Construction of Rural Multifunctional Landscape Corridor Based on MSPA and MCR Model—Taking Liukeng Cultural and Ecological Tourism Area as an Example

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Abstract: Rapid urbanization has caused serious negative impacts on the ecological and human landscapes of rural areas in China. By constructing a network of multifunctional landscape corridors, we can effectively connect landscape patches, reduce the danger of landscape fragmentation, and effectively protect rural areas’ ecological and human landscape resources. With the help of the Morphological Spatial Pattern Analysis (MSPA) research method, the source sites for constructing landscape corridors were selected from the core areas that play an essential role in the performance of regional ecological functions, using the Liukeng Cultural and Ecological Tourism Area as the study area. The results of MSPA analysis are incorporated into the construction of the landscape resistance surface, the landscape corridor network is constructed using the minimum resistance model (MCR) and gravity model, and the landscape corridor network is improved by adding ecological steppingstones and humanistic landscape nodes. The results showed that ten important corridors and 13 secondary corridors were constructed based on 12 source patches in the study area; 5 ecological steppingstones and ten humanistic landscape nodes were added to the optimized network, 21 corridors were added, and 48 ecological breakpoints were proposed to be restored. The optimized network closure (0.65), line point rate (2.15), network connectivity (0.73), and other indicators indicate that the optimized study area has good connectivity of landscape corridors. The study provides a comparative analysis of landscape granularity suitable for mesoscale. Integrating historical and humanistic landscapes into the construction of landscape corridors is an optimization of previous studies that focused only on natural ecology and neglected historical and humanistic landscapes. The study can be a reference for future research on multi-functional landscape corridors and ecological networks in mesoscale and rural areas. At the same time, the construction of multifunctional landscape corridors can promote the conservation of natural and historical human landscapes and the future development of tourism in rural areas.

Keywords: landscape corridor; countryside; landscape connectivity; Morphological Spatial Pattern Analysis (MSPA); minimum cumulative resistance model (MCR)

1. Introduction

The multifunctionality of rural landscapes plays an important role in maintaining sustainable socio-economic development and preserving traditional culture [1]. Chinese rural residents have followed the laws of natural evolution and built a stable landscape system consisting of “nature-society-economy” [2,3]. Rapid urbanization has led to the isolation of ecological and cultural landscapes, increased land use fragmentation, and reduced biodiversity in the countryside [4,5]. In this background, how to properly deal with the relationship between development and conservation, to deal with the contradiction between human and land, and to effectively integrate rural ecological and human resources while meeting rural socio-economic needs and agricultural production is gaining attention [6].
The landscape corridor is a pathway for material transport and energy flow [7], which effectively connects fragmented habitat patches and creates a connected ecological space to reduce the fragmentation of the landscape and achieve the effect of biological protection and environmental improvement [8]. In recent years, the important functions undertaken by landscape corridors have gradually been emphasized, and a lot of research on the construction of landscape ecological networks has been conducted both at home and abroad. Foreign scholars mainly consider the construction of landscape networks in ecologically fragile areas [9], historical and cultural sites [10,11], nature reserves [12] or highly concentrated lands [13,14] to seek a harmonious coexistence between human and natural ecological environment. Although the study of landscape network construction in China is later than in the West, many scholars have focused their research on different aspects: the ecological network can be planned and constructed based on urban and regional development [15,16], or natural landscapes such as nature reserves, rivers and lakes can be targeted to optimize their ecological network functions [17,18], or the ecological safety pattern can be focused on special areas with complex terrain and ecological sensitivity [19,20]; or the ecological network can be optimized for specific species to optimize their habitats [21,22].

The current research on landscape corridors in China is mostly based on protecting the natural environment, selecting the natural resources of the source as the ecological source, and building a landscape ecological network in harmony with the natural landscape [23]. The studies based on MSPA and MCR models in international journals in recent years have also mainly focused on the study of ecological networks and ecological security patterns in large-scale areas such as natural heritage areas [24], watershed scales [25], ecological headwaters [26], highland lake areas [27], national ecological parks [28], and urban centers of large cities [29], with less attention paid to the mesoscale, the ecological and humanistic landscape patterns and corridors in the rural areas. And the landscape has both natural and human attributes, which requires it to be studied in the context of the wholeness of nature and culture. The villages are relatively isolated geographically and culturally, so the rich historical and cultural resources can be preserved and developed [30]. Therefore, it is an effective measure to guide the healthy development of rural areas by paying attention to cultural resources while building landscape ecological corridors and achieving the multiple goals of protecting regional ecosystems and historical and humanistic resources. At the same time, domestic research on rural landscape corridors is mainly focused on the macro level, mostly taking counties, watersheds, or topographic areas as research objects. The specific layout research on landscape corridors at the medium and micro levels is relatively small. It lacks corresponding scientific method support, and the research on rural areas has been neglected for a long time. Located in the hilly area of central Jiangxi Province, the good natural scenery and rich human resources of Liukeng Cultural and Ecological Tourism Zone have led to the rapid development of tourism, which is typical of the rural areas subject to more significant human tourism activities. The selection of landscape granularity data in mesoscale studies has become an essential issue in research. Coarse-grained landscapes with fine-grained areas are most conducive to obtaining ecological benefits from large patches and to the survival of species in multiple habitats, including humans, and provide a more comprehensive picture of environmental resources and faculties [31].

This paper selects objects different from the previous watersheds, urban centers and other large-scale hierarchies and studies the Liukeng cultural eco-tourism area from the mesoscale hierarchy, exploring how to protect the harmonious symbiotic relationship between rural humanities, history, and ecological environment in the context of increasing expansion of human activities in the spatial pattern. Based on the more mature MSPA and MCR models, we compare and analyze the landscape granularity suitable for mesoscale, construct a mesoscale landscape corridor network structure evaluation system in combination with the current situation of the case, and optimize the landscape corridor network using humanistic landscape corridors, restoration of ecological breaks, and addition of ecological steppingstones. The scientific identification of ecological sources, construction of multi-functional landscape corridors, strengthening of ecological and humanistic nodes,
and formation of a reasonable network of multi-functional landscape corridors in the countryside. This way is expected to improve the overall ecological efficiency of the countryside, drive the development of regional tourism, protect the native culture, maintain the stability and sustainable development of the rural areas, and provide methodological references for the work related to rural ecological planning.

2. Research Area and Methods
2.1. Study Area Overview

Liukeng Cultural and Ecological Tourism Zone is a cultural and ecological tourism coverage area delineated in the Tourism Development Master Plan of Le’an County, Jiangxi Province, with the ancient village of Liukeng as the core, expanding upstream and downstream along the Wu River, including many surrounding villages and mountains; the area is located in the eastern part of Le’an County, Fuzhou City (Figure 1a), 115°42′31″ E–115°49′5″ E, 27°14′5″ N–27°19′22″ N, with a total area of about 57.25 km²; the area belongs to the subtropical monsoon climate zone, with a mild and humid climate, sufficient rainfall and four distinct seasons; the terrain in the territory is high from north to south and low in the middle, with Wu Jiang River crossing the middle of the study area and flowing gently from southeast to northwest, with low mountains, hills, hillocks and small basins interspersed, with elevations of 81–551 m. The ecological quality of the ecological tourism area of Liukeng is excellent, with a woodland area of 36.8 km², accounting for 64.43% of the total area (Figure 1b); biological resources are abundant, with a variety of wild animals such as hares and wild boars, as well as birds of prey such as turtledoves, egrets, and whiteheads [32]. At the same time, the region has a long history and culture. Not only the historical pattern of Liukeng Village is well preserved and rich in types of cultural relics and monuments, but also the ancient temple of Xiejia Village, the red stone pagoda of the Qing Dynasty, the Hidden Lotus Temple, and other human resources worth protecting.

Figure 1. (a) Location of the study area; (b) and current land use map.
2.2. Data Sources and pre-Processing

The basic data used in this study mainly includes land use data, elevation data and planning text data for the Liukeng Cultural and Ecological Tourism Zone in 2021, which are mainly obtained from (1) Google Earth satellite image data for the study area in 2021 with a resolution of 2 m; (2) ALOS digital elevation data of the study area with a resolution of 12.5 m; (Data source: https://search.asf.alaska.edu/, accessed on 16 December 2022) (3) The data of tourism landscape resource points in the study area and related thematic planning results, etc.

In processing the data, the satellite image map of the study area was first visually interpreted in ArcGIS to classify its land into seven categories: arable land, forest land, grassland, water, construction land, roads and other land, and to extract the vector data of construction land, roads and water bodies among them; And the land use type vector files were converted into raster files with different image sizes. This study’s slope and elevation data were obtained by placing ALOS digital elevation data in ArcGIS using projection, cropping, and slope analysis components.

2.3. MSPA-Based Ecological Source Site Identification

Morphological Spatial Pattern Analysis (MSPA) is a method by Vogt [33] et al. to identify and divide the raster data of an area into a series of operations with the help of the basic principles of mathematical morphology. This facilitates the precise decomposition of landscape space from the perspective of spatial morphological structure and is currently used in identifying and selecting ecological source sites [34,35].

The current land use types in the study area were used as the basis and converted into pixel-size raster layers. According to the research needs, three types of natural elements, forest, grassland, and water, were extracted as foreground, and the remaining four types were used as background, which were then converted into TIFF format binary raster files and imported into Guido Toolbox 3.0 software for analysis. After MSPA analysis, the foreground was divided into seven categories of non-overlapping landscape structures: Core, Islet, Perforation, Edge, Loop, Bridge, and Branch. Considering that the study area is small, but there are many large patches, the study granularity is too large to reflect the details of the landscape, while the granularity is too small to fragment the results. The results of MSPA with six different landscape grain sizes from 5 m to 80 m were compared and analyzed, and the final landscape grain size used in the study was determined to be 20 m (Figure 2). 20 m × 20 m can meet the accuracy requirements of the study data and can better preserve the important ecological patches in the study area.

Figure 2. Comparison of MSPA landscape types with different landscape grain sizes in the study area.
2.4. MCR-Based Resistance Surface Construction

The minimum cumulative resistance model (MCR) was first proposed by Knappen as a model to measure the spatial cost of species transfer from ecological source areas to other areas [36]. The model calculates the pathway with the least cumulative resistance in space by constructing a resistance surface to provide the best pathway for species migration dispersal and energy flow [37]. The basic equation of the minimum cumulative resistance model is as follows:

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

where \(D_{ij}\) represents the spatial distance of species from source \(j\) to landscape unit \(i\); \(R_i\) represents the magnitude of resistance of landscape unit \(i\) to species movement; \(f\) represents the minimum resistance on a landscape unit with a positive functional relationship with ecological processes [38], and MCR is the calculated result of the minimum cumulative resistance value.

First, based on the results of the MSPA analysis, the larger core area is the structural element in the ecological network, and considering that the ecological elements of woodland, grassland and water are extended and connected, it is identified as the ecological source area. After that, different resistance coefficients are assigned to different elements of the region in terms of the degree of interference and blocking effect on biological activities and energy transfer, and the regional resistance surface is obtained by superposition. In this paper, we refer to existing research [39, 40] considering the influence of both natural environmental factors and socio-economic factors on these ecological processes. Following the principles of easy access and quantifiability, we construct a system of resistance factors in the natural and social dimensions, including six indicators of elevation, slope, land type, distance from water bodies, distance from settlements, and distance from roads, and classify them according to the degree of resistance to ecological processes, and finally assign corresponding weights to each factor to obtain a resistance surface evaluation system for the study area (Table 1). After obtaining the resistance surface, the cost distance and cost path tools under the spatial analysis module of ArcGIS 10.2 software were used to generate the study area landscape corridors.

Table 1. Resistance factor assignments and weights.

<table>
<thead>
<tr>
<th>Resistance Factor</th>
<th>Classification</th>
<th>Resistance Assignment</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (m) [41]</td>
<td>&lt;100</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100–150</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>150–200</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200–300</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;300</td>
<td>90</td>
<td>0.08</td>
</tr>
<tr>
<td>Gradient/(°) [42]</td>
<td>0–2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2–5</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5–15</td>
<td>50</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>15–25</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;25</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Land type [43]</td>
<td>Ecological source sites</td>
<td>1</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>Core</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bridge</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Remaining forest land</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Remaining grass and water</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arable land</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other Sites</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roads, construction land</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>
Using the gravity model [47], the magnitude of the two interactions between patches is calculated and reflected in the matrix to reflect the importance of patch accessibility and connectivity: the greater the interaction, the more indispensable the connectivity between them. Therefore, the degree of interaction between each ecological source site and other source sites in the study area can be quantified to provide a basis for landscape corridor classification extraction. The calculation formula is as follows:

\[ G_{ab} = \frac{N_a N_b}{D_{ab}^2} = \frac{L_{max}^2 \ln(S_a) \ln(S_b)}{L_{ab}^2 P_a P_b} \]  

where \( G_{ab} \) is the interaction value between any two source patches a and b; \( N_a \) and \( N_b \) are the corresponding weight values between source a and b; \( D_{ab} \) is the standard value of corridor resistance between source a and b; \( P_a \) and \( P_b \) are the average resistance values of source a and b; \( S_a \) and \( S_b \) are the areas of source a and b; \( L_{ab} \) is the value of corridor resistance between source a and b; and \( L_{max} \) is the maximum value of minimum cumulative resistance in the area.

2.5. Evaluation of Landscape Corridor Network Structure

The structure of the constructed landscape corridor network is evaluated using the ecological network connectivity analysis method. Network connectivity is the number of relationships and degree of connectivity between ecological source sites and landscape corridor nodes. The degree of connectivity is a visual reflection of the complexity of the network system and the size of the ecological effectiveness of the landscape structure [48]. A higher degree of network connectivity is conducive to its ecological function. The network closure index (\( \alpha \) index), network connectivity index (\( \beta \) index), and network connectivity index (\( \gamma \) index) are often used to measure the structure of a network system, so this study takes the same approach to evaluate the structure of the corridor network.

The three indices are calculated as follows:

\[ \alpha = \frac{1 - v + 1}{2v - 5} \]  

\[ \beta = \frac{1}{v} \]
where $l$ is the number of corridors; $v$ is the number of corridor connection points, $V \geq 3$; $L_{\text{max}}$ is the maximum possible number of connected corridors. $\alpha$ index and $\gamma$ index take values in the range of $[0, 1]$, and $\beta$ index takes values in the range of $[0, 3]$. Larger values of the three indices imply higher connectivity of the network.

2.6. Optimization of Landscape Corridor Network

Through collecting relevant information and field research, the existing rural human resources in the study area, such as ancient villages and buildings, humanistic sites, historical and legendary places, etc., were organized and visualized using ArcGIS 10.2 software (Figure 3). The region’s human resources are overlaid with the landscape corridor system constructed through the MCR model so that the landscape corridor can connect and integrate human resources based on connecting natural ecological elements. A landscape corridor system combining natural ecological elements with historical and humanistic elements is formed by establishing humanistic landscape corridors, repairing ecological fracture points, and increasing ecological steppingstones to promote the formation of a landscape development model for rural areas where ecology and culture develop together.
3. Analysis of Results
3.1. Identification and Extraction of Ecological Source Sites
3.1.1. MSPA-Based Landscape Analysis

As seen in Figure 2, according to the analysis of MSPA results of different landscape granularity, when the landscape granularity is 5 m and 10 m, although the accuracy is high and woodland, grassland and water are identified as the vast area of the core area, the area of the edge area, the ring road, the bridging area and other areas located at the edge of the core area are too small and do not reflect the edge effect of landscape ecology; When the landscape granularity is 30 m, the analysis results in the identification of the Wujiang River and other woodlands in the study area as mostly bridging areas, so that the function of the ecological land as a source land in the central part of the study area is weakened; When the landscape granularity is 50 m and 80 m, the core area is reduced, and accordingly the other types of areas are too coarse and do not reflect the landscape details of the study area. Therefore, this paper chooses 20 m as the landscape granularity for the study, and the analysis results of the 20 m landscape granularity are tallied (Table 2).

Table 2. Statistical table of landscape type classification.

<table>
<thead>
<tr>
<th>Landscape Type</th>
<th>Area/hm²</th>
<th>% in Natural Landscape</th>
<th>% in Study Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>35.27</td>
<td>86.69</td>
<td>61.60</td>
</tr>
<tr>
<td>Bridge</td>
<td>0.27</td>
<td>0.67</td>
<td>0.47</td>
</tr>
<tr>
<td>Islet</td>
<td>0.03</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Perforation</td>
<td>0.09</td>
<td>0.22</td>
<td>0.15</td>
</tr>
<tr>
<td>Edge</td>
<td>4.66</td>
<td>11.46</td>
<td>8.14</td>
</tr>
<tr>
<td>Loop</td>
<td>0.02</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Branch</td>
<td>0.34</td>
<td>0.83</td>
<td>0.59</td>
</tr>
<tr>
<td>Total</td>
<td>40.68</td>
<td>100.00</td>
<td>71.06</td>
</tr>
</tbody>
</table>

From Figure 2 and Table 2, the area of ecological land such as woodland, grassland, and water in the Liukeng cultural ecotourism area is large, accounting for 71.06% of the whole study area, but it is mostly continuous in the mountainous area in the northeast and southwest of the study area, and less distributed in the central river valley. Among the seven types in the foreground, the core area reaches 35.27 hm², which is 86.69% of the area of natural landscape elements and accounts for 61.60% of the area of the whole study area. The scale of the core area is large, and woodland as the core area is distributed in patches in the south and north, and there are also small areas of grassland and rivers scattered as the core area in the middle; Collectively, the core area is well connected in all parts. The edge area is 4.66 hm², which accounts for 8.14% of the whole area and is second only to the core area in size, which indicates that the edge of the core area patch is more complete, and the edge area is well mosaic with the core area with low fragmentation. The bridging area and the spur reached an area of 0.27 hm² and 0.34 hm² respectively, which is 0.47% and 0.59% of the study area. The bridging area is mostly found in the central part of the region and consists mainly of rivers and smaller woodland patches. Both bridging areas and spurs can play a role in material and energy flow in the landscape ecological network, and the small size of these two reflects their limited role as green corridors for material and energy flow. The percentage of these two categories, pore and ring channel is very small, only 0.15% and 0.13% of the study area, implying that there are few fracture places within these patches and the integrity is good. Isolated islands are relatively isolated ecological patches that occupy a small study area and are scattered outside the core area. The islands can serve as steppingstones for organisms.

3.1.2. Extraction Analysis of Important Ecological Source Sites

Core areas provide the highest ecological benefits and play an important role in species conservation and ecological support and can be considered as source sites in the ecological network of the landscape; At the same time, a large core area can better ensure...
the protection of the ecosystem and the function of conservation [49]. Based on this, the area of each core patch was calculated and selected to exceed 0.5 hm$^2$, with a total of 12 patches (Figure 4, Table 3). The ecological source area of Liukeng tourism area is relatively large, with woodland, water, and grassland on the east and west sides, including most of the natural landscapes around Liukeng tourism area, such as Xuefeng Mountain, Beiling Ridges, Xishan Mountain, Xiangxu Peak and Yingzui Ridge. The distribution of ecological source sites is concentrated in the east and west, with more area in the east than in the west. The central part of the Liukeng tourist area is mostly for people’s production and living, so there is a lack of core area patches with larger areas. The total area of ecological source sites in the flow pit tourism area analyzed and screened by MSPA is 30.58 hm$^2$, accounting for 53.4% of the region’s total area.

Figure 4. Spatial distribution of ecological source sites in the study area.

Table 3. Composition of ecological source patches in Liukeng Cultural and Ecological Tourism Area.

<table>
<thead>
<tr>
<th>Patch Code</th>
<th>Patch Area (hm$^2$)</th>
<th>Patch Code</th>
<th>Patch Area (hm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.522</td>
<td>7</td>
<td>1.286</td>
</tr>
<tr>
<td>2</td>
<td>6.280</td>
<td>8</td>
<td>1.172</td>
</tr>
<tr>
<td>3</td>
<td>3.423</td>
<td>9</td>
<td>1.028</td>
</tr>
<tr>
<td>4</td>
<td>3.336</td>
<td>10</td>
<td>0.930</td>
</tr>
<tr>
<td>5</td>
<td>2.610</td>
<td>11</td>
<td>0.908</td>
</tr>
<tr>
<td>6</td>
<td>1.583</td>
<td>12</td>
<td>0.506</td>
</tr>
</tbody>
</table>

3.2. Landscape Corridor Network Construction Analysis
3.2.1. Construction of Resistance Surface Based on MCR Model

The comprehensive resistance surface of the landscape of the Liukeng tourism area is constructed based on six influence factors: elevation, slope, land type, distance from water bodies, distance from residential areas, and distance from roads. As can be seen
from Figure 5, the resistance values in the study area range from 10.81 to 83. In terms of spatial distribution, areas of relatively low resistance are in the northeast and southwest sides of the study area, which are areas of extensive woodland distribution; The areas with high resistance values are in the northwestern and central valleys of the study area. Although the Wujiang River flows through these areas, these areas are widely distributed with settlements and cultivated land where residents and tourists are active, affecting the smooth flow of natural ecological processes and therefore have high resistance values.

Figure 5. Integrated resistance surface of the study area landscape.

3.2.2. Extraction and Identification of Landscape Corridors

Based on the selected source patches and the landscape resistance surface formed by the overlay, the Cost Weighted and Cost Path tools in ArcGIS are used to generate the minimum cumulative cost surface for each ecological source site and the minimum cost path to other source patches, which can yield 66 potential landscape corridors. The relative importance of the landscape corridors was compared based on the gravity model calculating the interaction size between source patches (Table 4), while the importance of the landscape corridors was graded in relation to the actual conditions of the Liukeng tourism area and the location of the main natural elements and settlements. In this study, source site combinations with interaction sizes over four were selected, and the importance of the landscape corridors connecting them was set at level 1. Source site combinations with interaction sizes between 1 and 4 were connected by secondary landscape corridors, and other connections were considered potential corridors due to their low interaction strength. After sorting, ten important landscape corridors, 13 secondary ones, and the rest as potential corridors were obtained (Figure 6). These corridors together constitute the potential landscape corridor network system of the Liukeng Cultural and Ecological Tourism Zone.
Table 4. Interaction matrix between ecological source sites based on the gravity model.

<table>
<thead>
<tr>
<th>No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.4337</td>
<td>0.7284</td>
<td>0.5996</td>
<td>0.4303</td>
<td>0.6777</td>
<td>0.1526</td>
<td>1.6643</td>
<td>0.9299</td>
<td>0.6042</td>
<td>0.6546</td>
<td>1.0348</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>2.0073</td>
<td>0.9181</td>
<td>0.5137</td>
<td>4.9874</td>
<td>0.8809</td>
<td>0.2282</td>
<td>1.2965</td>
<td>13.3124</td>
<td>3.3102</td>
<td>0.3891</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.3016</td>
<td>1.5285</td>
<td>11.2314</td>
<td>0.2621</td>
<td>0.4845</td>
<td>4.6713</td>
<td>5.1801</td>
<td>36.9245</td>
<td>1.1612</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.1406</td>
<td>0.5130</td>
<td>0.5640</td>
<td>0.1813</td>
<td>0.3316</td>
<td>0.3732</td>
<td>0.1645</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1.5084</td>
<td>0.1243</td>
<td>0.4641</td>
<td>0.5549</td>
<td>0.9051</td>
<td>1.4047</td>
<td>1.1887</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0.4636</td>
<td>0.4202</td>
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From Table 4, the degree of interaction between source 6 and source 11 is relatively the highest. These two sources belong to the woodland in the eastern part of the flow pit tourist area, which is close and has good habitat quality, so the resistance of the landscape corridor is the least here and the most favorable to carry out the flow of material and energy, so this landscape corridor needs to be protected in a keyway. These two source patches are in the southeast and northwest corners of the flow pit tourism area, and the distance spans half of the study area. They must cross the area with a large landscape resistance value in the middle, so carrying out processes such as species migration and energy flow between the two sites is difficult. Overall, the number of important corridors connected with the source site 11 is the largest. The source site is in the eastern part of the Liukeng tourism...
area, which provides a good environment for the survival and migration of organisms in the vast surrounding woodland and plays an essential role in enhancing the landscape connectivity of the whole Liukeng tourism area.

From the spatial distribution of the landscape corridors in the Liukeng tourism area (Figure 6), the spatial distribution of the landscape corridor network in the Liukeng tourism area is uneven, and the important corridors are all located in the eastern part of the region. The ecological source sites in the region are distributed in a row, with good habitat quality and low landscape resistance. Hence, the landscape corridors are more complex and conducive to circling and diffusing various ecological processes between the source sites. In the central part of the Liukeng tourism area, many corridors connecting the eastern and western ecological sources pass through here, and it is vital to maintain the landscape connectivity in the central part. When carrying out development and construction, the damage to the landscape corridors caused by human production and living activities should be reduced as much as possible, and efforts should be made to achieve a harmonious coexistence between humans and nature. In the south and north of the Liukeng tourist area, the landscape corridor network is not well developed due to the lack of source patches and the influence of human activities, and there are only a few secondary or potential corridors. In the later landscape construction, attention should be paid to planning new ecological sources and corridors in the south and north of the region so that the landscape corridor system of the Liukeng tourism area can be improved.

3.2.3. Landscape Corridor Network Connectivity Analysis

The ecological resources within the study area are interconnected by the landscape corridors constructed by the least resistance model, forming a connected network of landscape corridor systems. Network closure index ($\alpha$ index), network connectivity index ($\beta$ index) and network connectivity index ($\gamma$ index) were used to evaluate and analyze the network structure of the landscape corridor. Based on the calculation of 12 ecological source sites and 23 important and secondary corridors in the Liukeng tourism area, the $\alpha$ index, $\beta$ index and $\gamma$ index of the Liukeng tourism area were obtained as 0.63, 1.92 and 0.68, respectively. The high $\alpha$ index of the Liukeng tourism area indicates that the landscape corridor network is closed to a high degree, and most of the area can form loops. From Figure 6, except for the absence of landscape corridors in the south, loops are formed in the east and west of the area, constituting a small circular landscape corridor. The $\beta$ index of the Liukeng tourism area is greater than 1, which indicates that the landscape corridor network is more complex, and the landscape corridors can be connected more effectively, except for patch 4 and patch 7, each patch is connected by multiple corridors. The $\gamma$ index of the Liukeng tourism area reflects the connectivity of its ecological source points, and the overall connectivity of the regional ecological source points is high, but again, the eastern part is better connected, and the southern source points lack effective connectivity. Generally, the level of closure and connectivity of the landscape corridor network in the Liukeng tourism area is high. The network structure is relatively perfect, but it is still necessary to pay attention to optimising the landscape corridor network in the south, give full play to the value of the source patches in the south, and focus on constructing the landscape corridor in the south.

3.3. Optimization of Landscape Corridor Network

3.3.1. Adding Key Ecological Steppingstones

Through the landscape corridor network of the Liukeng tourism area constructed in the previous step, it can be found that the essential landscape corridors are located in the woodland areas in the eastern part of the Liukeng tourism area. The resistance value between different source patches in these areas is low, and the connection degree is high, so the landscape corridor system formed is conducive to maintaining the stability of the landscape system in the area; At the same time, the east and the north also have certain landscape corridor distribution, forming a circuit; however, the south of Liukeng tourism
area lacks corridors, and although there are certain ecological source sites in the south, the distance and the obstruction of village construction in the middle make the source sites in the south less connected. Therefore, when optimizing the landscape corridor network, the focus should be on the connectivity of the southern region. Ecological steppingstones are small ecological patches distributed around large patches and act as an intermediate station in the progress of ecological processes. Add ecological steppingstone patches in the southern part of the Liukeng tourist area to enhance the connectivity between the southern ecological source and other sources and improve the skeleton of the landscape corridor network.

Based on the existing ecological source sites, five smaller ecological patches are selected as stepping stones in the south according to the distribution of the current landscape and core area of the Liukeng tourism area, and 14 new landscape corridors are determined through landscape corridor construction as well as gravity model analysis (Figure 7) to make up for the lack of landscape corridors in the south, reduce the fragmentation of the landscape structure, and provide for the circulation and diffusion of species and energy.

Figure 7. Study area steppingstones and additional corridors.

3.3.2. Connecting Rural Human Landscape

According to the investigation and collation of human landscape resources in the Liukeng tourism area (Figure 3), a total of 11 human landscape resources with humanistic value connotations, including Liukeng ancient village, ShuiYan Ming and Qing dynasty ancient architecture group, Wujiang River and ten miles of balsam forest etc. were collated. Through each human landscape resource to establish each ecological patch and other human landscape corridors, because the Wujiang River is a linear element throughout
the whole area, there are several corridors through. It is not considered a human node to build corridors connecting other nodes here. On this basis, we screen out the places with less resistance between humanistic landscape points and select 21 corridors to connect humanistic landscape resources and ecological resources in series. The newly established corridors can be connected to each natural and human node by establishing buffers on land and water, building green infrastructure, and adding small steppingstones to enhance the accessibility of each node.

After the improvement, 15 nodes and 35 corridors were added to the Liukeng tourist area, and 58 important and secondary corridors were optimized (Figure 8). The landscape corridor system can better connect the ecological patches around the Liukeng tourist area with the internal human landscape nodes through the landscape corridors and ecological steppingstones. The optimized landscape corridor system of the Liukeng tourism area was re-calculated for network connectivity, and the optimized obtained optimized $\alpha$ index, $\beta$ index, and $\gamma$ index were 0.65, 2.15, and 0.73, respectively. It shows that the landscape corridor network in the Liukeng tourism area is smoother than before, and the connectivity between nodes and corridors has been improved, while the whole landscape corridor system has achieved the dual objectives of connecting and protecting ecological landscape resources and human landscape resources.

![Figure 8. Humanistic landscape corridor construction.](image)

3.3.3. Restoration of Ecological Breakpoints

When improving and optimizing the landscape corridor network, attention needs to be paid to the continuity of the landscape corridors to ensure that the corridor connections are feasible. According to the comparison between the land use situation and the distribution of the landscape corridor network in the Liukeng tourism area, several types of landscapes,
such as woodland, grassland and farmland, are the main body of landscape corridor composition, which together guarantee the connectivity of the corridor. Ecological breakpoints are areas where ecological processes are impeded. The presence of some obstacles, such as human activities, will not only cause some disturbance to the surrounding habitats but will also cause a break in the initially connected corridor, impeding the movement process of ecological flows between regions and increasing the riskiness of the ecosystem. Therefore, the corridor design of these breakpoints needs to be improved to minimize the adverse effects of human activities. The landscape corridor network of the Liukeng tourism area was overlaid with the current roads and residential patches for superimposed analysis, and a total of 48 ecological fracture points were identified (Figure 9). In the real activities of constructing landscape corridor network, for settlements, we can use vegetation to set up isolation zones or open new connecting paths around to compensate for the breaks; for roads, we can take the form of flyovers to vertically separate human and vehicle activities from ecological processes, or re-plan unreasonable flow routes to enhance the stability of landscape corridor connections.

Figure 9. Distribution of conflict points between landscape corridors and roads.

4. Discussion

4.1. Identification and Extraction Analysis of Ecological Source Sites

Large-scale landscape patterns, From Figure 2 and Table 2, the landscape granularity of 20 m can not only reflect the pattern of different landscape types but also contain a variety of landscape and environmental resource information, which can satisfy the demand for data accuracy at the mesoscale.
4.2. Analysis of Landscape Corridor Network Construction

The construction of the landscape corridor network is mainly accomplished through the following three steps: firstly, based on the MCR model, the resistance surface is constructed by combining the current situation of the case, and the resistance values of different regions are determined [41–46]. In the process of selecting influence factors, different factors should be selected by integrating the special natural geography and human resources of rural areas; then, based on the identified ecological sources [34,35] and the construction of the resistance surface, the landscape corridors are extracted, and ten important corridors, 13 sub-corridors, and a number of other corridors are determined, which together constitute the potential landscape corridor network system in the study area. The relationship between landscape corridors and ecological sources can identify the imbalanced areas of the landscape corridor network, which raises problems and serves as the main direction of optimization; at the same time, through the analysis of the connectivity of the landscape corridor network, the structure of the landscape corridor network is evaluated and analyzed [48]. The key development areas of the landscape corridor network are identified.

4.3. Optimization Analysis of the Landscape Corridor Network

The optimization of the landscape corridor network can be achieved by increasing the number of ecological steppingstones, connecting the rural historical and humanistic landscapes, and repairing the ecological breaks. Among them, increasing ecological steppingstones and repairing ecological breakpoints are realized by restoring and repairing ecological resources. The difficulty of repairing ecological breakpoints and adding ecological steppingstones lies in the integrated consideration of the synchronized construction of a new multi-functional landscape corridor network system; The connection of the historical and human landscape of the countryside is the innovation of this paper; How to integrate the historical and humanistic landscape into the ecological landscape corridor, with the dual functions of landscape viewing and ecological restoration, is a difficult point. The authors argue that this can be achieved by linking natural and human landscapes and increasing the accessibility of nodes by creating waterway buffers, building green infrastructure, and adding small steppingstones. After simulation and optimization in the above three ways, the α, β and γ indices of the optimized network connectivity of the landscape corridor system in the study area are 0.65, 2.15, and 0.73, respectively, which are all improved.

5. Conclusions

Building a network of landscape corridors can play an important role in improving landscape fragmentation, enhancing the stability of regional landscape patterns, and protecting natural and humanistic landscapes. In this study, the Liukeng Cultural and Ecological Tourism Area is used as the study area, and the MSPA method is used to analyze the landscape types in the area and identify the core areas as the basis for establishing ecological source sites; Constructing, extracting and analyzing the network structure characteristics of the landscape corridor network using the MCR model and the gravity model; Finally, the landscape corridor network is optimized by adding key ecological stepping stones, connecting rural human landscapes and repairing ecological breaks.

The results show that: (1) the ecological function-oriented patches in Liukeng Cultural and Ecological Tourism Area are widely distributed, and the 12 source patches screened total 30.58 hm², which is 53.4% of the total area of the area; spatially, they are unevenly distributed, mainly concentrated in patches in the mountains in the eastern and western parts of the area, and there are fewer ecological source patches in the central part. (2) The MCR and gravity model extracted 23 landscape corridors in Liukeng cultural and ecological tourism area, including ten important corridors and 13 general corridors; at the same time, the spatial distribution of the regional landscape corridor network is uneven, with important corridors located in the eastern part of the region and less developed corridors in the southern and northern parts of the region; in general, the initial formation of the regional landscape corridor network is closed, the connection level is high, and the structure
of the corridor system is relatively complete. (3) To further improve the landscape corridor network of Liukeng Ecological and Cultural Tourism Zone, five new ecological stepping stones are added in the south of the area, and ten humanistic landscape nodes are connected in the area, adding a total of 35 landscape corridors and repairing 48 ecological fracture points, the optimized landscape corridor network is smoother than before, which is more conducive to maintaining the local natural ecology and humanistic landscape resources.

Constructs a landscape corridor and connects it with the humanistic landscape, which not only preserves the optimization of the overall landscape pattern on a larger scale, ensures the connectivity of the landscape ecological process and the ecological service function within the region, but also takes into account the protection of the rural cultural heritage in the region, and forming a multi-functional landscape corridor that combines history, culture and ecology, rather than just analyzing the structural form of the landscape corridor. It is recommended that based on the protection of ecological landscape corridors in rural areas it is recommended that historical and humanistic resources should also be integrated into the landscape corridors as optimizing elements.

This study initially constructs a landscape corridor network in the Liukeng cultural and ecological tourism area, evaluates the results and proposes an optimization strategy. However, it is still in the exploration stage, and some shortcomings need to be optimized: (1) In this study, the MSPA method considers the core area with a larger area and higher status in the overall landscape structure as ecological source patches. Although the ecological patches are considered in terms of location and area, the internal landscape components of the patches are not considered, and the connectivity of the patches is not calculated as the basis for judging the importance. (2) The essential ecological function of the landscape corridor is the channel for species migration, and the activity range and migration ability of local species also have an impact on the landscape corridor network, but this study did not select the local dominant species and give the landscape resistance value in a targeted way when constructing the network. More scientific methods of constructing landscape corridors should be continued in future research and practice.

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