Construction of the landscape ecological security pattern of the Yellow River Delta based on circuit theory

Rong Shan¹*, JianChun Li²
¹Shandong Normal University, Student, Jinan, China
²Shandong Normal University, Lecture, Jinan, China
* Corresponding author: Rong Shan@2965536827@qq.com.org

Abstract. With the rapid development of urbanization, land cover and land use patterns have changed, which damages the landscape structure, affects the transfer of material and energy, and reduces the value of ecosystem services. The construction of landscape ecological security patterns is an important challenge that could promote species exchange between biological groups and material and energy exchange between landscape elements and ensure regional ecological security. Few studies have focused attention on the randomness of species to path selection, thus failing to objectively reflect the process of species migration and diffusion. In this paper, according to the circuit principle, the current value between nodes was used to extract strategic points, and the ecological corridor was screened by the cost weighted distance, which is more in line with the analysis framework of species' random selection of a migration path. As an important place for human activities, river basins are important areas connecting surface water with groundwater, land cover and ecosystems. Based on the circuit principle, the landscape ecological security pattern of the river basin was constructed in this paper, which provided some new ideas for protection and management. Taking the Yellow River Delta in the lower reaches of the Yellow River in China as an example, the main conclusions were as follows: (1) The ecological sources of the Yellow River Delta were 34, with forest land and lakes as the main sources, and they were crucial to the stability of the regional ecological security pattern. A total of 49 ecological corridors were identified, among which 32 were key corridors and the rest were potential corridors. The key corridors throughout the whole region need priority protection and can be used as a core area for the observation and monitoring of natural resources. (2) Based on the circuit principle, 14 pinch points and 19 barrier points were identified, indicating that regional habitat connectivity must be further improved. Based on the concept of natural resources life community of mountains, rivers, forests, farmland, lakes and grass, the resource optimization strategy is proposed for the ecological security pattern, which is of great practical significance to maintaining the integrity of the river basin ecosystem.

1. Introduction
With the acceleration of urbanization, urban population growth and economic development increase the demand for natural resources. Most countries and regions are faced with challenges such as resource shortages, insufficient construction space, great pressure on cultivated land protection, and obvious degradation of the ecological environment, all of which restrict sustainable economic and social development. As an important developing country, China's rapid urban expansion and industrialization processes have caused serious damage to the ecosystem in many regions. The increasingly frequent ecological problems, such as floods and drought, soil loss and sharp biodiversity declines, have gradually awakened people's general awareness of ecological security. Under the
strategic positioning of "ecological priority and green development" in China, how to coordinate regional spatial land use and ecological security and reduce the adverse impact of human activities on the ecosystem have become the main topics of focus in regional ecological planning research.

The construction of landscape ecological security patterns has now formed the mainstream paradigm of "Source identification-Resistance surface construction-Corridor extraction-Security pattern construction" [1-3]. Traditional approaches regard ecological corridors as optimal paths for species migration and diffusion, ignoring the randomness of species selection migration paths, and different species usually choose different migration corridors.

In 2006, McRae first incorporated knowledge of circuit principles[4] from physics into landscape ecology. Assuming that the migration process of species in the landscape has similar electronics, namely, random flow in the circuit, multiple moving paths in the basic landscape surface can be identified. The relative importance of habitat nodes and corridors can be determined through the current intensity between the sources to predict species diffusion[5-6] and migration rules and identify the mobile path. This method is more consistent with real species movement[7]. The circuit principle integrates the structural corridor between the ecological sources and breaks through the limitation of the minimal cumulative resistance model identifying only the minimum cost path. Landscape connectivity mainly affects the identification of nodes and is of great significance to the protection and restoration of regional ecological security patterns.

Therefore, based on the statistical analysis of the natural resource observation data, the landscape connectivity of the ecological source patches is analyzed based on the circuit principle. Meanwhile, the corridor design model is used to generate corridors and identify ecological nodes based on the ecological resistance surface and the ecological source. Then, key and potential ecological corridors are identified, and pinch points are identified to be protected and control barrier points to provide a reference for the future development direction, ecological restoration and policy formulation of the river basin.

2. Analytical framework and methods

2.1. Analytical framework

As illustrated in Fig. 1, first, the habitat quality of the river basin was evaluated based on remote sensing, urban planning, roads, natural geography and land use data. Second, we determined the ecological source based on the principles of landscape ecology, constructed a comprehensive resistance surface combined with regional land use type, geomorphic factors and road factors, and used circuit theory and a corridor design model to identify the "ecological corridor", "pinch point" and "barrier point". Finally, according to the "pinch point", "obstacle point" and "ecological corridor", targeted restoration and control strategies were proposed to reconstruct the ecological security pattern of the basin.
2.2. Analytical methods

2.2.1. Ecological source selection

(1) Habitat Quality Model

The habitat quality model \cite{8} is one of the important modules of the InVEST model. In the application principle, the model is evaluated based on the grid, each endowed with a type of land use, and for each evaluated landscape, the model requires a density map (or intensity) of the threat factors on the entire landscape. Based on the above factors, threat data layers are used to assess the degree of habitat quality degradation on different land use types.

Habitat degradation comes from external threats, so habitat quality is evaluated based on the strength and sensitivity of the habitat to the threat source. The habitat quality index is calculated as follows:

\[
Q_{xj} = H_j \left[ 1 - \left( \frac{D_{xj}^z}{D_{xj}^z + K^z} \right) \right]
\]

where \(Q_{xj}\) denotes the habitat quality index of grid \(x\) on land use type \(j\); \(D_{xj}\) is the threat level of \(x\) grids on land use type \(j\); \(H_j\) is the habitat suitability; and \(k\) and \(z\) are scaling parameters that are constants. The value of \(Q_{xj}\) reflects the habitat quality and the fragmentation degree of the land use type under the influence of the threat sources. Plots with high scores show stable ecosystem structure and good habitat quality; in contrast, plots with low scores have poor interference resistance, and the ecological environment is prone to damage.

In determining the optimal granularity level, this paper amplified the granularity with a 30 m grid as the minimum resolution and 30 m as the step length. According to the regularity of the granularity effect of the landscape index, the optimal granularity of the landscape ecological security pattern was analyzed. Nearby ecological patches were constantly merged with increased granularity, and small patches were removed to form landscape components with better connectivity. Combined with the optimal granularity level, the habitat quality was divided into 5 levels by the natural breakpoint method, and the highest level of habitat was selected and systematically screened combined with the division of natural protection sites and forest parks in the river basin.

2.2.2. Construction of Composite Resistance surface

Specemovement between regions needs to overcome resistance, as the basic element of building the corridor, plays an important role in the construction of ecological security pattern. The construction of
comprehensive resistance surface is based on ecology and biology, which has an important role in solving the regional species movement. In this paper, the ecological drag surface model UEER using relative drag factors of different hierarchical sources are considered to calculate the resistance values. Four factors are considered in the model, including source, source grade, distance and base resistance characteristics. The ecological resistant surface can be calculated as follows:

$$UEER = f_{\min} \sum_{i=1}^{n} D_{ij} \times R_{i} \times K_{j}$$

where UEER is the minimum ecological cumulative resistance surface of urban expansion; f is an unknown negative function that represents a negative correlation between minimal cumulative resistance and ecological fitness; min indicates that a landscape unit takes the minimum cumulative resistance to different sources; Dij is the space distance from source j to grid I; Ri is the resistance coefficient of grid i in the process of movement; and Kj is the relative resistance factor of the grade of source j, where the higher the grade of urban land is, the stronger the expansion capacity is, and the smaller the relative resistance factor is.

2.2.3. Corridor construction and key point identification

(1) Corridor construction

McRae first proposed the isolation by resistance (IBR) model, which was used to predict the genetic characteristics of species in complex landscapes. This model was gradually used to predict the migration and diffusion process of biological populations, forming the circuit principle. The circuit principle treats individual species or gene streams as electrons, using the concept of alternative landscape resistance surfaces (resistance map) and treating better-quality plots as nodes (node) of alternative ecological sources. The higher the habitat quality is, the more conducive it is to species migration and the greater the conductivity is. Therefore, the connectivity and the number of potential paths between the two nodes can be reflected by the current voltage, which represents the number and probability of species migration, and the voltage represents the difference between the patches. Based on the Circuitscape4.0 platform, the method is calculated in pairs.

2.2.4. Key point identification

After identifying the ecological corridor, based on the Pinch point Mapper tool, different ecological nodes (source places) and input current were connected to other nodes for iterative calculation. The node that all current (species) must pass is the "pinch point", which is the area with the largest movement density of species, and key protection is required. Additionally, based on the Barrier Mapper tool, the search radius was set to 500 m, and the search was performed by the mobile window method (diameter of D). By representing the improvement coefficient (the size of the connectivity recovery value in unit distance). The greater the improvement coefficient is, the greater the landscape connectivity enhancement value is after this region is removed, thus identifying the birth region with the greatest impact on connectivity.

3. Study area

The Yellow River Delta is located at the mouth of the Yellow River along the Bohai Sea. It is formed by a large amount of sediment deposited by the mouth. It is the largest delta in China and the widest, most complete and youngest wetland in the temperate zone in China. The Yellow River Delta, located on the south bank of Bohai Bay and Laizhou Bay, is located between 117°31'-119°18' E and 36°55'-38°16' N, mainly distributed in Dongying City and Binzhou City, Shandong Province. It is a consortium of ancient, modern and modern deltas.

The Yellow River Estuary Wetland Ecological Tourism Area covers an area of 230,000 mu, all within the Yellow River Delta. The landform is mainly reed marshes and wetlands, followed by the estuary beach, winged-alkali fluffly salt beach wetland, scrub forest wetland and artificial locust forest wetland, integrating natural landscape and cultural landscape. The Yellow River Delta area has rich oil
resources, dense population and developed economy. The development and utilization of the Yellow River Delta has great significance in China’s national economy.

Fig. 2. Regional overview of the the Yellow River Delta.

In recent years, with accelerating urban construction, long-term interaction balance between human and environment is broken, serious Yellow River Delta, serious industrial wastewater pollution, unstable environmental quality, weak links in flood control and disaster reduction, prominent water resource utilization and arduous economic transformation and development, there are many potential ecological threats in the Yellow River Delta. The improvement of the ecological protection quality of the Yellow River Delta plays an important role in the ecological protection of the Yellow River, building the overall ecological security pattern of the Yellow River Delta, strengthening the overall protection and control of ecological elements, improving the stability of the ecosystem, enhancing the service function of the ecosystem, and promoting the harmonious coexistence between human and nature.

4. Result and discussion

4.1. Ecological source identification

When determining the optimal research scale, based on the ecological source, using the landscape pattern index under different granularity levels calculated by Fragstats, 600 m is finally determined as the key point of each landscape index, which can be used as an appropriate reference for the granularity selection of the ecological source. Due to the limited radiation range of fine fragment patches, patches with the area of habitat area greater than 2km² were selected as the ecological source in combination with relevant references.

After calculation, the habitat quality of the Yellow River Delta is shown in Fig. 3., and the average area above 0.43, and the overall habitat quality is high. The high-value area is concentrated in the north and northeast of the research area, with a large area and connected into pieces, mainly located in Wudi County, Lijin County, Kenli District and Laizhou City, and the land use types are mainly mountain and woodland. The low-value area is concentrated in the central and southern urban land, with a small area, mainly located in Dongying City and Shouguang City, accounting for 28.43% of the total area.

The study identified 34 sources, including Shandong Yellow River Delta National Nature Reserve, Mingyue Lake Wetland Park, National Urban Wetland Park, etc., with an area of 80.24km², accounting for 18.34% of the total area, including wetland, grassland and water areas, including wetlands are the main ecological source types.
4.2. Construction of comprehensive resistance surface

Based on the basis of ecological source data, the resistance value builds a comprehensive resistance surface. The area with large comprehensive resistance value is basically located in urban areas with dense manual activity and around roads. Although the farmland has well growing vegetation, due to the influence of human agricultural activities and manual control, the resistance value is 549.50, the minimum of 3.00 and the average value of 84.22. The overall resistance value distribution is relatively fragmented, similar to the basic resistance surface of land use type. After the superposition of the internal resistance value will be different changes in the factor resistance data. Except for the high-value area is concentrated in the central urban and eastern areas, the rest are distributed scattered.
4.3. Key ecological corridors identification
Ecological corridors are the basic structure to maintain regional ecological security by connecting different sources, increase the regional landscape connectivity and maximize the ecological benefits. The Yellow River Delta identifies 49 ecological corridors, including 32 key corridors, 17 potential corridors, and some of the key corridors and potential corridors overlap in specific sections (Fig. 5.), with a total of 236.12 km. Among them, the ecological sources in the east and the north are mainly connected by a short corridor within 1000m, showing fine fragmentation, accounting for 72.74% of the total number of key corridors, and the regional corridors overlap, which is the frequent manifestation of species movement. The ecological sources in the northwest and southeast, the main connecting corridors are 5~10km.

4.4. Key point identification and protection recommendations
Based on the circuit principle of this study, 14 "pinch points" were identified, most of which are in the ecological conservation section, indicating that the protected "pinch points" area can significantly improve landscape connectivity. The land use types of "pinch points" are mainly woodland and water, among which, 11 are river "pinch points". The study identified 19 "barrier points" (Fig. 7.), with land
types mainly for construction land, roads and rural settlements. Since such areas of human activities are often relatively dense, most of the spatial distribution are mostly located at the connection of ecological sources and ecological corridors, which are the key positions of communication. The smaller the area occupied by the barrier point, the smaller the difficult to remove the barrier point. The largest, the number of barrier points with the internal area of the Yellow River Delta is less than 1 hm², accounting for 82.43% of the total number of barrier points. Therefore, there is still large room for improvement in the overall landscape connectivity of the Yellow River Delta.

Fig. 6. Current strength and "pinch point" identification of the Yellow River Delta

Fig. 7. Improvement coefficient and identification of the Yellow River Delta

For the "key points" regional problems, relevant protection measures are put forward in combination with the actual situation of the region. In view of the river pinch points, restoring the river buffer zone, planting ecological protective forests along the coastline, strengthening wetland construction along the river, and improving wetland water conservation are important. Attention should be paid to river pollution control, the control of industrial pollution sources along the line should be strengthened, and the construction of urban sewage centralized treatment facilities should be sped up. Efficient and green pollution-free fertilizer should be promoted, and the development mode of combining industry, sightseeing, ecological functions and agriculture should be implemented. We
should establish a scientific research mechanism for pollution prevention and control, monitor on time, and grasp the dynamics of water environmental pollution in real time. In view of the woodland pinch points, attention should be given to returning farmland to forest and grassland and strengthening the construction of woodland on both sides of the river. Permanent basic farmland, towns, villages and mining rights that have been allocated into the core reserve areas are gradually withdrawn in a gradual and orderly manner. Having been transferred into the general control area the gradual exit in an orderly manner will affect the ecological function. Those that do not cause obvious impacts can be properly handled by measures such as adjusting the scope of general control areas according to laws and regulations to realize the overall protection of the natural ecosystem. Natural conservation sites and nature parks should be strengthened to maintain and protect the biodiversity of forest systems.

In view of the regional problems of "barrier points", combined with the actual situation of the analysis area, the "barrier point" area cannot be directly removed because of some traffic arteries and areas with important living functions; thus, targeted repair measures are proposed. Some functional backward earth and rock dams can be removed, the overflow dams and reservoirs are reserved for diversion and flood control, and vegetation protection along the coast is increased. We should establish a joint scheduling mechanism for the ecological water flow of important reservoirs and river sluice dams, vigorously implement wetland water diversion and water replenishment and saline-alkali land management projects, improve the connectivity of rivers, lakes and reservoirs, and improve the ecological function of wetlands.

5. Conclusion
Natural resources are an important material basis for economic and social development, and comprehensive observation of natural resources and understanding of regional natural resource endowments have become the key to regional sustainable development and ecological security guarantees. With the Yellow River Delta as the research area and remote sensing technology, combined with field research, regional topographic resources, water system resources, road network resources and transportation facilities resources and construction land utilization status were comprehensively observed through land use type data, road data and DEM data. Taking this as a data-based integrated circuit theory, we constructed the ecological safety pattern of the Yellow River Delta, identified important protection and repair areas, and obtained the following conclusions.

First, the landscape ecological security pattern of the Yellow River Delta based on the comprehensive observation data of natural resources identified 34 ecological sources with an area of 80.24km². It was mainly composed of woodland and waters with important ecological functions and rich biodiversity, among which 49 ecological corridors totaled 236.12km. In terms of spatial distribution, the ecological sources and corridors in the southeastern part of the river basin were relatively dense, and the habitat quality was good.

Second, the early urban development of the Yellow River Delta was relatively slow. In recent years, with the increasing density of agricultural activities, the expansion of cultivated land area and the expansion of construction land have posed a threat to the biodiversity of the Yellow River Delta to some extent. This paper identified 14 "pinch points" to be protected, strengthened the ecological service capacity, restored the quality of the ecological background, identified 19 "barrier points" to be repaired, and proposed restoration measures by classification, which still has great room for improving the overall habitat connectivity of the Yellow River Delta. Additionally, the government has set its strategic goal on the construction of an "eco-city". In the future, it will be necessary to grasp and balance various natural resources of mountains, rivers, forests, farmland, lakes, and grass and optimize the protection of pinch points and the restoration of barrier points.

Third, the study divisions were divided into ecological conservation areas, ecological improvement areas and development areas. Among them, the high habitat quality index was found for the ecological conservation area, mainly including ecological source land and other ecological land. Development and construction activities should be reduced in this area to focus on wetland ecological protection. The ecological improvement area was mainly composed of "pinch points", "barrier points" and
ecological corridors, and this area should focus on the protection and restoration of important strategic points, highlighting the construction of the urban wetland park and the urban Yellow River Delta landscape belt. Development areas are necessary areas for urban development and human activities.

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