Proceedings of the Fábos Conference on Landscape and Greenway Planning

Volume 7
Issue 1 *Moving towards Health and Resilience in the public realm*

Article 22

August 2022

BGI Cross-Scale Coupling Space Connecting Regional Greenway and Community

Jingyuan Yuan
Dept. of Landscape, School of Architecture, Harbin Institute of Technology

BING WU
Dept. of Landscape, School of Architecture, Harbin Institute of Technology, wubing@hit.edu.cn

Xiaoguang Liu
Dept. of Landscape, School of Architecture, Harbin Institute of Technology

Recommended Citation
Yuan, Jingyuan; WU, BING; and Liu, Xiaoguang (2022) "BGI Cross-Scale Coupling Space Connecting Regional Greenway and Community," *Proceedings of the Fábos Conference on Landscape and Greenway Planning*: Vol. 7: Iss. 1, Article 22.
DOI: https://doi.org/10.7275/b9cf-z288
Available at: https://scholarworks.umass.edu/fabos/vol7/iss1/22

BGI: Cross-Scale Coupling Space Connecting Regional Greenway and Community

Jingyuan Yuan[1], Bing Wu[1], Xiaoguang Liu[1]
[1]*Dept. of Landscape, School of Architecture, Harbin Institute of Technology; Key Laboratory of National Territory Spatial Planning and Ecological Restoration in Cold Regions, Ministry of Natural Resources, China*

Abstract

At present, China is advancing its territory spatial planning, implementing the requirements of the Paris Agreement and the Convention on Biological Diversity through the construction of the GI, reducing the impact of urban development on climate change, improving ecosystem services, and maintaining sustainable urban development. Regional territory spatial planning provides a planning method for urban and regional green infrastructure. However, there is a lack of research on the green infrastructure construction mode connecting the boundary space of these two scales of greenway networks. Greenway systems must be highly connected to maintain basic ecological functions (Forman 1995, Urban 2001, Coulon 2004). In this paper, the concept of Boundary Green Infrastructure (BGI) is proposed, that is, the ecological space where the urban green infrastructure (UGI) network and regional green infrastructure (RGI) network intersect at the boundary of urban areas. BGI has the capability of connecting two levels of the greenway network. This paper selects greenway systems in six European cities as case studies. By calculating the patch landscape stability, the best BGI distance threshold range was determined, and the BGI range was determined by comparing the differences between patch importance indexes. This paper analyzes the spatial pattern of BGI and summarizes the BGI planning strategy suitable for the sustainable development of Chinese cities, which also provides a reference for the GI system in Europe. It has been proved that BGI can strengthen the connection between urban and regional greenway networks, improve ecological functions, and connect cross-scale greenway networks. Based on the above methods, this paper analyzes the current BGI indicators of Harbin (the capital of Heilongjiang Province, China) and optimizes the BGI of Harbin's cross-scale greenway network. Thus, the landscape connectivity of the optimized greenway system can be improved, the ecological core area can be increased, and the ecological function can be advanced, which proves the feasibility of connecting the multi-scale greenway network with the BGI model.

Introduction

Building green infrastructure has a positive impact on maintaining ecosystem stability and protecting biodiversity. At present, the research on ecological networks composed of greenway systems mainly focuses on the atlas theory, the theory of landscape ecology, and the circuit theory. Generally, morphological spatial pattern analysis, minimum cumulative resistance model, connectivity index, and other methods are used to identify potential ecological networks, analyze and optimize the weak parts of landscape connectivity in ecological networks, and then optimize their ecological network structure.

The construction of GI in Europe is very successful, with typical representatives such as the Pan-European Biological and Landscape Diversity Strategy and General Guidelines for the Development of the Pan-European Ecological Network (Ke 2017). European GI is presented as a greenway system, which is a complete ecological network based on biodiversity conservation and bears recreational functions. When GI transitions from the urban area to the regional area, its function changes accordingly. In urban areas, the function of green infrastructure is to meet human communication, leisure, sports, and other recreational functions, which is called urban green infrastructure (UGI). For example, as a classic case of a European recreational greenway, the South East London Green Chain, which was founded in 1977, has built recreational spaces such as environmental protection bases, public rest places, corridors of history, and sports and fitness spaces in four administrative districts in the southeast (Yunbin, 2007). The recreational function of regional green infrastructure (RGI) in regional areas gradually declines, and maintaining the stability and integrity of the ecosystem becomes the main function, and its function changes from compound to single function. It is taking Notre Dame Forest in Parise as an example. While transitioning to regional natural space, green infrastructure is transformed into large ecological sources such as national parks and wildlife protection bases, with biodiversity conservation as the primary function. In Europe, GI exists continuously from city to region, and the function of GI in rural-urban fringe gradually changes from biodiversity conservation to recreation, which is a GI coupling space connecting two scales and changing functions. GI within this range is helpful to maintain the landscape connectivity of the ecological network and the functional diversity of the greenway.

At present, China is advancing territory spatial planning and building green infrastructure to improve ecosystem services and reduce the impact of urban development on climate change. It aims to implement commitments made in treaties such as the Paris Agreement and the Convention on Biological Diversity, improve people's living standards and maintain sustainable urban development. The municipal territory spatial planning demarcates a clear boundary line of urban space and divides the urban space into the regional area and urban area. For regional green infrastructure, the methods of "identifying ecological sources-building resistance surfaces-designing potential corridors-building ecological networks" are used to build ecological networks. By this method, urban areas are set as residential patches with great resistance, and RGI is arranged around them. The green space system in the urban area is planned as an urban green infrastructure (UGI) in the form of a network. These two different planning methods artificially divide GI into RGI and UGI, which are two networks lacking connectivity, forming blank space without the green infrastructure in the rural-urban fringe.

This paper proposes the concept of boundary green infrastructure (BGI): Boundary green infrastructure (BGI) is a transitional green infrastructure connecting urban green infrastructure (UGI) and regional green infrastructure (RGI). It is located in the rural-urban fringe of the transition from the urban area to the regional area. BGI has the characteristics of dual-scale coupling space and the landscape connection function of a two-level ecological network structure. By analyzing the scope, spatial pattern, and patch characteristics of BGI in European cases, this paper summarizes the planning strategies of BGI, tries to solve the above problems, and provides a reference for greenway construction in Europe.

BGI Scope

The spatial location of the BGI (shown in Figure 1.) spans the urban area boundary and extends to the regional area. This paper selected London and Sheffield in England, Paris and Toulouse in France, Hamburg and Berlin in Germany as case studies. Firstly, the urban area boundary of the case was determined, then all regional eco-patches beyond the boundary were identified and extracted. The best buffer distance inside and outside the urban area boundary was determined by the change of landscape connectivity distance threshold, and then the BGI range was determined.

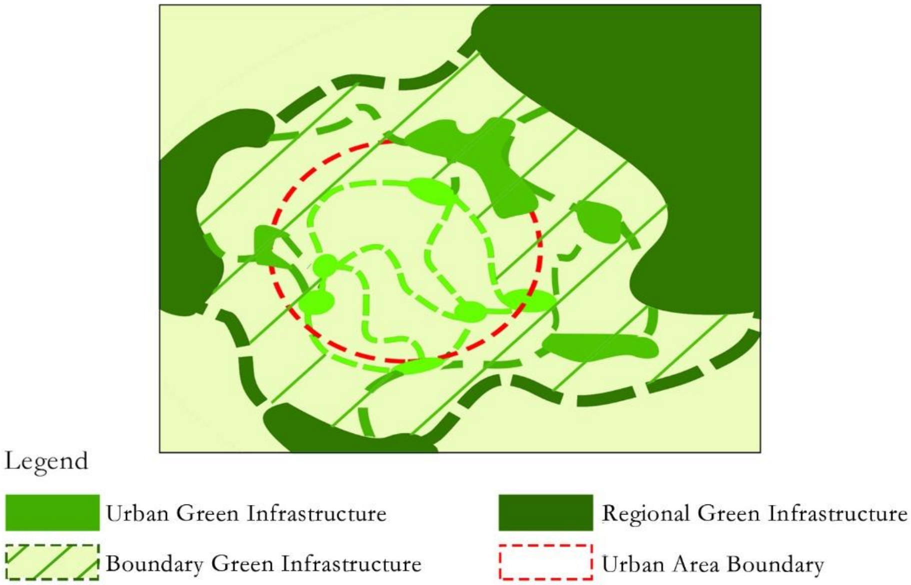

Figure 1. Diagram of BGI's location in the city

1. Determination of the urban area boundary

The information entropy model of land use types expresses the complexity and order of information through the number of land-use types and the proportion of land-use types. Therefore, this paper uses the standard deviation (S) to represent the complexity of land information, and the calculation formula is as follows (Liuyang, 2018):

$$S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - u)^2} \qquad (3\text{-}1)$$

In the formula, *S* is the standard deviation; *N* is the number of land types; *Xi* is the percentage of the area of a certain land type; *u* is the average area of land use type in a unit. In this paper, the land use data are reclassified into urban construction land and other land types by using the land use raster data with an accuracy of 30 m×30 m. When there is a single land type in the binary raster, the standard deviation is 0. If the standard deviation is not 0, it is a mixed type. According to this feature, the standard deviation threshold is set at 0.3~0.4 as the boundary between urban areas and other land-use types around it, to obtain the boundary information of urban areas. The standard deviation statistical method will lead to the phenomenon of "salt and pepper particles" in the boundary of the urban area, and the boundary of the urban area cannot be well extracted. Therefore, the kernel density analysis method is adopted to modify the results. Kernel density analysis can simulate the spatial distribution characteristics of construction land in the measurement of neighborhood density of construction point features (Cheng, 2019). When the binary raster data of land type is converted into point features, the result of kernel density analysis is very high when the data type is only urban area points. When the data type changes, the point density of the urban area decreases, and the kernel density decreases accordingly. Therefore, kernel density analysis can better reflect the spatial boundary of land use type change. The combination of the two methods can effectively avoid the interference of small construction land on the boundary of high-density urban areas, and at the same time ensure the accuracy of extracting the boundary of urban areas. The extraction results were shown in the urban area boundary in Figure 3.

2. Extraction of ecological patches outside urban areas
In this paper, the MSPA method was used to extract ecological patches in the region. Different landscape granularity can avoid the scale effect of different study areas, better retain the small but important landscape elements in the study area, and ensure the accuracy of data. Combined with the actual situation of the case study, the granularity of raster data of the regional scale analysis object was set as 100m×100m, and the granularity of urban-scale data was set as 30 m×30 m. Woodland and grassland in land use data were taken as the foreground of MSPA analysis, and other land-use types were taken as the background. The Software GuidosToolbox was used to conduct MSPA analysis on the assigned binary raster files, and seven landscape types with different functions were obtained. The ecological core areas with biodiversity conservation significance were extracted as BGI patches. The ecological patch with a core area $\geq 1km^2$ was selected in the urban area (Ya-ping 2016), and the ecological patch with a core area $\geq 5km^2$ outside the boundary of the urban area was selected as BGI ecological patch within the regional scope.

3. BGI space determination
BGI ecological patches need to be connected to two-scale ecological networks. In this paper, the best distance threshold between patches and regional and urban ecological networks was determined, and then the effective connection distance between BGI patches inside and outside the urban area boundary was determined, and finally, the BGI spatial range was determined. The landscape stability range of patches can be preliminarily judged by comparing and analyzing the number of links (NL) and the number of components (NC) among patches. According to the change of patch importance index, the appropriate landscape distance threshold can be further determined. The smaller the gap between patch importance indices, the more effective the selection of landscape distance threshold (Zhibo, 2019). The software Conefor2.6 was used to calculate the corresponding index, and the distance threshold range of landscape stability in urban and regional scales was selected. The best distance threshold of urban and regional scales was determined by comparing the difference in the patch importance index.

Combined with case studies and existing studies (Maoquan, 2019, Xiaolin, 2021, Tu, 2016), eleven distance thresholds of 200, 400, 600, 800, 1000, 1200, 1400, 1800, 2000, 2400, and 2800m were selected in the urban area to analyze the importance of ecological patches. At the regional scale, according to the distribution characteristics of ecological patches in the studied region, the regional green infrastructure outside the boundaries of urban areas was screened. Ten distances of 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500, 6000, and 6500m were selected to analyze the ecological patches. The NC and NL values of BGI patches were calculated and compared under different distance thresholds. Taking Hamburg as an example, when the regional distance threshold was less than 4500m, the NL value fluctuated up and the NC value fluctuated down, indicating that landscape stability was not good in this distance interval. When the distance threshold was between 4500m and 5500m, the decrease of NC value was slow and the increase of NL value was stable, indicating that the landscape stability was good in this range. When the distance threshold was larger than 5,500m, the NL value increased rapidly, the potential connections between ecological patches increased rapidly, and the landscape components decreased rapidly, which could not reach a stable state. Therefore, combined with the stability interval of NL and NC values, the best distance threshold range of BGI in Hamburg, Germany on the regional scale was determined to be 4500-5500m, as shown in Figure 2.

Table 1. Optimal distance threshold range for Hamburg urban scale

	200	400	600	800	1000	1200	1400	1800	2000	2400	2800
NL	0	1	2	6	9	13	14	21	28	32	37
NC	85	55	54	50	47	45	43	36	31	28	24

Table 2. Optimal distance threshold range for Hamburg region scale

	2500	3000	3500	4000	4500	5000	5500	6000	6500
NL	107	124	138	164	183	198	214	235	269
NC	119	98	90	82	73	69	65	58	51

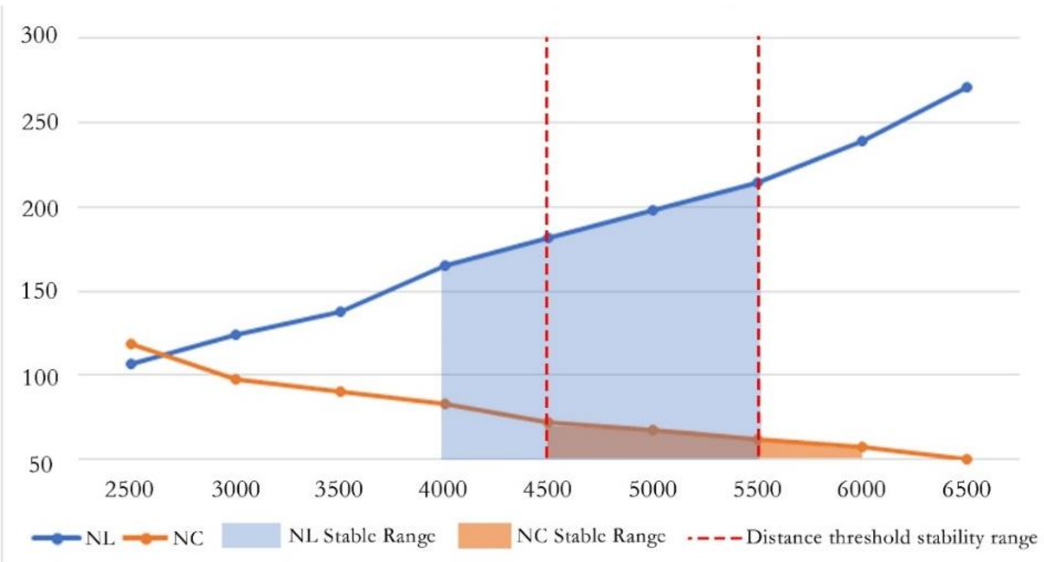

Figure 2. Optimal distance threshold range for Hamburg region scale

The above methods were used to obtain the best distance threshold range between regional and urban scales of BGI patches respectively, and the best distance threshold of urban and regional scales was finally determined according to the difference in patch importance index. According to the two-scale best distance threshold of the case city, the buffer zone was constructed, which was the BGI spatial range of the case city. The results were shown in Figure 3.

BGI Spatial Pattern

1. BGI patch distribution

BGI patches in the case cities were screened according to the designated BGI spatial range and the screening criteria of BGI eco patches. A total of 158 BGI patches were screened in the BGI range of each case, with a total area of 4121.86 km^2. The spatial distribution of BGI patches in each case is shown in Figure 3.

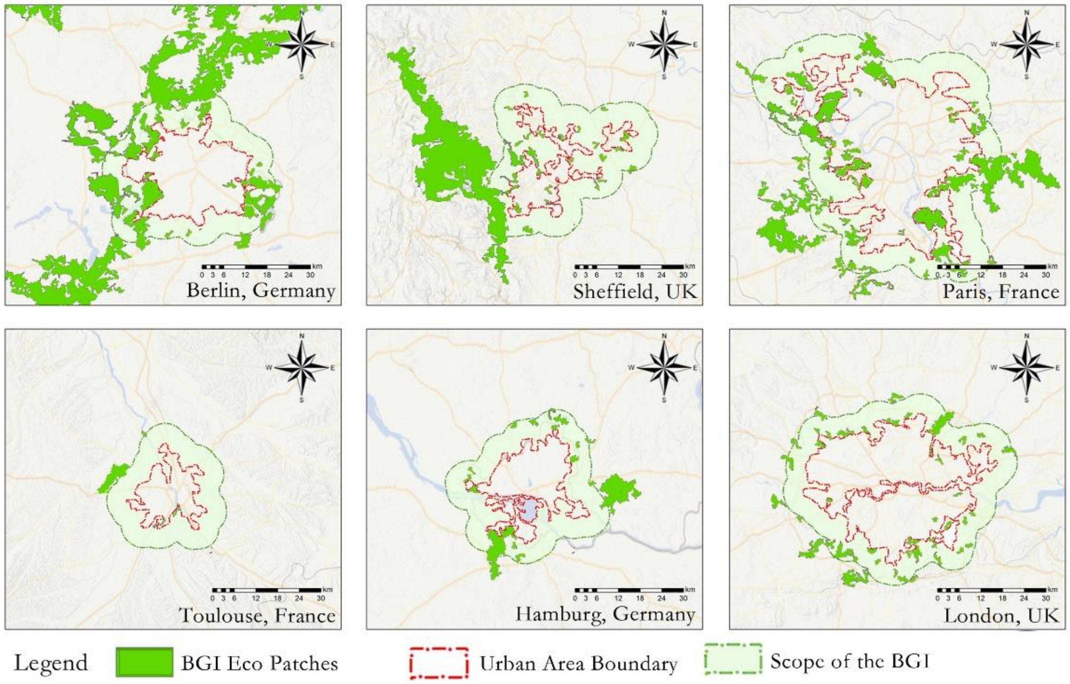

Figure 3. Scope of the BGI range and patch distribution of the case city

2. BGI spatial pattern

Pattern analysis of BGI patch distribution in case cities was carried out, and the results were shown in Table 3. The spatial pattern of BGI in Paris, France, and Berlin, Germany is similar. The proportion of BGI patches in BGI space is higher than 20%. The number of BGI patches and the total area of BGI patches are large, and the ecological patches of various types are clustered and distributed outside the urban areas, forming an enclosed ecological semi-ring. The spatial pattern of BGI in Sheffield, England, and Hamburg, Germany is similar, and the area of BG patch in BGI space accounts for more than 5%. BGI space contains not only large ecological patches but also small ecological patches distributed in scattered spots. Ecological patches with different areas together constitute the spatial pattern of BGI. Ecological space accounts for more than 5% of BGI space in London, which contains a large number of ecological patches, but the area is small and the type is single. As a large metropolitan area, London has a large population, a large urban area, and a shortage of ecological land. It is difficult to construct a large ecological patch for a small park green space with the main function of recreation. Therefore, in the BGI space of London, the BGI eco patches outside the urban area present a spatial pattern of scattered distribution. In the BGI space in Toulouse, France, ecological space accounts for less than 1%, and the total area of the BGI eco patch is only. The number and area of eco patches in BGI space are small, and the spatial pattern is fragmented and scattered.

Table 3. Analysis of BGI Spatial Pattern

Case City	Number of BGI patches	Total BGI patches area （km^2）	The proportion of patches area in the BGI space	Types of BGI Spatial Patterns
Berlin	26	2646.86	23.23％	Aggregated half-ring pattern
Paris	41	613.7	20.54％	

Sheffield	27	569.7	9.44%	Block-Point combination pattern
Hamburg	16	125.8	6.62%	
London	44	138.4	7.53%	Scatter distribution pattern
Toulouse	4	27.4	0.68%	Broken and fragmented pattern

Based on the above analysis, this paper divides the BGI spatial model into three spatial models suitable for urban development in China: a. Aggregated half-ring pattern, in which the surrounding regional ecological patches account for more than 1/3, and the patch area within the BGI range accounts for no less than 20%; b. Block-point combination pattern, which is composed of large patches, medium, and small patches, and the proportion of patch area within the range of BGI should not be less than 7-10%; c. The scatter distribution pattern, which is composed of small and medium-sized patches evenly distributed, and the proportion of patch area within the range of BGI should not be less than 8%.

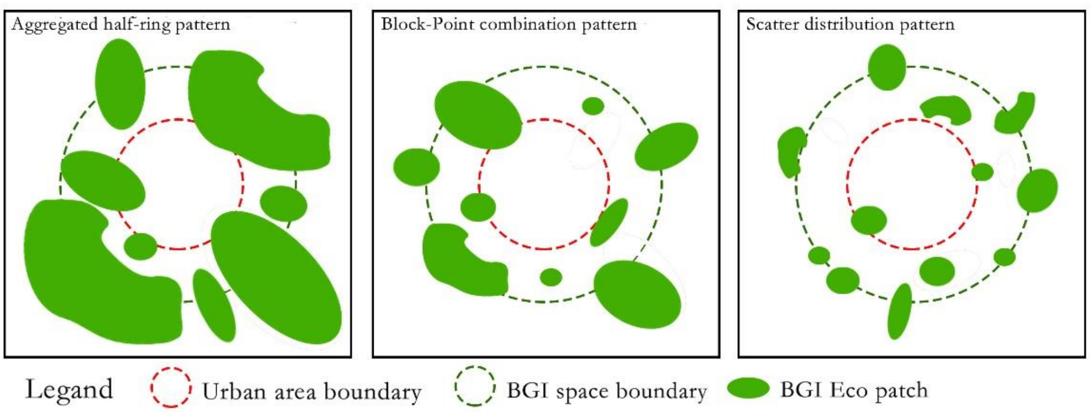

Figure 4. Schematic diagram of three BGI spatial patterns

3. Results-BGI Planning Strategy

Based on the BGI analysis of European cities, this paper proposes the following BGI spatial pattern planning strategies:

a. The proportion of eco patch area in BGI space determines the state of urban ecological space development. The higher the proportion, the less the area of other land types in the BGI space and the less the disturbance of human activities to the ecosystem. Among them, BGI with eco patch area accounting for more than 20%, such as the aggregated half-ring pattern in the case, is suitable for ecological cities; The ecological patch area accounts for 5-20% of BGI, such as the block-point combination pattern and the scatter distribution pattern in the case, which is suitable for the balanced development of economy and ecology; The area of eco patches accounts for less than 1%, such as the fragmented pattern in cases, which is a city whose ecological space needs to be upgraded.
b. BGI should enclose the urban area as far as possible. The higher the aggregation degree of eco patches in BGI space, the better the connectivity degree and the more stable the structure of the ecological network is, and the connectivity degree between RGI and UGI landscape can be improved, and the functional coupling degree of eco patches can be improved.
c. Large eco patches should be planned as much as possible in the BGI space. From the species point of view, biodiversity also increased with the increase of patch area; From the perspective of landscape heterogeneity, the larger the ecological patch area, the higher its heterogeneity. According to the development needs of different cities and the spatial pattern of land use, a

large area of eco patches should be planned in BGI space as much as possible to provide a guarantee for regional biodiversity protection.

d. The total number of effective eco patches of BGI should be higher than 15. In BGI space, the smaller the number of patches, the fewer landscape nodes connected between the region and the urban ecological network. Taking Toulouse, France as an example, there are only four small ecological patches far apart in BGI space. The lack of connection between eco patches is susceptible to interference from other land types.

BGI Research Case

Harbin is located in the south-central part of Heilongjiang Province (125°42'E-130°10'E，44°04'N-46°40'N). The research space is located in the main administrative district of Harbin, covering an area of 4187km^2, surrounded by the amount of farmland, in which small villages are scattered. In the municipal territory spatial planning, there is a lack of BGI space in the planned UGI eco network and the planned RGI eco network, which leads to the deficiency of GI.

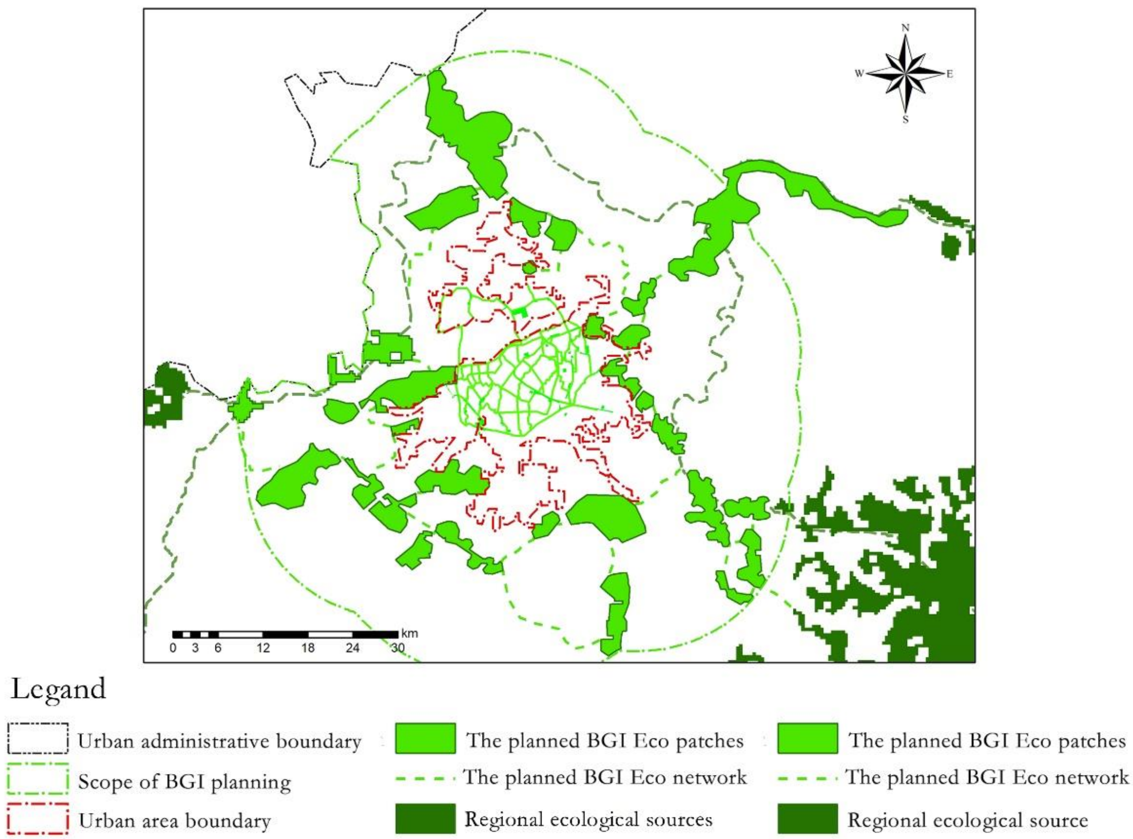

Figure 5. Harbin BGI planning

By analyzing the current situation of GI in Harbin and combining it with the development goal of the ecological city, the BGI planning target in Harbin is set as the block-point combination pattern, and the BGI space is constructed according to the BGI planning strategy. A number of small point-like eco patches near the urban area are added, forming a semi-ring shape. In the natural space far away from urban areas, small and medium-sized eco patches are added to form regional landscape greenways. The eco patch is connected to the regional ecological source, and the structural connection between the two levels of the ecological network is established. The BGI planning results are shown in Figure 5. A total of 31 eco patches are increased in BGI planning, including 27 small eco patches, 3 medium-sized eco patches, and 1 large eco patch. The total area of the eco patch is 657.7km^2, and the proportion of the eco patch to the BGI space area is 16.8%.

Discussion and Conclusion

This paper proposed the concept of BGI, a cross-scale coupling GI connecting UGI and RGI, and held that strengthening the construction of BGI is conducive to improving the ecosystem service function of GI and ensuring sustainable development of cities.

This paper put forward the extraction method of the urban area, based on multi-scale landscape connectivity analysis, the best distance thresholds of landscape connectivity at different scales were determined. Combined with the land use standard deviation method and nuclear density analysis method, the urban area boundary of European case cities was extracted and the urban area boundary was taken as the benchmark. The BGI space of European case cities was identified with the best threshold of multi-scale distance as the buffer distance.

Based on the BGI spatial analysis of case cities, this paper obtained four BGI spatial patterns: aggregated half-ring pattern, block-point combination pattern, scatter distribution pattern, and fragmented pattern. According to BGI patch area, quantity, proportion in BGI space, and spatial distribution characteristics, it is considered that the aggregated half-ring BGI spatial pattern is suitable for ecological cities, while the block-point combination and scatter distribution BGI spatial pattern are suitable for cities with balanced economic and ecological development. These three patterns can solve the problems of GI rupture between the two scales of China's municipal territory spatial planning, and fill in the gap in the GI planning method. At the same time, they also have a certain reference value for the construction of European urban greenway systems.

To verify the above views, the BGI planning of Harbin was studied according to the BGI planning strategy, and the BGI of Harbin was constructed according to the current situation by the block-point combination pattern. The planning results have shown that the BGI area increased, the connectivity of the two-level ecological network increased, and the spatial pattern was improved.

In the future, further optimization and discussion can be carried out in the following aspects:

a. In the BGI spatial extraction method, optimizing the selection conditions of ecological patch area and increasing the number of samples can increase the accuracy of multi-scale distance threshold analysis and improve the accuracy of BGI analysis.
b. Eco patches in the BGI space play a great role in the ecosystem service function of the whole BGI. Due to space limitations, this paper does not further discuss the types, functions, and connectivity of BGI patches. Landscape pattern indexes such as circuitry and contagion should be added in the future to further analyze the spatial pattern of BGI.

References:

Maoquan, W., Mengmeng, H., Tao, W., Chen F., Beicheng, X.2019. Recognition of urban ecological source area based on ecological security pattern and multi-scale landscape connectivity. Acta Ecologica Sinica, 39(13), 4720-4731.

Liuyang, D., Zhangfeng S., Yingming, K.2018. Built-up Area Extraction and Urban Expansion Analysis Based on Remote Sensing Images. Journal of Geo-information Science, 20(7), 996-1003. doi: 10.12082/dqxxkx.2018.170571.

Zhibo, D., Hongyuan, L., Weiqing, M.2019. Distance thresholds of wetland landscape connectivity in Tianjin Binhai New Area. Acta Ecologica Sinica, 39(17), 6534-6544. doi:10.5846/stxb201804190897.

Forman, R.1995. Some general principles of landscape and regional ecology. Landscape Ecology. doi: 10.1007/BF00133027.

Xiaolin, Z., Xiaobin, J., Bo, H., Rui, S., Xinyuan, L., Hanbing, L., Yinkang, Z.2021. Identification and optimization of ecological network in the plain area of the lower Yangtze River: A case study of Jintan District, Changzhou. Acta Ecologica Sinica, 41(09),3449-3461. doi: 10.5846 /stxb202004030793.

Coulon, A., Cosson, J, F, Angibault, J, M, Cargnelutti B, Galan, M., Morellet, N., Petit, E., Aulagnier, S., Hewison, A, J, M.2004. Landscape connectivity influences gene flow in a roe deer population inhabiting a fragmented landscape: an individual-based approach. Molecular Ecology,13(09), 2841-50. doi: 10.1111/j.1365-294X. 2004.02253.x.

Ke, A., Xiang, L., Nan-hua, Y.2017. From American "Greenway" to European Greenway: The Construction of Ecological Network in Urban and Rural Space——A Case Study of Zengcheng District of Guangzhou, Chinese Landscape Architecture, 2017(08),82-87.

Cheng, S., Jiachao, C., Caixia, L., Guantao, A.2019. Urban Vitality Zone and Central District Identification Based on Big Data: A Case Study in Guangzhou CityChinese Full Text. Urban Transport of China, 39(17) ,71-78. doi:10.13813/j.cn11-5141/u.2020.0028.

Urban, D., Keitt, T.2001. Landscape Connectivity: A Graph-Theoretic Perspective. Ecology, 82(5),1205-1218. doi:10.1890/0012-9658(2001)082 [1205:LCAGTP] 2.0.CO;2.

Yu, Y. P., Yin, H. W., Kong, F. H., Wang, J. J., & Xu, W. B. 2016. Scale effect of nanjing urban green infrastructure network pattern and connectivity analysis, Chinese Journal of Applied Ecology, 27(7), 2119-2127. doi: 10.13287/j.1001-9332.201607.006.

Ya-Ping, Y. U., Yin, H. W., Kong, F. H., Wang, J. J., & Wen-Bin, X. U. 2016. Analysis of the temporal and spatial pattern of the green infrastructure network in nanjing, based on mspa, Chinese Journal of Ecology, 35(06),1608-1616. doi: 10.13292/j.1000-4890.201606.026.

Zhang, Y. B., Ren-Wei, W. U. 2007. The theory and practice of greenway construction in europe, Chinese Landscape Architecture, ,2007(08):33-38.