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Green space system planning and optimization coupling landscape pattern analysis with spatial models: a case study of Fuzhou, China

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The network structure and connectivity of green spaces play a crucial role in ecosystem functionality. However, there are still many challenges in improving the structure of urban green space systems (GSS) through quantitative scientific methods. In particular, there is an obvious lack of how to integrate quantitative landscape pattern analysis with multi-scenario network analysis, which leads to insufficient scientific and operationalization of green space system optimization. This paper aims to present a methodological framework for planning and constructing green networks within urban green space system planning (GSSP), using the GSSP of Fuzhou as a case study. The results of the study show that: (1) 18 GPAs were classified with GPA 4 (2287.66 km^2) showing the highest connectivity importance (dPC = 88.459); (2) the Min River corridor (GPA 10) and urban coastal wetlands (GPA 17) emerged as strategically vital despite spatial constraints; (3) scenario analysis identified Scenario 1 (α = 0.26, CR = 0.999) as the optimal network configuration. This research establishes a structured GSSP approach that not only addresses urban ecological continuity issues but also provides a replicable model for enhancing biodiversity and ecological health in urban settings, offering insights and implications for achieving sustainable development goals in future regions.

KEYWORDS

ecological corridor, green infrastructure planning, green network, minimum resistance, gravity model, network analysis

1 Introduction

As an integral part of the terrestrial ecosystem, green space plays a crucial role in contributing to human health, urban development, and regional ecology (Hong et al., 2025; Garcia-García et al., 2020). However, research has shown that human activities have had a significant negative impact on green space ecosystems during urbanization (Ghale et al., 2025; Hasan et al., 2020). According to statistics, the built-up area of China increases from 2.24 × 104 km^2 to 6.37 × 104 km^2 from 2000 to 2022, with an average annual growth rate of about 4.87%. This means that the previous urban construction model is becoming more and more outdated in China, which is taking the road of sustainable development, and it is urgent to actively explore the optimization of urban green space system (Jiang et al., 2022).

Meanwhile, numerous studies have confirmed the critical role of green space connectivity in maintaining urban biodiversity and ecosystem services. For example, Fenoglio et al. (2020) showed that habitat fragmentation in urban areas leads to significant biodiversity loss, with insect populations in fragmented green spaces declining by as much as 40%. And Sun et al. (2024) found that increasing the connectivity and area of green spaces can achieve effective cooling. These further emphasize the importance of improving green space connectivity in building urban ecological patterns and promoting sustainable urban development.

In China, large-scale and rapid urbanization has drastically altered land use, particularly through extensive shrinkage and fragmentation of green space, leading to ecological degradation and environmental challenges (Luo et al., 2020; Kuang et al., 2020; Li et al., 2018). In recent years, China has issued a number of strategic documents, including the Strategy and Action Plan for Biodiversity Conservation and the Measures for Evaluation and Assessment of Ecological Civilization Construction Targets (Zhang et al., 2024), to actively promote the expansion of urban green space, the construction of ecological networks and the management of species conservation. Green Space System Planning (GSSP), a specialized form of urban planning in China, plays a vital role in protecting green spaces (Ministry of Housing and Urban-Rural Development, 2019). The focus of GSSP has shifted from primarily addressing urban areas to encompassing the entire city space, moving from secondary importance to a higher-level status that shapes the structure and development of cities. However, research on improving the structure of the city green space system (GSS) through quantitative scientific methods still faces many challenges. Previous studies have focused on green infrastructure and its connectivity at the urban or smaller scale (Zhao et al., 2019; Davies and Lafortezza, 2017). Moreover, converting complex assessment and calculation processes into concise and easy-to-understand image data to support planning needs further study.

This study takes the city GSSP of Fuzhou as an example, focusing on the continuity and connectivity of the GSS, addressing the critical challenge of balancing rapid urbanization with ecological conservation in coastal cities. Focusing on the continuity and connectivity of GSS, we develop an integrated framework for ecological network optimization that combines quantitative landscape analysis with spatial modeling. Firstly, green protected area (GPA) delineation based on Conefor connectivity analysis. Secondly, ecological corridors were constructed through ArcGIS minimum cumulative resistance (MCR) model and strategic nodes were identified using gravity model and network analysis. This paper seeks to answer the following questions: (1) What methods are employed in city-level GSSP? (2) Which tools and software packages can support the planning process? (3) How can assessments and calculations be transformed into clear, concise visual representations that support the planning process?

2 Study area, materials and methods

2.1 Study area

Fuzhou is located in the eastern part of Fujian Province, China, within the southeastern coastal region (Figure 1). It borders the East China Sea to the east, covering a total area of 11968 square kilometers and a coastline of 1137 km. The Min River flows through the city for 150 km, with over 30 tributaries. The city's landscape is primarily characterized by mountains and hills, while tidal flats, plains, and basins make up approximately 30% of the total land area. The forest coverage rate in Fuzhou is approximately 45%, and its rich landscape pattern provides a complex and diverse research scenario for GSSP. However, Fuzhou, as a rapidly urbanizing coastal capital city, faces typical problems such as

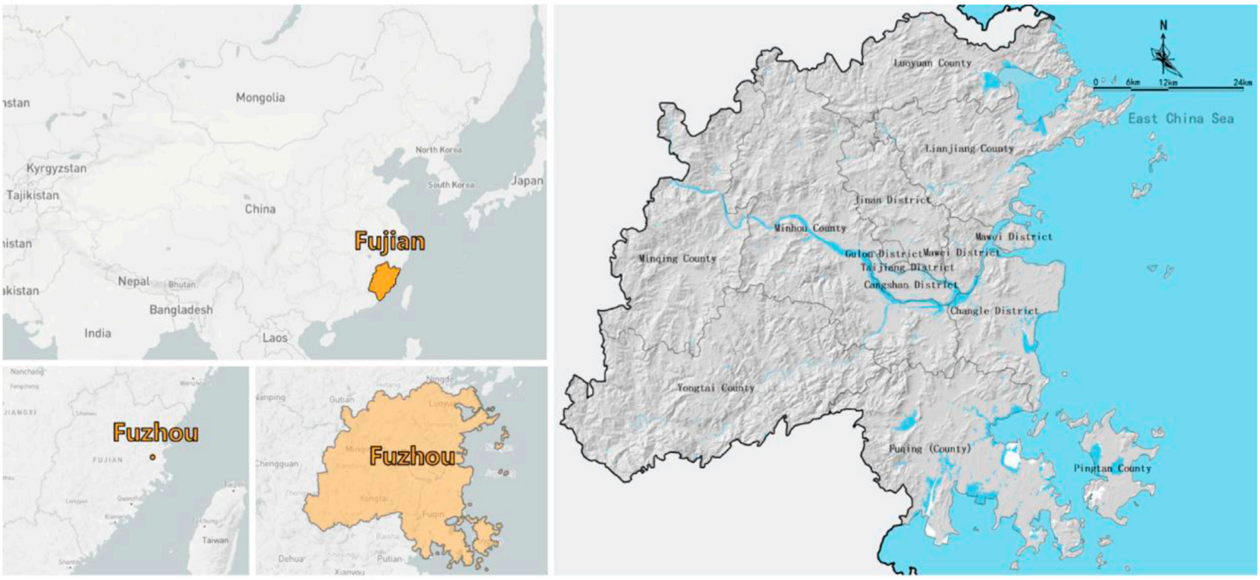


FIGURE 1
Location and map of Fuzhou.

green space fragmentation and impaired ecological connectivity, so it is urgent to optimize its green space system.

2.2 Materials and methods

Primary data for the analysis were sourced from relevant platforms, including the Geospatial Data Cloud and the Geographical Information Monitoring Cloud Platform (https://www.gscloud.cn/sources/?cdataid=302&pdataid=10, http://www.dsac.cn/DataDownLoad/Search?dataID=301400). Information related to the Fuzhou Master Plan was provided by the Fuzhou Planning and Design Institute.

The analysis began with GIS preprocessing of the necessary data. Fragstats 4.4 was then employed to conduct a landscape index analysis to assess current land use patterns. Following this, Conefor 2.6 was used to evaluate connectivity and classify ecological protection areas (GPAs). The minimum cumulative resistance model (MCR) was applied to identify ecological corridors, while the gravity model and network analysis methods were utilized to define the first-level corridors. Finally, green strategic nodes were identified through the intersection of the minimum and minimum-maximum resistance corridors, establishing the "area-corridor-node" structure within the city's GSSP (Figure 2).

2.3 Obtaining a land use raster map

GIS was used to correct and reclassify Fuzhou's land use status data (provided by the Fuzhou Planning and Design Institute), satellite image data, and the Master Planning. There are a total of five land use categories, including arable land, wood land, grass, waters and construction land. And then data were converted into Tiff files as the base map for the remaining analysis work, and resampling the resolution to 100 m, as shown in Figure 3.

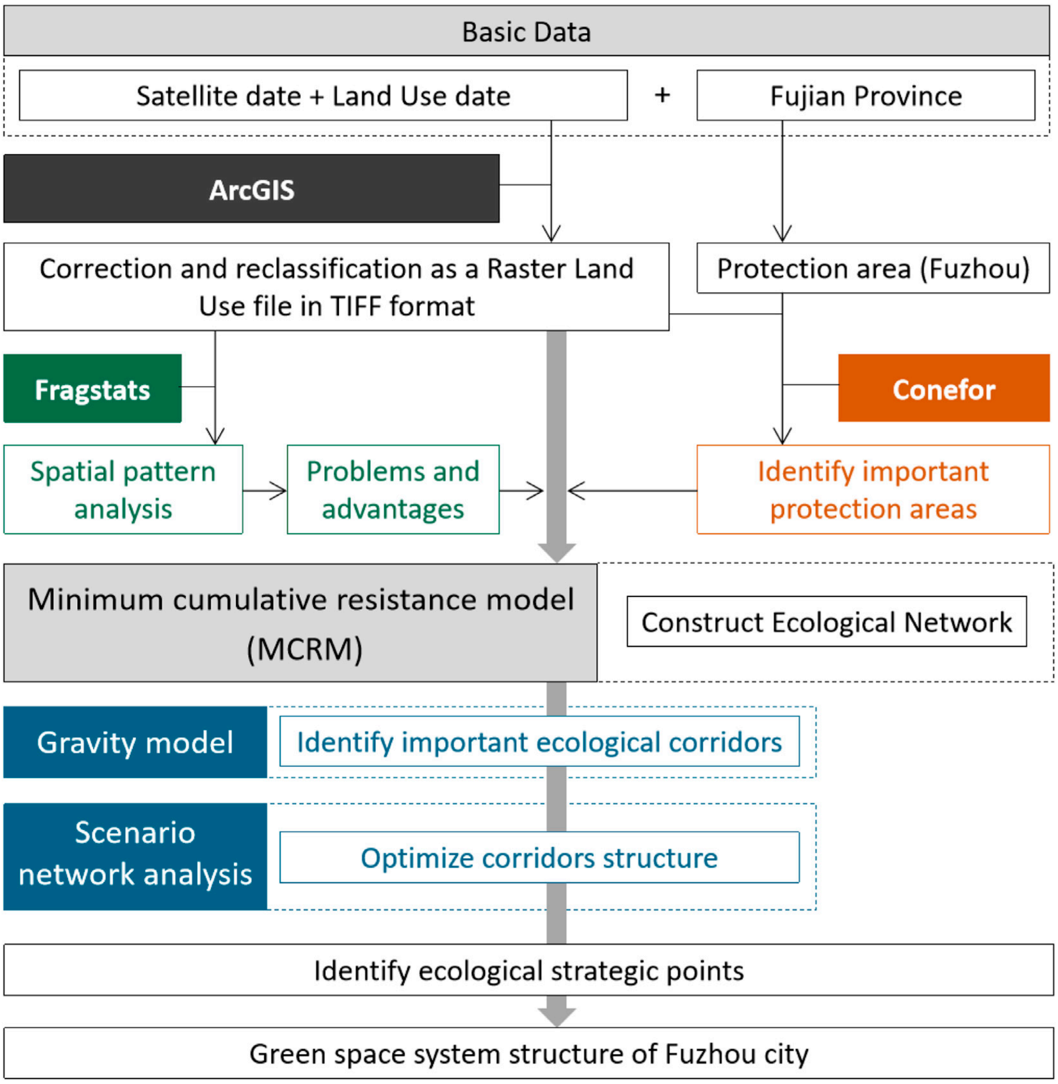


FIGURE 2
Visualization of the research process.

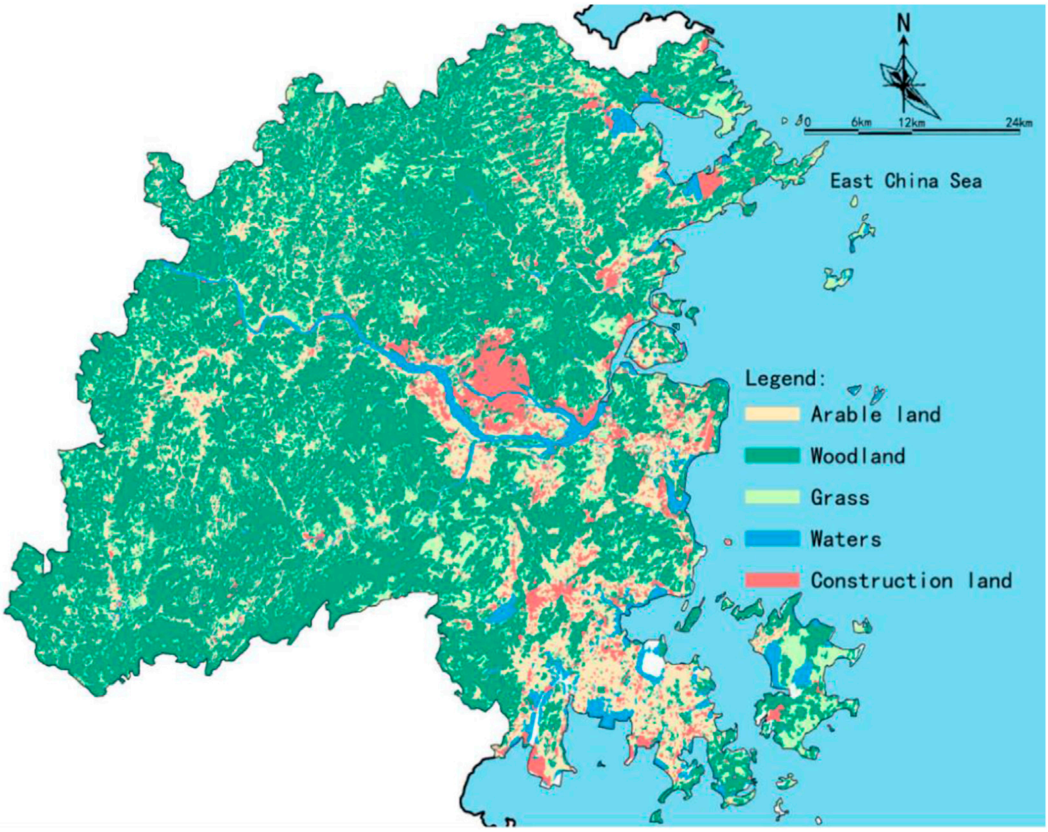


FIGURE 3
Fuzhou city land use status map.

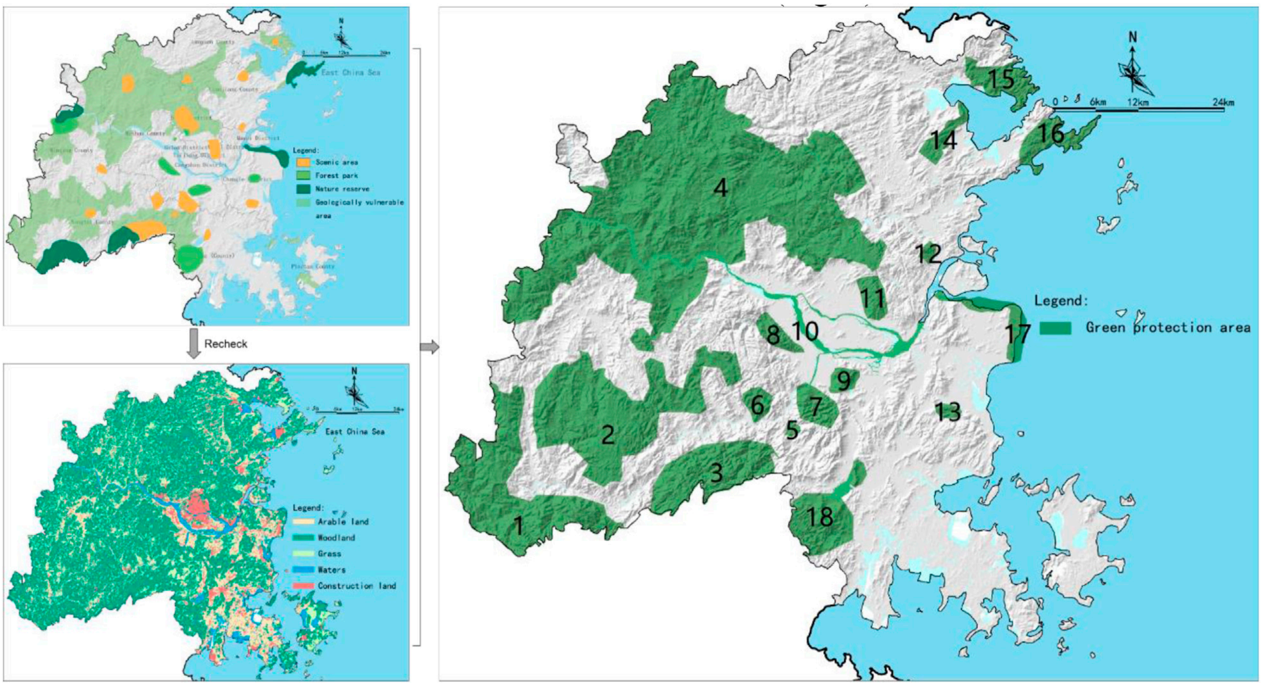


FIGURE 4
Process diagram of GPA determination in Fuzhou.

TABLE 1 Resistance values of different land use types in Fuzhou.

Land use type (current land use coding and classification in China)	Resistance value (range is 1–1000)
01 Arable land	50
02 Orchard land	50
03 Woodland	15
04 Grass	30
Construction land (including 05 commercial land, 06 industrial and mining storage land, 07 residential land, 08 public management domain public service land, 09 special land and 10 transportation land)	1000
11 Waters	500
12 Other land (unused land)	600

2.4 Landscape pattern evaluation method

Landscape pattern index analysis is a critical method in spatial pattern analysis and is considered essential for GSSP (Qiao et al., 2024). Fragstats, one of the most widely used landscape pattern analysis software packages, operates at three analytical scales—patch, class, and landscape—and can analyze over 60 landscape indicators (Bhattacharya et al., 2024). These pattern indices reflect properties such as the type, diversity, complexity, and connectivity of landscape patches. The results from the quantitative analysis of landscape patterns can significantly assist in GSSP. In this study, land use types were categorized into five classes: woodland, grassland, arable land, water, and construction land. Additionally, 11 landscape indices closely related to GSSP were selected for analysis, including class area (CA), percent of landscape (PLAND), and number of patches (NP).

2.5 Classification method of the GPA

Based on scenic areas, nature reserves, and geologically vulnerable zones identified in the Fuzhou Master Plan, ecological land types such as woodland, grassland, and water areas were re-evaluated to delineate 18 GPAs (Figure 4).

Many studies have pointed out that the connection between ecological areas plays a vital role for ecological functions, the maintenance of biodiversity, and ecological vitality (Pietsch, 2018; Montis et al., 2016). We used the probability of connectivity metric (*PC*) to analyze the relationship between GPA and took the importance level (*dPC*) as the primary basis for the classification of GPA. For detailed information on the *PC* and *dPC*, please see Saura

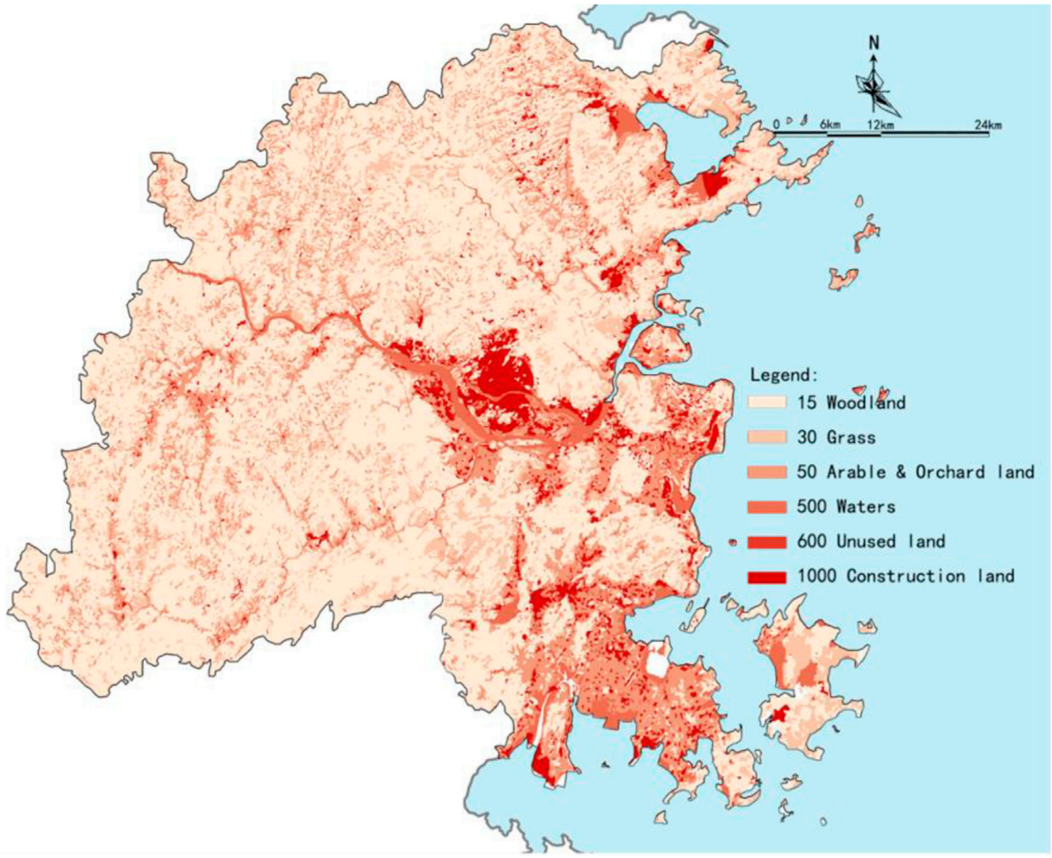


FIGURE 5
Resistance surface of land use in Fuzhou.

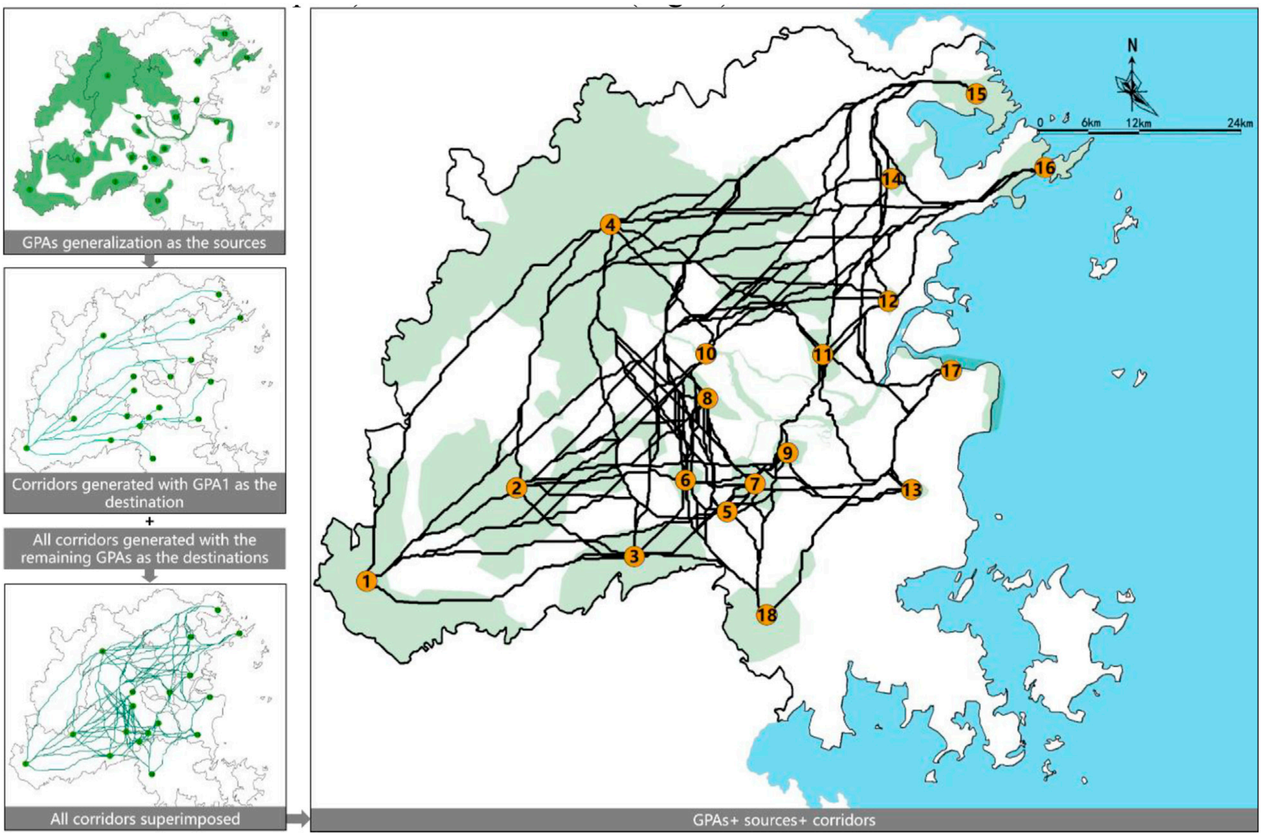


FIGURE 6
Schematic diagram of corridor generation, Fuzhou.

et al. (2011) and Saura and Torné (2009). The calculation formulas used were as follows (Equations 1, 2):

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} p_{ij} a_i a_j}{A^2} \tag{1}$$

$$dPC = \frac{PC - PC_{remove}}{PC} \times 100\% \tag{2}$$

where PC is a graph-based availability metric that quantifies functional connectivity, $0 \leq \mathrm{PC} \leq 1$, the larger the PC value is, the higher the connectivity degree of the GPA is; n represents the total number of GPA in the city area; p_{ij} is the maximum product of all path probabilities between GPA i and GPA j; a_i and a_j are the areas of GPA i and j; A is the total area of the city area; dPC is the change (in %) of the connectivity index after removing one GPA, it represents the importance level of one GPA; PC_{remove} is the overall index value of the remaining GPA after removing a single GPA.

2.6 Minimum cumulative resistance model

Minimum cumulative resistance model (MCR) is a model for calculating the minimum cumulative resistance from a grid-based map on which estimated dispersal resistances basic on landscape types (Guo et al., 2025; Sun et al., 2024). The calculation formula used was as follows (Equation 3):

$$V_{MCR} = f \min \sum_{j=n}^{i=m} \left(D_{ij} R_i \right) \tag{3}$$

where V_{MCR} is the value of the minimum cumulative resistance; f is a positive correlation function between the minimum cumulative resistance and the ecological process; min denotes the minimum value of cumulative resistance produced in different processes of patch i transforming into a different patch j; D_{ij} is the spatial distance between patch i and patch j; and R_i represents the resistance value that exists in the ecological transition. The system of the resistance value will have a significant impact on the results of V_{MCR}. The same patch may have different resistance value for different ecological processes.

Land use type was the main factor for the resistance surface of Fuzhou GSSP. Referencing related studies (Fu et al., 2020) and considering Fuzhou's actual situation, we built the resistance value system, as shown in Table 1. According to the resistance value, GIS (Arc Toolbox - Spatial Analyst - Raster Reclass - Reclassify) was used to develop the resistance surface graphics (Figure 5).

Scholars have used the MCR in the field of ecological planning, with some success (Zhu et al., 2020; Xu et al., 2018). In the Fuzhou GSSP, MCR was used to construct ecological corridors with minimal resistance and green strategic nodes.

TABLE 2 Function-based ecological corridor width specifications.

Type	Width (m)	Functions and features
Biological protection	3–12	Meet the function of protecting invertebrate populations
	12–30	The herbaceous plant diversity is on average more than two times that of the narrow zone; contains most marginal species of herbs and birds, but the diversity is low meet the needs of bird migration protect invertebrate populations protect fish and small mammals
	30–60	Contain more herbaceous plants and edge species of birds, but low diversity; meet the functions of animal and plant migration, spread and biodiversity protection protect fish, small mammals, reptiles and amphibians meet the needs of wild animals for habitat intercept more than 50% of the sediment flowing from the surrounding land to the river control the loss of nitrogen, phosphorus, and nutrients provide organic debris for fish and provide habitat for fish reproduction
	60–100	Herbs and birds with more diversity and internal species; satisfy the functions of animal and plant migration, spread and biodiversity protection the width of the road buffer to meet the migration and biological protection functions of birds and small organisms minimum corridor width for the survival of a variety trees
	100–200	Better protect birds and maintain biodiversity
	200–600	The forest edge effect area is usually 200–600 m; width of migration of medium and large mammals enough to create natural and species-rich landscape structures contain more plants and internal species of birds
Environmental protection	5–200	Effectively intercept and absorb nutrients such as N and P, and reduce sediment in runoff
	30–200	Reduce noise
	10–300	Windproof and moisture proof
	100–500	Effectively filter pollutants and suspended solids in the atmosphere
	≥100	Windbreak and sand fixation

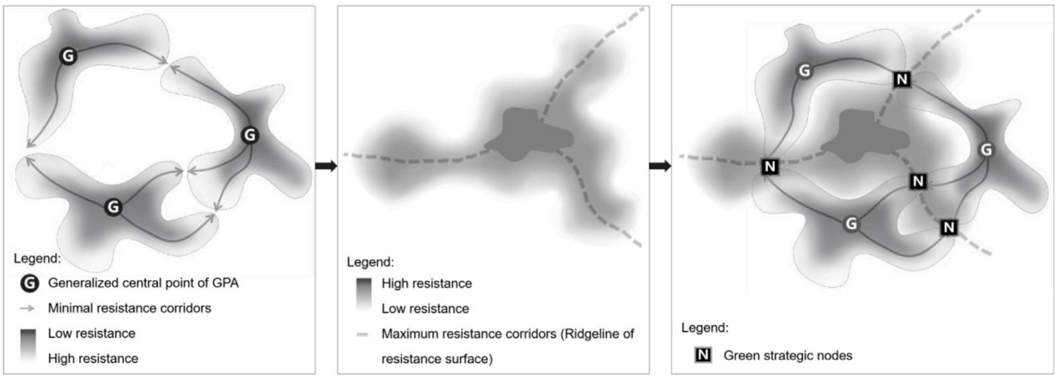


FIGURE 7
Recognition methods of the minimum-maximum value nodes.

2.6.1 Ecological corridors with minimal resistance

GIS (Data Management Tools - Features - Feature to Point) was used to turn GPAs into sources, and to execute path generation commands (Spatial Analysis - Distance - Cost distance/Cost path) to build corridors (Figure 6).

The ecological corridors of the GSS are comprehensive corridors used to prevent the problems of green space fragmentation and ecological function degradation caused by urban development. At the same time, these corridors also provide vital landscape passages (or greenways) for regional recreational activities. The corridors of Fuzhou's GSS were based on the minimum resistance between GPAs. The corridors' main functions determine its width (Liu et al., 2020; Peng et al., 2017), as shown in Table 2.

2.6.2 Green strategic nodes

The green strategic nodes of the GSS can be divided into two categories (Yu, et al., 2018). One is the current node, which is the

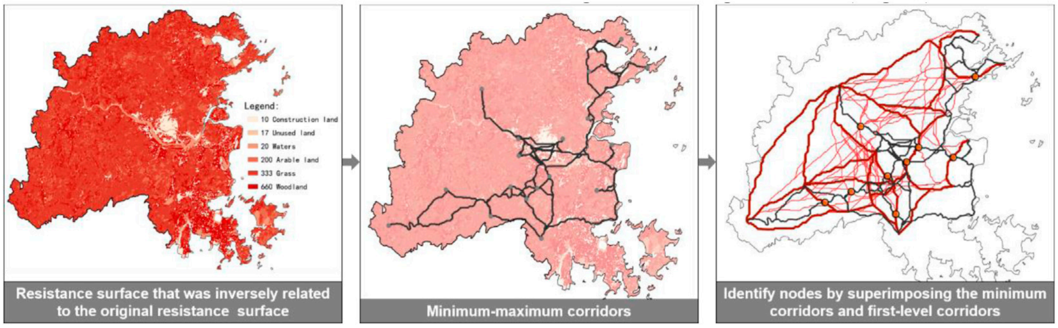
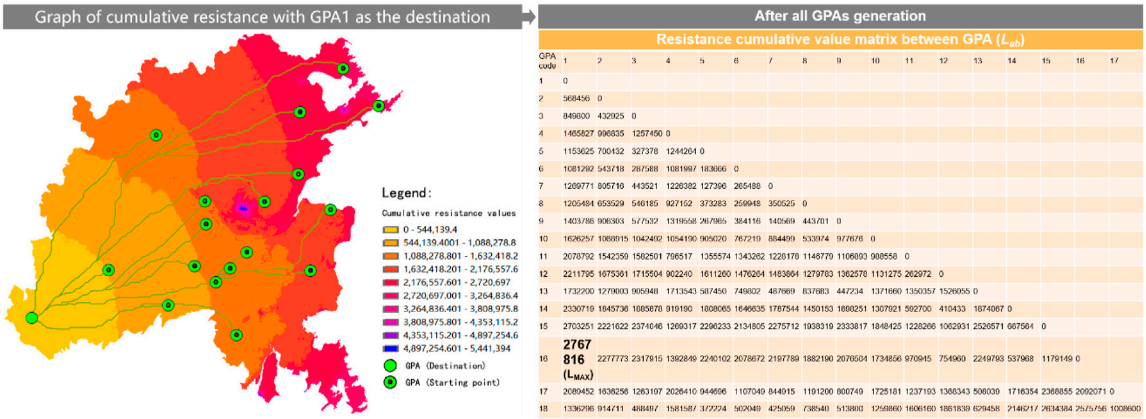


FIGURE 8
Diagram presenting the identification of the green strategic nodes for Fuzhou's GSSP.



After all GPAs generation

Resistance cumulative value matrix between GPA (L_{ab})

GPA code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0																
2	568456	0															
3	849800	432925	0														
4	1465827	996835	1257450	0													
5	1153625	700432	327378	1244264	0												
6	1081292	543718	287588	1081997	183666	0											
7	1269771	805716	443521	1226382	127396	265488	0										
8	1205484	653529	546185	927152	373283	259948	350525	0									
9	1403786	906303	577532	1319558	267965	384116	140569	443701	0								
10	1626257	1068915	1042492	1054190	905020	767219	884499	533974	977676	0							
11	2078792	1542359	1502501	796517	1355574	1343262	1228178	1146779	1106893	988558	0						
12	2211795	1675361	1715504	902240	1611260	1476264	1483864	1279783	1362578	1131275	262972	0					
13	1732200	1279003	905948	1713543	587450	749802	487669	837683	447234	1371660	1350357	1526055	0				
14	2330719	1845736	1885878	919190	1808065	1646635	1787544	1450153	1698251	1307921	592700	410433	1874067	0			
15	2703251	2221622	2374046	1269317	2296233	2134805	2275712	1938319	2333817	1848425	1228266	1062931	2526571	667564	0		
16	**2767816 (L_{MAX})**	2277773	2317915	1392849	2240102	2078672	2197789	1882190	2076504	1734856	970945	754960	2249793	537968	1179149	0	
17	2089452	1636256	1263197	2026410	944696	1107049	844915	1191200	800749	1725181	1237193	1368343	508039	1716354	2368855	2092071	0
18	1336296	914711	488497	1581587	372224	502049	425059	738540	513800	1259860	1606160	1861839	629458	2146217	2634384	2575756	1008600

FIGURE 9
Schematic diagram of L_{ab}.

intersection between the minimal resistance corridors, taking protected measures. The other is the minimum-maximum node, which is in the saddle formed at the tangent part of the equivalent resistance line centered on GPA. It is the minimum-maximum value on the resistance surface, which can be regarded as an area weak in ecological function. Taking a protection patch is the primary measure, and the identification method is as shown in Figure 7.

For the Fuzhou GSSP, we reconstructed a new resistance value that was inversely related to the original resistance value system, and repeated the ecological corridor construction process in GIS. The resulting ecological corridors could be regarded as the maximum corridors of the original resistance surface. The intersection areas of the minimum and the minimum corridors were the green strategic nodes (Figure 8).

2.7 The gravity model for the selection of first-level corridors

Usually, a gravity model provides an estimate of the volume of flows of, for example, goods, services, or people between two or more locations. In recent years, some scholars have used the model in the field of ecological planning and corrected the formula to better adapt to the actual requirements of the planning (Yang et al., 2017a). The formula as shown below (Equation 4):

$$G_{ab} = \frac{L_{\max}^{2} \ln\left(S_a S_b\right)}{L_{ab}^{2} P_a P_b} \tag{4}$$

where G_{ab} is the interaction force between GPA a and b, P_a and P_b are the resistance values of GPA a and b, S_a and S_b are the areas of GPA a and b, L_{ab} is the cumulative resistance value of the corridor between GPA a and b, and $L_{\max}$ is the maximum resistance of all the corridors in the study area. L_{ab} and $L_{\max}$ can be calculated by the Spatial Analyst Tools-Distance-Cost Distance command in GIS (Figure 9).

2.8 Network analysis

Combining with the dPC and G_{ab} of GPA, we simulated five scenarios of the first-level corridors network, which within all the potential ecological corridors generated (Figure 10). The network analysis method (Dalton et al., 1973; Haggett and Chorley, 1972) was introduced to evaluate the five scenarios. Taking the loop

Table of *dPC* value after normalization	
dPC value	GPA code
100.00	4
26.52	2
13.75	10
8.29	1
6.01	7
2.73	11
1.76	9
1.49	3
0.71	8
0.55	5
0.44	18
0.31	6
0.19	17
0.14	15
0.09	16
0.06	14
0.00	12
0.00	13

Table of G_{ab} value (more than 2 after normalization)					
GPA code (a-b)	G_{ab}	GPA code (a-b)	G_{ab}	GPA code (a-b)	G_{ab}
5-7	100	3-8	8	2-9	3
7-9	100	9-13	8	6-13	3
3-6	29	7-13	8	3-13	3
6-7	28	14-16	7	4-6	2
6-8	28	3-9	7	8-13	2
11-12	24	2-8	6	11-16	2
5-9	20	11-14	6	3-4	2
3-5	18	13-18	5	1-6	2
7-8	17	14-15	5	4-7	2
2-3	17	4-11	5	4-15	2
5-18	14	2-5	5	1-8	2
7-18	13	5-6	4	1-4	2
3-7	13	2-7	4	15-16	2
6-9	12	8-18	4	1-7	2
3-18	12	1-3	4	1-18	2
5-8	11	2-4	4	4-9	2
1-2	10	5-13	4	4-5	2
12-14	10	2-18	4	12-15	2
8-9	9	4-14	4	4-16	2
6-18	9	4-8	3	1-5	2
2-6	9	4-12	3	9-11	2
9-18	8	12-16	3	8-11	2

PS: GPA11 is Min river, and GPA17 is coastal wetland

FIGURE 10
The scenario simulations of the first-level corridors network in Fuzhou.

index α, the average connection index β, the network connection degree λ, and the cost ratio index CR represents the network relationship between GPA and first-level corridors. We compared the indexes of the scenarios and selected a better one. The indexes calculation formula as follows (Equations 5–8):

$$\alpha = \frac{l - v + 1}{2v - 5} \tag{5}$$

where α is the loop index, the number of loops present divided by the maximum number of loops possible; l is the number of corridors, and v is the number of GPA.

$$\beta = \frac{l}{v} \tag{6}$$

where β is the average connection index, if $\beta < 1$, there is a dendrogram that occurs; if $\beta = 1$, there is a single circuit; and if $\beta > 1$, it means more complex levels of connectivity exist.

$$\gamma = \frac{l}{l_{\max}} = \frac{l}{3\,(v - 2)} \tag{7}$$

where λ is the network connectivity index, the ratio of the number of links in a network to the maximum number of links possible.

$$CR = 1 - \frac{l}{d} \tag{8}$$

where CR is the cost ration and reflects the network's effectiveness, d is the accumulative resistance of the corridors calculated according to resistance value by using ArcGIS.

TABLE 3 Analysis results of Fuzhou landscape pattern indexes with class-level metrics.

Indicator type		Land use type				
Abbreviation	Name	Woodland (main land of GSS)	Grass	Arable and orchard land	Waters	Construction land
CA (ha)	Class area	698167.78	157771.81	197571.75	46132.09	60436.55
PLAND (%)	Percent of landscape	60.17	13.60	17.03	3.98	5.21
NP	Number of patches	936	3580	2171	527	1516
TE (km)	Total edge	26657.11	15924.07	17732.74	2479.96	4937.78
AREA MN (ha)	Mean Patch Area	745.91	44.07	91.01	87.54	39.87
TCA (ha)	Total core area	698167.78	157771.81	197571.75	46132.09	60436.55
CPLAND (%)	Core area percent of landscape	60.17	13.60	17.03	3.98	5.21
NDCA	Number of disjunct core areas	936	3580	2171	527	1516
CORE MN (ha)	Mean core area per patch	745.91	44.07	91.01	87.54	39.87
CONNECT	Connectance index	0.35	0.09	0.15	0.32	0.17
AI (%)	Aggregation Index	91.22	76.79	79.83	85.92	81.57

TABLE 4 Connectivity level of GPA in Fuzhou City.

dPC	dPC_N (normalized to 100)	Area (km^2)	GPA code
88.459	100.00	2287.66	4
23.467	26.52	658.75	2
12.169	13.75	82.40	10
7.338	8.29	522.93	1
5.324	6.01	66.28	7
2.420	2.73	50.48	11
1.565	1.76	30.49	9
1.324	1.49	266.36	3
0.637	0.71	42.54	8
0.490	0.55	8.07	5
0.393	0.44	183.56	18
0.278	0.31	35.74	6
0.175	0.19	77.30	17
0.127	0.14	96.15	15
0.089	0.09	86.92	16
0.055	0.06	47.19	14
0.007	0.00	12.90	12
0.006	0.00	15.84	13

GPA code corresponds to Figure 3.

3 Results

3.1 Status quo landscape indexes analysis with class-level metrics

The analysis results of landscape pattern indexes in Fragstats 4.2 are shown in Table 3. The woodland, which was the main component of the GPP, had apparent advantages compared with other types of land in terms of CA, CONNECT, AI, PLAND, and TE. The analysis showed the landscape base of Fuzhou city as well. For the GSSP, the main task was to protect the green quantity and maintain a green space structure.

3.2 Classification of the GPAs

Conefor is a software package that allows quantifying the importance of habitat areas and links for the maintenance or improvement of connectivity. We took the *dPC*, a significant index of Conefor, to evaluate the critical level of the GPA, setting a distance index of 1000 m and corresponding to a probability of 0.5. To facilitate the comparison between GPA, we normalized the results to 100, as shown in Table 4.

According to the *PC* and *dPC* formulas, the area of GPA has a positive relationship with its *dPC*. The results (Table 4) showed that for GPA 10, the Min River, although the area was small, but because it crossed the city and *dPC* was high. GPA 6, 7, 8, 9, and 11 were located in the urban area and also in the center of the entire city, a smaller area with a high *dPC* value, which meant an essential position in the overall structure of the GSS.

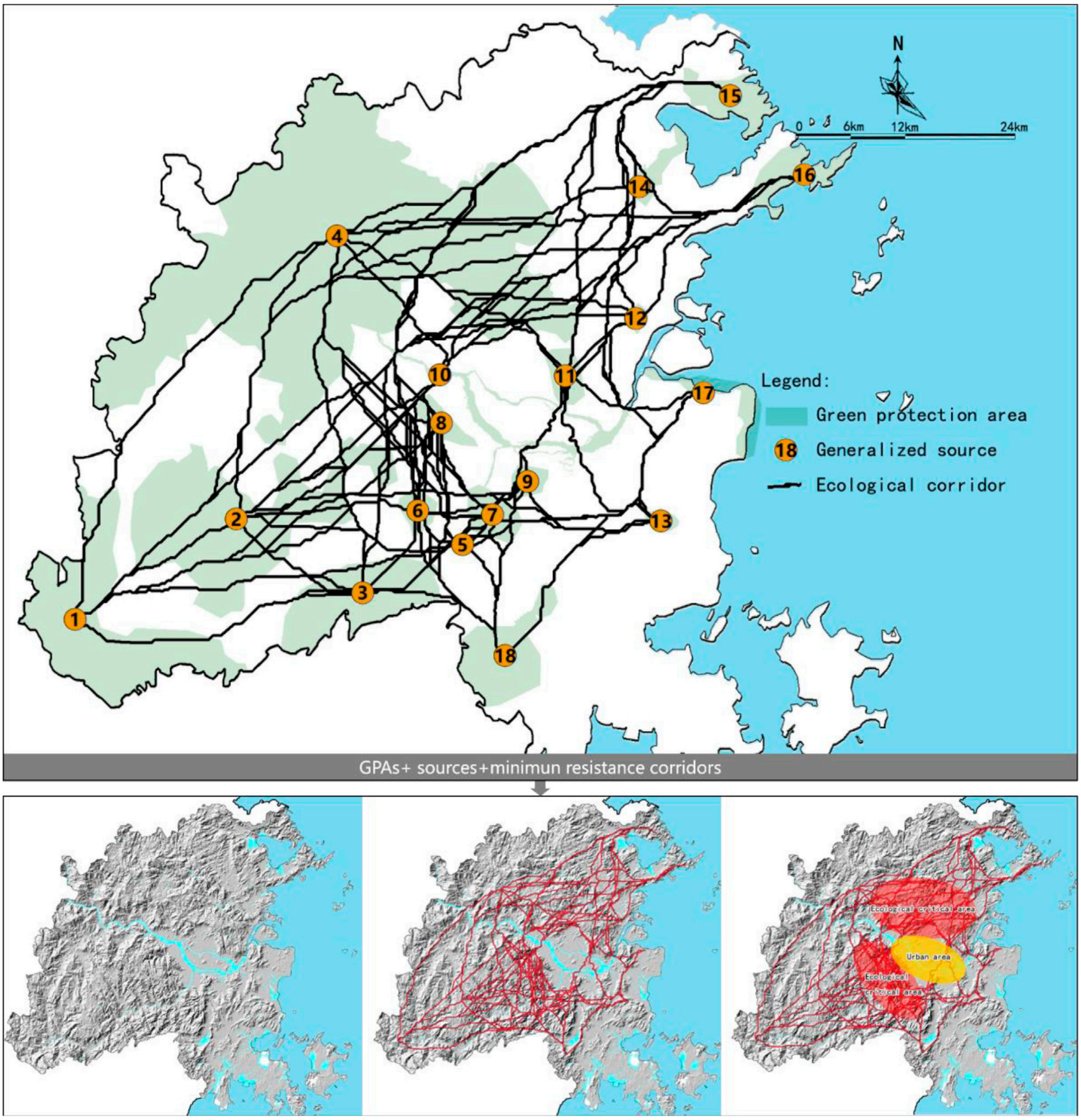


FIGURE 11
The minimum resistance corridors of the Fuzhou GSS.

3.3 The construction of minimum resistance corridors

As Figure 11 shows, mountains surround the north and southwest sides of the Fuzhou urban area, and the minimum resistance corridors between GPAs intersected in these areas, playing an essential role in the connectivity between GPAs and thus representing essential parts of Fuzhou's GSS.

3.4 First-level ecological corridors and network of GSS

We normalized the gravity model's calculation results to 100,helping to identify the optimal corridors for the first-level corridors (Table 5). According to the G_{ab} values, the gravity of GPA17 and other GPAs were minimal. However, as it was a coastal wetland with a unique landscape and a specific ecological function, we connected it to the first-level corridors. Five scenario networks were simulated for comparison, as

TABLE 5 Calculation results of the gravity model.

GPA code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2	10																
3	4	17															
4	2	4	2														
5	2	5	18	2													
6	2	9	29	2	4												
7	2	4	13	2	100	28											
8	2	6	8	3	11	28	17										
9	1	3	7	2	20	12	100	9									
10	0	0	0	0	0	0	0	0	0								
11	1	1	1	5	1	1	1	2	2	0							
12	0	1	1	3	0	1	1	1	1	0	24						
13	1	1	3	1	4	3	8	2	8	0	1	1					
14	0	1	1	4	0	1	1	1	1	0	6	10	0				
15	0	1	0	2	0	0	0	1	0	0	1	2	0	5			
16	0	1	0	2	0	0	0	1	0	0	2	3	0	7	2		
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	2	4	12	1	14	9	13	4	8	0	1	1	5	1	0	0	0

shown in Figure 10. Although the indexes α, β, and λ of scenario 5 were relatively better, we took scenario 1 as the final first-level network after careful consideration of CR and d, as shown in Figure 12.

The ecological corridor between GPA 9 and 11 was the only ecological corridor that spanned the entire urban area. It plays a crucial role in the green connection of the northern and southern urban areas, while also linking urban and suburban areas of Fuzhou. More attention should be paid to protection and construction of this vital corridor.

3.5 Green strategy nodes of GSS

As shown in Figure 13, the intersection of ecological corridors were the green strategic nodes. It was found that GPA 6, 7, 8, 9, and 11 were located at multiple intersections of ecological corridors, and played an essential role in the connectivity between GPAs. They could be regarded as GPAs of strategic importance.

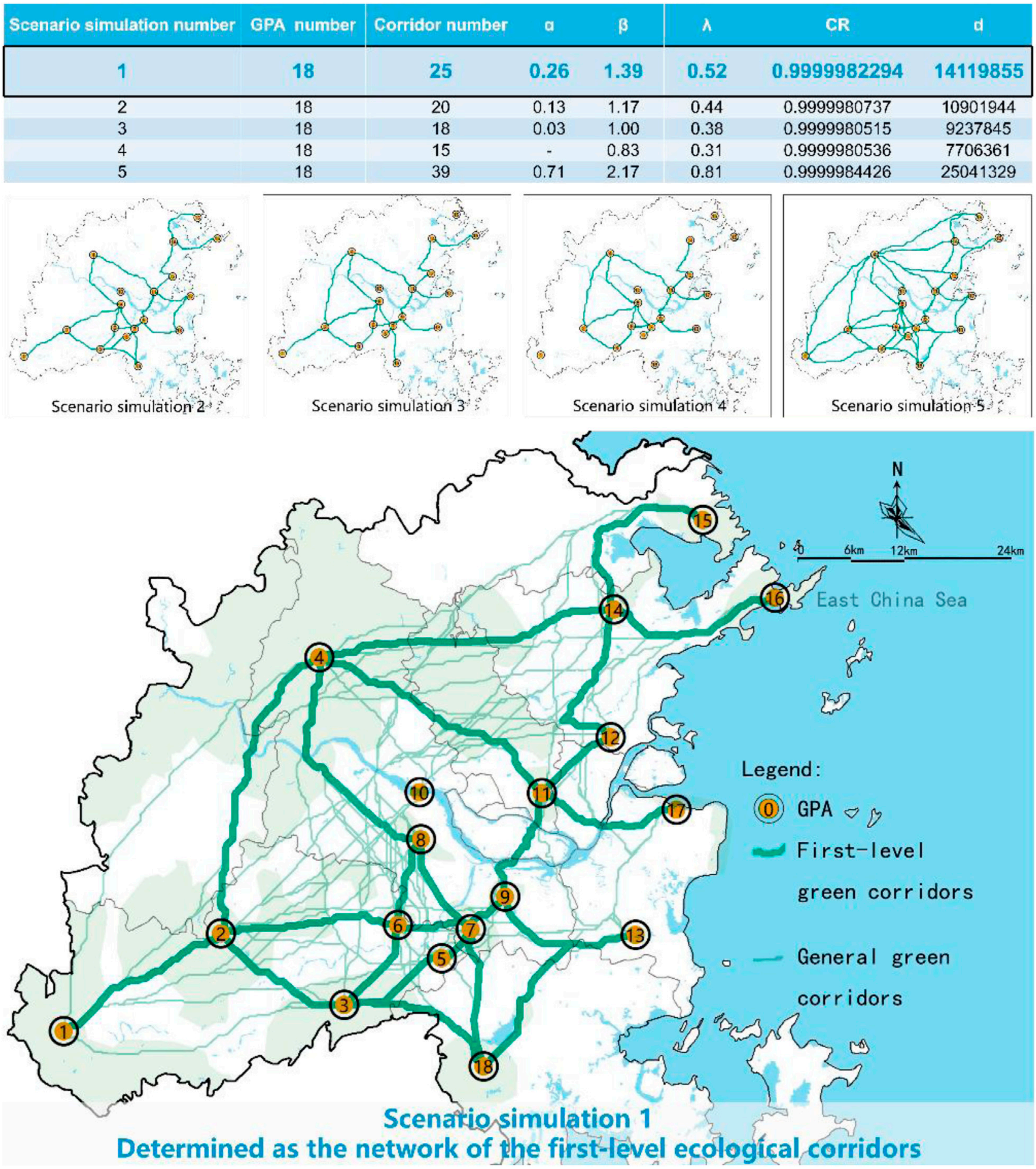
Since low-resistance woodland occupied a substantial part of Fuzhou City, the number of maximum resistance corridors generated was small, and the area where they intersected with the minimum resistance corridor is the minimum-maximum resistance strategic nodes. As shown in Figure 14, strategic nodes 1 and 2 were located in the urban area and the corridor between GPA 9 and 11, which were of strategic importance.

4 Discussion

This study aimed to develop an integrated framework for optimizing green space connectivity in Fuzhou's city-level GSSP, with particular focus on addressing ecological fragmentation in coastal urban environments. The analysis demonstrates that combining landscape pattern indices (Fragstats), connectivity metrics (Conefor), and spatial modeling (ArcGIS) effectively identifies strategic conservation areas and corridors. Notably, GPAs with high dPC values function as critical connectivity hubs, while the gravity-model-optimized network (Scenario 1) balances ecological and planning constraints. These findings advance previous green infrastructure studies by quantitatively linking landscape metrics to actionable planning decisions. At the same time, it is particularly important for the planning of green space systems in rapidly urbanizing coastal cities.

4.1 The classification of GPAs

This study uses the Conefor connectivity indicator to classify GPAs, which fits the international trend of prioritizing the protection of critical urban green spaces, while targeting the particular challenges of coastal urbanization in Fuzhou. Similar to the research of Verma et al. (2020), Kefalas et al. (2019), and Xu et al. (2018), individual diversities of GPA type and area were identified in Fuzhou. In particular, there was a significant difference between the area around the urban and suburban areas, as well as differences in functions, as also shown by the studies of García et al. (2020), and Li Collins et al., 2020. Conefor 2.6, which takes connectivity as the primary standard and characteristic, can quickly identify the importance value of a GPA (Qian et al., 2023). However, compared to the common single modeling strategy of MSPA and connectivity analysis in traditional GSSP



Scenario simulation number	GPA number	Corridor number	α	β	λ	CR	d
1	**18**	**25**	**0.26**	**1.39**	**0.52**	**0.9999982294**	**14119855**
2	18	20	0.13	1.17	0.44	0.9999980737	10901944
3	18	18	0.03	1.00	0.38	0.9999980515	9237845
4	18	15	-	0.83	0.31	0.9999980536	7706361
5	18	39	0.71	2.17	0.81	0.9999984426	25041329

FIGURE 12
Network analysis results and first-level ecological network of Fuzhou GSSP.

(Xu et al., 2023), this study proposes the Fragstats- Conefor framework in the source site identification stage. Ecological sources with higher conservation priority are identified through this dual-model extraction framework.

In the analysis process for Fuzhou City, it was found that some GPAs were small in size, but their location in a prominent position resulted in high *dPC* values. The recognition effect of Conefor has been confirmed by many studies (Jin et al., 2025; Luo et al., 2024), and the simplicity of the required necessary data and the ease of software operation make it a better choice for the city GSSP.

4.2 Green network analysis

In the process of constructing ecological corridors using the minimum resistance model (Guo et al., 2025), we found that the

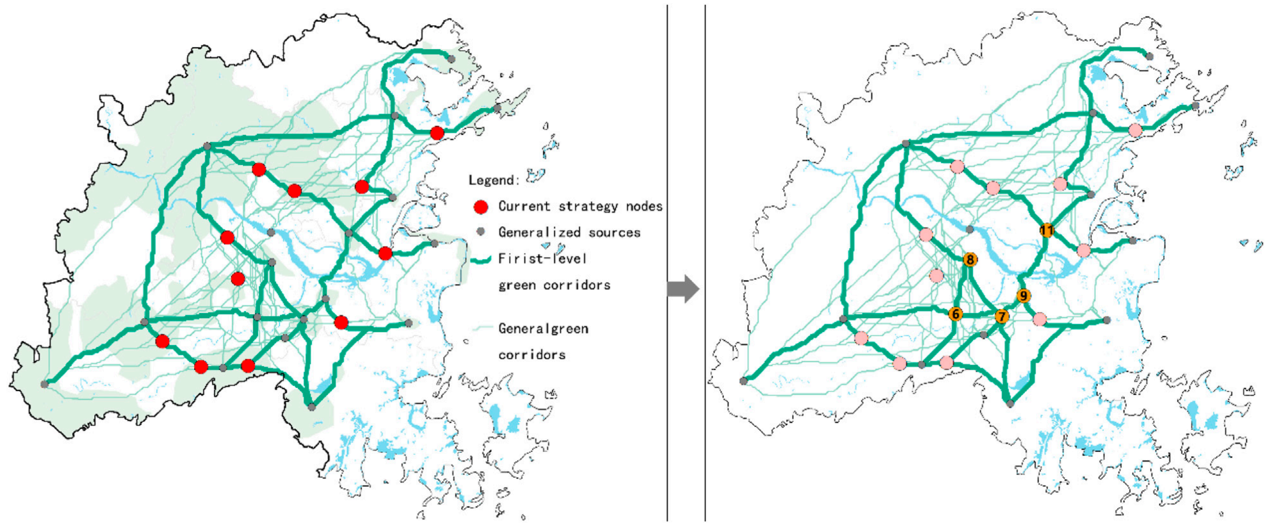


FIGURE 13
Current strategy nodes and GPA.

assignment of resistance values was somewhat subjective. The range of values used in different studies varied significantly (Fu et al., 2020), which had a substantial impact on the form of the corridors. Some studies employed a multiplex resistance surface, integrating data such as DEM, land use type, and NDVI (Yang et al., 2024). For the Fuzhou GSSP, after consulting with experts from relevant planning and management departments, we used land use type as the basis for the resistance surface. By considering the actual conditions, we ensured that the corridor simulations accurately reflected the situation on the ground.

Using the gravity model to quantify the G_{ab} between GPAs, and combining the GPA's *dPC*, Fuzhou GSSP constructed the first-level corridors. However, in the construction process, we found that although the gravity model's calculation process was relatively cumbersome, it was consistent with the *dPC* of GPA, and it could be helpful for the rationality of the first-level corridors selected. However, particular circumstances require special treatment. For example, the water-based GPA 10, Min River, and its *dPC* value was high, but the gravitational value with other GPAs was deficient because its resistance value was high. Moreover, due to its relatively large span, in the process of generating corridors by GIS, the location of the source point after generalization could not be determined accurately. Therefore, although it was a crucial GPA, it did not account for an essential status in ecological corridors construction.

As in the research of Lu et al. (2025) and Yang et al. (2017b), the *dPC* of GPA17 was low, and the gravitational values between it and other GPAs were also minimal. However, it was a coastal wetland, a critical ecological protection area, and an essential ecological park. The connection between this GAP and urban areas was deemed as highly necessary, so it was connected to the first-level corridors.

In terms of network structure, we introduced the loop index α, the average connection index β, the network connection degree λ, and the cost ratio index *CR* to evaluate the simulated first-level network. Related studies have confirmed that this approach has been effective in optimizing network structure (Yang et al., 2024).

4.3 Green strategic nodes

Basing on the previous research (Lu et al., 2025; Yang et al., 2024), we identified green strategic nodes of minimum-maximum resistance at the intersections of the minimum and maximum resistance corridors. Unlike the method of identifying the ridgeline of the resistance surface (Fu et al., 2022), the approach used in the Fuzhou GSSP identified fewer nodes. However, this method was more straightforward and better suited for large-scale ecological planning, such as city-level planning. During the identification process, we found that certain GPAs, such as GPA 6, 7, 8, 9, and 11, played a crucial role in the connectivity of GPAs (Figure 13). These GPAs acted as stepping stones and key building blocks for the green network, effectively linking urban green spaces with suburban green spaces, and can therefore be considered strategic GPAs.

4.4 Expansion of green space functions

This study focused solely on establishing the ecological structure of the GSS at the city level. However, to fully realize the potential of the green space system, more attention must be paid to its ecological and service functions (Cao et al., 2024). GSSP needs to integrate multiple functions with the local urban development context to ensure the rationality of the ecological structure and provide further guidance for urban GSSP.

4.5 Expansion of the use of the planning methods

The methodology adopted in the Fuzhou GSSP quantified relevant planning indicators, making the planning process more scientific and rational. The preliminary results of the green network in Fuzhou GSSP were largely consistent with the actual local conditions, providing

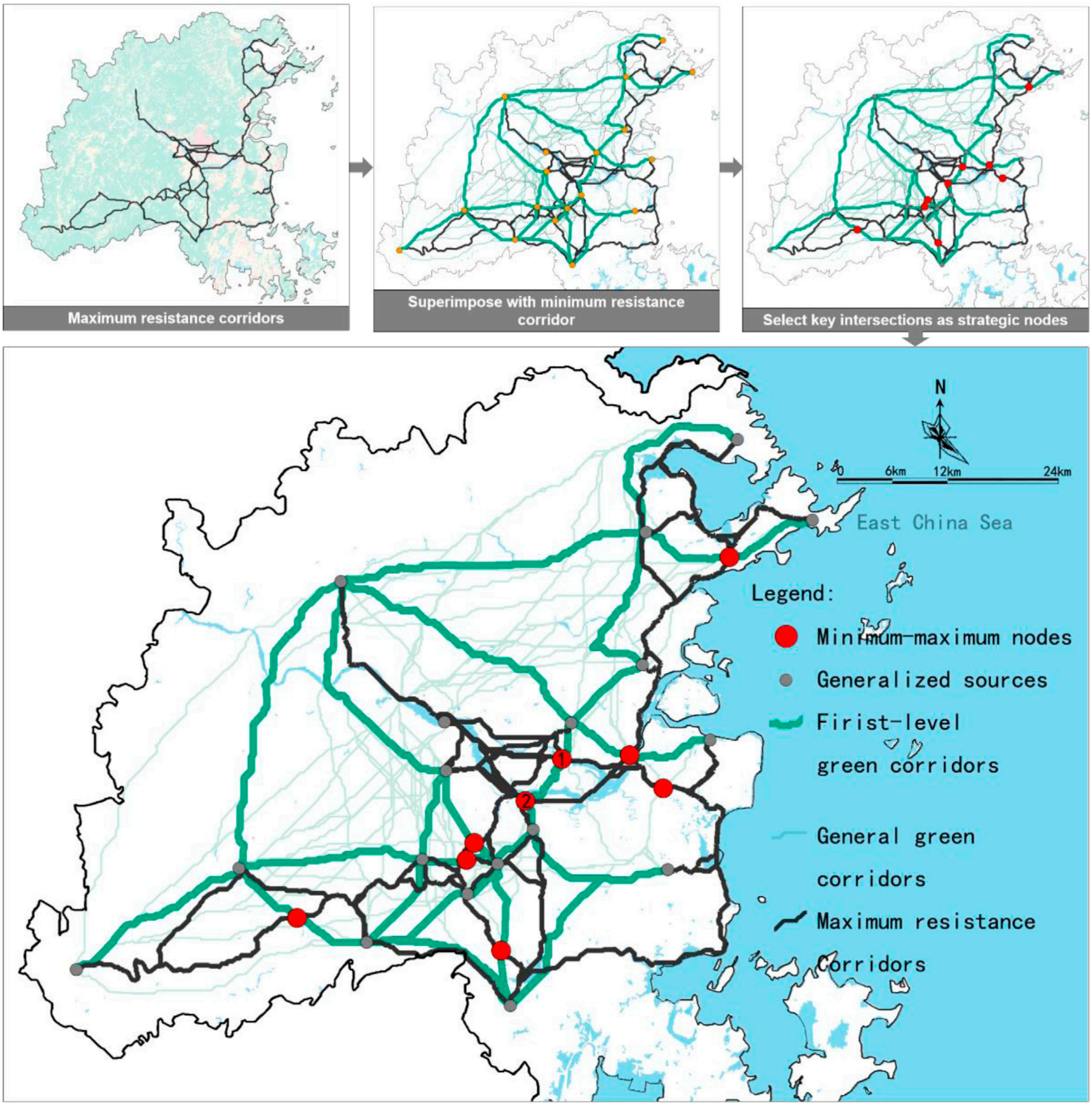


FIGURE 14
The minimum-maximum resistance strategic nodes of Fuzhou city.

functional guidance for future planning. However, in real-world planning projects, specific circumstances must still be considered, and adjustments should be made according to local conditions. As an ecological planning approach, this method can be applied to other planning areas such as Territorial Space Planning (Ministry of Natural Resources, 2025) and Nature Reserve System Planning, particularly in addressing landscape fragmentation. Secondly, this paper has not considered the needs of biodiversity conservation enough, and the response of different species to different environments varies. Therefore, subsequent studies can combine species distribution modeling and habitat suitability analysis to provide more precise protection for specific species in the region.

5 Conclusion

This study demonstrates a robust model for enhancing urban green infrastructure through strategic planning and implementation of the Green Space System Planning (GSSP) in Fuzhou, China. As rapid urbanization has exacerbated green space fragmentation and ecological connectivity degradation in coastal cities, this research addresses the critical gap in integrating quantitative landscape pattern analysis with spatial modeling for city-scale ecological network optimization. By combining Fragstats, Conefor, and ArcGIS-based resistance modeling, key results reveal that (1) 18 GPAs were classified with GPA 4 (2287.66 km^2) showing the highest connectivity importance (dPC = 88.459), (2) the Min River corridor (GPA 10) and urban coastal wetlands (GPA 17) emerged as strategically vital despite spatial constraints, and (3) scenario analysis identified Scenario 1 ($\alpha = 0.26$, CR = 0.999) as the optimal network configuration. These findings imply that the proposed framework not only resolves Fuzhou's ecological continuity challenges but also offers a transferable methodology for coastal cities grappling with similar urbanization pressures. However, limitations include the subjectivity in resistance value assignment and the exclusion of socioeconomic factors in corridor planning. Future work should incorporate dynamic urban growth projections and multi-stakeholder preferences into the model. Ultimately, this study advances the paradigm of evidence-based ecological planning, demonstrating how scientifically grounded GSSP can reconcile urban development with biodiversity conservation, thereby paving the way for sustainable urban futures.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JC: Writing – review and editing, Writing – original draft, Conceptualization, Funding acquisition, Visualization, Methodology. QZ: Visualization, Supervision, Writing – review and editing. SW: Writing – review and editing, Software, Visualization. YH: Software, Visualization, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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