

Article

Linking Ecosystem Service and MSPA to Construct Landscape Ecological Network of the Huaiyang Section of the Grand Canal

Feng Tang ^{1,2}, Xu Zhou ^{3,*}, Li Wang ² , Yangjian Zhang ², Meichen Fu ¹ and Pengtao Zhang ⁴

¹ School of Land Science and Technology, China University of Geosciences (Beijing), Beijing 100083, China; tangfeng@cugb.edu.cn (F.T.); fumeichen@cugb.edu.cn (M.F.)

² State Key Laboratory of Remote Sensing Science, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100101, China; wangli@radi.ac.cn (L.W.); zhangyangjian19@mailsucas.ac.cn (Y.Z.)

³ Land Consolidation and Rehabilitation Center, Ministry of Natural Resources, Beijing 100035, China

⁴ College of Land and Resources, Hebei Agricultural University, Baoding 071001, China; zhangpt@hebau.edu.cn

* Correspondence: zhouxu@lrcr.org.cn

Abstract: Rapid urbanization and drastic land-use change have led to landscape fragmentation and ecological environment deterioration in the regions along the Grand Canal. Building an ecological network is an important means to improve the connectivity of habitat patches and carry out ecological protection and restoration of territorial space, which is of great significance to ensure regional biodiversity and ecological security. In this article, we took the Huaiyang Section of the Grand Canal (Huaiyang Canal) as the study area, used the ecosystem service assessment model, morphological spatial pattern analysis (MSPA), and the landscape connectivity evaluation method to identify ecological sources, then used the minimum cumulative resistance (MCR) model and the gravity model to extract and grade ecological corridors. Based on these, the ecological network was constructed by combining the identification method of ecological nodes and ecological breakpoints. The aim of this was to provide a reference for the ecological space optimization of Huaiyang Canal and even the entire Grand Canal, the formulation of an ecological protection plan, and the implementation of territorial space ecological restoration. The results showed that the spatial distribution of the water conservation service, soil conservation service, carbon sequestration service, and biodiversity conservation service were significantly different, and the level of ecosystem services showed a trend of continuous degradation from 1990 to 2018. There were 12 ecological source patches comprehensively identified by multiple methods, with a total area of 2007.06 km². In terms of spatial distribution, large ecological source patches were mainly distributed in the central and western areas adjacent to the Grand Canal, while small ecological source patches were scattered in the eastern and southern border regions of the study area. The total length of ecological corridors was 373.84 km, of which the number of the primary ecological corridor, secondary ecological corridor, and tertiary ecological corridor were 9, 7, and 7, respectively, and the suitable width of the ecological corridor was 200–400 m. After optimization, the proposed ecological network was composed of 3 key ecological source patches, 9 important ecological source patches, 23 terrestrial corridors, 10 aquatic corridors, and 18 ecological nodes. Twenty-nine ecological breakpoints were key areas requiring ecological restoration. The overlap rate of the integrated ecosystem service change area and land-use change area was 99%, indicating that land-use change has a significant impact on regional ecosystem services. This study is of great significance for carrying out the ecological protection and restoration of the Huaiyang Canal and adjusting local land-use policies. It also provides a typical case demonstration for identifying an ecological network and formulating ecological restoration planning for other sections of the Grand Canal and cities along the canal.

Keywords: ecological network; ecosystem service; MSPA; MCR model; the Grand Canal



Citation: Tang, F.; Zhou, X.; Wang, L.; Zhang, Y.; Fu, M.; Zhang, P. Linking Ecosystem Service and MSPA to Construct Landscape Ecological Network of the Huaiyang Section of the Grand Canal. *Land* **2021**, *10*, 919. <https://doi.org/10.3390/land10090919>

Academic Editor: Le Yu

Received: 4 August 2021

Accepted: 30 August 2021

Published: 31 August 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The Grand Canal is the longest artificial canal in the world and is located in the plain area of eastern China. It has a total length of 2700 km, runs through eight provinces from north to south, including Beijing, Tianjin, Hebei, Shandong, Henan, Anhui, Jiangsu, and Zhejiang, and connects five major water systems, including the Haihe River, Yellow River, Huaihe River, Yangtze River, and Qiantang River [1]. For the past 2500 years, the Grand Canal has been an important transportation channel in China, effectively strengthening economic and cultural exchanges between the north and south of China and playing a positive role in promoting the economic prosperity and development of the regions along the canal [2]. Even now, it still plays an important role in cargo transportation, agricultural irrigation, flood discharge, regional allocation of water resources, and absorption of urban and industrial wastewater [3]. In the context of urbanization, population growth, and rapid industrial development, the intensification of human activities and long-term extensive land use have caused the Grand Canal to face water pollution, river occupation, insufficient ecological space, fragmentation of natural habitat patches, impairment of ecosystem functions, reduction of biodiversity, and other ecological problems, which have seriously hindered the sustainable development of the areas along the canal. In 2014, the Grand Canal was admitted to the World Cultural Heritage List at the 38th World Heritage Congress. Following this, the Chinese government began to strengthen the ecological protection of the Grand Canal and released the “Grand Canal Ecological Environment Protection and Restoration Special Plan” in 2020. In recent years, research on the Grand Canal has shown an increasing trend, but scholars have paid more attention to the social and economic benefits, cultural heritage value, traditional cultural protection, and heritage tourism of the Grand Canal [4–7], and paid less attention to the ecological and environmental problems of the Grand Canal. A few scholars have carried out studies on heavy metal pollution of sediments, water pollution, and water quality evaluation [3,8–10], but they mainly analyzed ecological and environmental problems from the perspective of a single natural element of water resources. The academic circle urgently needs to carry out ecological environment-related research from different perspectives to provide references for the scientific implementation of the Grand Canal’s ecological protection work.

The Grand Canal contains ten river sections, namely Tonghui River, North Canal, South Canal, Huitong River, Middle Canal, Huaiyang Canal, Jiangnan Canal, Zhejiang East Canal, Yongji Canal, and Tongji Canal. Among them, the Huaiyang Canal is the earliest river channel excavated in the Grand Canal, dating back to 486 BC. The Huaiyang Canal connects the Yangtze River and the Huaihe River. It is the busiest section of the Grand Canal and the starting point and main water delivery channel of the East Route of China’s South-to-North Water Diversion Project. Therefore, the Huaiyang Canal has an important position in the Grand Canal and even in China. The ecological problems of the Huaiyang Canal will affect the ecological security of the entire Grand Canal. To achieve the goal of ecological protection of the Grand Canal, it is necessary to give priority to environmental protection and ecological restoration in the Huaiyang Canal. The ecological network is a composite network composed of various biological habitats, ecological corridors, and ecological nodes that can ensure regional material circulation, energy exchange, and information circulation [11]. Constructing an ecological network can effectively connect fragmented habitat patches, strengthen the connectivity of regional landscapes, and improve the regional environment, thereby maintaining the stability of the ecosystem and ensuring regional ecological security [12–15]. Ecological network identification has become an important research method to ensure regional ecological security patterns and carry out ecological protection and restoration in territorial space [16]. Against the background of rapid urbanization resulting in the tension of the man–land relationship and prominent ecological problems and under the increasing realistic demand for environmental protection and ecological restoration of the Grand Canal, it is of great significance to carry out a typical case study of ecological network construction for the Huaiyang Canal to realize the goal of

ecological protection of the Grand Canal and the sustainable development of the regions along the canal.

The concept of ecological networks originated in Europe in the 1970s. With the enhancement of environmental protection awareness in the international community, the ecological network has gradually become a research hotspot in landscape ecology, geography, urban planning, and other disciplines [17–19]. In the 1990s, researchers in the ecological network began to emphasize the restoration of degraded ecosystems while protecting biodiversity. In addition, they also emphasized the complementarity analysis with landscape fragmentation. Research scales began to concentrate on large regional scales such as continental and national [20–23]. From the end of the 20th century to the present, ecological network planning and practice have been booming, the understanding of the ecological network of different disciplines has been constantly integrated, interdisciplinary research has been constantly rising, and the relevant research of ecological networks has also become more in-depth [24–28]. Overall, the current research on ecological networks has become increasingly mature. The construction of an ecological network has formed a basic mode, including ecological source identification, resistance surface generation, and ecological corridor extraction, and it is constantly shifting to quantification [29]. The research scale has covered different countries [30,31], provinces [32,33], cities [34,35], urban central district [36], counties [37,38], and other administrative division scales. The study area has involved desert oasis [39], plateau [40], mountainous area [41], estuary delta [42], watershed [43,44], urban agglomerations [45,46], and other different types of regional spaces. In terms of research topics, many scholars have focused on the structure of ecological networks [25,28], identification of ecological networks [47,48], ecological network evaluation [45,49], and ecological network optimization measures [36,50] conducted in a series of studies. Among the functional components of the ecological network, scholars pay more attention to the identification of the ecological sources and the construction of the ecological corridors. There are two main types of ecological source identification methods. The first type is the direct determination method, that is, the nature reserve [51], urban green space [52], and regional land cover types [15] are directly selected as ecological sources. The second type is the model evaluation method, which identifies ecological sources through ecosystem service supply and demand measurement [53], key ecosystem service analysis [54,55], ecological risk assessment [47], granularity reverse method [56], ecological sensitivity assessment [57], MSPA [29,35], and other evaluation methods. Most studies on the extraction of the ecological corridors were based on land-use types to construct comprehensive resistance surfaces and then used the minimum cumulative resistance model to generate potential ecological corridors. This conventional approach ignored the ecological forces between ecological sources and failed to distinguish the relative importance of corridors [29]. It is worth noting that most of the existing studies adopted the subjective selection method or the single ecological index evaluation method to identify the ecological source, which may miss important habitat patches. There are few studies that integrated multiple evaluation methods from different perspectives to comprehensively determine the ecological source. In the process of extracting an ecological corridor, the focus is on the spatial distribution characteristics, location, and length information of the corridor, and there is insufficient research on the grade division and the optimal width threshold of the ecological corridor.

Given the above considerations, this paper integrated multiple evaluation methods and models from the perspectives of ecosystem services and landscape patterns to construct an ecological network of the Huaiyang Canal, aiming to provide a reference for the ecological space optimization of Huaiyang Canal and even the entire Grand Canal, the formulation of an ecological protection plan, and the implementation of a territorial space ecological restoration project. The detailed research objectives were to (1) analyze the spatio-temporal variation characteristics of ecosystem services from the four dimensions of water conservation, soil conservation, carbon sequestration, and biodiversity conservation of the Huaiyang Canal from 1990 to 2018; (2) integrate the ecosystem service evaluation

model, MSPA, and the landscape connectivity evaluation method to comprehensively identify ecological sources; (3) adopt the MCR model and the gravity model to extract and grade the ecological corridor; and (4) construct the ecological network based on the identification of ecological sources, corridors, nodes, and breakpoints, and propose policy recommendations for regional ecological protection and ecological restoration. During the research process, we introduced a scientific conjecture, that is, in the process of rapid urbanization, dramatic land-use change has a significant impact on regional ecosystem services, and the ecological network is an effective tool to mitigate land-use change and achieve regional ecological protection.

2. Materials and Methods

2.1. Study Area

The Huaiyang Canal refers to the section of the Grand Canal located in Huai'an and Yangzhou, Jiangsu Province. It has a total length of more than 170 km, runs through ten county-level administrative districts from north to south, including Huaiyin District, Qingjiangpu District, Huai'an District, Hongze District, Jintu County, Baoying County, Gaoyou County, Jiangdu District, Hanjiang District, and Guangling District, and connects two major water systems of the Huaihe River and the Yangtze River (Figure 1). It is the oldest artificial canal with a history of more than 2500 years and is still an important transportation channel in China. The Huaiyang Canal has promoted the industrial and agricultural development and urban prosperity of Huai'an and Yangzhou. However, in the process of urbanization, the explosion of population, the blind exploitation of land resources, the disorderly expansion of construction space, and the massive disturbance of human activities have caused a lot of ecological problems such as serious water and soil pollution, fragmentation and low connectivity of natural landscape patches, loss of species habitats, and the reduction of biodiversity, which have seriously threatened the sustainable development of counties along the canal. This study takes 10 county-level administrative districts along the Huaiyang Canal as the research object, with a total area of 11,520 km².

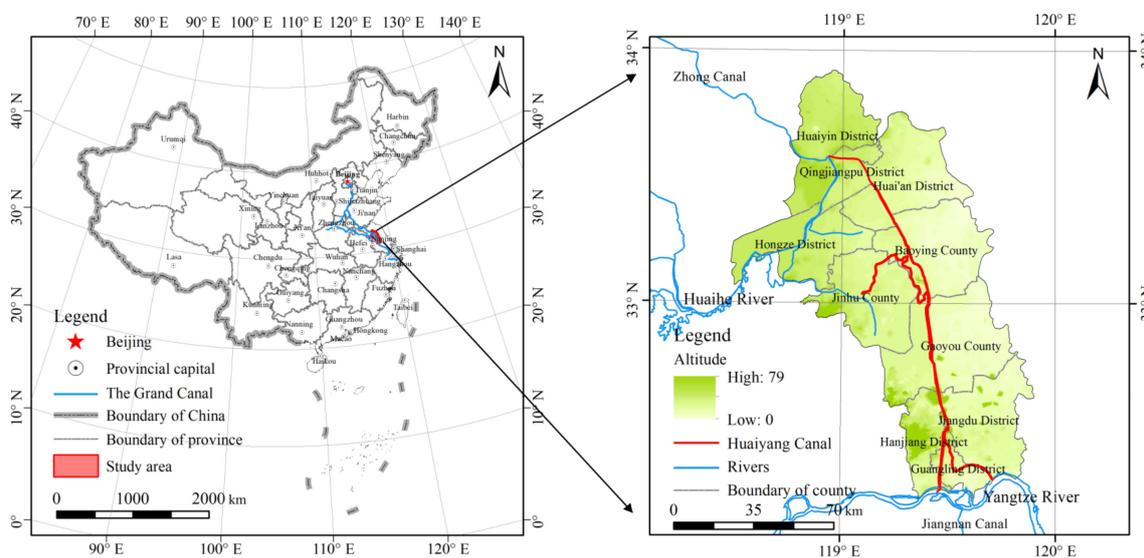


Figure 1. Location of the study area.

2.2. Data Sources and Preprocessing

The data sources used in this study include 7 aspects: (1) Land-use 30 m × 30 m raster data from 1990, 2000, 2010, and 2018 were provided by the Chinese Academy of Sciences' Resource and Environmental Sciences Data Center (<http://www.resdc.cn/>, accessed on 6 November 2020); (2) the temperature and precipitation were derived from the observation data of 21 meteorological stations around the Huaiyang Canal, downloaded from the China Meteorological Data Network (<http://data.cma.cn/>, accessed on 14 May 2021), the

temperature and precipitation $30\text{ m} \times 30\text{ m}$ raster data were obtained using the inverse distance weighted interpolation tool in ArcGIS platform, and on this basis, the actual evaporation $30\text{ m} \times 30\text{ m}$ raster data were calculated using Takahashi's formula [58]; (3) elevation and slope were extracted from the $30\text{ m} \times 30\text{ m}$ DEM data downloaded from the China Geospatial Data Cloud Platform (<http://www.gscloud.cn/>, accessed on 23 March 2021); (4) the annual normalized vegetation index (NDVI) $30\text{ m} \times 30\text{ m}$ raster data in 1990, 2000, 2010, and 2018 were produced by the Google Earth Engine platform; (5) the soil type data were obtained from the World Soil Database (HWSO) on a scale of 1:1 million; (6) the 2018 night light data were derived from the annual night light data product provided by Elvidge et al. [59], which was synthesized on the basis of the monthly NPP-VIIRS night light data provided by NASA/NOAA; and (7) the traffic network and river system were obtained from the Open Street Map database (<http://download.geofabrik.de/>, accessed on 23 March 2021).

With reference to the Land-Use/Land-Cover Remote Sensing Monitoring Data Classification System of the Chinese Academy of Sciences, and according to the research needs and actual land-use situation in the Huaiyang Canal, we used the ArcGIS platform to divide the original land-use raster data into fifteen categories: Paddy field, dry land, forestland, shrubland, sparse woodland, other woodland, high coverage grassland, river canal, lake, reservoir and pond, bottomland, urban land, rural residential land, industrial and traffic land, and bare land (Figure 2). In order to express them more clearly, we have further reclassified the paddy field and dry land into farmland, reclassified the forestland, shrubland, sparse woodland, and other woodland into woodland, reclassified the high coverage grassland into grassland, reclassified the river canal, lake, reservoir and pond, and bottomland into water area, reclassified the urban land, rural residential land, and industrial and traffic land into construction land, and reclassified the bare land into unused land. The evaluation unit was a $30\text{ m} \times 30\text{ m}$ raster unit, and all spatial data were processed as a $30\text{ m} \times 30\text{ m}$ raster layer on the ArcGIS platform.

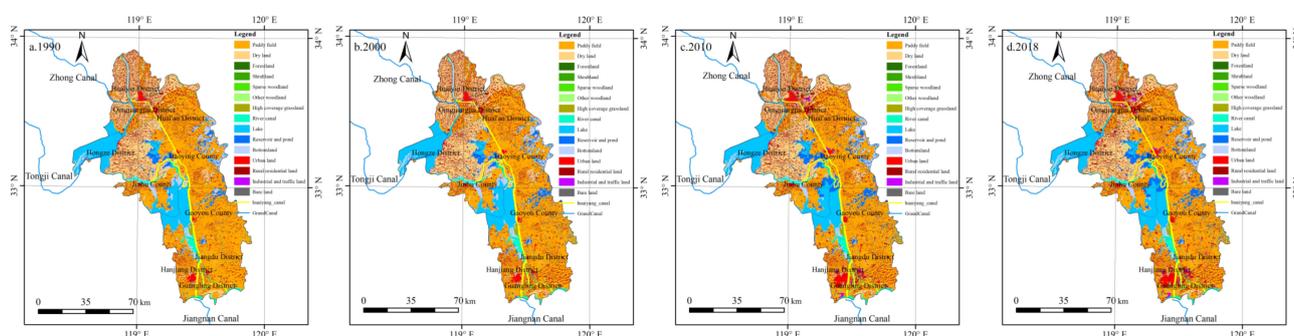


Figure 2. Spatial distribution of land-use types in the Huaiyang Canal.

2.3. Research Framework

As shown in Figure 3, this research framework was divided into the following four steps. Firstly, water conservation, soil conservation, carbon sequestration, and biodiversity conservation were selected to evaluate the importance of ecosystem services by using the RUSLE equation and the InVEST model, then the spatio-temporal evolution characteristics of single and integrated ecosystem services were analyzed. Secondly, from the perspective of landscape pattern, the MSPA and landscape connectivity evaluation were carried out by Guidos software and Conefor software according to the spatial distribution data of land use to obtain the important landscape patches, and on this basis, the ecological sources were identified jointly with the ecosystem service evaluation results. Thirdly, the ecological resistance coefficient was determined according to the land-use type, and the comprehensive resistance surface was obtained by modifying the coefficient using night light data. The potential ecological corridor was extracted by the MCR model and minimum cost path method, and the ecological corridor was graded by the gravity model.

Fourthly, ecological nodes and ecological breakpoints were identified through spatial overlay analysis, and then the ecological network of the study area was constructed jointly with the analysis results of ecological sources and corridors.

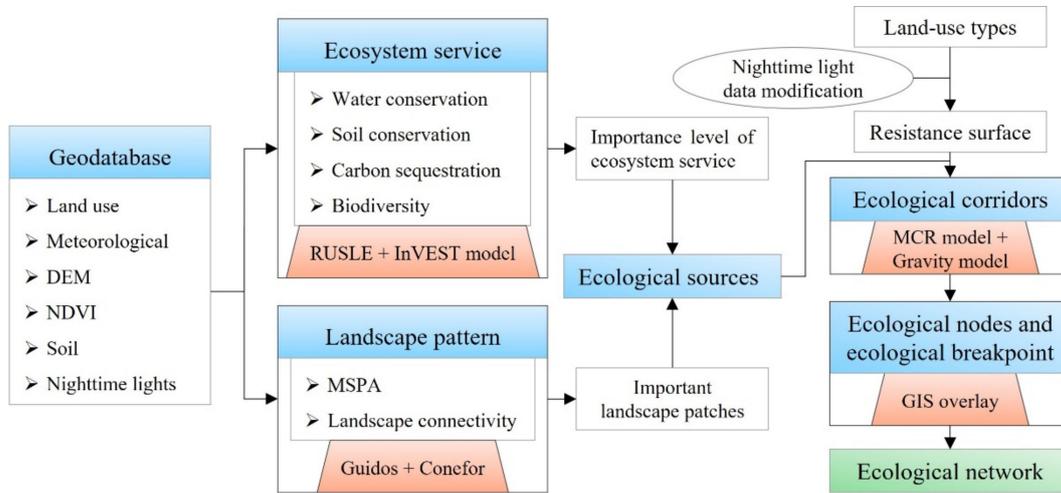


Figure 3. Logical framework and flowchart of this study.

2.4. Research Methods

2.4.1. Ecosystem Service Evaluation

Water Conservation Service

Water conservation refers to the regulation and supply of water by the ecosystem, and it is estimated using the method of the ratio coefficient of runoff rainfall to rainfall [17]. The equation is as follows,

when the underlying surface is soil:

$$V_s(x) = \sum P_{mean}(x) \times K_W \times R_W, \quad (1)$$

when the underlying surface is water:

$$V_{WC} = \sum P_{mean}(x) - ET_a(x), \quad (2)$$

where $V_s(x)$ is the annual amount of water conservation per unit area of grid x when the underlying surface is soil (m^3/m^2), $P_{mean}(x)$ is the monthly precipitation of grid x (mm), K_W is the ratio of runoff rainfall to total rainfall, R_W is the runoff reduction coefficient of surface vegetation, $V_{WC}(x)$ is the annual amount of water conservation per unit area of grid x when the underlying surface is water (m^3/m^2), and $ET_a(x)$ is the actual monthly evapotranspiration (mm).

Soil Conservation Service

As an important regulation service provided by the ecosystem, soil conservation service refers to the erosion control ability of the ecosystem to prevent soil loss and the ability to maintain sediment accumulation [60]. In this paper, the modified soil loss equation (RUSLE) was used to estimate the potential and actual soil erosion, and the difference between the two was taken as the amount of soil conservation. The calculation formula [61] is as follows:

$$A_c = A_r - A, \quad (3)$$

$$A_r = R \times K \times LS, \quad (4)$$

$$A = R \times K \times LS \times C \times P, \quad (5)$$

where A_c , A_r , and A are the amount of soil conservation, potential soil erosion, and actual soil erosion, respectively ($\text{t}\cdot\text{km}^{-2}\cdot\text{a}^{-1}$), and R is the rainfall erosivity factor ($\text{MJ}\cdot\text{mm}\cdot\text{km}^{-2}\cdot\text{h}^{-1}\cdot\text{a}^{-1}$), which is calculated by using the empirical formula proposed by Wischmeier and modified by Arnoldus [62]. K is the soil erodibility factor ($\text{t}\cdot\text{km}^2\cdot\text{h}\cdot\text{km}^{-2}\cdot\text{MJ}^{-1}\cdot\text{mm}^{-1}$), which is calculated using the K value estimation method developed in the EPIC model by Williams et al. [63], L is the slope length factor (dimensionless) and is calculated using the empirical formula proposed by Wischmeier [64], S is the slope factor (dimensionless) and is calculated using the formula proposed by Liu [65], C is the vegetation and management factor (dimensionless) and is estimated using NDVI, and P is the water and soil conservation measure factor (dimensionless). Different land-use types can indirectly determine regional water and soil conservation measures. The value of P ranges from 0 to 1, where 0 means that soil erosion will not occur and 1 means that no soil and water conservation measures have been taken. With reference to relevant studies [66,67], the P values of farmland, grassland, woodland, construction land, water area, and unused land were assigned 0.5, 0.8, 0.8, 0, 0, and 1, respectively.

Carbon Sequestration Service

The level of carbon sequestration in an ecosystem is an important indicator of its ability to regulate climate, and it is also a key issue in the game between coordinating economic development and ecological protection. We used the Carbon module of the InVEST model to estimate the carbon sequestration capacity of the study area. The carbon sequestration evaluation in this module includes four basic carbon pools (aboveground biomass, underground biomass, soil, and dead organic matter). Since it is difficult to obtain the carbon pool data of dead organic matter, only the other three carbon pools were considered in this paper. The calculation formula is as follows:

$$C_i = C_{i\text{-above}} + C_{i\text{-below}} + C_{i\text{-soil}}, \quad (6)$$

$$C_{total} = \sum_{i=1}^n C_i \times S_i, \quad (7)$$

where C_i is the total carbon density of land-use type i (t/hm^2), $C_{i\text{-above}}$ is the aboveground biomass carbon density of land-use type i (t/hm^2), $C_{i\text{-below}}$ is the underground biomass carbon density of land-use type i (t/hm^2), $C_{i\text{-soil}}$ is the soil carbon density of land-use type i (t/hm^2), C_{total} is the total amount carbon sequestration of the ecosystem (t), S_i is the area of land-use type i (hm^2), and n is the number of land-use types and is 6 in this study.

The determination of carbon density data included the following three steps. Firstly, according to the study by Zhu et al. [68], we obtained the aboveground biomass carbon density, belowground biomass carbon density, and soil carbon density of farmland, woodland, grassland, water area, construction land, and unused land in the Qihe River Basin. Second, looking up the literature, we obtained the average annual temperature of the Qihe River Basin and the Huaiyang Canal Basin, which were 11.9°C and 15.4°C , respectively, and the average annual precipitation was 573.7 mm and 1000 mm, respectively. Third, the carbon density data in our study area were revised by using the relationship models of biomass carbon density and soil carbon density with temperature and precipitation, respectively, from the studies of Chen et al. [69], Giardina et al. [70], and Alam et al. [71] (Table 1).

Table 1. Carbon density of different land-use types (t/hm^2).

Land-Use Type	$C_{i\text{-above}}$	$C_{i\text{-below}}$	$C_{i\text{-soil}}$
Farmland	45.56	8.61	130.75
Woodland	631.75	137.59	217.59
Grassland	4.42	27.88	120.49
Water area	0.45	0	79.63
Construction land	0.11	0	71.67
Unused land	0.11	0	73.23

Biodiversity Conservation Service

Biodiversity is the cornerstone of the survival of human society. We selected the habitat quality index to comprehensively evaluate biodiversity conservation service. The habitat quality index is calculated by the Habitat Quality module of the InVEST model, whereby the value of the index ranges between 0 and 1; the greater the index, the higher the habitat quality and the greater the biodiversity [72,73]. The equation is as follows:

$$Q_{xj} = H_j \left[k^z / \left(D_{xj}^z + k^z \right) \right], \tag{8}$$

where Q_{xj} is the habitat quality of grid x in land-use type j , D_{xj} is the threat level of grid x in land-use type j , H_j is the habitat suitability of land-use type j , k is a half-saturation constant, which is usually half of the maximum value of D_{xj} , and z is the normalisation constant, which is usually 2.5. D_{xj} is calculated by

$$D_{xj} = \sum_{r=1}^R \sum_{y=1}^{Y_r} \left(w_r / \sum_{r=1}^R w_r \right) r_y i_{rxy} \beta_x S_{jr}, \tag{9}$$

where R is the number of threat factors, y is the number of grids on the raster layer of the threat factor r , Y_r is the number of grids occupied by the threat factor on the land-use type layer, w_r is the weight of the threat factor, r_y is the threat factor value of grid y , i_{rxy} is the habitat threat level of grid x from threat factor r on grid y , β_x is the reachability level of grid x , and S_{jr} is the sensitivity of land-use type j to threat factor r . i_{rxy} is calculated by

$$i_{rxy} = 1 - (d_{xy} / d_{rmax}), \tag{10}$$

where d_{xy} is the straight-line distance between grid x and grid y and d_{rmax} is the maximum influence distance of threat factor r .

The data required to run the InVEST habitat quality module include land-use cover maps, threat factors layers, the impact distance of threat factors, the sensitivity of habitats to threat factors, and the distance between habitats and threat factors sources. Referring to the relevant literature [72–76], and combining the knowledge of experts, we selected paddy field, dry land, urban land, rural residential land, and industrial and traffic land as the threat factors, assigning the maximum stress distance and weight of each threat factor, and assigning the sensitivity of various habitat types to the threat factors (Tables 2 and 3).

Table 2. Attributes of threat factor.

Threat Factor	Maximum Distance (km)	Weight	Spatial Decay Type
Paddy field	6	0.6	Exponential
Dry land	6	0.6	Exponential
Urban land	10	0.9	Exponential
Rural residential land	8	0.7	Exponential
Industrial and traffic land	12	1	Linear

Integrated Ecosystem Services

Based on the evaluation of the four single ecosystem service indicators of water conservation, soil conservation, carbon sequestration, and biodiversity conservation, we adopted the linear weighted sum method to evaluate the level of integrated ecosystem services. The calculation formula is as follows:

$$ES_i = \sum_{j=1}^m \sum_{i=1}^n w_j \times x_{ij}, \tag{11}$$

where ES_i is the level of integrated ecosystem services of grid i , w_j is the weight of ecosystem service index j , and x_{ij} is the normalised value of index j in grid i . Considering that the

four ecosystem services were equally important to the Huaiyang Canal, the weights of water conservation, soil conservation, carbon sequestration, and biodiversity conservation were all assigned 0.25. To better analyze the variation characteristics of ecosystem services, we used the natural breakpoint method to divide the level of ecosystem services into four grades, including extremely important, moderately important, slightly important, and non-important.

Table 3. The habitat suitability and sensitivity of land-use type to each threat factor.

Land-Use Type	Habitat Suitability	Paddy Field	Dry Land	Urban Land	Rural Residential Land	Industrial and Traffic Land
Paddy field	0.3	0	0.2	0.6	0.4	0.5
Dry land	0.3	0.2	0	0.6	0.4	0.5
Forestland	1	0.8	0.8	0.9	0.8	0.9
Shrubland	0.9	0.5	0.5	0.8	0.7	0.8
Sparse woodland	0.8	0.5	0.5	0.7	0.6	0.7
Other woodland	0.7	0.4	0.4	0.6	0.5	0.6
High coverage grassland	0.8	0.5	0.5	0.6	0.5	0.6
River canal	1	0.8	0.7	0.9	0.8	0.9
Lake	1	0.8	0.7	0.9	0.8	0.9
Reservoir and pond	0.9	0.8	0.7	0.9	0.8	0.8
Bottomland	0.7	0.7	0.6	0.8	0.7	0.7
Urban land	0	0	0	0	0	0
Rural residential land	0	0	0	0	0	0
Industrial and traffic land	0	0	0	0	0	0
Bare land	0.1	0.1	0.1	0.2	0.2	0.1

2.4.2. Identification of the Ecological Source

The ecological source is the foundation of an ecological network. This paper identified the ecological sources from two dimensions. One was based on the ecosystem service evaluation results, where the regions with an extremely important grade in the level of integrated ecosystem services were selected as ecological sources. The other was to extract important landscape patches from the land-use status through MSPA and landscape connectivity evaluation and determine them as ecological sources.

MSPA is an image-processing method proposed by Vogt et al. [77] that can accurately distinguish various landscape types and their structural composition. According to the actual situation of the study area, the woodland and water area were regarded as the foreground elements and the other land types were regarded as the background elements. The Guidos Toolbox software was used for MSPA, and seven types of landscapes with non-overlapping foreground elements were obtained, namely core, islet, perforation, edge, loop, bridge, and branch [78]. The core was extracted from the output result data, and possible connectivity index (PC) and plaque importance index (dPC) were selected to evaluate landscape connectivity using the Conefor software [79]. The calculation formula is as follows:

$$PC = \left(\sum_{i=1}^n \sum_{j=1}^n a_i \cdot a_j \cdot p_{ij}^* \right) / A_L^2, \quad (12)$$

$$dPC = (PC - PC_{rem}) / PC \times 100, \quad (13)$$

where PC is the possible connectivity index, n is the total number of landscape patches, a_i and a_j are the areas of patches i and j , p_{ij}^* is the maximum probability of species directly spreading between patches i and j , A_L is the total area of the entire landscape, PC_{rem} is the connectivity index of the remaining patches after removing a single patch, and dPC is the importance of the patch, where the larger the dPC value, the higher the importance of the patch in the landscape connection.

2.4.3. Construction of Ecological Resistance Surface

Ecological resistance reflects the hindrance degree to the migration and communication of species in different landscape types, which is mainly determined by the type of land

cover and the degree of human disturbance. With reference to relevant studies [55,80,81], the ecological resistance of woodland, grassland, water area, farmland, unused land, and construction land were assigned 1, 10, 50, 100, 200, and 250, respectively. We used the night light data to modify the ecological resistance coefficient of the land-use type to obtain the comprehensive resistance surface. The formula is as follows:

$$R_i^* = NL_i / NL_a \times R_i \quad (14)$$

where R_i^* is the ecological resistance value of grid i after correction, NL_i is the night light coefficient of grid i , NL_a is the average night light coefficient of land type a corresponding to grid i , and R_i is the basic resistance value of grid i .

2.4.4. Extraction of Ecological Corridor

The MCR model was used to obtain the minimum cumulative resistance surface of ecological sources expansion, and the minimum cost paths were simulated to determine the species migration corridor. The calculation formula of the MCR model [82] is as follows:

$$MCR = f_{\min} \sum_{j=n}^{i=m} (D_{ij} \times R_i), \quad (15)$$

where MCR is the minimum cumulative resistance value from the ecological source to each grid in the study area, f is the positive function of the migration process, D_{ij} is the distance from the ecological source j to grid i , and R_i is the resistance coefficient of grid i .

Based on the minimum cumulative resistance surface and the ecological source, the Cost Path tool of the ArcGIS platform was used to calculate the minimum cost path between the ecological sources to generate potential ecological corridors. Then the gravity model was used to calculate the interaction intensity among ecological sources, and the relative importance of ecological corridors was quantitatively evaluated [57], and the corridors were graded. The calculation formula is as follows:

$$G_{ab} = \frac{N_a N_b}{D_{ab}^2} = \frac{\left[\frac{1}{P_a} \times \ln S_a \right] \left[\frac{1}{P_b} \times \ln S_b \right]}{\left(\frac{L_{ab}}{L_{max}} \right)^2} = \frac{L^2 \max \ln S_a \ln S_b}{L^2_{ab} P_a P_b}, \quad (16)$$

where G_{ab} is the interaction intensity between ecological source patches a and b , N_a and N_b are the weights of source patches a and b , P_a and P_b are the average resistance values of source patches a and b , S_a and S_b are the areas of source patches a and b , L_{ab} is the cumulative resistance value of the corridor between source patches a and b , and L_{max} is the maximum cumulative resistance value of all corridors in the study area.

The ecological corridor constructed based on the MCR model is a conceptual network expressing path, and its ecological service function can be played only when it has a certain width. With reference to relevant studies [18,57,83], this study carried out buffer analysis of 100, 200, 400, 600, 800, 1000, 1200, and 1500 m for the extracted ecological corridor, and carried out statistical analysis on the area of each land-use type within the above width to determine the ecological corridor width in the study area.

2.4.5. Identification of Ecological Nodes and Breakpoints

Ecological nodes are the key points in the ecological network and are the resting places in species migration. We used the natural break point method to divide the minimum cumulative resistance surface into four grades, including source buffer, low resistance area, medium resistance area, and high resistance area, which were spatially superimposed with the ecological corridors. The intersection points among ecological corridors and the intersection points of ecological corridors and different grade boundaries of the minimum cumulative resistance surface were regarded as ecological nodes.

The ecological breakpoints are the gaps in the corridor, which are formed by the traffic network passing through the ecological corridors. Ecological breakpoints reduce the connectivity of the ecological corridors and hinder the normal circulation of ecological flows between different sources and are not conducive to the communication and diffusion of species [66]. We identified the intersection points of the ecological corridors and the main roads in the study area as the ecological breakpoints.

3. Results

3.1. Spatio-Temporal Evolution of Ecosystem Services

From the perspective of a single ecosystem service level, the spatial distribution of each ecosystem service in the Huaiyang Canal differed significantly (Figure 4), and the four ecosystem service levels all showed varying degrees of decline from 1990 to 2018. In terms of spatial distribution, the high-value areas of water conservation service were mainly distributed in the central and western water areas, and the low-value areas were concentrated in the northern and southern urban areas. The distribution characteristics of soil conservation service were higher in the north and lower in the south, higher in the east and lower in the west. The high-value areas of carbon sequestration service were distributed sporadically, while the low-value areas coincided with the construction land and water area. Biodiversity service showed the characteristics of a staggered distribution of high and low value areas. The high-value areas were highly overlapped with woodland and water areas, while the low-value areas were distributed in clumps and spots throughout the study area and highly overlapped with construction land. In terms of changing trends, from 1990 to 2018, the low-value areas of water conservation service showed a trend of continuous expansion, and the water conservation service level per unit area decreased from 225.03 mm to 217.69 mm. The variation of soil conservation service in different periods was small, and the soil conservation amount per unit area was basically maintained at 15.07 t/hm². Carbon sequestration service has showed a continuous downward trend, and the total amount of carbon sequestration decreased from 1.7463×10^8 t in 1990 to 1.6948×10^8 t in 2018. The level of biodiversity service has declined from 1990 to 2018, and low-value areas have shown a trend of continuous expansion. The average level of habitat quality has decreased from 0.418 to 0.384.

The level of integrated ecosystem services in the Huaiyang Canal was dominated by the slightly important grade and the moderately important grade, followed by the non-important grade, and the area of the extremely important grade was the least. The integrated ecosystem services in the Huaiyang Canal showed a trend of continuous degradation from 1990 to 2018. In terms of spatial distribution, the extremely important grade was mainly distributed in the central and western water concentrated area, the moderately important grade was adjacent to the extremely important grade and was mostly distributed in the central and eastern regions of the study area, the slightly important grade was concentrated in the northern area, and the non-important grade was distributed sporadically throughout the study area and highly overlapped with construction land (Figure 5). In terms of time variation trends, from 1990 to 2018, the extremely important grade has shown a continuous decreasing trend, and its ratio of the total area decreased from 15.91% to 11.92%. The non-important grade has shown a continuously rising trend, and its ratio of the total area increased from 12.49% in 1990 to 16.15% in 2018. Both the moderately important grade and the slightly important grade have shown the characteristics of first an increase and then a decrease. The area of moderately important grade decreased slightly while the area of slightly important grade increased slightly from 1990 to 2018 (Figure 6).

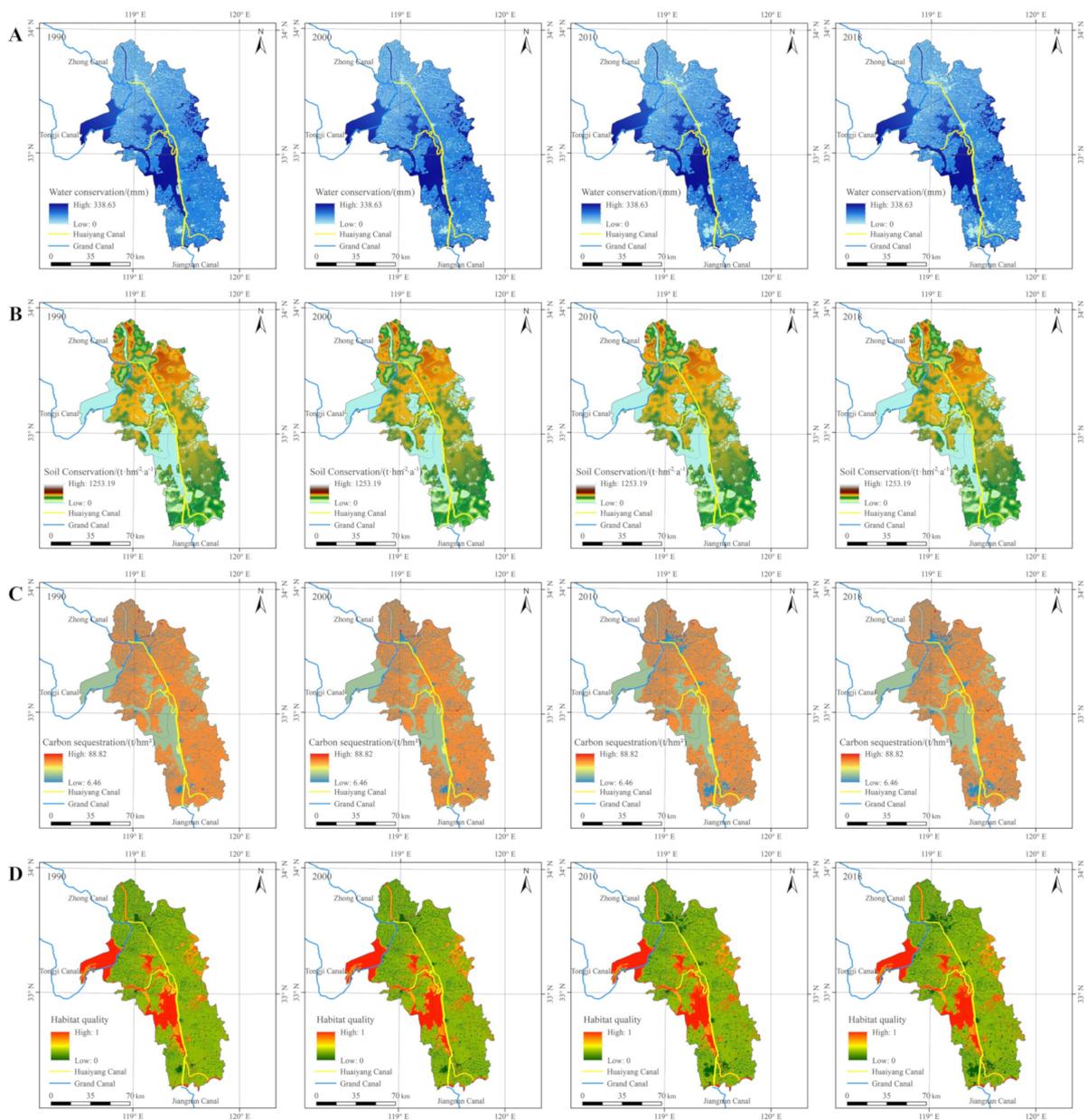


Figure 4. Spatial distribution of each ecosystem service in the Huaiyang Canal from 1990 to 2018 (Note: (A) water conservation service; (B) soil conservation service; (C) carbon sequestration service; (D) biodiversity conservation service).

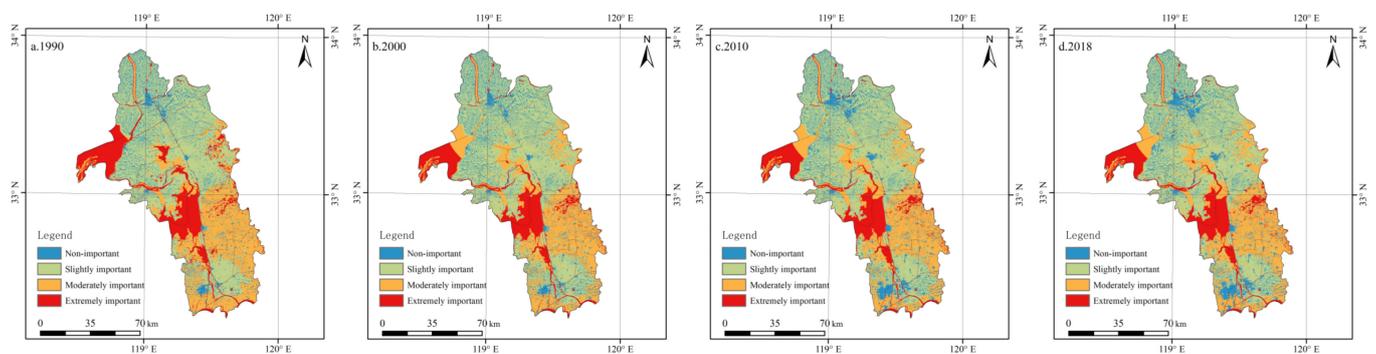


Figure 5. Spatial distribution of integrated ecosystem service in the Huaiyang Canal from 1990 to 2018.

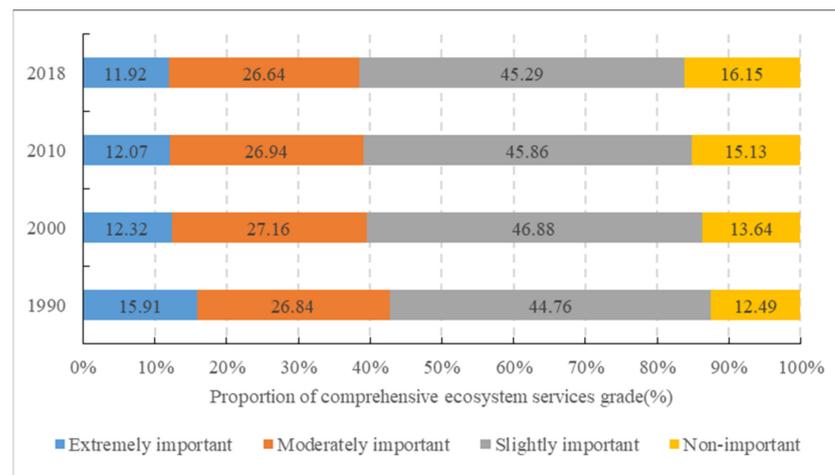


Figure 6. Area ratio of each integrated ecosystem service grade from 1990 to 2018.

3.2. Ecological Source Analysis

This study took the woodland and water area in the Huaiyang Canal as the foreground elements to conduct MSPA (Figure 7a), then counted the area and ratio of each landscape type (Table 4). Among the seven landscape types in the foreground, the core type had the largest area of 1905.91 km², accounting for 74.29% of the foreground landscape, followed by the edge type, accounting for 12.37% of the foreground landscape, indicating that the core patches in the study area were highly dispersed. The scattered small patches in the core type were deleted, and the adjacent patches were merged. Based on Formulas (12) and (13), Conefor software was used to evaluate the landscape connectivity of 33 core patches. The evaluation results showed that the core patches with a dPC value less than 1 were small in area, poor in landscape connectivity, and close to the construction land of the study area, which was easily disturbed by human activities and could not be determined as the ecological sources. Therefore, the core patches with a dPC value greater than 1 were determined as the ecological sources. The area of ecological sources obtained by MSPA and landscape connectivity evaluation was 1886.14 km², and the area of ecological sources obtained by integrated ecosystem services evaluation was 1309.28 km². The two were spatially superimposed and combined to obtain the ecological sources in the study area. There were 12 ecological source patches, with a total area of 2007.06 km². From the perspective of spatial distribution characteristics (Figure 7b), large ecological source patches were mainly distributed in the central and western regions of the study area and were close to the Grand Canal, while small ecological source patches were scattered in the eastern and southern border regions of the study area.

3.3. Analysis of Ecological Corridor Path and Width

The constructed ecological resistance surface (Figure 8a) showed that the ecological resistance of the study area presented the characteristics of polycentric outward diffusion. The two large-scale high-value agglomeration centers formed by ecological resistance were in the central urban area of Yangzhou City in the south and the central urban area of Huai'an City in the north. In addition, there were several small-scale high-value ecological resistance clusters in the middle regions of the study area. These areas have concentrated construction land and are heavily disturbed by human beings, which seriously hinder landscape connectivity and species migration. The low-value areas of ecological resistance were mainly distributed in the middle regions of the study area and were dominated by water area and farmland. There were 66 potential ecological corridors in the study area extracted by the MCR model and the least-cost path method. Due to the overlap or similarity of many corridor paths, to reduce the construction cost, redundant corridors were deleted according to the distribution characteristics of the corridors and the substitutability of their functions. Finally, 23 ecological corridors were obtained in the study area, with a

total length of 373.84 km (Figure 8b). Based on the gravity model, the relative importance of the 23 ecological corridors was analyzed, and the natural break point method was used to divide the ecological corridors into three grades. The results showed that there were nine primary ecological corridors with a total length of 53.81 km, seven secondary ecological corridors with a total length of 146.05 km, and seven tertiary ecological corridors with a total length of 173.98 km (Figure 9).

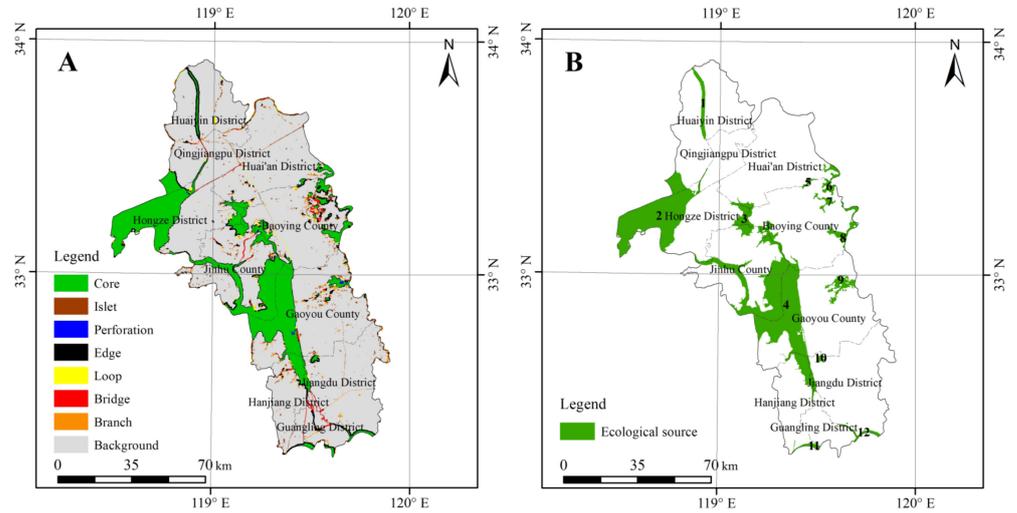


Figure 7. Landscape pattern based on MSPA (A) and spatial distribution of ecological sources (B).

Table 4. Area of each landscape type based on MSPA.

Landscape Type	Area (km ²)	Proportion of Forestland and Water Area (%)	Proportion of Total Area (%)
Core	1905.91	74.29	16.55
Islet	103.39	4.03	0.89
Perforation	4.36	0.17	0.04
Edge	317.35	12.37	2.76
Loop	38.23	1.49	0.33
Bridge	87.48	3.41	0.76
Branch	108.78	4.24	0.94
Total	2565.5	100	22.27

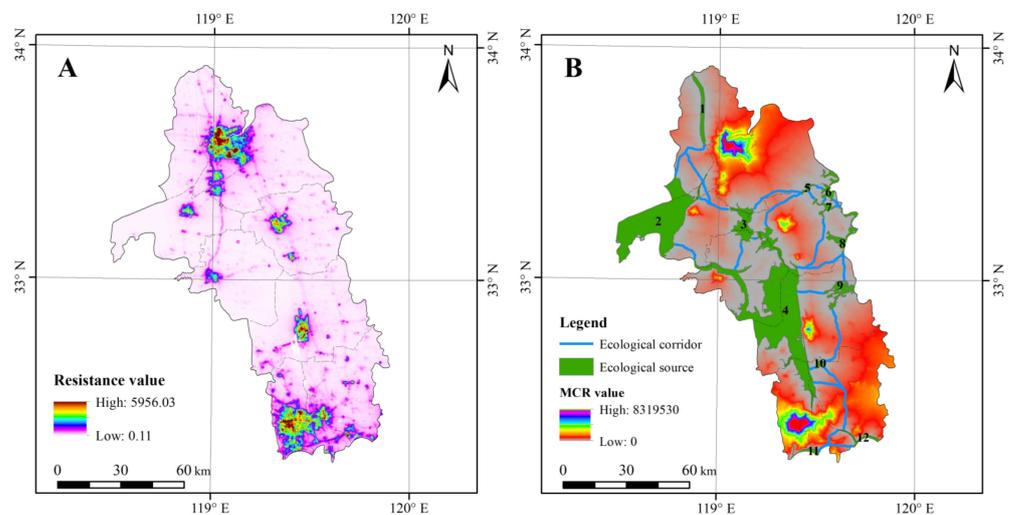


Figure 8. Ecological resistance surface (A) and spatial distribution of ecological corridors (B).

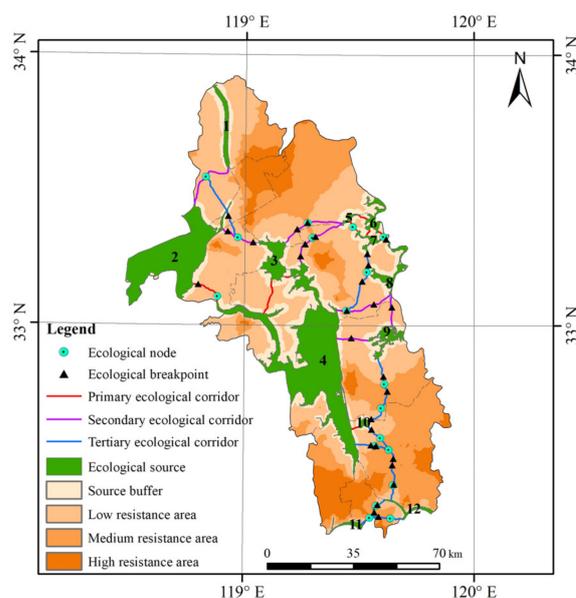


Figure 9. Spatial distribution of the ecological network.

By analyzing the area of current land-use types in different buffer zones of corridors (Table 5) it was found that the distribution area of each land-use type in different widths of corridors was quite different. Among them, the ratio of farmland, woodland, and water area fluctuated significantly, while the difference of other land-use types was small. With the increase of the ecological corridor width, the area ratio of farmland decreased first and then increased, and the inflection point appeared at 400 m. The area ratio of construction land decreased first, then increased and decreased again, and the lowest point appeared at 200 m. The area ratios of woodland and water area both increased first and then decreased, and the inflection points appeared at 200 m and 400 m, respectively. The area ratio of grassland decreased first, then increased and decreased again, and the highest point appeared at 400 m. Most of the ecological corridors are built in areas with less human disturbance and more ecological land. Within the width range of 200–400 m, the ecological corridor had the smallest proportion of construction land and farmland, and was less disturbed by human activities, while the ecological land such as woodland, grassland, and water area accounted for the largest proportion, which can lay a certain foundation for the future interior landscape construction of the corridor and reduce the construction cost. In addition, the wild animals in Yangzhou and Huai'an are mostly birds, and there are no large wild animals. However, there are small and medium-sized mammals such as the hog badger, dog badgers, raccoon dog, vulpes, otter, and *mustela sibirica*. This width range reached the width required by the migration of small and medium-sized mammals in the research results of Zhu et al. [84], and could effectively realize species migration, diffusion, and biodiversity conservation in the study area. Therefore, the width of the ecological corridor was determined to be 200–400 m.

3.4. Analysis of Ecological Node and Breakpoint

Ecological nodes can provide resting places for species to move between different habitats, while ecological breakpoints are dangerous zones that species need to cross during migration. This study has identified 18 ecological nodes and 29 ecological breakpoints. The ecological nodes in the southern ecological corridors were denser, while those in the northern ecological corridors were more scattered, and there were no ecological nodes in seven corridors, which was related to the large difference in the distribution of minimum cumulative resistance distance in the southern regions. The superposition results of ecological nodes and the current land-use distribution map showed that three ecological nodes were distributed on woodland, and the remaining ecological nodes were distributed

on farmland. Farmland is the largest land-use type in the study area, and it is also the land-use type with more human intervention except for construction land. In the future, it is necessary to increase green space and vegetation coverage at the locations of these 15 ecological nodes to provide safe midway rest space for species migration. The distribution of ecological breakpoints was also uneven, mainly concentrated in the secondary ecological corridor and the tertiary ecological corridor, and only two ecological breakpoints in the primary ecological corridor, which was related to the dense traffic network in the southern and central regions and the sparse traffic network in the eastern and western regions. The ecological sources, ecological corridors, ecological nodes, and ecological breakpoints were spatially superimposed to obtain the ecological network of the study area (Figure 9).

Table 5. Area of each landscape type based on MSPA.

Land-Use Type	Corridor Width (m)							
	100	200	400	600	800	1000	1200	1500
Farmland	69.67	69.48	68.19	70.54	70.45	71.03	71.79	72.31
Woodland	3.05	3.62	3.15	1.83	1.61	1.31	1.26	1.07
Grassland	0.26	0.23	0.28	0.15	0.13	0.13	0.13	0.13
Water area	5.71	7.02	7.59	6.62	6.68	6.02	5.76	5.69
Construction land	21.31	19.65	20.79	20.86	21.13	21.51	21.05	20.78
Unused land	0	0	0	0	0	0	0.01	0.02
Total	100	100	100	100	100	100	100	100

4. Discussion

4.1. Ecological Network Optimization

The ecological source is the most important component of the ecological network and the key area for protecting regional biodiversity and providing ecosystem services, which must be protected as a priority [66]. This study has identified 12 ecological source patches, but the area of the source patches was quite different. The number of ecological source patches on the west side of the Grand Canal was small but the patch area was large, while the number of ecological source patches on the east side of the Grand Canal was large but the patch area was small. To better protect the ecological sources, they were ranked and graded according to the patch importance index (dPC). Using Conefor software to calculate the dPC index of 12 ecological source patches, the results showed that the largest dPC index was ecological source patch 4 reaching 80.47, followed by ecological source patch 2 and ecological source patch 3, which were 45.51 and 10.39, respectively. The dPC indices of the remaining nine ecological source patches were all less than 5. The greater the dPC index, the more important the ecological source patch. Ecological source patches 2, 3, and 4 not only had large a dPC index, but also their area accounted for 85% of the total area of ecological sources. In addition, these three ecological source patches were all concentrated on the west side of the Grand Canal and were adjacent to each other. Therefore, ecological source patches 2, 3, and 4 were classified as key ecological sources, and the remaining nine ecological source patches were classified as important ecological sources (Figure 10). Ecological corridors provide channels for species to migrate between different habitats and are of great significance to the flow of matter, energy, and genes in nature [11,57]. There are many rivers and lakes in the study area, and almost every ecological source patch contains a large area of water, which is relatively rich in aquatic wildlife. The ecological corridors constructed above were mainly for terrestrial species. The current landscape in the corridor was dominated by farmland, and the water area was small, which is not conducive to the migration of aquatic animals among ecological sources. From the river distribution maps of Yangzhou city and Huai'an city, the important rivers connected with ecological source patches were extracted as aquatic corridors to optimize the corridor network. There were 10 aquatic corridors with a total length of 553.58 km, the main body of which was distributed symmetrically with the Grand Canal as the center. After optimization, the ecological corridor in the study area was finally composed of 23 terrestrial corridors and 10

aquatic corridors (Figure 10), with a total length of 927.42 km, which greatly improved the service value of the corridor network. The existence of ecological breakpoints reduces the success rate of species migration and is the key ecological restoration area. Great attention should be paid to the ecological breakpoints on the ecological corridor network, and certain engineering measures should be taken to repair and improve them, such as speeding up the construction of underground passages, tunnels, and overpasses to change the flow routes of vehicles and people and reduce the impact of human activities on the spread of species. After restoration by engineering and biological means, ecological breakpoints can also be transformed into ecological nodes to strengthen the integrity of the ecological landscape and corridor network [80].

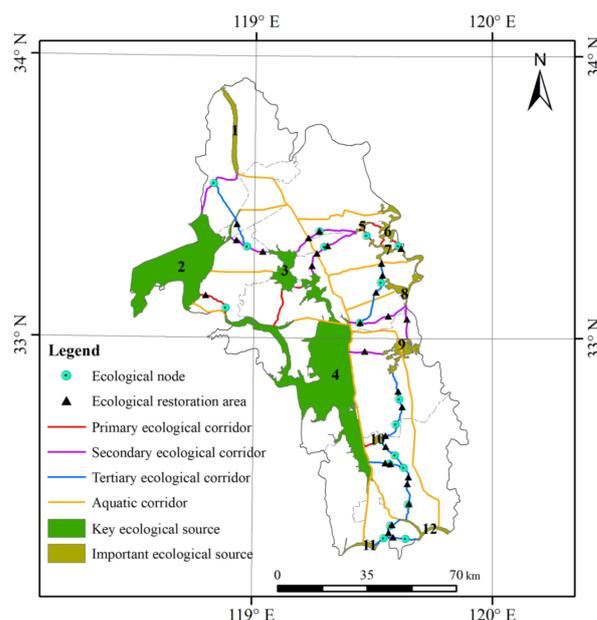


Figure 10. Spatial distribution of the ecological network after optimization.

4.2. Corroboration of the Scientific Conjecture

From 1990 to 2018, the cities and counties along the Huaiyang Canal have experienced rapid growth in urbanization, and the average urbanization level of the study area has risen from less than 30% to more than 60%. In the process of rapid urbanization, the ecosystem of Huaiyang Canal has deteriorated significantly. Our research has shown that water, soil, and carbon sequestration, as well as biodiversity conservation services, have steadily declined from 1990 to 2018. The level of integrated ecosystem services was changed in 519.66 km² of the study area from 1990 to 2018. At the same time, land use was changed in 513.47 km². By spatially superimposing the integrated ecosystem services and land-use change areas in the ArcGIS platform, we found that the overlap rate of the two areas was 99%, indicating that land-use change was the main driver of the ecosystem services change in the study area. Degradation was the main feature of changes in the ecosystem services level from 1990 to 2018, which was closely related to the expansion of the construction land. The increase of the ecosystem services level in very few areas benefited from the partial growth of water area and woodland. Dong et al. explored the nexus among land-use change, ecosystem, and human well-being in terms of nitrogen flows and found that land-use change had a significant impact on the environmental performance and ecosystem services [85]. Arunyawat and Shrestha used the InVEST model to assess the ecosystem services in Northern Thailand and analyzed the impact of land-use change on ecosystem service [86]. Kim and Kwon simulated urban land-use change impacts on regional ecosystem services using a patch-based cellular automata model in different urban management scenarios regarding green space policies in Ansan, South Korea [87]. Koo et al. presented a stakeholder-based modeling approach to assess

the potential impact of land-use patterns and land-use changes on ecosystem services in two districts of northern Ghana, West Africa [88]. Bai et al. used the InVEST model and environmental setting scenarios to analyze the impact of land use and climate change on water-related ecosystem services in Kentucky, USA [89]. All of these research studies found that the land-use change had a significant impact on regional ecosystem services, which indirectly attested our conjecture. This study constructed the landscape ecological network of the Huaiyang Canal based on the analysis of ecosystem services and land-use changes. The ecological network improves the connectivity of the important ecological patches and effectively enhances the circulation of material flow, energy flow, and information flow in the regional ecological space. Against the background of rapid urbanization resulting in the prominent ecological problems and under the increasing realistic demand for ecological protection of the Grand Canal, the construction of the ecological network has become an important tool for ecological protection in the study area. In addition, the ecological network can limit the expansion of construction land while preventing the shrinking of ecological space, thereby mitigating the dramatic changes in regional land use.

4.3. Policy Implication

As an effective tool to strengthen the flow of ecological elements and maintain the migration of species, the landscape ecological network can provide a foundation for regional territorial space optimization and ecological protection and restoration, and it is gradually integrated into regional ecological planning and land use planning [17,29]. The study results can be connected with the territorial space planning of the study area, and the ecological network can be used to adjust the ecological protection red line delineated by the local government and optimize the ecological protection space in the counties along the Huaiyang Canal. The ecological network is composed of ecological sources, corridors, and nodes. Different protection policies need to be formulated for these different functional components of the ecological network.

The boundary line of the ecological sources should be strictly controlled. Within the ecological source patches, the occupation of construction land should be strictly restricted, the buildings that have been built should be demolished as much as possible and constructed in alternative places, the buildings that cannot be demolished should be delimited, and their expansion to the surrounding areas should be strictly prohibited. In the periphery of the ecological source patches, a certain width of the ecological buffer zone should be built to reduce the impact of human activities on the ecological sources. Partial areas in ecological source patches with beautiful scenery and good tourism resources can be considered as opened to the public, so as to develop the tourism industry to increase income and invest the income into the construction of the ecological network. For the terrestrial corridors, in the future construction process, the land-use cover in the terrestrial corridors should be mainly woodland and grassland. Since the current landscape land is mainly farmland, it is necessary to carry out the project of returning farmland to forestland and grassland in the terrestrial corridors, increase the density of green vegetation coverage, and promoting the conversion of construction land and farmland to ecological land. In addition, based on the consideration of landscape aesthetics, the types of plants in the terrestrial corridors should be constructed into a composite three-dimensional space structure including tall trees, shrubs, and herbs. For the aquatic corridors, the improvement of the aquatic environment needs to be focused on. In the context of rapid urbanization, the Huaiyang Canal and other rivers in the study area are faced with the problems of discharge pollution of industrial wastewater and urban domestic sewage, water quality deterioration, and river occupation. In the future, it is necessary to carry out water quality dynamic monitoring and water quality improvement projects in these aquatic corridors, prevent the expansion of construction space and agricultural space from occupying the ecological space of the river, strive to increase the green space along the aquatic corridors and improve the vegetation coverage of the riverbank, and improve the aquatic environment through river dredging and water pollution treatment. For the ecological nodes, the internal land-

use structure should be adjusted, the intensity of tree planting should be increased to achieve full coverage of vegetation, and small ponds should be constructed to meet the drinking water demand of animals in the process of migration. Ecological isolation zones can be set up around ecological nodes to prevent the intervention of human activities. The ecological network is an elastic ecological protection space, and the path and width of the corridor especially can be appropriately contracted and expanded in accordance with the practical problems faced in the construction process. In the early stage of the planning and construction, organization and leadership should be centralized by a unified department. In the later stage of management and maintenance, the local government can assign dedicated personnel to maintain and manage each corridor and each ecological source patch by referring to China's current river chief system, using incentives to attract social organizations and the public to participate in the construction and protection of the ecological network [17].

4.4. Limitations and Outlook

In this study, the ecological network of the Huaiyang Canal was built based on the current land-use situation, and the future planning land use situation was not fully considered. With the increase of roads in the future, it will inevitably have a certain impact on the ecological corridors, and the number of ecological breakpoints will also increase. Therefore, it is necessary to monitor the areas that may produce ecological breakpoints, and reserve space for the construction of ecological corridors in the process of road construction. The habitat suitability and migration and diffusion ability of species affect the structure of ecological network to a certain extent. Different species have different requirements for habitat patches and corridors, and different species have different landscape resistance values. Therefore, the impact of regional species on ecological network should be considered when constructing an ecological network [57,90]. Due to the insufficient grasp of species data in Yangzhou and Huai'an, this study did not consider the living characteristics of different local species when constructing the resistance surface. The analysis of the ecological corridor width also only considered the distribution structure of land-use types in different buffer zones without considering different species demand, and the corridor width obtained by analysis was only an interval range rather than a specific value. In the future, it is necessary to strengthen the collection of species data in the study area, further deepen the research on corridor width and ecological node patch construction through field visits and surveys, and further analyze the impact of species on the functional components of ecological network.

5. Conclusions

From the perspectives of ecosystem services and landscape patterns, this study integrated the ecosystem service evaluation models, MSPA, and landscape connectivity evaluation methods to identify ecological sources, then used the MCR model and the gravity model to extract ecological corridors, and further construct the ecological network of the Huaiyang Canal. Our research provides a scientific basis for the formulation of ecological protection planning, the implementation of ecological restoration projects, and the adjustment of land-use policies in the study area. It also provides a typical case reference for constructing an ecological network and formulating ecological restoration planning in other sections of the Grand Canal and counties along the canal. The results showed that the spatial distribution of water conservation service, soil conservation service, carbon sequestration service, and biodiversity conservation service were significantly different, and both the single ecosystem service level and the integrated ecosystem service level showed a trend of continuous degradation from 1990 to 2018. There were 12 ecological source patches identified by ecosystem service evaluation and MSPA, with a total area of 2007.06 km². In terms of spatial distribution, large ecological source patches were mainly distributed in the central and western regions of the study area and close to the Grand Canal, while small ecological source patches were scattered in the eastern and southern

border regions of the study area. There were 23 ecological corridors extracted by the MCR model and the minimum cost path method, with a total length of 373.84 km. According to the gravity model, there were nine primary ecological corridors, seven secondary ecological corridors, and seven tertiary ecological corridors. The suitable width of ecological corridors in the study area was 200–400 m. After optimization, the proposed ecological network was composed of 3 key ecological source patches, 9 important ecological source patches, 23 terrestrial corridors, 10 aquatic corridors, and 18 ecological nodes, with 29 ecological breakpoints that were key areas requiring ecological restoration. The overlap rate of the integrated ecosystem service change area and land-use change area was 99%, indicating that land-use change has a significant impact on regional ecosystem services.

Author Contributions: Conceptualization, F.T. and X.Z.; methodology, F.T. and L.W.; software, F.T. and Y.Z.; validation, X.Z., L.W., and M.F.; formal analysis, F.T. and X.Z.; investigation, F.T. and Y.Z.; resources, X.Z., L.W., and M.F.; data curation, F.T. and Y.Z.; writing—original draft preparation, F.T.; writing—review and editing, X.Z., L.W., and M.F.; visualization, F.T. and Y.Z.; supervision, P.Z.; project administration, M.F.; funding acquisition, L.W. and P.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Project of China (Grant No. 2016YFC0502501), the National Natural Science Foundation of China (Grant No. 41871347), and the Social Science Foundation of Hebei Province (Grant No. HB19YJ020).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Li, Y.; Wu, L.Y.; Han, Q.; Wang, X.; Zou, T.Q.; Fan, C. Estimation of remote sensing based ecological index along the Grand Canal based on PCA-AHP-TOPSIS methodology. *Ecol. Indic. Toxicol.* **2021**, *122*, 107214. [[CrossRef](#)]
- Shen, L.; Gan, Y.; Li, C.Y.; Wang, C. Pollution level and ecological risk assessment of heavy metals in riverside sediments of the Grand Canal (Beijing, Tianjin and Hebei section). *Bull. Environ. Contam. Toxicol.* **2020**, *105*, 440–445. [[CrossRef](#)] [[PubMed](#)]
- Wang, X.L.; Han, J.Y.; Xu, L.G.; Zhang, Q. Spatial and seasonal variations of the contamination within water body of the Grand Canal, China. *Environ. Pollut.* **2010**, *158*, 1513–1520. [[CrossRef](#)]
- Li, J.T.; Zhang, H.F.; Sun, Z.F. Spatiotemporal variations of land urbanization and socioeconomic benefits in a typical sample zone: A case study of the Beijing-Hangzhou Grand Canal. *Appl. Geogr.* **2020**, *117*, 102187. [[CrossRef](#)]
- Cai, J.D.; Peng, J. Introduction of Beijing-Hangzhou Grand Canal and analysis of its heritage values. *J. Hydro-Environ. Res.* **2019**, *26*, 2–7. [[CrossRef](#)]
- Zhang, M.K.; Lenzer, J.H. Mismatched canal conservation and the authorized heritage discourse in urban China: A case of the Hangzhou Section of the Grand Canal. *Int. J. Herit. Stud.* **2020**, *26*, 105–119. [[CrossRef](#)]
- Xu, Y.; Rollo, J.; Jones, D.S.; Esteban, Y.; Tong, H.; Mu, Q. Towards Sustainable Heritage Tourism: A Space Syntax-Based Analysis Method to Improve Tourists' Spatial Cognition in Chinese Historic Districts. *Buildings* **2020**, *10*, 29. [[CrossRef](#)]
- Zhuang, W.; Liu, Y.X.; Chen, Q.; Wang, Q.; Zhou, F.X. A new index for assessing heavy metal contamination in sediments of the Beijing-Hangzhou Grand Canal (Zaozhuang Segment): A case study. *Ecol. Indic.* **2016**, *69*, 250–260. [[CrossRef](#)]
- Piao, H.T.; Jiao, X.C.; Gai, N.; Chen, S.; Lu, G.H.; Yin, X.C.; Yamazaki, E.; Yamashita, N.; Tan, K.Y.; Yang, Y.L.; et al. Perfluoroalkyl substances in waters along the Grand Canal, China. *Chemosphere* **2017**, *179*, 387–394. [[CrossRef](#)]
- Shi, X.L.; Liu, X.J.; Liu, G.J.; Sun, Z.Q.; Xu, H.L. An approach to analyzing spatial patterns of protozoan communities for assessing water quality in the Hangzhou section of Jing-Hang Grand Canal in China. *Environ. Sci. Pollut. Res.* **2012**, *19*, 739–747. [[CrossRef](#)] [[PubMed](#)]
- Liu, X.Y.; Wei, M.; Zeng, J.; Zhang, S. Ecological network analysis and construction: A case study of the urban agglomeration of the Min River Delta, China. *Resour. Sci.* **2021**, *43*, 357–367. [[CrossRef](#)]
- Pili, S.; Serra, P.; Salvati, L. Landscape and the city: Agro-forest systems, land fragmentation and the ecological network in Rome, Italy. *Urban For. Urban Green* **2019**, *41*, 230–237. [[CrossRef](#)]
- Cunha, N.S.; Magalhães, M.R. Methodology for mapping the national ecological network to mainland Portugal: A planning tool towards a green infrastructure. *Ecol. Indic.* **2019**, *104*, 802–818. [[CrossRef](#)]
- Edge, C.B.; Fortin, M. Habitat network topology influences the importance of ecological traps in metapopulations. *Ecosphere* **2020**, *11*, e03146. [[CrossRef](#)]

15. Zhao, S.M.; Ma, Y.F.; Wang, J.L.; You, X.Y. Landscape pattern analysis and ecological network planning of Tianjin City. *Urban For. Urban Green* **2019**, *46*, 126479. [[CrossRef](#)]
16. Zhang, X.L.; Jin, X.B.; Han, B.; Sun, R.; Liang, X.Y.; Li, H.B.; Zhou, Y.K. Identification and optimization of ecological network in the plain area of the lower Yangtze River: A case study of Jintan District, Changzhou. *Acta Ecol. Sin.* **2021**, *41*, 3449–3461.
17. Tang, F.; Wang, L.; Zhang, P.T.; Fu, M.C. Construction of county-level ecological security pattern based on ecological protection red line and network in China. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 263–272. [[CrossRef](#)]
18. Liu, S.L.; Hou, X.Y.; Yin, Y.J.; Cheng, F.Y.; Zhang, Y.Q.; Dong, S.K. Research progress on landscape ecological networks. *Acta Ecol. Sin.* **2017**, *37*, 3947–3956.
19. Gurrutxaga, M.; Lozano, P.J.; Barrio, G.D. GIS-based approach for incorporating the connectivity of ecological networks into regional planning. *J. Nat. Conserv.* **2010**, *18*, 318–326. [[CrossRef](#)]
20. Ahern, J. Planning for an extensive open space system: Linking landscape structure and function. *Landscape Urban Plan.* **1991**, *6*, 131–145. [[CrossRef](#)]
21. Linehan, J.; Gross, M.; Finn, J. Greenway planning: Developing a landscape ecological network approach. *Landscape Urban Plan.* **1995**, *33*, 179–193. [[CrossRef](#)]
22. Mackovčín, P. A multi-level ecological network in the Czech Republic: Implementating the territorial system of ecological stability. *GeoJournal* **2000**, *51*, 211–220. [[CrossRef](#)]
23. Jongman, R.H.G.; Bouwma, I.M.; Griffioen, A.; Jones-Walters, L.; Doorn, A.M.V. The pan European ecological network: PEEN. *Landscape Ecol.* **2011**, *26*, 311–326. [[CrossRef](#)]
24. Gobster, P.H.; Westphal, L.M. The human dimensions of urban greenways: Planning for recreation and related experiences. *Landscape Urban Plan.* **2004**, *68*, 147–165. [[CrossRef](#)]
25. Bascompte, J. Ecology structure and dynamics of ecological networks. *Science* **2010**, *329*, 765–766. [[CrossRef](#)]
26. Säterberg, T.; Sellman, S.; Ebenman, B. High frequency of functional extinctions in ecological networks. *Nature* **2013**, *499*, 468–470. [[CrossRef](#)]
27. Delmas, E.; Besson, M.; Brice, M.; Burkle, L.A.; Riva, G.V.D.; Fortin, M.; Gravel, D.; Guimarães, P.R., Jr.; Hembry, D.H.; Newman, E.A.; et al. Analysing ecological networks of species interactions. *Biol. Rev.* **2018**, *94*, 1–21. [[CrossRef](#)] [[PubMed](#)]
28. Guimarães, P.R., Jr. The structure of ecological networks across levels of organization. *Annu. Rev. Ecol. Evol. Syst.* **2020**, *51*, 433–460. [[CrossRef](#)]
29. Guo, J.X.; Hu, Z.Q.; Li, H.X.; Liu, J.L.; Zhang, X.; Lai, X.J. Construction of municipal ecological space network based on MCR model. *Trans. Chin. Soc. Agric. Mach.* **2021**, *52*, 275–284. [[CrossRef](#)]
30. Jongman, R.H.G.; Külvik, M.; Kristiansen, I. European ecological networks and greenways. *Landscape Urban Plan.* **2004**, *68*, 305–319. [[CrossRef](#)]
31. Izakovičová, Z.; Swiader, M. Building ecological networks in Slovakia and Poland. *Ekologia* **2017**, *36*, 303–322. [[CrossRef](#)]
32. Zhang, L.Q.; Peng, J.; Liu, Y.X.; Wu, J.S. Coupling ecosystem services supply and human ecological demand to identify landscape ecological security pattern: A case study in Beijing-Tianjin-Hebei region, China. *Urban Ecosyst.* **2017**, *20*, 701–714. [[CrossRef](#)]
33. Peng, J.; Yang, Y.; Liu, Y.X.; Hu, Y.N.; Du, Y.Y.; Meersmans, J.; Qiu, S.J. Linking ecosystem services and circuit theory to identify ecological security patterns. *Sci. Total Environ.* **2018**, *644*, 781–790. [[CrossRef](#)]
34. Dong, J.Q.; Peng, J.; Xu, Z.H.; Liu, Y.X.; Wang, X.Y.; Li, B. Integrating regional and interregional approaches to identify ecological security patterns. *Landscape Ecol.* **2021**, *36*, 2151–2164. [[CrossRef](#)]
35. Wang, S.; Wu, M.Q.; Hu, M.M.; Fan, C.; Wang, T.; Xia, B.C. Promoting landscape connectivity of highly urbanized area: An ecological network approach. *Ecol. Indic.* **2021**, *125*, 107487. [[CrossRef](#)]
36. Song, S.; Xu, D.W.; Hu, S.S.; Shi, M.X. Ecological Network Optimization in Urban Central District Based on Complex Network Theory: A Case Study with the Urban Central District of Harbin. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1427. [[CrossRef](#)]
37. Orantes, M.J.C.; Kim, J.; Kim, J. Socio-Cultural Asset Integration for a Green Infrastructure Network Plan in Yesan County, Korea. *Sustainability* **2017**, *9*, 192. [[CrossRef](#)]
38. Jiang, X.; Zhao, T.Y. Research on the Spatial Structure of County Greenway Network Based on Gravitation-Resistance Measurement-A Case Study of Ning'an in China. *Sustainability* **2020**, *12*, 1352. [[CrossRef](#)]
39. Yu, Q.; Yue, D.P.; Wang, Y.H.; Kai, S.; Fang, M.Z.; Ma, H.; Zhang, Q.B.; Huang, Y. Optimization of ecological node layout and stability analysis of ecological network in desert oasis: A typical case study of ecological fragile zone located at Deng Kou County (Inner Mongolia). *Ecol. Indic.* **2018**, *84*, 304–318. [[CrossRef](#)]
40. Fu, Y.J.; Shi, X.Y.; He, J.; Yuan, Y.; Qu, L.L. Identification and optimization strategy of county ecological security pattern: A case study in the Loess Plateau, China. *Ecol. Indic.* **2020**, *112*, 106030. [[CrossRef](#)]
41. Zhou, D.; Song, W. Identifying ecological corridors and networks in mountainous areas. *Int. J. Environ. Res. Public Health* **2021**, *18*, 4797. [[CrossRef](#)] [[PubMed](#)]
42. Cong, P.F.; Chen, K.X.; Qu, L.M.; Han, J.B.; Yang, Z.X. Determination of landscape ecological network of wetlands in the Yellow River Delta. *Wetlands* **2020**, *40*, 2729–2739. [[CrossRef](#)]
43. Kharrazi, A.; Akiyama, T.; Yu, Y.D.; Li, J. Evaluating the evolution of the Heihe River basin using the ecological network analysis: Efficiency, resilience, and implications for water resource management policy. *Sci. Total Environ.* **2016**, *572*, 688–696. [[CrossRef](#)]
44. Shi, F.N.; Liu, S.L.; Sun, Y.X.; An, Y.; Zhao, S.; Liu, Y.X.; Li, M.Q. Ecological network construction of the heterogeneous agro-pastoral areas in the upper Yellow River basin. *Agric. Ecosyst. Environ.* **2020**, *302*, 107069. [[CrossRef](#)]

45. Zhou, D.; Lin, Z.L.; Ma, S.M.; Qi, J.L.; Yan, T.T. Assessing an ecological security network for a rapid urbanization region in Eastern China. *Land Degrad. Dev.* **2021**, *21*, 2642–2660. [[CrossRef](#)]
46. Dai, L.; Liu, Y.B.; Luo, X.Y. Integrating the MCR and DOI models to construct an ecological security network for the urban agglomeration around Poyang Lake, China. *Sci. Total. Environ.* **2021**, *754*, 141868. [[CrossRef](#)] [[PubMed](#)]
47. Xu, W.X.; Wang, J.M.; Zhang, M.; Li, S.J. Construction of landscape ecological network based on landscape ecological risk assessment in a large-scale opencast coal mine area. *J. Clean. Prod.* **2021**, *286*, 125523. [[CrossRef](#)]
48. Jalkanen, J.; Toivonen, T.; Moilanen, A. Identification of ecological networks for land-use planning with spatial conservation prioritization. *Landsc. Ecol.* **2020**, *32*, 353–371. [[CrossRef](#)]
49. Jakiel, M.; Bernatek, A. Assessment of an ecological network at local scale in the context of landscape changes: A case study from NE Poland. In *Landscape Analysis and Planning*; Springer Geography, Springer International Publishing: Cham, Switzerland, 2015. [[CrossRef](#)]
50. Zhang, R.; Zhang, L.; Zhong, Q.C.; Zhang, Q.P.; Ji, Y.W.; Song, P.H.; Wang, Q.Q. An optimized evaluation method of an urban ecological network: The case of the Minhang District of Shanghai. *Urban For. Urban Green* **2021**, *62*, 127158. [[CrossRef](#)]
51. Shi, F.N.; Liu, S.L.; An, Y.; Sun, Y.X. Biodiversity conservation of mountains-rivers-forests-farmlands-lakes-grasslands using an ecological network: A case study on the Zuoyoujiang River basin in Guangxi Province, China. *Acta Ecol. Sin.* **2019**, *39*, 8930–8938.
52. Jia, Z.Y.; Chen, C.D.; Tong, X.X.; Wu, S.J.; Zhou, W.Z. Developing and optimizing ecological networks for the towns along the Three Gorges Reservoir: A case of Kaizhou New Town, Chongqing. *Chin. J. Ecol.* **2017**, *36*, 779–782. [[CrossRef](#)]
53. Jiang, H.; Peng, J.; Dong, J.Q.; Zhang, Z.M.; Xu, Z.H.; Meersmans, J. Linking ecological background and demand to identify ecological security patterns across the Guangdong-Hong Kong-Macao Greater Bay Area in China. *Landsc. Ecol.* **2021**, *36*, 2135–2150. [[CrossRef](#)]
54. Shen, J.K.; Guo, X.L.; Wang, Y.C. Identifying and setting the natural spaces priority based on the multi-ecosystem services capacity index. *Ecol. Indic.* **2021**, *125*, 107473. [[CrossRef](#)]
55. Xiao, S.C.; Wu, W.J.; Guo, J.; Ou, M.H.; Pueppke, S.G.; Ou, W.X.; Tao, Y. An evaluation framework for designing ecological security patterns and prioritizing ecological corridors: Application in Jiangsu Province, China. *Landsc. Ecol.* **2020**, *35*, 2517–2534. [[CrossRef](#)]
56. Chen, C.L.; Shi, L.; Lu, Y.; Yang, S.; Liu, S.F. The optimization of urban ecological network planning based on the minimum cumulative resistance model and granularity reverse method: A case study of Haikou, China. *IEEE Access* **2020**, *8*, 43592–43605. [[CrossRef](#)]
57. Tang, F.; Zhang, P.T.; Zhang, G.J.; Zhao, L.; Zheng, Y.; Wei, M.H.; Jian, Q. Construction of ecological corridors in Changli County based on ecological sensitivity and ecosystem service values. *Chin. J. Appl. Ecol.* **2018**, *29*, 2675–2684. [[CrossRef](#)]
58. Takahashi, K.; Wang, C.G. The empirical formula of evaporation estimated by monthly mean temperature and precipitation. *Meteorol. Sci. Technol.* **1980**, *S4*, 48–50. [[CrossRef](#)]
59. Elvidge, C.D.; Zhizhin, M.; Ghosh, T.; Hsu, F.C.; Taneja, J. Annual time series of global VIIRS nighttime lights derived from monthly averages: 2012 to 2019. *Remote. Sens.* **2021**, *13*, 922. [[CrossRef](#)]
60. Yang, L.L.; Gong, J.; Xu, C.X.; Cao, E.J.; Li, H.Y.; Gao, B.L.; Li, Y. Spatiotemporal variations and influencing factors of soil conservation service in Ziwuling Area. *J. Soil Water Conserv.* **2021**, *35*, 188–197. [[CrossRef](#)]
61. Liu, H.; Liu, Y.X.; Wang, K.; Zhao, W.W. Soil conservation efficiency assessment based on land use scenarios in the Nile River Basin. *Ecol. Indic. Toxicol.* **2020**, *119*, 106864. [[CrossRef](#)]
62. Arnoldus, H.M.J. *An Approximation of the Rainfall Factor in the Universal Soil Loss Equation*; John Wiley and Sons Ltd. Press: Chichester, UK, 1980; pp. 127–132.
63. Williams, J.; Nearing, M.; Nicks, A.; Skidmore, E.; Valentin, C.; King, K.; Savabi, R. Using soil erosion models for global change studies. *J. Soil Water Conserv.* **1996**, *51*, 381–385.
64. Wischmeier, W.H. Use and misuse of universal soil loss equation. *J. Soil Water Conserv.* **1976**, *31*, 5–9.
65. Liu, B.Y.; Xie, Y.; Zhang, K.L. *Soil Erosion Prediction Model*; China Science and Technology Press: Beijing, China, 2001.
66. Tang, F. Research on Ecological Security Pattern in Qinglong County based on Ecological Protection Red Line and Ecological Network. Master's Thesis, Hebei Agricultural University, Baoding, China, 2019.
67. Zha, L.S.; Deng, G.H.; Gu, J.C. Dynamic changes of soil erosion in the Chaohu Watershed from 1992 to 2013. *Acta Geogr. Sin.* **2015**, *70*, 1708–1719. [[CrossRef](#)]
68. Zhu, W.B.; Zhang, J.J.; Cui, Y.P.; Zheng, H.; Zhu, L.Q. Assessment of territorial ecosystem carbon storage based on land use change scenario: A case study in Qihe River Basin. *Acta Geogr. Sin.* **2019**, *74*, 446–459. [[CrossRef](#)]
69. Chen, G.S.; Yang, Y.S.; Xie, J.S.; Du, Z.X.; Zhang, J. Total below ground carbon allocation in China's forests. *Acta Ecol. Sin.* **2007**, *27*, 5148–5157.
70. Giardina, C.P.; Ryan, M.G. Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature. *Nature* **2000**, *404*, 858–861. [[CrossRef](#)] [[PubMed](#)]
71. Alam, S.A.; Starr, M.; Clark, B.J.F. Tree biomass and soil organic carbon densities across the Sudanese woodland savannah: A regional carbon sequestration study. *J. Arid. Environ.* **2013**, *89*, 67–76. [[CrossRef](#)]
72. Tang, F.; Fu, M.C.; Wang, L.; Zhang, P.T. Land-use change in Changli County, China: Predicting its spatio-temporal evolution in habitat quality. *Ecol. Indic.* **2020**, *117*, 106719. [[CrossRef](#)]

73. Tang, F.; Fu, M.C.; Wang, L.; Song, W.J.; Yu, J.F.; Wu, Y.B. Dynamic evolution and scenario simulation of habitat quality under the impact of land-use change in the Huaihe River Economic Belt, China. *PLoS ONE* **2021**, *16*, e0249566. [[CrossRef](#)] [[PubMed](#)]
74. Terrado, M.; Sabater, S.; Chaplin-Kramer, B.; Mandle, L.; Ziv, G.; Acuña, V. Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning. *Sci. Total Environ.* **2016**, *540*, 63–70. [[CrossRef](#)]
75. Sun, X.Y.; Jiang, Z.; Liu, F.; Zhang, D.Z. Monitoring spatio-temporal dynamics of habitat quality in Nansihu Lake basin, eastern China, from 1980 to 2015. *Ecol. Indic.* **2019**, *102*, 716–723. [[CrossRef](#)]
76. Xu, L.T.; Chen, S.S.; Xu, Y.; Li, G.Y.; Su, W.Z. Impacts of Land-Use Change on Habitat Quality during 1985–2015 in the Taihu Lake Basin. *Sustainability* **2019**, *11*, 3513. [[CrossRef](#)]
77. Vogt, P.; Ferrari, J.R.; Lookingbill, T.R.; Gardner, R.H.; Riitters, K.H.; Ostapowicz, K. Mapping functional connectivity. *Ecol. Indic.* **2009**, *9*, 64–71. [[CrossRef](#)]
78. Saura, S.; Vogt, P.; Velázquez, J.; Hernando, A.; Tejera, R. Key structural forest connectors can be identified by combining landscape spatial pattern and network analyses. *Forest Ecol. Manag.* **2011**, *262*, 150–160. [[CrossRef](#)]
79. Pascual-Hortal, L.; Saura, S. Comparison and development of new graph-based landscape connectivity indices: Towards the prioritization of habitat patches and corridors for conservation. *Landscape Ecol.* **2006**, *21*, 959–967. [[CrossRef](#)]
80. Gao, J.B.; Du, F.J.; Zuo, L.Y.; Jiang, Y. Integrating ecosystem services and rocky desertification into identification of karst ecological security pattern. *Landscape Ecol.* **2020**, *36*, 2113–2133. [[CrossRef](#)]
81. Peng, J.; Li, H.; Liu, Y.; Hu, Y.; Yang, Y. Identification and optimization of ecological security pattern in Xiong'an New Area. *Acta Geogr. Sin.* **2018**, *73*, 701–710. [[CrossRef](#)]
82. Knaapen, J.P.; Scheffer, M.; Harms, B. Estimating habitat isolation in landscape planning. *Landscape Urban Plan.* **1992**, *23*, 1–16. [[CrossRef](#)]
83. Xu, W.J.; Chen, C.; Zhang, Z.; Shao, X.L.; Zhang, X.H.; Zhang, Y. Ecological corridor construction based on important ecological nodes in Duliujian River Basin. *Res. Environ. Sci.* **2018**, *31*, 805–813. [[CrossRef](#)]
84. Zhu, Q.; Yu, K.J.; Li, D.H. The width of ecological corridor in landscape planning. *Acta Ecol. Sin.* **2005**, *25*, 2406–2412.
85. Dong, X.B.; Ren, J.H.; Zhang, P.; Jin, Y.; Liu, R.R.; Wang, X.C.; Lee, C.T.; Klemes, J.J. Entwining ecosystem services, Land Use Change and human well-being by nitrogen flows. *J. Clean. Prod.* **2021**, *308*, 127442. [[CrossRef](#)]
86. Arunyawat, S.; Shrestha, R.P. Assessing Land Use Change and Its Impact on Ecosystem Services in Northern Thailand. *Sustainability* **2016**, *8*, 768. [[CrossRef](#)]
87. Kim, I.; Kwon, H. Assessing the impacts of urban land use changes on regional ecosystem services according to urban green space policies via the patch-based cellular automata model. *Environ. Manag.* **2021**, *61*, 192–204. [[CrossRef](#)]
88. Koo, H.; Kleemann, J.; Furst, C. Impact assessment of land use changes using local knowledge for the provision of ecosystem services in northern Ghana, West Africa. *Ecol. Indic.* **2019**, *103*, 156–172. [[CrossRef](#)]
89. Bai, Y.; Ochuodho, T.O.; Yang, J. Impact of land use and climate change on water-related ecosystem services in Kentucky, USA. *Ecol. Indic.* **2019**, *102*, 51–64. [[CrossRef](#)]
90. Chen, N.N.; Kang, S.Z.; Zhao, Y.H.; Zhou, Y.J.; Yan, J.; Lu, Y.R. Construction of ecological network in Qinling Mountains of Shaanxi, China based on MSPA and MCR model. *Chin. J. Appl. Ecol.* **2021**, *32*, 1545–1553. [[CrossRef](#)]