International Journal for Housing Science and Its Applications
Publish August 10, 2025. Volume 46, Issue 4 Pages 128-140

https://doi.org/10.70517/ijhsa46410

The Role Mechanism of Multifunctional Ecological Corridor Construction in Enhancing the Ecological Resilience of Cities--The Case of Ecological Restoration Project in Chengdu Ringed City Ecological Zone

Qi Zhang[1,2,*], Zhigang Li[1], Yong Zhu[3] and Xinli Fu[1]
[1] School of Urban Design, Wuhan University, Wuhan, Hubei, 430000, China
[2] Research Center of Park City Index, Chengdu, Sichuan, 610000, China
[3] Chengdu Institute of Planning and Design, Chengdu, Sichuan,610000, China
Corresponding authors: (e-mail: 18781074767@163.com).

Abstract Global urbanization process leads to ecological habitat fragmentation and biodiversity reduction. This study investigates the mechanism of multi-functional ecological corridor construction in enhancing urban ecological resilience, taking the ecological restoration project of Chengdu Ring Road Ecological Zone as an example. Using the theory of landscape ecology, the study constructed an ecological resilience assessment model from the three dimensions of ecological source identification, resistance surface construction and corridor identification, combined with the “patch-corridor-substrate” model, to analyze the role of ecological corridors in enhancing the ecological resilience of the city. The results show that the critical area for restoration of Chengdu Ring Road Ecological Zone is 277.77km², of which Jinjiang District accounts for 85.20%; the total length of the critical area for corridor restoration is 416.0717km, and the restoration needs of Jinjiang, Wuhou, and Jinniu Districts account for 81.53% of the total length of the critical area for corridor restoration; The Ecological Priority Development (ELP) scenario, with the shortest length of ecological corridors (9.2498km) and the highest network transmissibility, showed the best ecological resilience. The study confirms that multifunctional ecological corridors significantly enhance urban ecological resilience by improving habitat connectivity, enhancing network structural stability, and improving damage resistance. The ecological network with ecological priority development shows higher connectivity robustness and vulnerability robustness in the face of both random and deliberate attacks. The results of the study provide a scientific basis for the construction of urban ecological security patterns and the enhancement of resilience.

Index Terms multifunctional ecological corridor, urban ecological resilience, ecological network, ecological restoration, connectivity, habitat quality

I. Introduction

The global urbanization process has profoundly affected natural ecosystems, resulting in fragmentation of ecological habitats and a sharp decrease in biodiversity. In particular, the rapid expansion of Chinese cities and infrastructure construction have caused serious damage to the original natural environment [1]. In order to address these challenges, the concept of ecological corridors has been gradually introduced into urban planning, with the aim of restoring and maintaining ecosystem integrity through the construction of a green corridor connected to isolated ecological patches [2]-[4].

In the rapid urbanization stage with incremental development as the keynote, ecological corridors have made a significant contribution to the protection of ecological spatial patterns in megacities [5]. Ecological corridors are ecological elements connecting and linking green areas, water systems, farmlands, forests, wetlands, parks and other ecological elements to form a band-shaped green open space with a certain width that connects mountains and waters, and has a complex function [6]. The construction of ecological corridors is not just a simple expansion of the urban green space system, but a crucial part of the urban ecological network [7], [8]. They constitute urban “ecological corridors”, provide wildlife habitats and migration paths, and are conducive to biodiversity conservation [9], [10]. At the same time, ecological corridors have the compound functions of culture, education and sports on the basis of guaranteeing the connectivity of green open space, which can truly transform ecological resources into ecological benefits available to urban residents [11]-[13]. Ecological corridors also regulate urban climate, improve air quality and provide recreational space, which is important for improving the quality of life of urban residents [14], [15].

Global urbanization has profoundly affected natural ecosystems, resulting in fragmentation of ecological habitats and a sharp decline in biodiversity. Especially in China, the rapid expansion of cities and the construction of infrastructures have caused serious damage to the original natural environment. In order to address these challenges, the concept of ecological corridor has been gradually introduced into urban planning, which aims to restore and maintain ecosystem integrity by building a green corridor connected to isolated ecological patches. In the rapid urbanization phase, where incremental development is the main theme, ecological corridors have made a significant contribution to the protection of the ecological spatial pattern of megacities. Eco-corridors are ecological elements connecting and linking green areas, water systems, farmlands, forests, wetlands, parks and other ecological elements to form a band-shaped green open space with a certain width that connects mountains and waters and has a complex function. The construction of ecological corridors is not just a simple expansion of the urban green space system, but a crucial part of the urban ecological network. They constitute urban “ecological corridors”, provide wildlife habitats and migration paths, and are conducive to biodiversity conservation. At the same time, ecological corridors serve a composite function of culture, education and sports on the basis of ensuring the connectivity of green open spaces, which can truly transform ecological resources into ecological benefits available to urban residents. Eco-corridors also regulate urban climate, improve air quality and provide recreational space, which is important for improving the quality of life of urban residents.

Nowadays, with the rise of the concept of urban resilience, urban ecosystems should have the ability to maintain structural stability and functional continuity under external disturbances. As a key component of urban ecological networks, ecological corridors, with their multifunctionality and connectivity, play an important role in enhancing urban ecological resilience. However, the mechanism of how ecological corridors affect urban ecological resilience is still not well studied, and systematic assessment methods and models need to be established. Taking the ecological restoration project of Chengdu Ring Road as an example, this study explores the mechanism of multifunctional ecological corridor construction on urban ecological resilience from the perspectives of ecological resilience and landscape ecology. The study firstly establishes an ecological source identification method based on the theory of “patch-corridor-substrate” in landscape ecology, and builds a comprehensive resistance surface and corridor identification model by combining land use characteristics and ecosystem service function assessment; secondly, from the connotation of ecosystem resilience, the study builds a resilience assessment model with two dimensions, namely, the landscape background and the risk-connectivity-potential; and finally, the study analyzes the structural characteristics of the ecological network and the resilience of ecological networks through simulation of different scenarios. Finally, we analyze the structural characteristics and damage resistance of ecological networks through different scenarios, and assess the influence mechanism of ecological corridors on urban ecological resilience.

II. Ecological corridor theory under ecological resilience

II. A. Basic Theory of Toughness

II. A. 1) Evolution and meaning of toughness

Urban resilience is currently emerging at the intersection of interdisciplinary research, centered on its inherent ability to withstand disasters, its swiftness in repairing damaged organizations, and its adaptive growth in the aftermath of a crisis. Essentially, a city's ability to quickly get back on track after a disaster relies on the efficient response of social entities and management structures to the shock and subsequent reconstruction strategies. Further, cities must demonstrate sufficient resilience to avoid structural collapse when carrying stress. In the early stages of a disaster, it is critical to ensure that basic social functions are restarted quickly, and resilience in this phase directly affects the vulnerability of the city as a whole. Rapid action not only mitigates short-term damage, but also lays a solid foundation for subsequent reconstruction [16]. Subsequently, the city's resilience evolves through the injection of long-term mechanisms that take into account the lessons learned and feedback from the disaster. Good city managers not only correct apparent deficiencies, but also anticipate ways to improve future resilience. Thus, the cornerstone of urban revitalization is to build wisdom and strength to face future challenges while recovering immediately. Urban resilience is not just about short-term recovery, but also about adapting flexibly to changes in the environment and formulating forward-looking strategies to minimize potential risks and enhance long-term survival and development. In short, a resilient city should have the ability to recover quickly during a crisis and to continue to improve and renew itself after the crisis.

II. A. 2) Characterization of toughness

(1) Multifunctionality and diversity

Infrastructure in the city should be multifunctional in order to withstand external disturbances in a variety of ways, emphasizing the linkage of elements and avoiding fragmentation of urban elements. Diversity is reflected in both the ecological and social aspects, with the ecological aspect emphasizing the maintenance of biodiversity, and the social aspect emphasizing functional diversity and cultural pluralism [17].

(2) Adaptability and Resilience

Resilience can actively learn and adapt to external uncertainties, and will adjust its structure and function according to environmental changes to achieve a new balance. The construction of resilient cities should pay more attention to multifunctionality and backup measures, so that the city can face risks in a more diverse way of response [18].

(3) Redundancy and modularity features

Resilience In order to ensure that the city can spread the risk through time and space when disturbed, the system needs to have a certain function of the backup facility module to achieve a certain degree of functional duplication. Thereby, when a localized area of the system is damaged, it will not affect the operation of the system as a whole. This study emphasizes the redundancy and modularity characteristics of resilience to optimize the urban river and promote sustainable urban development [19].

(4) Connectivity and efficiency

Resilience supports connectivity and cooperation among subsystems within a system. Connectivity and efficiency are used to integrate urban green spaces, transportation networks, and urban rivers to form a continuous stormwater management system that achieves effective urban flood management and expands plant and animal habitats [20].

(5) Creativity

Creativity is the ability of the city to learn accordingly, to learn lessons and transform them through external disturbances, so that the urban system can be gradually upgraded to a more advanced state. Innovation that promotes pluralistic social participation. With a resilience perspective, urban river corridor landscapes are upgraded to new forms, giving them the coping capacity to withstand rain and flooding as well as the ability to maintain the identity of the public space in everyday life [21].

II. A. 3) References to tenacity theory in ecological landscapes

After a long period of accumulation and development, resilience theory has penetrated into many disciplines and fields, and related concepts such as “resilient city” and “resilient landscape” have emerged. This study aims to explore the application of resilience theory in urban planning, with resilient landscape as the focus of the study.

Urban resilience, as a concept of urban development, stems from a deep insight into the structural and functional stability of urban systems in the face of changing challenges. Proposed by the Resilience Alliance in 2007, the concept emphasizes the ability of cities to absorb and reorganize when they encounter disruptions, as well as the durability of maintaining their essential characteristics. Within this framework, scholars have thoroughly explored the connotation of resilient cities and their qualities, however, the corresponding assessment system and enhancement strategies have not yet formed a complete and theoretically verified system. Among the existing studies, some scholars analyzed the concept of urban resilience from the perspectives of ecology, economy, society, and infrastructure services [22]. Some scholars have constructed a resilience evaluation index system covering the dimensions of appropriateness, multi-functionality, redundancy and stability [23]. Summarizing these studies, the core concerns of urban resilience cover key factors such as ecological environment, infrastructure, technological system, economic and social development. Based on this, this study will deeply explore the multidimensional composition of urban resilience. Particularly in terms of the ecological, functional, and landscape aspects of urban ecological corridors, the results of this study are expected to provide useful strategies and insights into the sustainable development of cities.

II. B.Basic Theory Research on Ecological Corridors

II. B. 1) Connotation of ecological corridors

The concept of ecological corridor was introduced into China late, initially at the beginning of the 21st century, there are “green corridor”, “green channel” and other forms of concept, followed by “greenway”, “green corridor” and so on, nowadays the theoretical research related to ecological corridor has been more mature and systematic [24]. In this paper, the ecological corridor is defined as a linear or strip-shaped landscape infrastructure that is different from the adjacent environment, and is an important part of the most basic landscape model “patch-corridor-substrate”. It is a long, narrow, land-based space that is distinct from the surrounding substrate and connects small local populations, allowing species to migrate or stay temporarily in population patches, facilitating genetic exchange between populations to reduce the risk of extinction, and greatly enhancing local biodiversity and improving urban ecological conditions. Its main component is vegetation cover, which also has space for social functions such as landscape viewing and recreation. There is no strict restriction on the type of land use, including native natural land use, as well as urban construction land use, especially large-scale ecological corridors, but the scope of land use involved needs to be clarified at the planning and design levels.

II. B. 2) Theories related to ecological corridors

The theory of "patch-corridor-substrate" mainly comes from the field of landscape ecology and is applied in the field of green space planning, which emphasizes the interaction between ecological processes and landscape pattern, and through systematic analysis, finally produces the landscape pattern of "patch-corridor-substrate", i.e. the city is a landscape module composed of landscape substrate, corridor and patch, in which all elements have interaction and certain connections, thus constituting a dynamic balance that is constantly changing. Through systematic analysis, it finally produces the landscape pattern of "patch-corridor-substrate", i.e., the city is a landscape module composed of landscape substrate, corridor and patch, in which all the elements are interacting with each other with certain connections, thus constituting a dynamic and balanced landscape ecosystem that is constantly changing.

(1) Patch

A patch is a spatial unit that is different from the surrounding matrix and has a certain internal homogeneity. The plaque in the urban landscape system is the large and small block green space, which is of great significance for the healthy development of urban ecosystems, and its size, number, shape and location all affect the role of the landscape to a certain extent [25].

There should be different sizes of patches in the city, each playing a different role, large patches can form the source of species, for the protection of species diversity, providing open space, regulating the urban climate plays a significant role, large patches and small patches form a composite structure, together with the formation of a variety of habitats and high-quality composite ecological network. The greater the number of patches in the urban system, the more diversified the habitat types, the more favorable the protection of ecosystem diversity, and vice versa, i.e., the decrease in the number of habitats, which will pose a threat to biodiversity and increase the possibility of species extinction. The shape of the patch also greatly affects the effective use of urban ecological resources, the more zigzagging and curved the boundary of the patch, the greater the contact surface between it and the surrounding substrate, and at the same time, it can also enhance the ornamental value of the landscape, while for economic patches such as nurseries and farmland, which are mainly used for the purpose of production, it is more suitable for the regular and compact boundary form [26]. In addition, the location of the patch directly affects the landscape structure of the whole city, and choosing a good location for the patch can maximize its ecological effect.

(2) Corridor

Corridor, which is the subject of theoretical research in this paper, refers to the line or band space that is distinguished from the surrounding matrix and has the function of connectivity. Corridor is important for the continuity and integrity of the landscape system, which not only connects the patches and becomes the migratory corridor for organisms, but also serves as an important ecological element, playing an important ecological function of regulating rainfall and flooding, water conservation, air circulation, and improvement of microclimate, etc. [27]. Corridor can also be regarded as a strip or line of patches.

Corridors can also be regarded as strip or line patches, and their important structural characteristics include connectivity, width, composition, form, internal environment, and their relationship with other corridors, patches and the overall matrix in the whole landscape system. There is often not only one corridor in an urban landscape system, but multiple corridors that cross to form a network, creating a close connection with each other and making the whole landscape structure more complex and systematic. The main elements, functions and principles will be discussed later.

(3) Substrate

Matrix, also known as liner or mold, is the background ecosystem or land use type in the landscape mosaic structure, which has an important role in controlling and supporting the dynamic operation of the landscape, and it is the element with the most extensive role, the highest connectivity and the most complex systematic operation in the landscape system. In the urban ecological pattern, the substrate can be artificial elements such as structures, roads, paving, etc., or industrial land, residential land, commercial land, etc. [28], which is the "mother" or background environment to undertake the ecological functions of patches and corridors, providing conditions for the ecological security pattern to function and interacting and promoting each other to form a system. It provides the conditions for the ecological security pattern to function, and interacts and promotes with it to form a systematic landscape network.

III. Research methodology

III. A. Ecological source area identification

For typical ecosystems in the region, quantitatively assessing the supply capacity of ecosystem services and identifying key areas for ecosystem service supply is an effective method for source selection. This study, considering the land-use characteristics and ecological conditions of the Chengdu Ring Road Ecological Zone, selects three aspects—carbon sequestration and oxygen release, soil conservation, and water conservation—to assess the ecosystem service functions of the Chengdu Ring Road Ecological Zone. The carbon sequestration and oxygen release functions were expressed in terms of net primary productivity (NPP) and calculated with the help of CASA model [29]:

$$NPP(i,t) = LAR(i,t) \times \alpha(i,t) \tag{1}$$

where, $NPP(i,t)$ represents the net primary productivity of vegetation on the i grid during the t time period, $LAR(i,t)$ represents the light and effective radiation absorbed by vegetation on the i grid during the t time period, and $\alpha(i,t)$ represents the light energy conversion rate of vegetation on the i grid during the t time period.

In this study, the modified universal soil erosion equation (RUSIE) was used to calculate the soil conservation function, and soil conservation was calculated based on the difference between potential soil erosion and actual soil erosion:

$$SC = R \times K \times L \times S \times (1 - C \times P) \tag{2}$$

where SC is the average annual soil conservation (thm^{-2}a^{-1}), R is the rainfall erosivity factor (MJmmhm^{-2}h^{-1}a^{-1}), K is the soil erodibility factor.

(thMJ^{-1}mm^{-1}), L is the slope length factor, S is the slope gradient factor, C is the vegetation cover factor, and P is the soil conservation measures factor.

The water conservation capacity is estimated by the water balance method, which is based on the principle of system wholeness, and considers the water input and output to account for the amount of water held by the ecosystem, and requires three parameters: precipitation, evapotranspiration, and surface runoff, which is simple and easy to operate, and is capable of calculating the amount of water conservation more accurately, and has been widely used. The formula is as follows:

$$WC = \sum_{i=1}^{n} (P_i - R_i - ET_i) \times A_i \times 10^{-3} \tag{3}$$

where, WC is the amount of water conservation (m^3), P_i is the amount of rainfall (mm), R_i is the amount of surface runoff (mm), ET_i is the amount of evapotranspiration (mm), A_i is the area of the i ecosystems (m^2), and n is the total number of ecosystem types in the study area. Surface runoff R_i is the product of rainfall P_i and the surface runoff coefficient, which was obtained mainly by reviewing the literature.

Complete and stable ecosystem service functions play an important role in maintaining regional ecological security, and ecosystem service functions are of equal importance, so in this study, the three ecosystem service functions were analyzed by equal weighting superposition, and the natural breakpoint method was used to grade ecosystem service functions, and the area with higher ecosystem service functions was selected as the ecological source area.

III. B. Resistance surfaces and corridor construction

The resistance surface reflects the obstacles encountered by biological migration. In this study, we used the resistance coefficient and correction factor method to construct a comprehensive resistance surface with reference to the conclusions of the research on the construction method of resistance surface. Digital elevation, land use type, normalized vegetation index (NVI) and slope data were selected to construct the comprehensive resistance surface of Chengdu Ring Road Ecological Zone, and the resistance value was set with reference to relevant studies, and the evaluation factor characteristics were divided into intervals and set to a value of 10-100, with the larger value representing the greater resistance. The weights of the evaluation factors were calculated by hierarchical analysis.

In this study, nighttime lighting data (NTL) and topographic location index were combined to construct a comprehensive correction index for the comprehensive resistance surface of Chengdu ring ecological zone. The nighttime lighting data can continuously reflect the spatial distribution characteristics of anthropogenic factors such as urbanization, economic conditions and population density, while the topographic level index is calculated by combining digital elevation and slope data, which can effectively portray the natural resistance encountered by organisms migrating. The formulas for calculating the topographic position index and the resistance surface correction index are as follows:

$$D_i = \ln\left[\left(\frac{G_i}{G_{ave}}+1\right)\times\left(\frac{PD_i}{PD_{ave}}+1\right)\right] \tag{4}$$

$$S_i = \alpha D_i + \beta L_i \tag{5}$$

$$RE_i = \frac{S_i}{S_a} \times RE \tag{6}$$

where D_i is the topographic position index of grid i, G_i and PD_i represent the numerical elevation and slope of grid i, G_{avv} and PD_{ave} represent the average elevation and slope of Chengdu ring city, respectively, is the combined correction index weighted by the topographic position index and the nighttime lighting data, and is the parameter, is the corrected combined resistance value, is the average combined correction index of the land use type corresponding to the grid, and is the resistance value of a certain direction in the space of the grid.

III. C. Ecological resilience assessment

III. C. 1) Ecological resilience assessment modeling

This study considers that ecological resilience consists of two parts: the ecological function possessed by the ecosystem itself and the ability to digest disturbances. With reference to the research on the ecological resilience of Chengdu, the model is modified by taking into account the actual situation of the Chengdu Ring Road Ecological Zone. Based on the landscape background, the strength of the ecosystem's native ecological function is measured, and the ecosystem's ability to resolve risks is quantified based on the perspective of “risk, connectivity and potential”. The ecological resilience of the study area is summarized in Equation (7):

$$R_i = \frac{E_{RSi}}{E_{RSMAX}} \times W_{ERS} + \frac{E_{Ri}}{E_{RMAX}} \times W_{ER} \tag{7}$$

In the formula: R_i is the ecological resilience of grid i, E_{RSi} is the ecological resilience of grid i based on ecological background, E_{RSMAX} is the maximum value of ecological resilience based on ecological background, E_{Ri} is the ecological resilience of grid i based on 'risk, connectivity, potential', E_{RMAX} is the maximum value of ecological resilience based on 'risk, connectivity, potential', W_{ERS} is the weight of ecological resilience based on ecological background, W_{ER} is the weight of ecological resilience based on 'risk, connectivity, potential'. Based on scholars' research experience, W_{ERS}, W_{ER} is assigned a value of 0.5.

(1) Construction of ecological resilience assessment model based on landscape background

Landscape background reflects the scale and pattern of different landscape element types in space. Different landscape element types have different impacts on ecological resilience. In addition to landscape type, ecological diversity is also one of the necessary characteristics of a resilient city, and the larger and higher quality of regional biomass, the stronger the ecosystem's ability to support internal and mitigate external risks. Therefore, habitat quality is used to portray the impact of landscape element types on ecological resilience, and biological abundance is used to characterize the biodiversity of the study area, both of which combine to reflect the strength of ecological functions of ecosystems, as detailed in equation (8):

$$E_{RSi} = Q_{Hi} \times A_i \tag{8}$$

where, E_{RSi} is the ecological resilience level of Grid i based on landscape background, Q_{Hi} is the habitat quality of Grid i, and A_i is the biological abundance index of Grid i.

Referring to the calculation method of T192-2015, the calculation is based on CLCD land cover data, see Equation (9) and (10) for details:

$$A_i = A_{bio} \sum (W_k \times P_k) \tag{9}$$

$$A_{bio} = \frac{100}{A_{MAX}} \tag{10}$$

where, A_i is the bioabundance index of grid i, A_{bio} is the bioabundance normalization index, W_k is the weight of land cover type k, P_k is the probability of land cover type k appearing in the grid (i.e., the proportion of the land cover type in the grid area), and A_{MAX} is the maximum bioabundance value before normalization.

(2) Construction of an ecological resilience assessment model based on "ecological risk, connectivity and potential".

Ecosystems mitigate ecological risk and maintain ecological balance by absorbing urban pressure. The greater the potential of the ecosystem, the more urban pressure is absorbed and the stronger the ecological resilience. Therefore, the ecological risk, ecological connectivity and ecological potential are combined to measure the ability of ecosystems to cope with risks, as shown in Equation (11):

$$E_{\mathrm{R}i} = \frac{E_{\mathrm{SV}i}}{E_{\mathrm{RI}i}} \times C \tag{11}$$

where, E_{Ri} is the ecological resilience level of Grid i based on "ecological risk, connectivity and potential", E_{SVi} is the ecosystem potential of Grid i, E_{RIi} is the ecosystem risk of Grid i, and C is the landscape connectivity.

Ecological risk: High-intensity human activities and land development will cause fragmentation of ecological patches and increase ecological risk. As a carrier of human activities, changes in the utilization pattern of land affect the ecosystem function, which in turn affects the probability and intensity of ecological risk, so the level of ecological risk is measured based on the land use perspective, as detailed in Equation (12):

$$E_{\mathrm{RI}i} = \sum \frac{S_k \times W_k}{S} \tag{12}$$

where, E_{RIi} is the ecosystem risk of grid i, k is the utilization type of each land, S_k is the area of type k within grid i, W_k is the weight of type k, and S is the area of grid i.

Ecological connectivity: Ecological connectivity refers to the level of conductivity in which spatial ecological risks spread and are absorbed by ecosystems. The level of ecological connectivity depends on the overall landscape connectivity and the connectivity of important patches. It has been shown that woodland has important ecological significance to urban landscape, and the ecological connectivity of the study area was measured by spreading degree and patch cohesion, where spreading degree describes the overall landscape connectivity and patch cohesion describes the connectivity of the woodland, as detailed in Equation (13):

$$C = 0.5 \times r_{CONTAG} + 0.5 \times r_{COHESION} \tag{13}$$

where, C is the ecological connectivity, r_{CONTAG} is the spread index, and $r_{COHESION}$ is the patch cohesion index.

$$E_{SV} = \sum (S_i \times V_{Ci}) \tag{14}$$

where, E_{sv} is the ecosystem potential, V_{ct} is the coefficient of ecological potential per unit of land of type i, and S_i is the area of land of type i.

III. C. 2) Ecological corridor identification

Based on the previously mentioned ecological source identification and scenic resistance surface construction, the extraction method of inter-source ecological corridors is proposed in this subsection.

Inter-source ecological corridors are extracted using the least cumulative resistance model. The least cumulative resistance model converts the landscape resistance encountered by species during migration between sources into the "cost" consumed by species during migration, and the path that consumes the least "cost" is the inter-source ecological corridor. The least cumulative resistance model has been shown to be effective in identifying least-cost corridors between habitats. The formula (15) is as follows:

$$M_{CR} = \int MIN \sum_{j=n}^{i=m} D_{ij} \times R_{Ii} \tag{15}$$

where, $\int MIN$ is the minimum cumulative resistance value, D_{ij} is the diffusion distance from the source i to the landscape unit j and R_{1i} is the ecological resistance of the landscape unit i. The 2020 ecological corridors were extracted using the cost connectivity tool in ArcGIS10. 6 software.

IV. Case studies

IV. A. Landscape Planning and Design of Chengdu Ring City Ecological Restoration Area

IV. A. 1) Planning interpretation

The ecological restoration of Chengdu City Ring is shown in Figure 1.

(1) Chengdu City Ring Ecological Zone - Jincheng Greenway Planning and Phase I and Phase II Construction Programs

1) Adjustment of Phase II Planning Program: The site is part of Beihu Road Area, the main greenway, which is partially overlapped with Beihu Sanyou Park (secondary station), and is the third phase of the Jincheng Greenway, which has not yet been fully constructed.

2) Level 1 Station Planning: Beihu Area is adjacent to the Level 1 Station Panda Town in the west, and there is a Level 1 Station Xinzhi Xueyuan on the site, whose characteristic themes are panda and joyful learning.

3)Tier II Stage Station Planning: The Phase II planning scheme assigns the Beihu Three Friends Garden into the scope of the site, whose theme is characteristic landscape, and the Xiangcheng Wetland Garden on the north side of the interior of the site, whose theme is characteristic botanical gardens.

4) Tertiary Stage Planning: 7 forested courtyards are planned within the site.

(2) Optimization and upgrading of the master plan of Chengdu City Ring Ecological Zone

The program puts forward the main strategy: vigorously strengthen the ecological function to create a high-quality park bottom, including:

1) Water network pattern: reduce the planning of large-scale lakes, respect the original West River Drainage East Lake Pond water network substrate conditions, the implementation of water system restoration projects, enhance the regional storage capacity, to ensure that the amount of water is sufficient. North Lake area has a new North Lake, the old North Lake North Lake wetlands and other waters.

2) Distribution of farmland: Strictly abide by the red line of farmland, strictly protect permanent basic farmland, and promote the restoration of farmland by combining the vacating of low-end functions and the cleanup of unauthorized building. There is a permanent basic farmland area on the northeast side of the North Lake Area.

3) Regional blue-green space: the use of the ring around the city ecological zone to build a regional blue-green space key skeleton, to the periphery of the extension of various types of parks, the North Lake area is an important green space, connecting the Panda Base and Phoenix Hill Park, Vihe ecological corridor.

4) Peripheral ecological corridor network: along the multi-scale bar-shaped green corridor connecting water systems, wetlands, mountains, parks, focusing on the biological migration corridor between the Ring Road Ecological Zone and the west of the essence of the irrigation area of the important water system, the east of Longquan Mountain. As the largest wedge-shaped green area in the Ring Road Ecological Zone, Beihu Area has an important ecological corridor with Longqing Ecological Zone in the northeast, and gradually connects and penetrates with the green corridor of the central city, which is the key habitat source in the regional ecological network, and Beihu Area is very crucial for the maintenance of the regional landscape and ecological pattern of Chengdu.

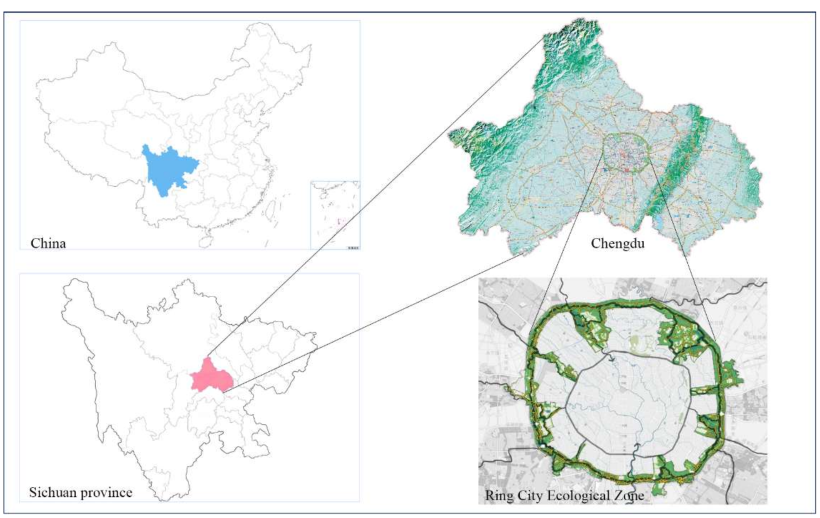


Figure 1: The ecological restoration of Chengdu City Ring

IV. A. 2) Relevant planning

In the ecological space classification control, there are a large number of agricultural production-type spaces and some scenic recreation-type spaces within the North Lake Area. In the detailed zoning plan, there are more agricultural fields, drains, pits and ponds that need to be restored in the various sub-districts within the North Lake Area, and it is necessary to connect the regional water system as much as possible and further optimize and improve the vegetation configuration.

(1) Peripheral linkage: The plan emphasizes strengthening the construction of TOD sites, accelerating the organic linkage of the site's internal and peripheral featured functional areas, using Beihu to link with the central area of the city, and using the internal Chengmian Expressway as an important extension of the city's internal and external areas.

(2) Overall positioning: Chengdu Research Base of Giant Panda Breeding as the golden name card of Beihu, mountains, water, forests, fields, lakes and cities to build a natural base, Chengdu - Panda International Tourism Resort, the best exploration of the relationship between people, pandas, and nature, Chengdu Park City, exploring the relationship between pandas and human beings, and the characteristics of the park to explore the relationship between pandas and human beings in a harmonious coexistence.

(3) Functional zoning: generally divided into Chengdu Giant Panda Breeding Base, Cultural and Creative Performing Arts Expo Town, Boutique Botanical Garden, Agricultural Farm Landscape Area, Theme Hotel Gathering Area, the North Lake Area mainly contains the latter two functional areas, and the subsequent design of the site will also use the conceptual plan as a planning reference to comply with the above planning and related planning requirements.

IV. B. Diagnostic results of key areas for ecological source and corridor restoration

IV. B. 1) Key regional administrations for ecosystem restoration

Table 1 shows the ecological source land restoration key area administrative statistics, this paper diagnoses the source land toughness very low value area and lower value as the first level of restoration key area, with a total area of 277.77km^2, in the southern part of the watershed is mainly located in the edges of the source land patches of the better quality of each habitat, which are finely shaped, in the northern part of the watershed is mainly located in the Jinjiang region of the poorer habitat state of the source land patches. Diagnosis of ecological resilience moderate regional source land for secondary restoration area, a total area of 1955.4471km^2, in the south is mainly located in the edge of the ecological quality of higher patches, in the middle of the watershed is mainly located in the west of the Chenghua and Qingyang districts, the southeastern corner of the Wuhou County area of habitat quality is average or lower patches.

Table 1: Restoration of key regional regions

Administrative region	Key areas of ecological restoration			
	The area of the key zone for first-level restoration /km2	Proportion / (%)	The area of the key zone for secondary restoration /km2	Proportion / (%)
Jinjiang	236.6484	85.20%	84.6485	4.33%
Qingyang	15.5495	5.60%	289.4254	14.80%
Jinniu	2.3669	0.85%	150.0985	7.68%
Wuhou	3.9748	1.43%	371.4598	19.00%
Chenghua	10.1648	3.66%	900.5496	46.05%
Longquanyi	2.7698	1.00%	123.8485	6.33%
Shuangliu	6.2958	2.27%	35.4168	1.81%
Research area	277.77	100%	1955.4471	100%

The land use types of the ecological source land restoration critical areas were counted, as shown in Table 2. Grassland, wetland and water body dominate in the critical area for source land restoration, with a total area of 255.2088km^2, accounting for 91.88% of the area of the critical area for source land restoration. Grassland dominates the key area of source land restoration level 2, indicating that the ecological quality of grassland in the watershed is impaired or the grassland is still degraded, which needs to be protected and restored. In summary, the source land restoration key area still maintains the ecological space substrate such as grassland, wetland, water body, woodland, shrubland, etc., and at the same time, there are part of cultivated land and other production space with ecological function, and part of construction land and unutilized land in the restoration key area.

Table 2: Ecological source restoration key areas of land use type

Land use type	Key areas of ecological restoration		
	The area of the key zone for first-level restoration	The area of the key zone for secondary restoration	Total
Woodland	0.5485	31.5941	32.1426
Grass	24.8495	1679.4165	1704.266
Ploughing	0.1755	46.1625	46.338
Shrub	0.3856	63.5188	63.9044
Glacier snow	1.7985	0.0346	1.8331
Water body	45.2648	12.7856	58.0504
Wetlands	185.0945	18.1498	203.2443
Unexploited	16.9452	101.6482	118.5934
Construction land	0.3466	1.1498	1.4964

IV. B. 2) Diagnostic results of critical areas for corridor rehabilitation

According to the administrative unit zoning of Chengdu Ring City Ecological Zone, the key areas for corridor restoration were counted, as shown in Table 3. Statistical corridor restoration key area length, Jinjiang, Wuhou, Jinniu in turn, 144.4896km, 114.4989km, 80.1994km, respectively accounted for 34.73%, 27.52%, 19.28% of the total area of corridor restoration key area, statistical corridor to be restored, the area of corridor restoration key area in Jinjiang, Wuhou, Jinniu and Longquanyi corridor restoration key area is 80.0489km^2, 71.8168km^2, 72.8395km^2 and 0.9785km^2, accounting for 29.31%, 26.30%, 26.67% and 0.36% of the total area of corridor restoration critical area. In summary, whether in terms of the length of restoration or the area of restoration, Jinjiang, Wuhou, and Jinniu are much larger than the other administrative districts, indicating that the internal corridors of the two counties and one district are seriously damaged, with impeded ecological circulation, and in urgent need of ecological restoration.

Table 3: The corridor fixes key areas

District	The ecological corridor fixes key areas			
	Repair length /km	Proportion	Repair length /km	Proportion
Jinjiang	144.4896	34.73%	80.0489	29.31%
Qingyang	35.4858	8.53%	23.8487	8.73%
Jinniu	80.1994	19.28%	72.8395	26.67%
Wuhou	114.4989	27.52%	71.8168	26.30%
Chenghua	39.3485	9.46%	23.5495	8.62%
Longquanyi	2.0495	0.49%	0.9785	0.36%
Shuangliu	0	0.00%	0	0.00%
Research area	416.0717	100%	273.0819	100

IV. C. Toughness evaluation

IV. C. 1) Structural characteristics of urban ecological networks

In order to rationally coordinate economic development and ecological protection, the study designed three scenarios (BAU, RED, and ELP), in which the BAU scenario (natural development) was generated based on the historical trend of land use change with a baseline state without policy intervention, the RED scenario (economic priority development) aimed to maximize economic efficiency, and the ELP scenario (ecological priority development) aimed to maximize improve ecological efficiency.

Figure 2 shows the characteristic indicators of UEN, the connectivity and aggregation of ecological network nodes were the highest in 2020, 3.4158 and 0.1569, respectively, and the lowest in the ELP scenario, which indicates that the ecological nodes have a higher number of connections with other nodes and a higher probability of interconnection between nodes.The shortest length of ecological corridors was found in the ELP scenario (9.2498), which indicates that organisms flowed through corridors with the highest efficiency. In addition, the RED scenario had the worst transmissibility of the ecological network, indicating that the outcomes of biological or ecological events propagated the slowest throughout the network and had the lowest ecological network stability, while the ELP scenario was the opposite. Therefore, the enhancement of ecological network structural resilience was related to ecological corridor length and network transmissibility, and the shorter the corridor length and the better the network transmissibility the higher the ecological network resilience.

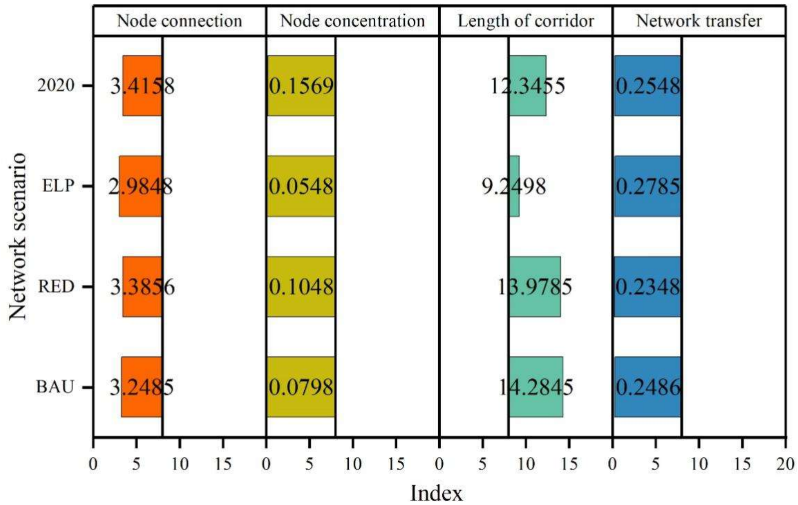
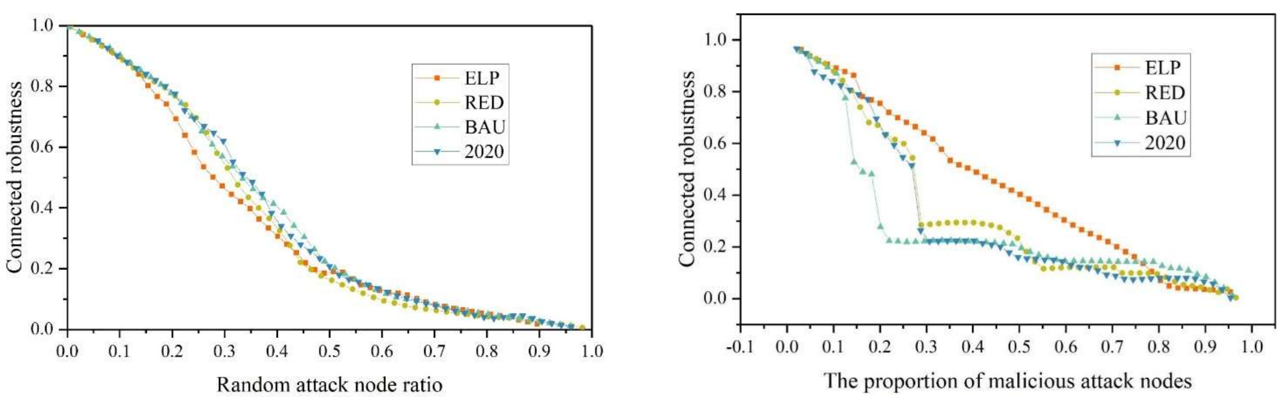


Figure 2: UEN feature index

IV. C. 2) Destruction resistance analysis

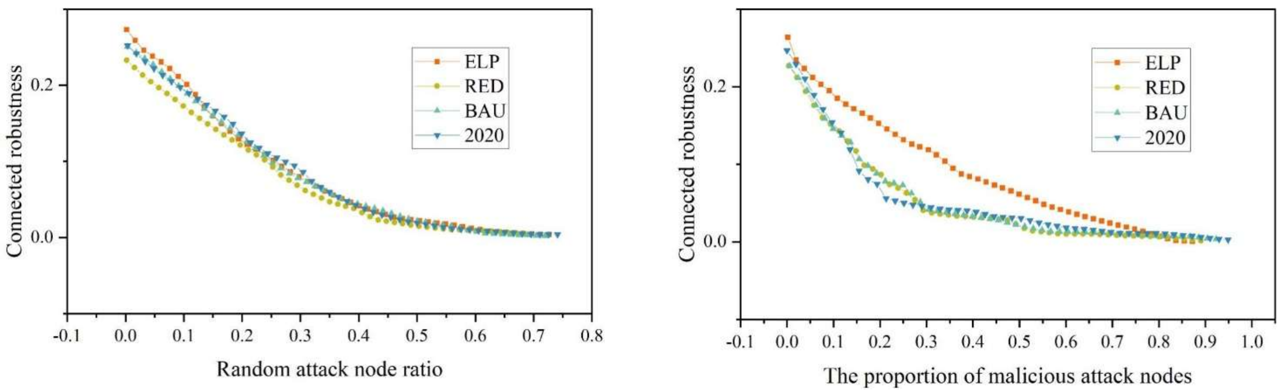
Determining the ability of nodes to operate the ecological network in the face of destructive events is necessary to measure the functional resilience of the network. In this study, we simulated the connectivity robustness of ecological networks under different attacks, Fig. 3 shows the connectivity robustness of ecological networks under different attacks, Fig. (a) is a random attack, and Fig. (b) is a deliberate attack, under the random attack, the initial value of all network scenarios is greater than 0.9, indicating that the ecological networks' own connectivity capacity is better when they are not attacked. Under random attack, the proportion of node deletion when the ecological network collapses is similar and the decreasing trend is basically the same for all scenarios, indicating that the network connectivity is similar. Under deliberate attack, the ecological network of BAU scenario is the first to collapse, and the connectivity robustness drops to about 0.5 at the proportion of nodes intentionally attacked is 0.15. The ELP scenario has the highest connectivity. In addition, the connectivity robustness of the BAU, RED, and 2020 networks decreases sharply at node deletion ratios of 15% to 30%. There is no significant inflection point in the connectivity robustness of the ecological network under the ELP scenario, indicating that the network remains stable after the destruction of important nodes.



(a) Random attack (b) Deliberate attack

Figure 3: The interconnected robustness of the ecosystem under different attacks

Fig. 4 shows the fragile robustness of the ecological network under different attacks, Fig. (a) shows random attack and Fig. (b) shows deliberate attack. The initial value of vulnerability robustness under random attack is the largest in ELP scenario with 0.27294, which is the best operational efficiency when the network is not attacked. The initial value of RED scenario is the lowest with 0.23289 which may be related to the pursuit of maximizing the economic benefits and the highest level of urbanization. With the deletion of ecological nodes, vulnerability robustness are linearly decreasing trend, and the decline under deliberate attack is faster than random attack, in the simulation of random attack network nodes, the node decline trend is basically the same. When nodes of high importance are attacked, the fragile robustness of the ecological network in BAU, RED and 2020 decreases sharply, and the ELP scenario still decreases steadily, indicating that the operational efficiency of the ecological network in the ELP scenario is significantly higher than that in the other three scenarios, which is basically the same as the trend of the connectivity robustness.



(a) Random attack (b) Deliberate attack

Figure 4: The vulnerability of the ecosystem in different ways of attack

V. Conclusion

In this study, the role mechanism of multifunctional ecological corridor construction in enhancing urban ecological resilience was explored in Chengdu Ring City Ecological Zone as an example. Through ecological source identification and corridor construction, the study found that the area of key areas for secondary restoration in Chengdu Ring City Ecological Zone amounted to 1955.4471km², of which Chenghua District accounted for the highest proportion (46.05%); the restoration area was dominated by grassland (1704.266km²), indicating that the impaired ecological quality of grassland was the focus of regional ecological problems. Through the characterization of the urban ecological network structure, the connectivity of the ecological network nodes in 2020 reaches 3.4158, and the aggregation degree is 0.1569, which are higher than other scenarios. The Ecological Priority Development (ELP) scenario showed the best network transmissibility, and the length of ecological corridors was reduced to 9.2498 km, which significantly improved the efficiency of biological flow. Destruction resistance analysis showed that the ecological network of the natural development (BAU) scenario was the most fragile under the deliberate attack scenario, and the connectivity robustness decreased to 0.5 when the node deletion ratio was 15%; whereas, the connectivity robustness of the ecologically prioritized development (ELP) scenario did not have an obvious inflection point, showing higher network stability. The study confirms that the scientific construction of multifunctional ecological corridors can effectively improve urban ecological resilience and provide important support for the construction of urban ecological security patterns by optimizing the network structure, improving connectivity, and enhancing the resistance to destruction.

References

[1] Yuan, Y., Bai, Z., Zhang, J., & Xu, C. (2022). Increasing urban ecological resilience based on ecological security pattern: A case study in a resource-based city. Ecological Engineering, 175, 106486.

[2] Peng, J., Zhao, H., & Liu, Y. (2017). Urban ecological corridors construction: A review. Acta Ecologica Sinica, 37(1), 23-30.

[3] Hong, W., Guo, R., Su, M., Tang, H., Chen, L., & Hu, W. (2017). Sensitivity evaluation and land-use control of urban ecological corridors: A case study of Shenzhen, China. Land Use Policy, 62, 316-325.

[4] Shen, J., & Wang, Y. (2023). An improved method for the identification and setting of ecological corridors in urbanized areas. Urban Ecosystems, 26(1), 141-160.

[5] Chen, R., Carruthers-Jones, J., Carver, S., & Wu, J. (2024). Constructing urban ecological corridors to reflect local species diversity and conservation objectives. Science of the Total Environment, 907, 167987.

[6] Tang, Y., Gao, C., & Wu, X. (2020). Urban ecological corridor network construction: An integration of the least cost path model and the InVEST model. ISPRS International Journal of Geo-Information, 9(1), 33.

[7] Hou, W., Zhou, W., Li, J., & Li, C. (2022). Simulation of the potential impact of urban expansion on regional ecological corridors: A case study of Taiyuan, China. Sustainable Cities and Society, 83, 103933.

[8] Huang, X., Wang, H., Shan, L., & Xiao, F. (2021). Constructing and optimizing urban ecological network in the context of rapid urbanization for improving landscape connectivity. Ecological Indicators, 132, 108319.

[9] Mahmoudzadeh, H., Masoudi, H., Jafari, F., Khorshiddoost, A. M., Abedini, A., & Mosavi, A. (2022). Ecological networks and corridors development in urban areas: An example of Tabriz, Iran. Frontiers in Environmental Science, 10, 969266.

[10] Chen, C. Y., Chuang, Y. H., Chen, H. W., & Teng, C. S. (2024). Optimizing ecological corridors for urban sustainability by using remote sensing and decision modeling. International Journal of Environmental Science and Technology, 1-16.

[11] Li, F., Liu, X., Zhang, X., Zhao, D., Liu, H., Zhou, C., & Wang, R. (2017). Urban ecological infrastructure: an integrated network for ecosystem services and sustainable urban systems. Journal of Cleaner Production, 163, S12-S18.

[12] Gregory, A., Spence, E., Beier, P., & Garding, E. (2021). Toward best management practices for ecological corridors. Land, 10(2), 140.

[13] Fan, F., Wen, X., Feng, Z., Gao, Y., & Li, W. (2022). Optimizing urban ecological space based on the scenario of ecological security patterns: The case of central Wuhan, China. Applied Geography, 138, 102619.

[14] Su, J., Yin, H., & Kong, F. (2021). Ecological networks in response to climate change and the human footprint in the Yangtze River Delta urban agglomeration, China. Landscape Ecology, 36, 2095-2112.

[15] Feng, Y., Ping, L., Hongliang, W., & Jianglin, Y. (2024). Evaluation of the impact of climate change on the ecological resistance and ecological corridors based on set pair analysis theory. Ecological Indicators, 163, 112050.

[16] Gonzalez-Quintero, C., & Avila-Foucat, V. S. (2019). Operationalization and measurement of social-ecological resilience: a systematic review. Sustainability, 11(21), 6073.

[17] McCollum, A. R., Stevenson, K. T., Tayne, K., DeMattia, E., Jeffs, P., & Busch, K. C. (2025). Educating for psychological, community, and ecological resilience: a case study from North Carolina, USA. Journal of Environmental Studies and Sciences, 1-10.

[18] Abdel-Fatah, M. A., & Ewies, E. F. (2025). Green Nanotechnology Applications for Ecosystem Sustainability. Egyptian Journal of Chemistry.

[19] Antonescu, D., & Florescu, I. C. (2025). Theoretical Approaches to Urban Resilience.

[20] Dibaba, W. T., Dibaba, B. T., & Hirpa, G. D. (2025). Spatiotemporal analysis of the wetland dynamics using geospatial techniques: case of Gojeb River sub-basin, Ethiopia. Environmental Monitoring and Assessment, 197(8), 844.

[21] Shi, S., & Nisar, A. (2025). The Effects of Circular Economy, Green Finance, and ICT Developments on Resource Productivity aimed Ecological Sustainability: Evidence from OECD Countries Using a CS-ARDL Approach. Problemy Ekorozwoju, 20(2), 223-244.

[22] Datola, G. (2023). Implementing urban resilience in urban planning: A comprehensive framework for urban resilience evaluation. Sustainable Cities and Society, 98, 104821.

[23] Feng, X., Zeng, F., Loo, B. P., & Zhong, Y. (2024). The evolution of urban ecological resilience: An evaluation framework based on vulnerability, sensitivity and self-organization. Sustainable Cities and Society, 116, 105933.

[24] Jianguang Yin,Qingquan Wei,Dongliang Shao,Zhiwei Luo & Ling Ji. (2025). The impacts of power transmission and transformation projects on ecological corridors and landscape connectivity: a case study of Shandong province, China. Scientific Reports,15(1),6709-6709.

[25] Cláudia Oliveira Fernandes,Catarina Patoilo Teixeira & Mariana Veludo. (2025). Greening urban landscapes: A systematic literature review of planting design for resilient and livable cities. Urban Forestry & Urban Greening,107,128793-128793.

[26] Thornton, D. H., Branch, L. C., & Sunquist, M. E. (2011). The influence of landscape, patch, and within-patch factors on species presence and abundance: a review of focal patch studies. Landscape Ecology, 26(1), 7-18.

[27] Peng, J., Zhao, H., & Liu, Y. (2017). Urban ecological corridors construction: A review. Acta Ecologica Sinica, 37(1), 23-30.

[28] Kietzka, G. J., Pryke, J. S., & Samways, M. J. (2015). Landscape ecological networks are successful in supporting a diverse dragonfly assemblage. Insect Conservation and Diversity, 8(3), 229-237.

[29] Miguel Fuentes,Juan Pablo Cárdenas,Gastón Olivares,Eric Rasmussen,Carolina Urbina,Soledad Salazar & Gerardo Vidal. (2025). Harnessing network science for urban resilience: the CASA model's approach to social and environmental challenges. Applied Network Science,10(1),12-12.