Ecological remediation zoning of territory based on the "Source-Stream-Sink" Coupler: Case study of Liuzhou city, China

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Abstract. Rapidly increasing demand for land and natural resources has produced problems of man-land contradiction and ecological destruction, threatening the ecosystem's healthy development. Traditional research was often carried out in multiple departments, mainly in ecological remediation projects that have not been inspected by the whole organization system. The master plan formulated by the government department was severely disconnected from the project of local units. No quantitative models have been established to clarify the complex nonlinear relationships between projects, so our cognition of monomer's ecological remediation and the overall pattern are fuzzy. Coupling ecological source and overall pattern allows us to coordinate the relationship between them and enables us to explore the most efficient ecological remediation solutions. We created the "Source-Stream-Sink" Coupler (SSSC) using ecological security patterns to simulate ecological source and the overall pattern coupling and to explore the integration of the two. SSSC simulates the whole process of land ecological remediation pattern construction. It includes three sub-steps: (1) identifying the "Source" of nature; (2) finding "Stream" act on connections; (3) plotting "Sink" with agglomeration effects. We chose Liuzhou city as a case study research area, verifying SSSC can smoothly operate the whole process from ecological source recognition to pattern construction by conducting field research and data embedding. This allows us to identify an optimal ecological remediation zoning of territory pattern.

1. Introduction
Ecological remediation of territory, as one of the 15 major research topics explicitly included by the Ministry of Natural Resources in the "14th Five-Year Plan for the Preparation of Natural Resources", has become an important topic in national territory spatial planning at this stage. Similar to the ecological security pattern, which was one of the three strategic layout optimization goals of the land and space development pattern proposed in the report of the 18th National Congress of the CPC, ecological remediation of territory also attaches importance to the design and optimization of complex coupling systems of ecological space, living space and production space[1]. Doing a good job in ecological remediation of territory is of great significance for practicing ecological protection[2], promoting the construction of ecological civilization, and ensuring the sustainable development of land and space.

Many experts in the fields of ecology, geography, land science, urban and rural planning, remote sensing and geographic information science led by the Institute of Geographic Sciences and Resources of the Chinese Academy of Sciences have conducted in-depth discussions on the core issues and key directions of land and space ecological restoration. Some experts believe that the "theoretical support"
and "review of progress" of land and space ecological restoration are important cognitive foundations for scientifically carrying out ecological remediation of territorial space. They discuss, for example, the core theoretical support of landscape ecology, and summarize the research progress of ecological restoration[3]. Ecological experts attach great importance to "problem diagnosis". They believe that understanding the background of natural resources and diagnosing typical ecological problems are important prerequisites for implementing ecological restoration of land and space[4]. They have carried out related research on typical regions such as the Pearl River Delta, the Yangtze River Delta, and the ecologically fragile areas in the west. In addition, someone regard that ecological remediation zoning, identification of key areas, and implementation of targeted policies are important starting points for the orderly advancement of regional land and space ecological restoration[5]. They focus on the application of technical services, such as ecosystem service supply and demand, ecological security pattern, and multi-objective genetic algorithm in the land space ecological restoration zoning and identification of key areas[5, 6].

In this paper, we draw on the current theories and technologies of many leading scholars and describe the "Source-Stream-Sink" Coupler (SSSC) model, which operates complex interactions between ecological source upgrades to ecological restoration zoning. It draws on the general paradigm of previous studies of ecological security patterns: "identification of origin-establishment of resistance surface-construction of corridor", and has been improved and upgraded. Thus we are able to run delimitation procedures for ecological restoration areas, related research results based on the results of SSSC will serve the local region and have a positive impact on the wider area.

2. Materials and Methods

2.1. Study area and data
Liuzhou, the largest industrial city in Guangxi, is an important logistics transit base from inland China to asean. Liuzhou City is in southern China, north-central Guangxi (Figure 1), and the middle reaches of the Liujiang River, the second largest tributary of the West River in the Pearl River system. The area where Liuzhou is located spans the transition from the second step to the third step in China, and belongs to the karst mountainous area of Southwest China. The rapid development of Liuzhou and the persistent problems of soil and water loss put pressure on both resources and the natural environment. Liuzhou has become an area where the quality of the ecological environment continues to decline and the conflict between society and environmental optimization due to rapid urbanization and industrialization. Sustainable development of Liuzhou city's territorial space faces enormous challenges.
In June 2019, General plan of Liuzhou city's territorial space was printed and distributed by Liuzhou, which means that Liuzhou took the lead in initiating the compilation of national territory spatial planning in Guangxi. As the only pilot city in China that implements the "three rules" of the overall spatial planning, urban master planning, and overall land use planning, Liuzhou proposed the following main objectives of the plan. First of all, finding resource endowments, environmental carrying capacity, characteristics of economic and social development stages. Secondly, solving outstanding problems in land space development, protection and governance. Next, constructing a territorial space pattern with intensive production space, liveable living space and sustainable ecological space. Finally, drafting a set of territorial space development and protection systems that are reasonably used for the regulation of territorial space use. Under such a circumstance, we use Liuzhou as a representative study area to investigate what are reasonable national territory spatial planning and which way is most efficient to achieve success in ecological remediation of territorial space. Integrating large-scale spatial partitioning and small-scale plaque extraction in this case study area will benefit local ecological remediation of territorial space and provide decision support for national territory spatial planning in other regions in China.

The data used in this paper were obtained mainly from the following sources: Guangxi Statistical Yearbook (2011–2018), Guangxi Land Resources Yearbook (2013), Liuzhou Statistical Yearbook (2011–2018), 2019 Liuzhou national territory spatial planning Tri-Tune Database, Landsat 8 OLI satellite images, data on the Open Street Map platform, U. S. Geological Survey MOD13Q1 Product Library Products. The software used in this paper was mainly the following: ENVI5. 1, ArcGIS, MapGIS, QGIS, Fragstats, etc.

2.2. "Source-Stream-Sink" Coupler

The "Source-Stream-Sink" Coupler (SSSC) simulates the coupling and evolution of ecological sources and corridors using environmental ecology. Among them, "Source" is the plaque source, which is the most simple natural background; "Sink" is the integrated sink, which is the morphological pattern and action space formed by the interconnection and collision of plaque sources, have two kinds of forms: corridor and the network; "Stream" is the process of connecting and interacting with "Source" and "Sink", and it is the only way to achieve "Source" to "Sink", and "Sink" acts on "Source". Integration framework and operational process of SSSC are shown in Figure 2. We used SSSC to calculate and regulate the interactions between various activities and elements of ecological system and resource utilization.
Ecological security patterns are at the core of SSSC, enabling it to transform and deductive the interactions between ecological sources and corridors. Ecological security patterns combine qualitative with quantitative methods[7]. Ecological security patterns attach more importance to the support of ecological sources for the stability and sustainability of ecosystems than the previous ecological source identification method by using connectivity models such as minimum cumulative resistance model, gravity model and hydrological analysis, circuit theory, etc. "Source identification-Resistance surface establishment-Corridor construction" has become a general paradigm of ecological security pattern research, which perfectly fits SSSC. Therefore, we used ecological security patterns as the core of SSSC to deduce the coupling between ecological sources and the process of forming corridors, which are a series of complex connections between ecological patches and the overall environmental system. We investigated local ecological sources from many aspects, including land use, ecological sensitivity and ecosystem services to improve our understanding of the natural background. We also constructed the ecological corridors in several ways, including circuit theory and minimum cost path method. The complex relationships between ecological sources and overall pattern are revealed by SSSC.

Figure 2. Integration framework and operational process of SSSC.

2.3. Operation paradigm

2.3.1. Identifying "Source". The task of this part is to identify the ecological source of Liuzhou. Firstly, we applied Fragstats landscape pattern analysis software, adopted the moving window method, selected the radius 500m window, and analyzed the spatial distribution characteristics of landscape pattern indexes such as landscape agglomeration/fragmentation (AI, PD), diversity (PR, SHDI) in Liuzhou. Secondly, we used the unit area value equivalent factor method to quantitatively evaluate the ecosystem service value level of Liuzhou, and integrated the unit area ecosystem service function value base equivalent to calculate the Liuzhou ecosystem service function value. Finally, we carried out an assessment of the sensitivity of the ecological environment in Liuzhou, which can reflect the restoration ability of Liuzhou's ecological land under the disturbance of the internal and external
environment. Terrain, vegetation, water area, agricultural land, natural disaster, soil and water conservation and construction land were extracted as the factor layers of sensitivity evaluation and were assigned with grade. According to the Tri-Tune Database data, using the AHP method, we take \( F_i \) as the ecological sensitivity index of the i-th factor, \( W_i \) as the impact factor of the i-th factor, and \( T_i \) as the comprehensive evaluation score of ecological sensitivity. The corresponding mathematical expression is:

\[
T_i = \sum_{i=1}^{n_{\text{an}}} F_i W_i
\]  

(1)

2.3.2. Connecting "Stream". In this part, we need to strengthen the spatial coupling between ecological sources, that is, to tap potential ecological corridors. Ecological corridors are the expression carriers of "Stream" and the connection link forming the "Sink" of the ecological network. It will be scattered in the relatively isolated urban parks, street green spaces, gardens, nature reserves, agricultural land landscape patches such as rivers, rivers, and mountains are connected to form a dynamic green landscape structural system with certain self-sustainability, and a continuous and complete ecological network is embedded in the urban and regional bases. We use habitat patches identified in 2.3.1 as habitats with good habitat quality or high ecosystem service value as their ecological source, and input their area (S) and weight (N) in the database. In the case of complete data preparation, by using the Circuitscape and Linkage Mapper platforms, with the help of circuit theory and gravity models, we pair the ecological source patches and label their resistance value (P) after choosing a paired calculation mode. Iteratively calculate the normalized resistance value (D) and interaction strength (G) between plaques. Finally, \( L \) will be extracted as the cumulative resistance value between plaques, and its larger values value (such as \( L_{\text{max}} \)) will be extracted as potential main ecological corridors. We can remove redundant L caused by a small value or passing the same patch, and we can get a "Stream" with reasonable distribution and strong connectivity. Arbitrarily selected two plaques a and b, there should be the following mathematical relationship between them:

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

(2)

2.3.3. Plotting "Sink". "Sink" is a collection of "Source", "Stream" is its generation pathway. According to the ecological security pattern theory, we take temporary habitat, barrier point and fragile point as its research subject, ecological remediation zoning and overall pattern will be its ultimate manifestation. In this part, Linkage Mapper will be the main tool for identifying the three subjects. It will be used to obtain temporary habitats by meeting potentially important ecological corridors, identify barrier points through mobile window search method and obtain fragile points by identifying the fractures of ecological corridors.

3. Results and discussion

3.1. Operation results

We accurately identified the natural background and ecological source of Liuzhou through "Source" sub-step. Figure 3 shows the statistics of land use landscape pattern index run by SSSC. We find that the natural ecological background of Liuzhou is superior. Ecological space accounts for 73.36% of the total land use, of which forest land is the absolute dominant landscape type; agricultural space accounts for 21.66% of the total land use, of which cultivated land is the main dominant landscape type; urban space accounts for 4.66% of the land, of which residential and transportation land is the main dominant landscape type. Simultaneously, we compare the data from Figure 4 and found that the value of ecosystem services of forest land is the largest, accounting for about 82% of the total value,
and about 15% of the water area. The spatial distribution of ecosystem service value in Liuzhou city is generally characterized by "low in the middle and high in the north and south", which is closely related to the spatial distribution pattern of mountain forest ecosystem with high ecosystem service value. Based on the comprehensive evaluation results, the optimal landscape components are selected, and the weak and fragmented and sensitive habitat patches produced by the evaluation results of ecosystem service level and sensitivity are deleted. We can preliminary draw the ecological source.

Based on the ecological source selected initially, we extract corridors with interaction forces greater than 800 as important corridors in the city. Then Figure 5 is drawn as the coupling of "Source" and "Stream". We find that in Liuzhou, there are many alternative paths for biological migration in the north and southeast regions; the connectivity of ecological corridors in the central and southern regions is low, and some are broken. This is mainly due to the distribution of ecological sources mainly in nature reserves and forest parks herein.

The identification of the key nodes of the ecological network, just the aggregation "Sink", is the final sub-step and other operating results. We identify the main temporary habitats in Liuzhou City that need to be planned, constructed or repaired, and find that most of them are woodland, grassland and gardens (Figure 9), which are mostly distributed in key parts between long-distance ecological corridors, and there are many in urban areas. The similarity of similar patches is relatively sparse, and it is better to be near liuzhong (Figure 6). Barrier points are mainly agricultural and forestry land and river waters (Figure 10). Most of them are located in suburban areas, and they are an important matrix for ecological corridors in the central and southern regions. Due to the vicinity of human production and living areas, they have strong interference effect on migratory organisms. Affected by geology and geomorphology, barrier points have strong connections between the river and the floodplain (Figure 7). Fragile points are fragmented and fragmented, which are the obstacle to the formation of a complete ecological pattern. These points are mainly land for urban construction and agricultural and forestry plantation in the central and southern regions, mostly roads, dry land and arbor land (Figure 8, Figure 11). Improving the quality of forest land and planting area and returning farmland to forests in some drylands are good strategies to them.
Figure 5. Extraction results of ecological sources and ecological corridors

Figure 6. Spatial distribution and Connection of "temporary habitats" plaque.

Figure 7. Spatial distribution and Connection of "barrier points" plaque.

Figure 8. Spatial distribution and Connection of "fragile points" plaque.

Figure 9. Area and type of "temporary habitats" plaque.

Figure 10. Area and type of "barrier points" plaque.

Figure 11. Area and type of "fragile points" plaque.
3.2. Ecological remediation zoning of territory
We delineated the "three vertical and four horizontal" ecological restoration network pattern. At the same time, we identified the core of Liuzhou's ecological restoration pattern. It is located at the intersection of ecological corridors and is the core of ecological security in the southwestern area. We have also defined five major areas of ecological restoration zoning. They are the northern ecological protection and restoration area, the western farmland protection and improvement area, the eastern natural disaster prevention area, the habitable town development area in the central mountain area, and the southern ecological protection and restoration area. Their respective duties, together with the ecological corridor, constitute the most basic layout of ecological restoration in Liuzhou under the background of national territory spatial planning.

4. Conclusion
We used Liuzhou as a case study to build ecological source and the overall pattern coupling and derived some meaningful conclusions. First, the identification of ecological sources is the most important basic step to solve ecological rickets and build an overall pattern. However, blindly delineating the source area and neglecting to explore the connection between them can cause breakpoints in restoration projects. Thus the key to the rational use of ecological source areas is to grasp the process of coupling between source patches. Second, process integration cannot be ignored. Efforts to build corridors between specific ecological sources will be the basis for precise spatial division. For example, after identifying the resistance surface between plaques, it is easier to get the key areas of ecological remediation. Third, the results of UEC modeling show that, the core idea of ecological remediation zoning by applying the ecological security pattern research paradigm can optimize the multi-level repair network system and establish a multi-scale welfare guarantee for landscape sustainability.

Overall, SSSC can have a positive effect on ecological remediation zoning of territory. SSSC can help determine the most suitable ecological restoration zoning, as the ecological security pattern provides a general research paradigm for national territory spatial planning. It is foreseeable that the
model will be the territorial spatial planning of other similar regions, and it also applies to situations similar to those observed in Liuzhou.

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