establish a potential ecological network of pairwise sources via the cost distance method (Cayh-path); Figure 7 shows our results. We identified 66 ecological corridors. We used the gravity model to quantify the interaction forces among the 12 ecological sources and calculated the importance of the ecological corridors between them (Table 4). We categorized ecological corridors with interaction force values higher than 50 as important corridors and those with values lower than 50 as general corridors. We identified 26 important corridors and 40 general corridors, which formed our ecological corridor network for the Dianchi Lake area. Several important corridors connected the high-quality natural resources in the north and south areas of Dianchi lake, with most corridors distributed in the Dianchi Lake and northern forest regions. The intensive urbanization and human activities in Kunming, which is located to the east of the Dianchi Lake ecological source, made it unsuitable for a biological flow channel. As a result, forming a relatively complete ecological network was difficult. Most of the biological flow could only run from south to north. Dianchi Lake became the main core of the ecological network, representing an important area for the reproduction, transition, and flow of species across the whole region. However, their simplicity, length, and weak connection with the eastern regions meant that the corridors were not ideal for the flow and exchange of species.

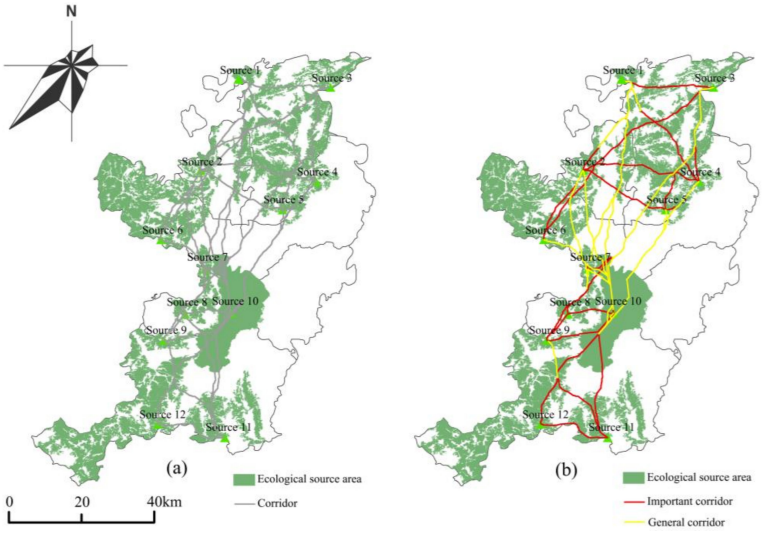


Figure 7. Ecological corridor network: extraction results of ecological corridors based on MCR (**a**), and selection results of ecological corridor based on gravity model evaluation (**b**).

Table 4. Interaction force matrix of ecological sources.

Number	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	84.03	151.48	55.76	42.56	27.35	16.98	10.93	9.89	18.43	7.13	7.87
2		0.00	47.73	62.44	71.16	127.55	55.56	25.98	20.53	44.85	12.06	13.32
3			0.00	97.07	54.18	19.78	15.75	10.81	9.98	18.41	7.20	7.94
4				0.00	322.47	23.55	25.75	16.15	14.76	32.74	9.63	10.63
5					0.00	38.88	48.31	24.94	21.62	56.17	13.02	14.37
6						0.00	202.93	58.11	39.31	91.38	17.83	19.66
7							0.00	222.26	94.16	393.72	28.31	31.36
8								0.00	540.36	466.46	43.95	68.42
9									0.00	281.04	68.60	145.17
10										0.00	77.93	86.01
11											0.00	241.60
12												0.00

(2) Optimization of ecological corridor network

Considering the poor integrity and functional defects of the existing ecological network, rather than starting again from scratch in our study of the lake's ecological area, we used the Conefor unicom index as the main indicator of success to select, in addition to the original 12 sources, five areas larger than 1000 hm^2 with a potential ecological source connectivity greater than 0.1. The selected sources had high-quality ecological environments but poor connectivity with other sources, thus representing useful stepping-stone areas. Future planning and construction projects should consider the importance of stepping-stone patches and improve the ecological network by building ecological corridors. We used the MCR model and cost distance method to identify 70 corridors between potential and existing ecological sources and applied the gravity model to select 56 corridors with strong interaction forces. After eliminating 13 repeated corridors, we finally established an ecological network for the Dianchi Lake region. We identified 26 important corridors, 40 general corridors, and 43 potential corridors (Figure 8). We used the network structure index to quantitatively analyze the ecological corridor network before and after optimization. The α index (loop pass degree), β index (line point rate), and γ index (connectivity degree) were 2.895, 5.5, and 2.2 before optimization and 3.206, 6.412, and 2.422 after optimization, respectively.

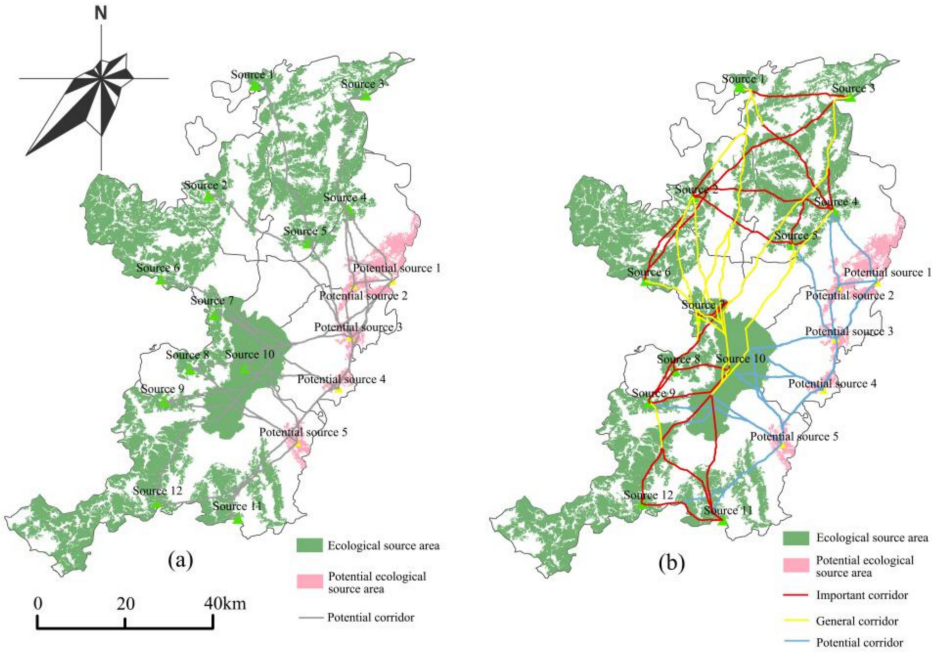


Figure 8. Optimization results of ecological corridor network: extraction results of potential corridors based on MCR (**a**), and selection results of comprehensive corridor based on gravity model evaluation (**b**).

(3) Construction of ecological security pattern

The construction of the ecological security pattern included corridor distribution, stepping-stone construction, and ecological node selection. Ecological nodes are springboards and turning points of species, generally located at the weakest point of corridor function and mainly composed of minimum path and maximum path crossing points or minimum path crossing points [24]. The study area was strongly influenced by human activities, and the internal land use of the ecological source area was complex and heterogeneous. In our selection of ecological corridors, we did not follow the methods of other studies, which only connected the edges of the ecological source areas and ignored the connectivity within the source area. We also divided the ecological nodes into in-source nodes and out-source nodes according to their functional focus. The nodes within the sources were focused on the protection and regulation of the current environmental situation, so as to provide optimal conditions for the flow of species, while the nodes outside the sources were focused on improving the balance between human activities and ecological concerns

and providing the basic conditions for the flow of species between sources. By analyzing and screening the "ridge lines" and "valley lines" in the resistance surface model using ArcGIS, we extracted 21 ecological nodes, including 13 nodes inside the sources and eight nodes outside the sources, as shown in Figure 9.

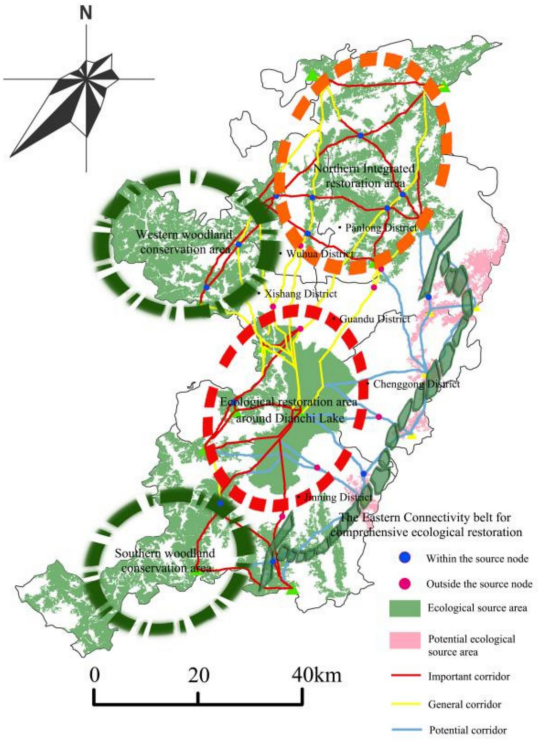


Figure 9. Ecological security pattern for Dianchi Lake area.

By analyzing the characteristics and problems of the study area, we established an ecological security pattern strategy for the Dianchi Lake region. Specifically, using Dianchi Lake as the core for guidance, we constructed an ecological protection pattern based on a "one core, three regions, and one axis" model, as shown in Figure 9.

One core: The ecological restoration area around Dianchi Lake. This area mainly consists of Dianchi Lake and the surrounding coastal wetlands and green space. As the largest freshwater lake in the Yunnan–Guizhou Plateau, Dianchi Lake is Kunming's "mother" lake, and it presents advantages over other areas in terms of both its ecological value and geographical location. Thus, in addition to the current ecological protection line around Dianchi Lake, we should draw a ring around the Dianchi Lake ecological restoration area, within which any development and construction activities that are not conducive to the area's ecological protection are banned. The Dianchi Lake source area should play a central role in the ecological security pattern of the region, and planners should improve the construction of the ecological corridor network and increase its connectivity with other regions by implementing greenways, including lake, riverfront, and urban greenways, so as to establish a high-quality urban plateau lake environment.

Three regions: (1) Comprehensive ecological restoration area in the north. This area covers important mountain forest ecological sources such as Changzi Mountain and Shiyangquan Mountain, as well as water ecological sources such as Songhuaba Reservoir and Panlong River. It is rich in ecological and tourist resources and provides an important urban water source. However, as Wuhua, Xishan, Panlong, and Guandu, four regions with a long history of development and a high intensity of human activity, separate this region from Dianchi Lake, the connectivity between the two areas is poor, and the construction of an ecological corridor would be time-consuming and difficult. At the same time, it is a key area for the future construction of an urban ecological greenway and the improvement of regional ecological protection. Planners should establish an ecological restoration area,

ecological conservation area, and ecological construction area in combination with the "Green Yunnan" and Dianchi Lake regional hierarchical protection plans. (2) Western woodland conservation area and (3) southern woodland conservation area. These areas lie to the west of the Xishan and Qipan mountain ranges and to the south of the Jining district and Lvpao mountain ranges, respectively. The characteristics of the two regions are obvious. Their environments mostly comprise mountainous forest, which makes development and construction difficult, and their connection with the main urban areas of Kunming is weak; hence, the impact of human activities is small. Therefore, the ecological environment in these regions is of high quality, and the degree of ecological fragmentation is low. We should protect these regions' ecological environments, build urban greenways around the mountains, and enhance the connectivity between these and other regions so as to provide an environment conducive to the flow and reproduction of species.

One belt: Eastern integrated ecological restoration connectivity belt. This area is located to the east of Dianchi Lake, representing the main extension area for Kunming's future urban development, connecting the Guandu, Chenggong, and Jinning districts. It has a large longitudinal span and is a potential source area with weak connectivity. The planning and construction of the new airport and high-speed railway and the isolation effects of the main traffic routes are the main reasons for the serious fragmentation and poor connectivity of this region. Planners should restore the ecological damage, establish ecological stepping-stone areas, and plan corresponding corridors to improve the region's connectivity and enhance the ecological exchange with the southern and northern regions and Dianchi Lake.

4. Discussion

We selected the six administrative regions connected to Dianchi Lake as the study area and, considering the relevant planning policies, focused on the balance between urban construction and ecological environment improvement in the plateau lake city. We explored the relationship between human activities and natural species flow to construct a comprehensive resistance surface, ecological corridor network, and ecological security pattern for the Dianchi Lake region. Our conclusions are presented below.

Using MSPA and Conefor software, we identified 12 ecological sources and five potential ecological sources through the comprehensive evaluation of spatial morphology distribution, source area, global connectivity index (dIIC), and patch importance index (dPC). According to the experimental results [39–43], which are basically consistent with the experimental results obtained in related studies, the ecological source areas with high quality can be selected through MSPA and landscape connectivity evaluation, and the areas with good water resources in the region can often become important patches [15]. Through evaluation of landscape connectivity based on Conefor, the combination of two indices (dIIC and dIIC) can enrich the research level and increase the applicability of the results [29]. Considering the regional scale of the study, patches larger than 1000 hm^2 were selected as ecological sources, which are giant patches. Some high-quality sources with smaller areas and some ecological corridor networks linking them may be omitted. In the future, corridor networks with specific functions can be further constructed in smaller precision areas.

Most studies chose a single method to determine factor weights [15,16], which may make the results of resistance surface construction more subjective. We used the analytic hierarchy process (AHP) and entropy weight method to assesses the weight of natural (elevation, slope direction, slope, distance from water source, and normalized difference vegetation index) and human (land-use type and distance from the road and human footprint) factors to build natural and artificial factor resistance surface models, eventually constructing an integrated resistance surface model. This can solve the problem of strong subjectivity of the build results of the resistance surface to a certain extent. However, the method of determining factors and weights selected in this study still has some limitations. The scientific system for the selection of different categories of factors and the determination of weights needs to be further optimized with more research samples.

We identified and optimized an ecological network for the study area using the MCR and gravity models. We used the network structure index to quantitatively analyze the ecological corridor network before and after optimization, improving the α index (loop pass degree), β index (line point rate), and γ index (connectivity degree) to 0.311, 0.912, and 0.222, respectively. Lastly, we identified 26 important ecological corridors, 40 general ecological corridors, and 43 potential ecological corridors. The important corridors were distributed among the sources with high ecological quality, such as the mountainous forest areas of the Jiyaoshan and Changzi Mountains in the north and south, and the sources that demonstrated strong interaction forces with the Dianchi Lake body and the western forest area. Generally, the corridors were distributed in areas with strong human influence and weak interaction between sources (such as Wuhua, Xishan, Panlong, and Guandu) and other highly developed urban areas. The potential ecological corridors were distributed in the eastern regions with strong ecological isolation due to human construction projects, such as high-speed railways, and they connected the potential sources with important sources that had poor ecological quality. Similar to other research conclusions, frequent human activity areas [17] have a strong impact on the habitat and flow of other organisms, and the nature of land changed by human beings is an important reason for aggravating habitat fragmentation [44].

Through the identification of corridors and sources and reference to existing planning policies, we constructed a comprehensive resistance surface and ecological corridor network for the study area. Within this network, Dianchi Lake was the core source, and, using its geographical location as a guide, we established a nuclear, triaxial, and one-belt ecological security pattern for the Dianchi Lake area based on nodes (or points), corridors (lines), and sources (faces) [2]. Both the design of eco-centric node strengthening and the preservation of important node layering must be balanced to successfully protect the region's ecological security pattern [45]. We also offered suggestions for ecological control, restoration, and construction according to the corridor plans of different administrative regions and the types of ecological sources.

5. Conclusions

Compared with previous studies, this study selected representative plateau lakes and urban areas with relatively developed urbanization as the study area. Although the study area has unique natural conditions and biodiversity resources, the rapid urbanization and frequent human activities lead to the deterioration of the regional ecological environment and serious landscape fragmentation. The ecological sources identified in this study using MSPA and Conefor software have the advantages of improved spatial scale, ecological connectivity, objectivity, and comprehensiveness. We considered the influence of eight human and natural factors on the construction of the ecological corridors, and, using a comprehensive weighting method (which combined the analytic hierarchy process (AHP) and entropy weighting method), we calculated the primary and secondary factors. We used the MCR model to construct resistance surface models for both human and natural factors, and we established a comprehensive resistance surface model based on logic and objectivity. Lastly, we constructed and optimized the ecological corridor network using the gravity model and network structure index analysis. We established the ecological security pattern by combining different sources, corridors, and node types. We also proposed strategies for different regions at the district and county level according to the geographical characteristics and planning policies of the study area.

An ecological corridor is a channel for biological flow, which human activities easily disrupt. We considered the geographical characteristics of the urbanized plateau lake study area in the selection of the natural (such as altitude, slope, and distance to water source) and manmade (such as land-use type and the distance from roads and human footprints) resistance factors, and we focused on balancing urban development and ecological security in our solution. This study can provide a useful reference for biodiversity protection and urban development planning in the Dianchi Lake area in the future. It also provides some

methods for constructing ecological corridor network and protecting ecological security pattern in other regions. In view of some shortcomings and limitations of this study, we believe that future studies should be conducted on more specific species and target regions.

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References

1. Yuan, B.; Fu, L.; Zou, Y.; Zhang, S.; Chen, X.; Li, F.; Deng, Z.; Xie, Y. Spatiotemporal change detection of ecological quality and the associated affecting factors in Dongting Lake Basin, based on RSEI. *J. Clean. Prod.* **2021**, *302*, 126995. [CrossRef]
2. Dong, J.; Peng, J.; Liu, Y.; Qiu, S.; Han, Y. Integrating spatial continuous wavelet transform and kernel density estimation to identify ecological corridors in megacities. *Landsc. Urban Plan.* **2020**, *199*, 103815. [CrossRef]
3. Conine, A.; Xiang, W.-N.; Young, J.; Whitley, D. Planning for multi-purpose greenways in Concord, North Carolina. *Landsc. Urban Plan.* **2004**, *68*, 271–287. [CrossRef]
4. Fábos, J.G. Green way plann in gin the United States: Its origins and recent case studies. *Landsc. Urban Plan.* **2004**, *68*, 321–342. [CrossRef]
5. Gu, F.; Huang, Y.X.; Chen, C.M.; Cheng, D.L.; Guo, J.L. Construction and optimization of ecological network for nature reserves in Fujian Province, China. *Chin. J. Appl. Ecol.* **2017**, *3*, 1013–1020. [CrossRef]
6. Biondi, E.; Casavecchia, S.; Pesaresi, S.; Zivkovic, L. Natura 2000 and the Pan-European Ecological Network: A new methodology for data integration. *Biodivers. Conserv.* **2012**, *21*, 1741–1754. [CrossRef]
7. Luo, Y.M.; Li, C.R.; Xie, Y.S.; Wang, Q.N. Landscape connectivity of urban parks in the downtown of Chengdu. *Chin. J. Ecol.* **2020**, *39*, 3796–3807. [CrossRef]
8. Heintzman, L.J.; McIntyre, N.E. Assessment of playa wetland network connectivity for amphibians of the south-central Great Plains (USA) using graph-theoretical, least-cost path, and landscape resistance modelling. *Landsc. Ecol.* **2021**, *36*, 1117–1135. [CrossRef]
9. Luo, Y.; Wu, J.; Peng, J. Using stepping-stone theory to evaluate the maintenance of landscape connectivity under China's ecological control line policy. *J. Clean. Prod.* **2021**, *296*, 126356. [CrossRef]
10. Wu, Y.R.; Wu, J.J.; Bi, X.L.; Li, Y.Z.; Xiao, L.X. To evaluate wetland landscape connectivity in the Yellow River Delta by integrating minimum cost distance model and circuit theory model. *J. Ecol.* **2022**, *42*, 1315–1326. [CrossRef]
11. LaRue, M.A.; Nielsen, C.K. Modelling potential dispersal corridors for cougars in midwestern North America using least-cost path methods. *Ecol. Model.* **2008**, *212*, 372–381. [CrossRef]
12. Pinto, N.; Keitt, T.H. Beyond the least-cost path: Evaluating corridor redundancy using a graph-theoretic approach. *Landsc. Ecol.* **2008**, *24*, 253–266. [CrossRef]
13. Chen, X.P.; Chen, W.B. Construction and evaluation of ecological network in Poyang Lake Ecological Economic Zone. *Appl. Ecol.* **2016**, *5*, 1611–1618. [CrossRef]
14. Jiang, S.M.; Zhang, Y.Q.; Tao, H.C. Construction and evaluation of Green space ecological network in Guangzhou. *J. Sun Yat-Sen Univ.* **2016**, *55*, 162–170. [CrossRef]
15. Wang, X.R.; Wan, R.R.; Pan, P.P. Construction and regulation of ecological security pattern in Taihu Lake Basin—Minimum cumulative resistance model based on spatial morphology. *J. Ecol.* **2022**, *42*, 1968–1980. [CrossRef]
16. Yao, C.Y.; An, R.; Dou, C.; Liu, Y.L. Research on Construction and Evaluation of Forest Land Ecological Network inThree Gorges Reservoir Area Based on MSPA and MCR Model. *Resour. Environ. Yangtze Basin* **2022**, *31*. [CrossRef]
17. Ai, J.W.; Yu, K.Y.; Huang, R.X.; Geng, J.W.; Xie, Z.; Liu, J. The impact of wind power pojects on potential ccological coridors based on the MSPA-MCR Model. *Acta Ecol. Sin.* **2023**, *43*. *in press*.
18. Li, Y.X.; Li, J.; Chen, H.; Wang, Z.J. Landscape connectivity evaluation and temporal-spatial characteristics of Guiyang City from 2008 to 2017 based on MSPA and MCR models. *Chin. J. Ecol.* **2022**, *41*, 1240–1248. [CrossRef]

19. Wu, Z.M.; Yu, Z.X.; Li, Y.; Liu, J. Study on land use evolution and landscape ecological security evaluation in Dianchi Lake Basin. *J. Southwest For. Univ.* **2021**, *41*, 122–129. [CrossRef]
20. Liao, Z.M.; Wang, X. Habitat quality assessment of Dianchi Lake Basin Based on invest model. *Three Gorges Ecol. Environ. Monit.* **2022**, *7*, 11. [CrossRef]
21. Wu, L.Y. Biological species List of Yunnan Province. In *Yunnan Ecological Yearbook*; Yunnan University Press: Kunming, China, 2016; pp. 130–132. (In Chinese)
22. Liu, C.H.; Yang, J.B.; Yin, L. Progress, achievements and prospects of biodiversity protection in Yunnan Province. *Biodivers. Sci.* **2021**, *29*, 200–211. [CrossRef]
23. Wang, S.M.; Dou, H.S. *Lakes of China*; Science Press: Beijing, China, 1998. (In Chinese)
24. Bai, L.F. Study on the Ecological Environment Changes in the Contemporary Dianchi Lake Basin and the Urban Development of Kunming (1949–2009). Ph.D. Thesis, Yunnan University, Kunming, China, 2010.
25. Wang, T.; Li, J.; Chen, C.Y.; Wang, R.F. Zhang lieqin Analysis of decoupling between urban land expansion and economic development in the area around Dianchi Lake. *China's Land Resour. Econ.* **2019**, *2019*, 672–699. [CrossRef]
26. Saura, S.; Pascual-Hortal, L. *Conefor Sensinode 2.2 User's Manual*; University of Lleida: Catalonia, Spain, 2007.
27. Saura, S.; Pascual-Hortal, L. A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study. *Landsc. Urban Plan.* **2007**, *83*, 91–103. [CrossRef]
28. Pascual-Hortal, L.; Saura, S. Comparison and development of new graph-based landscape connectivity indices: Towards the priorization of habitat patches and corridors for conservation. *Landsc. Ecol.* **2006**, *21*, 959–967. [CrossRef]
29. Qi, K.; Fan, Z.Q. Evaluation method for landscape connectivity based on graph theory: A case study of natural forests in Minqing County, Fujian Province. *Acta Ecol. Sin.* **2016**, *36*, 7580–7593. [CrossRef]
30. Yang, X.M. *Study on Water System Connectivity Evaluation Based on Graph Theory—Taking Jiaodong Area as an Example*; Jinan University: Guangzhou, China, 2014.
31. Yi, F.J.; Huang, D.; Liu, J.H.; Qiu, J. Wetland change and ecological health evaluation in Hanjiang River Basin. *J. Geo Inf. Sci.* **2017**, *19*, 70–79. [CrossRef]
32. Li, J.; Yang, L.; Yang, L.; Zhang, C.; Huo, Z.; Chen, M.; Luan, X. Quantitative evaluation of urban ecosystem service flow based on Entropy Theory—Taking Beijing as an example. *J. Appl. Ecol.* **2018**, *29*, 987–996. [CrossRef]
33. Zhang, Y.S.; Qiao, Z.T.; Jing, J.H. Acquisition of equipment testability optimal diagnosis scheme based on comprehensive weight multi-attribute decision model. *Comput. Meas. Control.* **2014**, *22*, 2826–2829.
34. Linehan, J.; Gross, M.; Finn, J. Greenway planning: Developing a landscape ecological network approach. *Landsc. Urban Plan.* **1995**, *33*, 179–193. [CrossRef]
35. Chen, C.D.; Meurk, D.; Colin, I.E.; Maria, S.H.; Wu, S.J. Identifying and evaluating functional connectivity for building urban ecological networks. *Acta Ecol. Sin.* **2015**, *35*, 6414–6424. [CrossRef]
36. Chen, L.D.; Fu, B.J. Ecological significance and application of landscape connectivity. *J. Ecol.* **1996**, *15*, 37–42.
37. Yuan, Z.; Zhao, M.D.; Tian, T.; Liu, R.J. Research on Xi'an urban green corridor network planning. *J. Cent. China Norm. Univ.* **2016**, *50*, 923–929. [CrossRef]
38. Qin, Z.B.; Xuan, J.; Huang, L.J.; Liu, X.Z. Ecological network construction of island city based on MSPA and MCR model—Taking Pingtan Island in Fujian Province as an example. *Res. Water Soil Conserv.* **2022**, *20*, 30. [CrossRef]
39. Kong, Y.; Wang, S.Y. Construction of urban and rural ecological network in Yanqing District of Beijing based on MSPA model. *J. Beijing For. Univ.* **2020**, *42*, 113–121. [CrossRef]
40. Liu, X.; Wei, M.; Zeng, J.; Zhang, S. Ecological network analysis and construction: A case study of the urban agglomeration of the Min River Delta, China. *Resour. Sci.* **2021**, *43*, 357–367. [CrossRef]
41. Huang, M.-Y.; Yue, W.-Z.; Feng, S.-R.; Cai, J.-J. Analysis of spatial heterogeneity of ecological security based on MCR model and ecological pattern optimization in the Yuexi county of the Dabie Mountain Area. *J. Nat. Resour.* **2019**, *34*, 771–784. [CrossRef]
42. Gao, Y.; Mu, H.K.; Zhang, Y.L.; Tian, Y.; Tang, D.W.; Li, X. Research on construction path optimization of urban-scale green network system based on MSP Aanalysis method: Taking Zhaoyuan City as an example. *Acta Ecol. Sin.* **2019**, *39*, 7547–7556. [CrossRef]
43. Huang, H.Y.; Gao, K.Y.; Liu, J. Building Green Infrastructure Network of Fuzhou Using MSPA. *Chin. Landsc. Arch.* **2019**, *35*, 70–75. [CrossRef]
44. Chen, N.N.; Kang, S.Z.; Zhao, Y.H.; Zhou, Y.J.; Yan, J.; Lu, Y.R. Construction of ecological network in Qinling Mountains of Shanxi, China based on MSPA and MCR model. *Chin. J. Appl. Ecol.* **2021**, *32*, 1545–1553. [CrossRef]
45. Xu, L.; Zhang, Z.; Tan, G.; Zhou, J.; Wang, Y. Analysis on the Evolution and Resilience of Ecological Network Structure in Wuhan Metropolitan Area. *Sustainability* **2022**, *14*, 8580. [CrossRef]