Greenway Planning of Guangdong Province

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Abstract

Guangdong Province is located in the southernmost region of mainland China with a total area of 180,000 square kilometers. The GDP ranks first in China, and the economic aggregate accounts for 1/8 of China's total. As the economic development continues, the fragmentation of ecological land is becoming more dangerous. To solve this problem, the local government organized the master planning of environmental protection. The provincial greenway planning (also called ecological corridor) proposed in this paper is an essential part of it. The total length of planned greenways in Guangdong Province is 2,836 kilometers, and its primary function is biodiversity conservation. In the master planning of environmental protection, the planning of the ecological red line has already identified ecological patches. By constructing the provincial backbone greenway to connect ecological patches and form an ecological network, it can guarantee the ecological area of an economic priority development zone like Guangdong Province to provide sustainable ecosystem services. In this paper, the traditional Minimum Cumulative Resistance method (MCR) has been optimized based on graph theory, by using the betweenness of the edge (route or corridor) and selecting the least connected subgraph with the highest betweenness of the potential greenway by irreplaceable conditions to determine the irreplaceable backbone route and key strategic points. Under the premise of ensuring connectivity, the goal of planning the least number of greenways, the smallest footprint, and the constant value of ecosystem service is achieved. In this method, the backbone structure of the eco-network that maintains ecological security is established, nodes are found which are important hub locations in the eco-network but poor ecological conditions, and greenway route redundancy problem generated by the MCR method was solved, land resources and funds are saved, the guidance and control functions of the provincial greenway system are realized. The plan has been reviewed by the local government and entered the implementation phase.

Introduction

As China is in the stage of rapid urbanization, both government authorities and scholars in various fields are committed to solving the ecological fragmentation caused by the disorderly development of cities. For China, which has a vast land area, limited resources, and numerous land management departments, a provincial greenway can control and guide the development of land use, alleviate the current ecological pressure, promote the sustainable development and virtuous cycle of ecological environment. We participated in the project of overall planning of ecological and environmental protection of Guangdong Province, China in 2016. The provincial greenway planning introduced in this paper is an essential part of it. Its innovation included an optimization method for suitable macro greenway construction in this economic priority zone. This new method will construct a provincial greenway with guidance and irreplaceable value.

Background and Literature Review

At present, the Minimum Cumulative Resistance model (MCR) is the most adopted route selection technique in greenway research and practice (Zhang 2017), because the MCR model can simulate the trend of biological and energy flow in the landscape (Knaapen 1992). However, the potential routes identified by the MCR model show redundant characteristics on the provincial scale (Rayfiled 2010). It cannot balance the land demand between eco-protection and urban construction with the most compact structure. To carry out the detailed planning and development of provincial greenway, the MCR model needs to be optimized. According to the three steps of the model, scholars in related fields conducted optimization studies from three perspectives: source select (Xu 2015), resistance surface construction (Peng 2018) and route determination (Tang 2018). At the macro scale, the topological properties of the greenway are more obvious. Scholars of the ecological network have optimized the greenway structure by combining coulomb force, connectivity, skeleton tree and other theories (Yu 2018). However, these studies have not explored the guiding function and irreplaceable characteristics of the provincial greenway. Following the conclusions of network science, the connecting edges are more likely to be damaged and interfered with than the nodes in the greenway system (Zeng 2012). Therefore, it is a prerequisite for further greenway planning and construction to judge the critical difference of potential routes. In network structure analysis, Edge-betweenness index is the proportion of the shortest path between the connected Edge and the whole shortest path in the network (Freeman 1977), in other words, it quantified the importance of each edge by using the path of calculating the frequency of biological and landscape flow. This paper optimizes the traditional construction method by edge betweenness, combines the backbone route and key strategic point into a provincial greenway that can guide the provincial ecological planning and control the land use. The difference of greenway before and after optimization was compared, and the advantage and possibility of the optimization method are verified.

Goals and Objectives

Many developing countries around the world are in the stage of rapid expansion. There is a shortage of land resources, but residents' demand for quality of life is increasing year by year. The unordered expansion of construction land has caused high pressure on the environment and landscape, especially in the economic priority development areas, which has caused the conflict between urban construction and ecological protection for land resources. To solve these problems, this paper, from the perspective of maintaining ecological security in the province, explores the provincial greenway construction method that can control and guide the evolution of land use. Guangdong Province is one of the most developed regions in China. Its challenges and solutions have strong representativeness and practical promotion value.

Methods

In this paper, the optimization method of provincial greenway construction is achieved through the combination of the edge betweenness index and the MCR model. The optimized process is shown in Figure 1. The optimized method uses the minimum number of corridors and the occupied area to maintain the connectivity between the sources, it saves land and financial resources; highlights the components that play a core role in the greenway system and guides the spatial utilization and land evolution control.

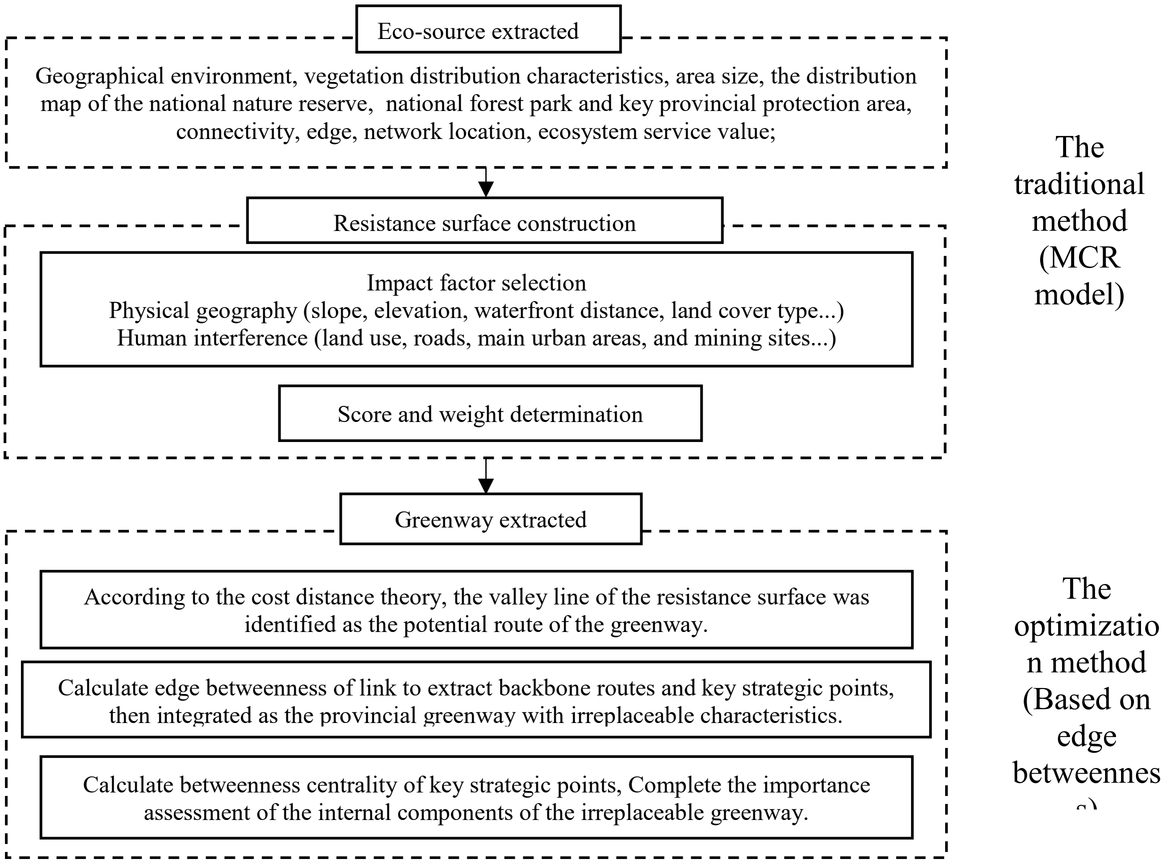


Figure 1. Flow chart of provincial greenway construction method

$$MCR = f_{min} \sum_{j=n}^{i=m} (D_{ij} \times R_i) \qquad (1)$$

MCR means the value of minimum cumulative resistance,
D_{ij} is the spatial distance between source *j* and destination *i*,
R_i is the resistance coefficient of destination *i* on the movement of representative species.

a) First, adopt MCR model (formula 1) to identify potential routes: preprocess land use data, land cover data and digital elevation model based on ArcGIS and ENVI platform, Select influence factors by considering two factors, human disturbance (land use type, road, main urban area, mining point) and natural environment (slope, elevation, waterfront distance, land cover type...), and rate them to construct a landscape resistance surface; and calculate the valley line of resistance surface as the potential route.

b) Secondly, calculate the edge betweenness index to extract the backbone route and key strategic points to construct the provincial greenway. The extraction process is shown in Figure 2 and Figure 3. Backbone route is the backbone part of a potential route because connectivity is not only one of the essential functions of the greenway, but also the primary feature that will affect other functions. In a complex network, the edge is more likely to be attacked than one point. Based on the premise of ensuring the connection between source points, we extract the Minimum spanning tree consisting of the potential route and source area (Girvan 2002). Edge betweenness of potential routes represents a proportion of the number of the shortest path passing through the link to that the total number of the shortest path in the network. Edge betweenness is (e_{lk}) of a link (e_{lk}) (e_{lk} is the link between adjacent nodes l and k.) can calculate by *formula 2*. The calculation process refers to Kruskal algorithm and avoids the process of having to count repeatedly using spatial superposition because Kruskal cannot distinguish different routes between two identical nodes.

(1) Calculate the value of edge betweenness of all connected edges in the network (*formula 2*);
(2) Remove the connecting edge with the minimum amount of edge betweenness;
(3) Repeat step (2), until there is only one connecting edge between each pair of nodes in the greenway system.

$$\boldsymbol{b_e(e_{lk}) = \sum_{S \neq t \in V} \frac{\sigma_{s,t}(e_{lk})}{\sigma_{s,t}}} \quad \textbf{(2)}$$

V represents a collection of all nodes in a network,

$\sigma_{s,t}$ represents the total number of shortest paths from node s to node t,

$\sigma_{s,t}(e_{lk})$Represents the number of shortest paths through the link *elk* in all shortest paths from node *s* to node *t*.

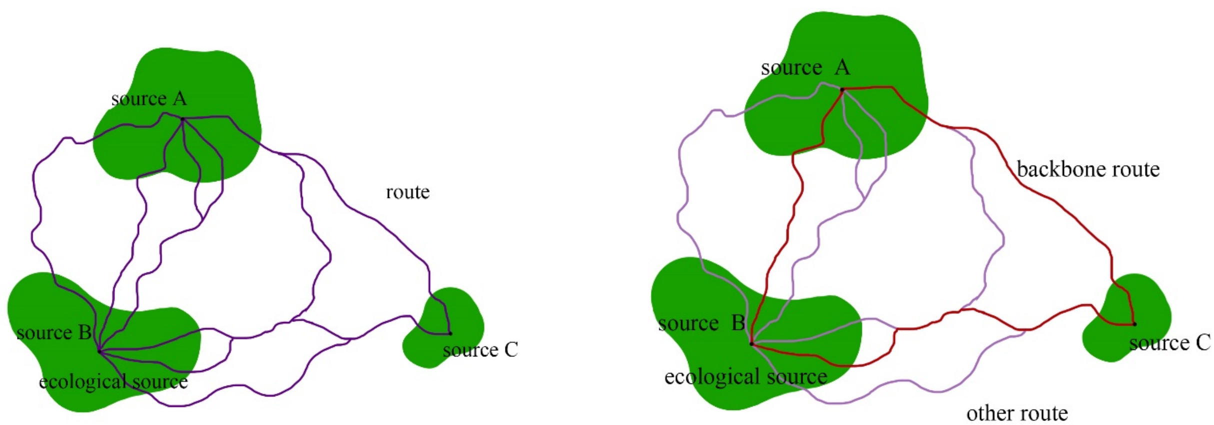


Figure 2. Schematic diagram of backbone route extraction

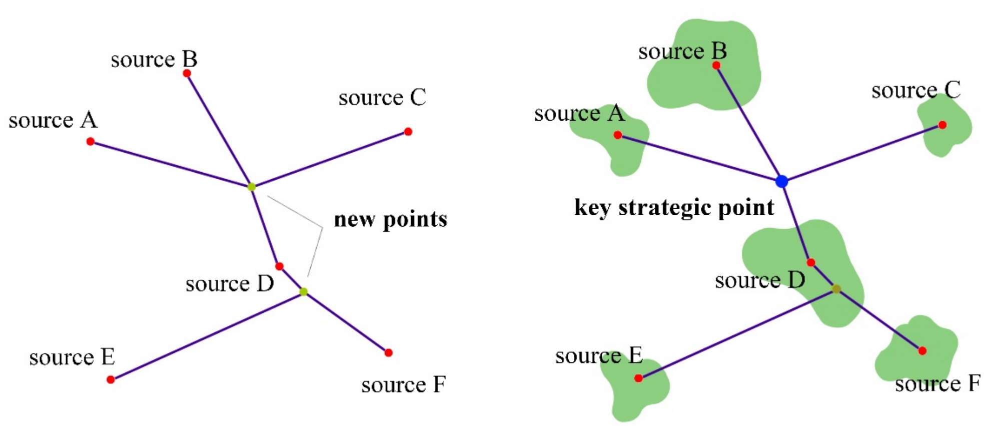


Figure 3. Schematic diagram of key strategic point extraction

The key strategic point is part of the newly generated node, which is not located in the eco-source. As key strategic points occupy an essential position as transportation hubs in the network structure, but if the ecological environment is not good enough, the strategic point needs priority and key construction.

c) Finally, calculate the betweenness centrality of key strategic points to compare the important differences of provincial greenway's internal components (*formula 3*). Because of the location and connected link are different key strategic points have essential importance. Calculate edge betweenness can extract both irreplaceable nodes and links, but only directly reflect the importance of each link. Betweenness centrality represents the number of paths through a node, shows the importance of each node. Calculation principle of Jenks natural breaks class. The calculation process of $g(i)$ of betweenness centrality is shown in formula 3.

$$g(i)=\sum_{\{j,k\}}\frac{C_i(j,k)}{C(j,k)} \tag{3}$$

$g(i)$ is betweenness centrality of node i;
$\{j,k\}$ represents node pairs (regardless of the sequence of j and k);
$C(j,k)$ is the number of shortest paths of node j and node k;
$C_i(j,k)$ is the number of shortest paths of node j and node k which through node i.

Results

Based on the optimization method proposed in this paper, we extracted the ecological source area (Figure 4.), constructed landscape resistance surface (Figure 5.), and identified potential routes (Figure 6.). Simplified eco-source and potential route were indicated as points and lines and defined the minimum spanning tree with the maximum sum of edge betweenness (Figure 8) by comparing the value of edge betweenness (Figure 7.). The results include 29 backbone routes and 11 key strategic points. Key strategic points are divided into five levels by Jenks natural discontinuity method, the grading process and results are shown in Figure 9. and Figure 10.

The method produced a Guangdong provincial greenway with a total length of 5493km by integrating backbone routes and key strategic points (Figure 11). The greenway includes 20 eco-sources, 29 backbone routes, and 11 key strategic points. Compared with the optimized method of greenway building, the traditional way identifies potential route with 10244km length. It will not only occupy a lot of land resources, money, and workforce but also obscure the key position of backbone routes, result in it difficult to get attention and targeted construction and management. Especially in the economic priority development area with the land shortage, the greenway with a total length and a large area is bound to be difficult to reach an agreement with many land management subjects, resulting in implementation difficulties. Optimized by edge betweenness, the redundancy problem of potential routes has solved, route number and greenway area significantly reduced, this method resolved the contradiction between urban construct and environment protect, and thereby enhanced the greenway's ability to control space and land use efficiently and effectively.

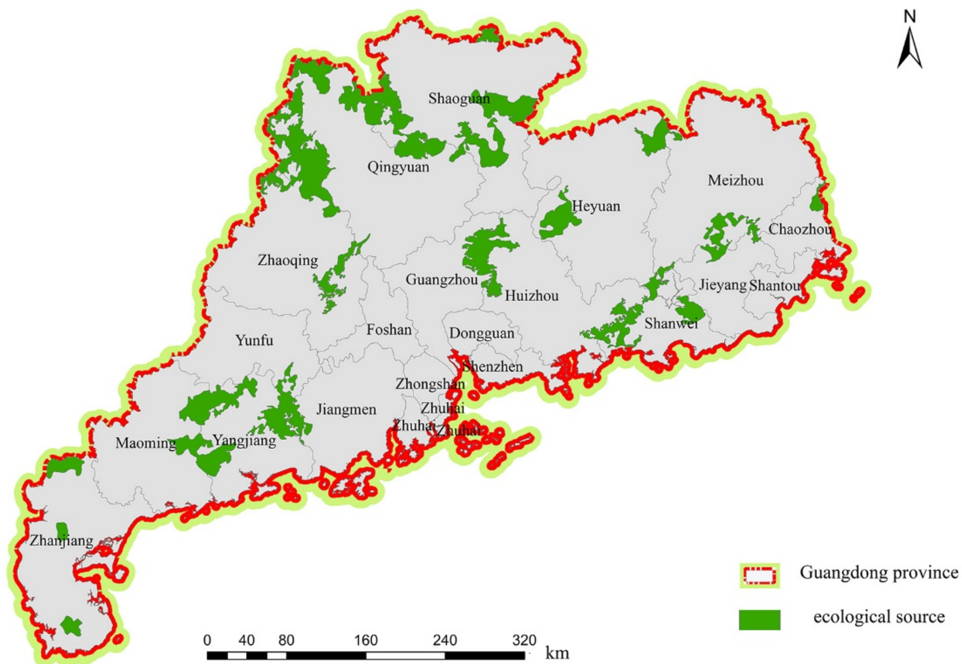


Figure 4. Distribution of ecological source

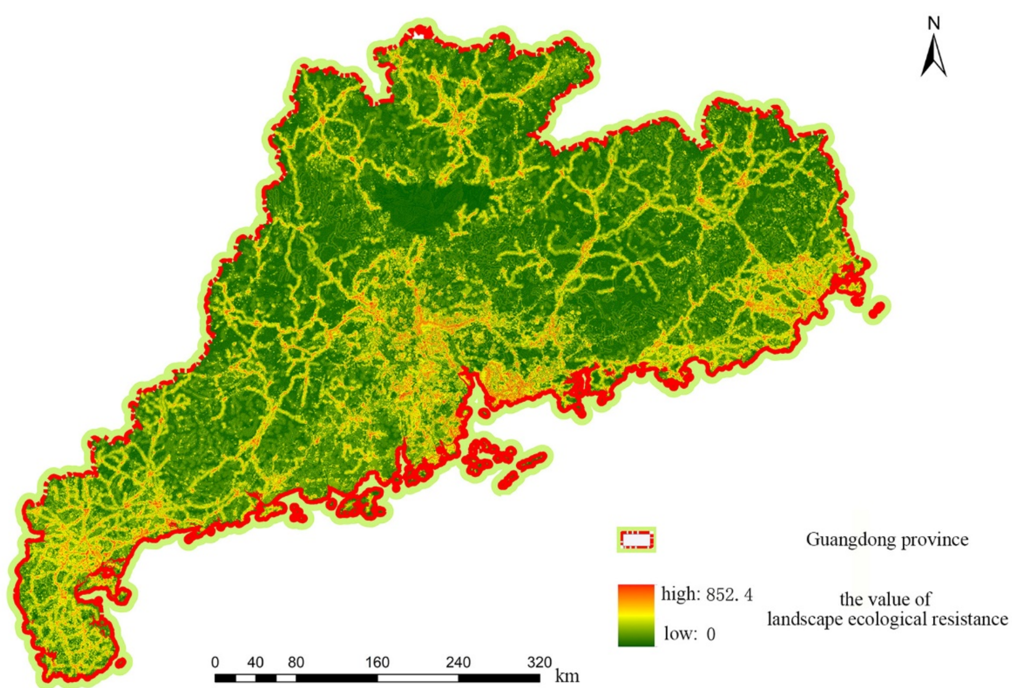


Figure 5. Landscape ecological resistance

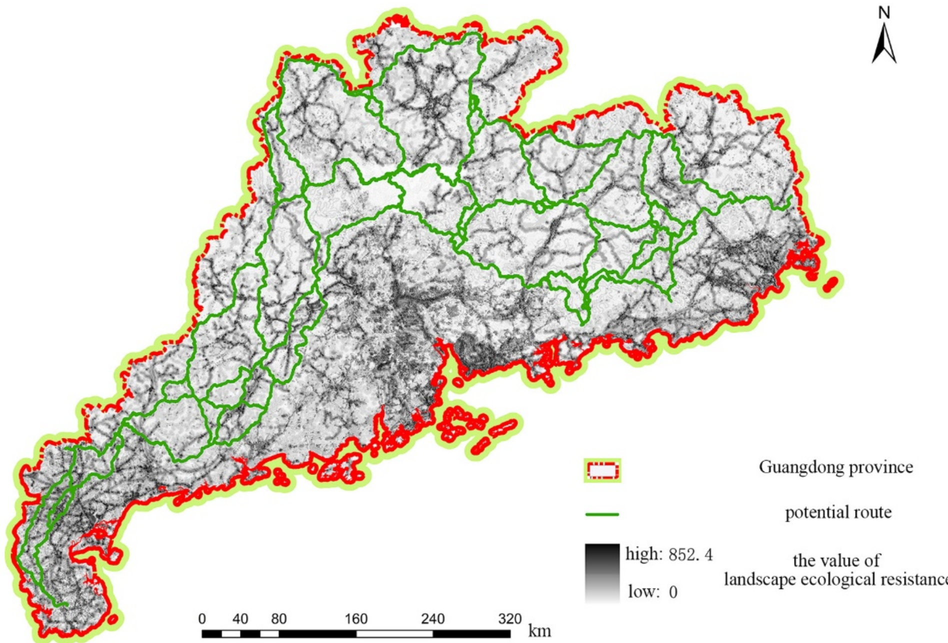


Figure 6. Potential routes

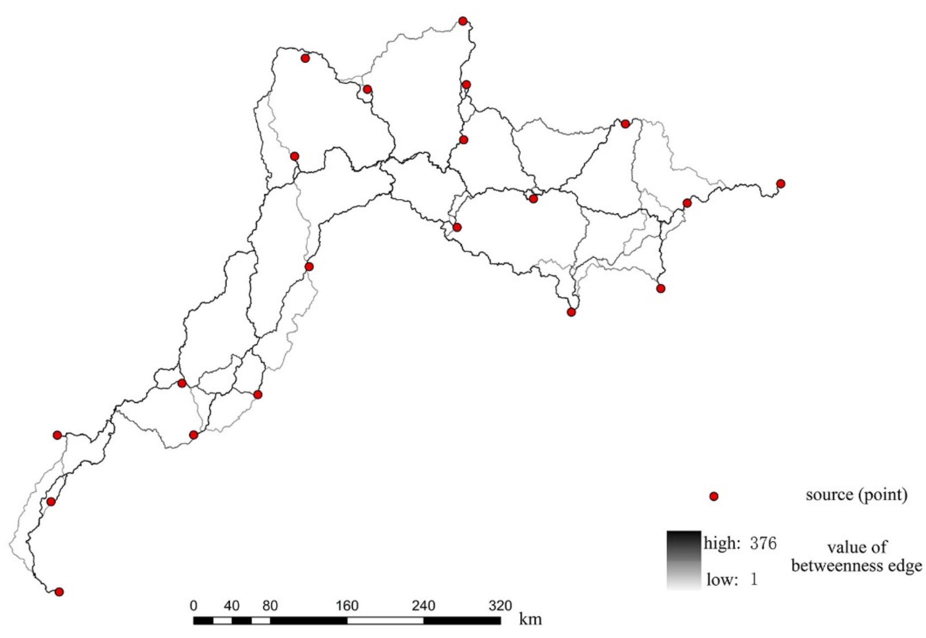


Figure 7. The value of the edge betweenness of potential routes

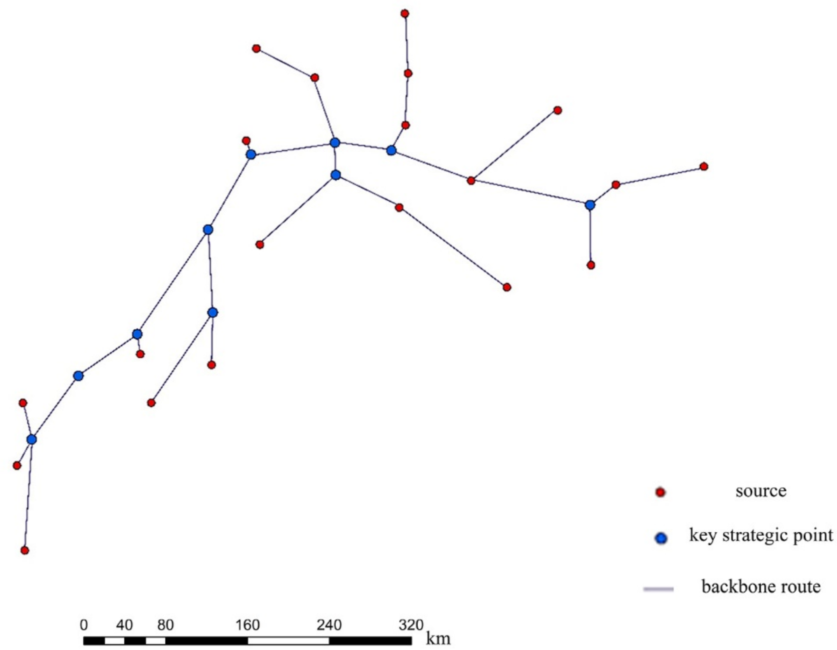


Figure 8. Schematic topology diagram of the route and key strategic point

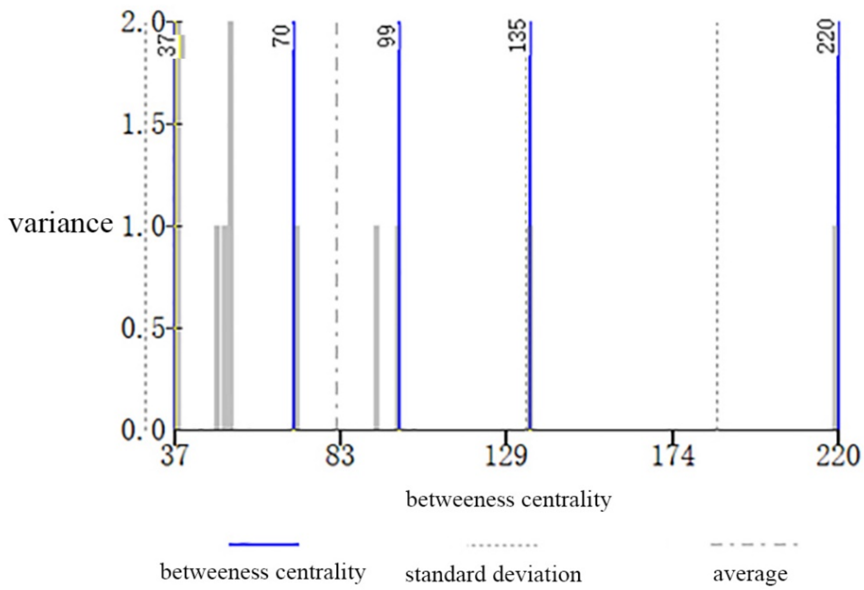


Figure 9. Results of natural break class for backbone key strategic point

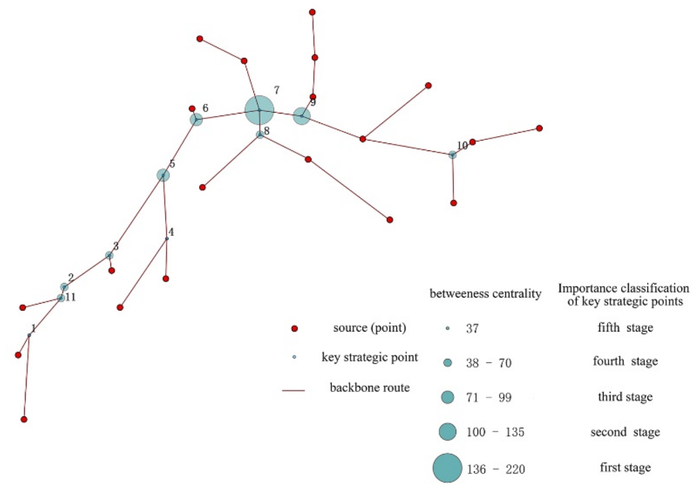


Figure 10. Schematic diagram of importance classification of key strategic points

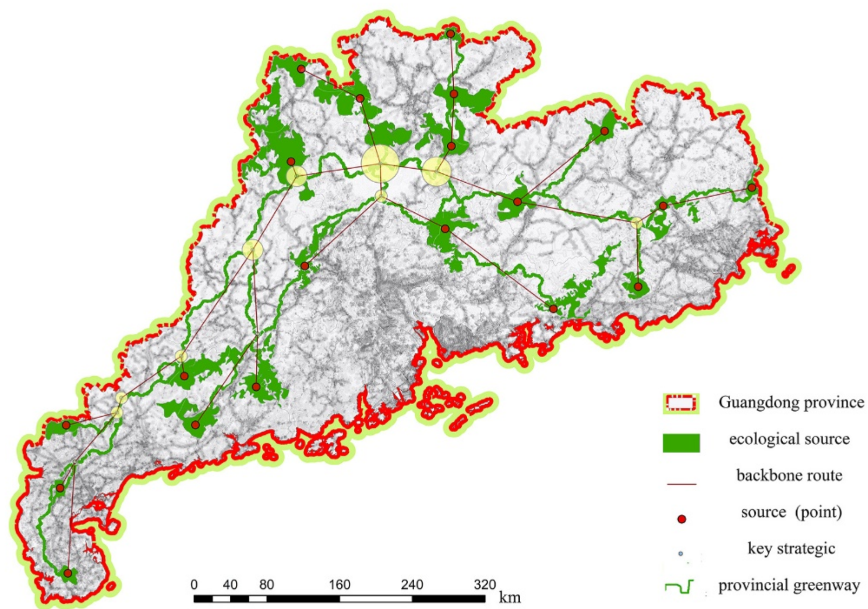
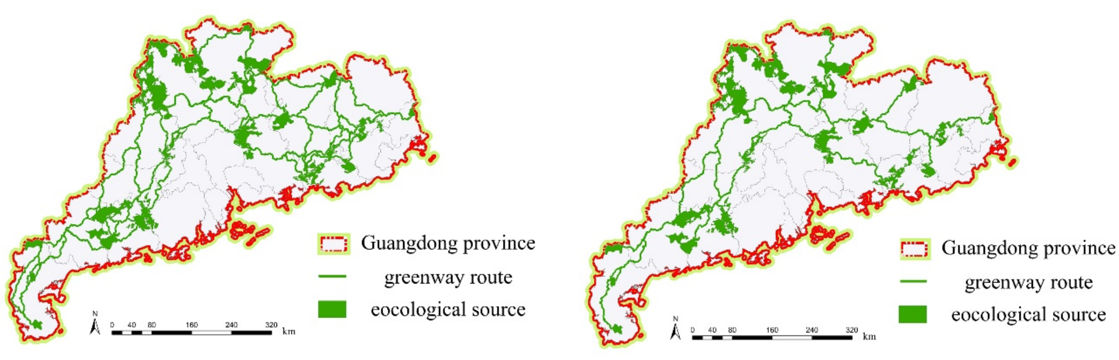


Figure 11. Greenway of Guangdong province



(a) Potential route (b) Irreplaceable route

Figure 12. The contrast between the potential route and irreplaceable route

Discussion and Conclusion

Current studies always quantify a greenway's service mostly by area (Liu 2017), but the area is only one of the influence factors. Structure plays a more critical role at the macro scale and planning process (Martin 2016). From the perspective of evolution, "area" reflects the service that greenway can play at present, while the structure considers the service that it may provide after its future development and evolution. Constructing a greenway is based principally on connecting eco-sources, and the overall purpose is to ensure basic eco-security on the current and to evolve a more advanced eco-security pattern in the future. (Check if my editing gives the correct reading?) There is a difference in importance of the route and node of the greenway structure. Edge betweenness index can reflect the importance of the backbone route, but cannot reveal the significance of key strategic point intuitively. The intermediate centrality can measure the difference of node hub property, complete the critical comparison of the irreplaceable structure of internal. Greenway is a dynamic system and a land use model (Yu 2004), which plans the future development trend of ecological space by changing the current landscape composition. The urgent problem that the provincial greenway needs to solve is to alleviate ecological fragmentation and establish the most basic ecological security. The land resources in the economic priority development area are especially tight. The irreplaceable key structure is extracted for the greenway construction, which can significantly reduce the length and area of the greenway and is more easily supported by the land management department. Compared with the greenway identified by the MCR and the greenway constructed by the irreplaceable route, the length of the greenway constructed by the irreplaceable route is shorter, and the total length of the greenway is reduced from 10,244 km to 5,493 km. Using potential routes to guide greenway construction, cannot reflect the critical position of the backbone route, it will consume fewer land resources and require less capital. The irreplaceable structure is the key structure of determining provincial eco-security, using it to guide construction will solve the problem of redundancy of potential route by the traditional method, alleviate the contradiction between urban construction and eco-protection, and strengthen the function of the greenway to control and guide the evolution of the landscape.

Based on the above studies, we come to the following conclusion: (a) provincial greenway is a sustainable way of land use with a compact structure, it should not be constructed with the redundant potential route. It can effectively solve the redundancy problem when the traditional greenway construction method is applied to the provincial scale by the MCR model combined with edge betweenness index；(b) Network structure is an important factor affecting the function of the provincial greenway. Edge betweenness can quantify the importance of irreplaceable routes and nodes (backbone route and key strategic point); calculate betweenness centrality value can further to rank the significance of key strategic points. Complete the importance comparison of the internal components of the irreplaceable structure; (c) The provincial greenway, which is composed of backbone routes and key strategic points, uses the minimum number of routes and covers a minimal area to realize the connectivity between source areas, and establishes the most basic ecological security pattern, which provides the possibility for further evolution into a more secure ecological environment. It minimizes the conflict between ecological protection and urban construction and is more easily supported by land management departments to carry out construction.

In this paper, there are some limitations in the research on the optimization of greenway construction method based on the edge betweenness index. This paper focuses on the greenway structure before and after optimization and has not conducted a quantitative evaluation of its ecological services. Some scholars have evaluated the greenway's construction concerning landscape index, but they have not evaluated the ecological services quantified which supported by the structure. Future research can further explore the impact of greenway structure on its ecosystem services and long-term evolution. The key strategic point is an essential component of the security pattern that can provide ecological protection. Based on the characteristics of network structure, this paper classifies the key strategic points in the irreplaceable greenway simply by the method of betweenness centrality and natural discontinuity. However, it does not consider the effects of land use type, a division of administrative region, economy, transportation, and other factors. In future studies, they could discuss the above factors to delimit the importance of key strategic points in more detail; in this paper, only from the perspective of network structure, the greenway is optimized by edge betweenness index, which has not been compared with other optimization methods.

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