HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

ECOLOGICAL CONNECTIVITY NETWORKS IN LUOHE REGION, CHINA AND IN BUDAPEST AGGLOMERATION AREA, HUNGARY

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LIST OF ACRONYMS

AI – Aggregation Index

AREA_AM – Patch Area_Area–Weighted Mean

BAA – Budapest Agglomeration Area

BCA – Budapest Central Area

CP – City in the Park

CR – Critically endangered

DD – Data Deficient

dPC – Degree of Probability of Connectivity

ED – Edge Density

ECN – Ecological Connectivity Network

EGC – Ecological Garden City

EN – Endangered

ESP – Ecological Security Pattern

EU – European Union

EW – Extinct in the Wild

EX – Extinct

GYRATE_AM – Radius of Gyration_Area–Weighted Mean

GI – Green Infrastructure

IALE – International Association of Landscape Ecology

IUCN – International Union for Conservation of Nature

IUPN – International Union of the Protection of Nature

LC – Least Concern

LCA – Luohe Central Area

LCP – Least-cost Path

LGC – Landscape Garden City

LPI – Largest Patch Index

LR – Luohe Region

LULC – Land Use/Land Cover

MSPA – Morphological Spatial Pattern Analysis

NE – Not Evaluated

NFC – National Forest City

NDVI – Normalized Difference Vegetation Index

NP – Number of Patches

NT – Near Threatened

PEBLDS – Pan–European Biological and Landscape Diversity Strategy

PEEN – Pan–European Ecological Network

PD – Patch Density

PLAND – Percentage of Landscape

QGIS – Quantum Geographic Information System

RK – Resistant Kernel

SSC – Shanshui City

TEWN – Trans–European Wildlife Networks Project

TNSFP – Three–North Shelterbelt Forest Program

UNICOR – UNIversal CORridor and network simulation model

VU – Vulnerabl

1. INTRODUCTION

1.1 Background

Habitat fragmentation and habitat loss

Human activities result in habitat loss and fragmentation which are increasingly disrupting natural ecosystems (HADDAD et al. 2015, SAUNDERS et al. 1991) and wildlife populations (FAHRIG, MERRIAM 1994, WIENS 1995) across the world. Most researchers do not differentiate between habitat loss and habitat fragmentation when they measure fragmentation (FAHRIG 2003). In effect, landscape fragmentation and degradation cause habitat loss and impact the movement of species (CLOSSET-KOPP et al. 2016).

Habitat loss refers to the reduction of natural habitats or ecosystems influenced by human activities such as agriculture, urbanization, deforestation, resource extraction and so on, the natural habitats or ecosystems may not be capable to provide the food, water, and places for species' survival (NWF 2024, UGC 2024). Habitat loss can reduce the species richness (FINDLAY, HOULAHAN 1997, SCHMIEGELOW, MÖNKKÖNEN 2002, STEFFAN-DEWENTER et al. 2002, WETTSTEIN, SCHMID 1999), slow down the population growth rate (BASCOMPTE et al. 2002, DONOVAN, FLATHER 2002), and decrease the genetic diversity (GIBBS 2001) in biodiversity perspective. **Habitat fragmentation** is a landscape-scale, dynamic process (MCGARIGAL, CUSHMAN 2002) including both habitat loss and break apart of habitat (large, continuous of natural habitat patches are split apart into small, isolated fragments) (***Figure 1.1***) (FAHRIG 2003), is also a form of habitat loss. Generally speaking, habitat fragmentation and habitat loss can reduce landscape connectivity. Thus, maintaining landscape connectivity and mitigating habitat fragmentation may be critical for ecological processes such as gene flow, dispersal, and migration (RUDNICK et al. 2012). Therefore, ecological connectivity is the key way to preserving biodiversity, to reducing habitat fragmentation and safeguarding the species' survival.

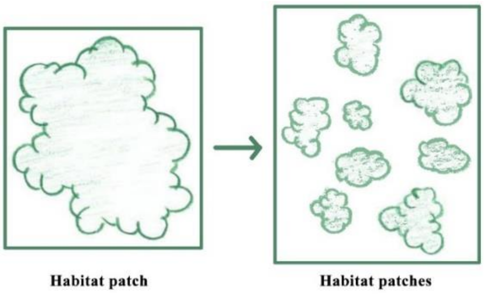

Figure 1.1: Habitat fragmentation

Ecological Connectivity Networks

Ecological Connectivity Networks [1] (ECNs) can provide conservation solutions to mitigate the damage caused by intensified land use (JONGMAN 2008) by promoting landscape connectivity and reducing landscape fragmentation (UPADHYAY et al. 2017) through facilitating gene flow, migration, dispersal of species (RICOTTA et al. 2000). Therefore, an optimized ECN spatial pattern is of great significance for the sustainable development of urban and rural ecosystems (RUIZ-GONZÁLEZ et al. 2014).

The increasing awareness of habitat fragmentation and landscape degradation has rapidly increased demand for modeling tools to simulate and evaluate ECNs. RUDNICK et al. (2012) illustrated modeling methods for evaluating landscape connectivity, and noted that Least-Cost Path (LCP)[2] (ADRIAENSEN et al. 2003) and UNIversal CORridor (UNICOR) cumulative resistant kernel[3] (COMPTON et al. 2007, LANDGUTH et al. 2012) analyses are some of the methods most frequently used to map ECNs (CUSHMAN et al. 2014, CUSHMAN et al. 2018, KASZTA et al. 2020a). Different input data from different methods generate different outcomes and meet diverse requirements to help planners in mapping ECNs and prioritizing protection priorities[4], which prompts researchers to explore the limitations and advantages of different modeling methods for assessing connectivity networks (e.g., RUIZ-GONZÁLEZ et al. 2014, ZELLER et al. 2018).

1.2 Challenges analysis

Challenges about ecological connectivity networks in Luohe region and generally in China

With the rapid increase of industrialization and urbanization, natural ecosystems and ecosystem services in China are experiencing landscape fragmentation and degradation due to urban sprawl (PENG et al. 2018a, UPADHYAY et al. 2017). Despite being one of the largest nations in the world, with the world's largest population and one of the fastest-growing economies, there have been relatively few landscape-scale assessments of the structure, function, and optimality of ecological networks. And few of these have been completed in China. In 1979, Three-North Shelterbelt Forest Program[5] was the first exploration of ecological construction to improve the desert environment in China. After the 1990s, the Chinese government announced a set of urbanization policies that

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[1] Ecological Connectivity Networks: see the definition in 3.3

[2] Least-Cost Path: see detailed information in 3.9.3

[3] UNIversal CORridor cumulative resistant kernel: see detailed information in 3.9.4

[4] Protection priority: protection priority is to protect the critical green space based on the urgency and importance of green space.

[5] Three-North Shelterbelt Forest Program: see in 3.4

resulted in the creation of vast urban development, but also the first coordinated efforts to enhance green areas for health, aesthetic, and biodiversity values. These included initiatives such as Landscape Garden City, Forest City, Ecological Garden City, and City in the Park. Jinping Xi, president of the People's Republic of China, proposed the Two Mountains Theory in 2005: “Mountains of gold and silver are not as good as lucid waters and lush mountains”. In recent years, national planning in China has increasingly considered the security and health of ecological processes to protect ecosystems systematically (PENG et al. 2018a). Therefore, how to protect the resilience and health of ecological systems is identified as a critical challenge in urban planning in China and around the world.

Challenges about ecological connectivity networks in Budapest region and generally in Hungary

The land use/land cover (LULC) around the whole world is changing because of human activities, such as development of residential area, construction of transportation system, resulting in habitat loss and fragmentation, poor connectivity of habitat patches, and the ecosystem degradation (GAO et al. 2017, HARRIS 1984, ZHANG et al. 2014, STARR et al. 2016). Hungary as a European Union (EU) country faces a decrease in habitat patches and an increase in fragmentation, biodiversity conservation is the key topic for maintaining the ecosystem (WATSON et al. 2019). Hungarian government issued spatial planning instruments to increase the landscape connectivity at national, regional, and local levels. Spatial Development Strategy, County Spatial Development Strategy, and Local Development Strategy were issued as strategic instruments at national, regional, and local level respectively; National Land Use Framework Plan, County Land Use Framework Plan, and Land Use Plan were issued as land use planning instruments in national, regional and local level respectively (DTP 2021a). Hungary participated in a lot of European programs to restore and manage ECN and increase board accessibility for species movement, such as the Pan – European Ecological Network (PEEN) for Central and Eastern Europe (2002), Emerald Network (1989) (also known as Network of Areas of Special Conservation Interest), Natura 2000 (1992), the Trans-European Wildlife Networks Project (TEWN) (2010), and the EU Birds and Habitats Directives (2014). Hungary designated the Hungarian National Ecological Network to include the ecological network into the administrative planning system and to fit the PEEN level (DTP 2021b). Therefore, how to balance human needs and biodiversity conservation is the main challenge in Hungary and the EU.

2. OBJECTIVES TO ACHIEVE

The objectives of the research are based on the process where I conducted a gap analysis, defined general goals, formulated research questions, and developed hypotheses.

2.1 Gaps analysis

Based on the mapping methods and study areas, I raised **three research gaps** in the field of this dissertation.

(1) Several studies have assessed ecological network connectivity for species of conservation concern in many parts of the world (e.g., CUSHMAN et al. 2014 and 2016, KASZTA et al. 2019 and 2020a, ASHRAFZADEH et al. 2020), **relatively few have explicitly evaluated the sensitivity of these network predictions to the dispersal ability of focal organisms**, particularly in the context of urban landscape planning. This is particularly important for the long-term and healthy growth of medium-sized cities to enable them to optimize planning designs for multiple objectives including quality of human life and also ecological sustainability and biodiversity conservation, as dispersal ability has been shown to be the most important factor affecting functional connectivity in several taxonomic groups (e.g., CUSHMAN et al. 2010a, ASH et al. 2020). **The few ecological network assessments that have explicitly assessed the effects of dispersal ability have found strong influences on predictions and conclusions regarding conservation recommendations** (e.g., CUSHMAN et al. 2010a, 2013b and 2016; RIORDAN et al. 2016, MACDONALD et al. 2018).

(2) Luohe city was designated a National Landscape Garden City in 2002 and a National Forest City in 2010, which have directed development to enhance green open space for the physical and mental health of residents. Its developments of ecological connectivity networks and green urbanization represent an example of a national focus on green development. While Luhoe is a city that focuses on green development, **there has been relatively little quantitative and analytical work** to assess the effectiveness and optimize the future development of green infrastructure in the region. **Little is known about how multi-dispersal scenarios can influence the ecological connectivity network in the Luohe region**.

(3) Budapest as the capital city of Hungary has a well-kept pre-war cityscape with massive landmarks. The Castle Hill, the River Danube embankments, and Andrássy út have been officially designated as UNESCO World Heritage Sites. Regional spatial plans have been elaborated in the Budapest Agglomeration Area (BAA). Its developments of urban planning give an example for EU cities that focus on the transregional planning. **Relatively few studies have illustrated the**

modeling methods to map and prioritize ECN in this region or elsewhere. Despite their broad usage in ecology, **little is known about the differences in the predictions of different connectivity modeling methods and their performance in terms of how well they predict functional connectivity or ecological integrity** (e.g., ZELLER et al. 2018), especially in urban settings.

2.2 Goals

The goals in this dissertation are divided into two levels: regional level including Luohe region (LR) **(*Figure 4.1*)** and Budapest agglomeration area (BAA) **(*Figure 4.4*)** and central area level including Luohe central area (LCA) **(*Figure 4.1*)** and Budapest central area (BCA) **(*Figure 4.4*)**. The main goals at regional level are to compare least-cost path analysis and UNICOR cumulative resistant kernel analysis frequently used in mapping ecological connectivity networks to explore the accessibility and applicability of these two methods, to assess the pattern of green network connectivity, and to rigorously prioritize the design of the ecological connectivity networks in species perspective and in spatial perspective. The main goals at the central area level are to explore the detailed information on ecological connectivity networks, and to rank the protection priority in species perspective. I applied the UNIversal CORridor and network simulation model (UNICOR) (LANDGUTH et al. 2012) and least-cost path (LCP) analyses (including LCP analysis by cost path and LCP analysis by Linkage Mapper) to simulate, map and evaluate the ECNs for multi-dispersal scenarios in LR, China, where intensive construction activities over the past several decades have resulted in massive and rapid land use change and reduction in natural ecosystems and habitats. I used the same method in BAA, Hungary, where human activities have reduced the biodiversity of wildlife which resulted in habitat loss and fragmentation. I also applied UNICOR in LCA, and in BCA where the intensive residential areas are.

To provide this critical information, I have goals like below:

(1) to compare the differences and similarities of mapping methods ("LCP analysis" and "UNICOR analysis") in the LR and BAA and the differences and similarities of ecological connectivity networks in the LR, BAA, LCA, and BCA.

(2) to explore the relationship between landscape connectivity[6] and landscape composition[7].

(3) to evaluate the landscape fragmentation in LR, BAA, LCA and BCA.

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[6] Landscape connectivity: see the definition in 3.2

[7] Landscape composition: see the definition in 3.5

(4) to map and compare the connectivity (resistant kernels[8](RK)) and the wildlife pathways (factorial LCPs) at multi-dispersal scenarios in the LR, BAA, LCA, and BCA, and to explore the relationship between RK and factorial LCP.

(5) to develop optimized ecological networks in order to prioritize protection in species perspective in the LR, BAA, LCA, and BCA and in spatial perspective in the LR and BAA.

(6) to identify the high connectivity areas in LR and BAA.

(7) to explore and describe the relation between ECNs and linear landscape elements (water surfaces and roads) in the LR and BAA.

2.3 Research questions and hypotheses

I raised eight research questions based on research goals and hypotheses based on the research questions accordingly.

Least-cost path analyses (including by cost path and by Linkage Mapper) map **functional ecological networks**[9] based on land use map to provide a simple and easy-to-understand illustration of potential paths without the consideration of species limits. UNICOR analysis considers land use map and species' dispersal ability to model enriched information of corridors and corridor strength for multi-dispersal thresholds. I raised the first question based on the mapping methods:

(1) How do mapping methods affect the ECNs? What are the differences among the mapping methods?

Hypothesis related to question one:

- Different mapping methods use different types of core area inputs, resulting in totally different resistant surfaces to represent the connectivity and completely different types of corridors.

Built-up areas and roads as impervious surfaces have the highest **resistance surfaces**, they can impede species movement as barriers. Different cities have different amounts of built-up areas and roads, usually, central areas have a higher ratio of built-up areas and roads than the regions themselves. I raised the second question based on the impervious surfaces (built-up area and road):

(2) How does the ratio of the highest resistance surfaces (including built-up areas and roads)

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[8] Resistant kernel: see the definition in 3.9.4

[9] Functional ecological networks: see in 3.2

affect the whole landscape connectivity? To what extent does this ratio affect the ratio of low, medium, and high connectivity areas and low, medium, and high connectivity paths?

Hypothesis related to question two:

- Different ratios of the highest resistance surfaces affect landscape connectivity differently with different dispersal abilities, the higher the ratio of the highest resistance surface is, the lower the landscape connectivity is. The areas with similar ratios of the highest resistance surfaces have similar landscape connectivity, while the areas with different ratios of the highest resistance surfaces have different landscape connectivity.
- Low ratios of the highest resistance surfaces affected that landscape connectivity had remarkable differences with short-distance dispersal abilities, and slight differences with long-distance dispersal abilities. High ratios of the highest resistance surfaces did not affect largely landscape connectivity in case of the short-distance dispersal ability species, but did affect landscape connectivity with the long-distance dispersal abilities.

Fragmentation analysis quantifies the landscape structure and composition. Landscape metrics in FRAGSTATS were used to measure landscape fragmentation, and different landscape metrics can provide valuable information on different aspects of **spatial patterns** of habitat patches and the degree of fragmentation or connectivity within a landscape. RK and factorial LCP represent the landscape connectivity, connected areas[10] represent the areas where the value of RK is larger than 0, and meaningful paths[11] represent the areas where the value of factorial LCP is larger than 0. I raised the third question based on landscape fragmentation and connectivity:

(3) How does landscape fragmentation affect landscape connectivity for species with different dispersal abilities?

Hypothesis related to question three:

- As landscape fragmentation decreases, landscape connectivity increases.
- Species with short-distance dispersal abilities may be more affected by landscape fragmentation than those with large-distance dispersal abilities.

Species movement and presence in one area represents the landscape connectivity in this area, the landscape connectivity defines how long the species can move and where they can appear. I raised the fourth questions based on species dispersal and movement:

(4) How to rank the protection priority of ecological connectivity network in species

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[10] Connected areas: see in 4.2.5.1

[11] Meaningful paths: see in 4.2.5.2

perspective?

Hypothesis for question four:

- Species dispersal ability has a significant positive relationship with landscape connectivity, meaning that as species dispersal ability increases, landscape connectivity also increases.
- The species' sensitivity to land use types defines the protection priority in species perspective.

Least-cost path analysis extracts the path that has the cheapest movement cost without consideration of species dispersal, UNICOR analysis calculates the possible rate of species present in the study area extent. Combining least-cost path analysis and UNICOR analysis can extract the advantages of both analyses to get the protection priority. I raised the fifth question based on ecological connectivity networks by least-cost path analysis and UNICOR analysis:

(5) How do the least-cost path analysis and UNICOR analysis define the protection priority in spatial perspective?

Hypothesis for question five:

- Landscape connectivity has a significant negative relationship with the protection priority in spatial perspective, meaning the areas with higher landscape connectivity are less important and urgent to protect.
- The species' sensitivity to land use types defines the protection priority in spatial perspective.

Core areas have the lowest **resistance** for species movement, and the built-up areas have the highest resistance for species movement. They are two important factors that define the spatial pattern of corridors and the location of the highest connectivity areas. I raised the sixth questions here:

(6) How do the lowest resistance surface (core areas) and the highest resistance surface (built-up areas) affect the spatial pattern of ecological connectivity networks and the spatial distribution of the highest connectivity areas?

Hypothesis for question six:

- The areas near to the lowest resistance surface have low resistance, and the location of core areas defines the location where the corridors and the highest connectivity areas appear. The areas near to the highest resistance surface have high resistance and the density of built-up areas affects the density of corridors.
- Ecological connectivity networks pass through the low resistance areas and avoid the high

resistance areas.

- The highest connectivity areas are located in conservation areas or hilly areas.

The ecological network is partly based on corridors. The corridors are linear elements of the landscapes and are mostly represented by vegetated surfaces (green spaces, forests, wetlands, etc). Planners build ENs along rivers and roads to increase landscape connectivity by using the pattern of existing linear elements. Budapest has limited green space along the river compared with green space along the road; while in Luohe city, the amount of green spaces along the river is similar to the amount of green spaces along the road. Road direction in Luohe usually is from South to North and East to West; Road direction in Budapest has radial direction. I raised the seventh question based on the linear elements of the landscape (river and road):

(7) To what extent linear do elements of landscape (rivers and roads) contribute to the spatial pattern of the ecological connectivity networks?

Hypothesis for question seven:

- The density of green spaces along the river influences the density of green spaces away from the river in the whole city, and river direction influences the direction of ecological corridors. Road direction influences the direction of ecological corridors.
- Ecological connectivity networks are mostly along the roads and the rivers.

Kernel connectivity represents the predicted spatially explicit dispersal rates across the study area extent (CUSHMAN et al. 2011). Factorial LCP analysis showed the optimal routes of potential corridors across all combinations of source points, and reflected the relative strength of linkage across the landscape (CUSHMAN et al. 2018). I raised the eighth question based on the kernel connectivity and factorial LCP connectivity:

(8) What is the relationship between landscape connectivity and species dispersal[12] ability? What is the relationship between kernel connectivity and factorial LCP connectivity?

Hypothesis for question eight:

- Kernel connectivity will increase with dispersal ability increase, and factorial LCP connectivity will increase with kernel connectivity increase.

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[12] Species dispersal: see in 3.2

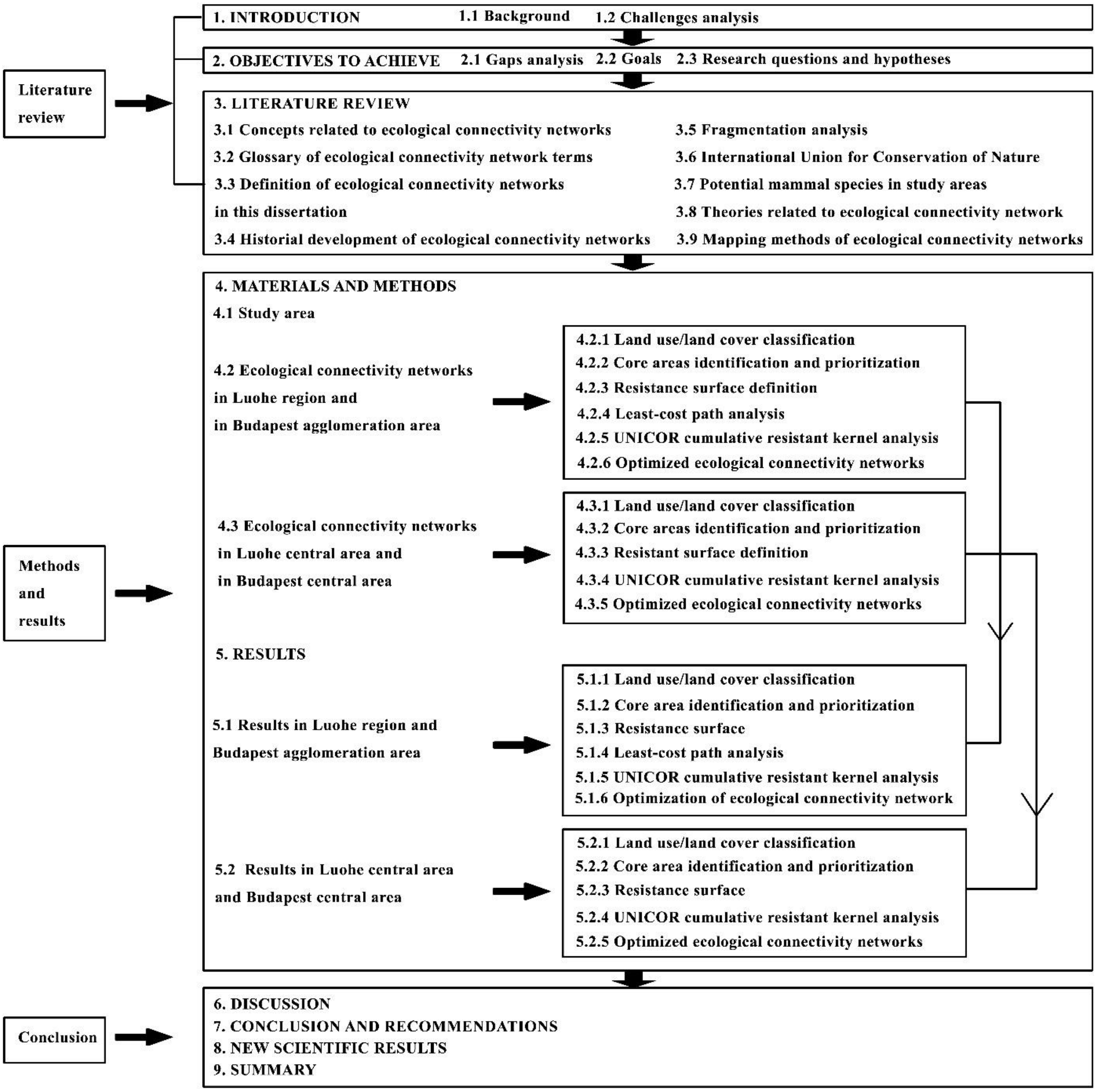


Figure 2.1: Framework of this dissertation

3. LITERATURE REVIEW

3.1 Concepts related to ecological connectivity networks

The concepts related to ECN based on the structure mostly include parkways, green belt, greenways, green infrastructure, ecological corridor/habitat corridor, ecological network/habitat network, and ecological security pattern in the whole world based on the different country environments.

Parkways

The Oxford Advanced Learner's Dictionary (2012) defined a parkway as a wide road with vegetation along the sides or middle. The first parkways were proposed in the United States by Frederick Law Olmsted and Calvert Vaux in 1860 as the road to connect urban parks (JONGMAN, PUNGETTI 2004). These routes serve aesthetic and recreational purposes, linking the city with urban parks surrounded by trees (JONGMAN, PUNGETTI 2004). Olmsted and Vaux developed the world's first parkway named Eastern Parkway in 1866 for "pleasure-riding and driving" or scenic road to Prospect Park (NYCP 2024).

Green belt

The Oxford Advanced Learner's Dictionary (2012) defined a green belt as an open area around a city where the built-up area is strictly managed. The green belt was developed by Ebenezer Howard in England in 1898 to stop the urban sprawl of London and to divide the inner city with parks, and the commercial and industrial areas should be built along the green belt (JONGMAN, PUNGETTI 2004). The difference between the parkway and the green belt is that the parkway has a linking function and the green belt has a dividing function.

Greenways

The concept of greenways was recommended as a new tool to have access to open space for people where they live and to link rural landscape and urban space in the President's Commission on Americans Outdoors in the United States in 1987 (PCAO 1987, FABOS, AHERN 1996, JONGMAN, PUNGETTI 2004). The most representative and understandable definition of greenways was that greenways are land networks consisting of linear landscape elements that are designed for multiple functions with ecological, recreational, cultural, aesthetic, or other utilizations (AHERN 1995).

Green infrastructure

Green Infrastructure (GI) was firstly used in the early 1990s to distinguish the term of greenways, green space, and urban forests (CULLEN 2013, BENEDICT, MCMAHON 2002). In 1994, Buddy MacKay who is the chair of the Florida Greenways Commission (the name of the commission now is Florida Greenways and Trails Council), wrote a report about a GI project – Florida Greenway Project, and firstly used the GI as a term to plan and manage Florida's infrastructure for the communities (CULLEN 2013). The conceptions of GI are different in different spatial scales and different usages, mainly it was divided into three types: (1) GI as conserved green space. Researchers and committees applied GI to undeveloped lands and defined it as an interconnected network of green spaces and natural areas (BENEDICT, MCMAHON 2002, TCF 2023, PCSD 1999). (2) GI as stormwater management. GI used soils, vegetation, and natural processes to soak up and store water (USEPA 2023). (3) GI as an urban forest. GI usually was used in the literature to treat trees and to manage urban forests as GI (MCPHERSON, PEPER 1995, CODER 1998, COSTELLO, JONES 2003). Nowadays, the European Commission defined GI as a systematic network of natural and semi-natural areas with other environmental elements to provide complete ecosystem services such as air quality, water purification, recreation space, and climate adaptation (EEC 2024).

Ecological corridor

The corridor is a narrow landscape strip which is essential for gene flow and dispersal (PENG et al. 2018b). The purposes of the ecological corridor are originally used for connecting fragmented habitats of wild animals and wildlife protection, so it is also called wildlife corridor, habitat corridor, or green corridor. Ecological corridor has many different definitions, the most popular definition is a linear feature of vegetation and at least connects two different habitat patches (SAUNDERS, HOBBS 1991) with multi-functions, such as ecological, social, cultural, and other functions (PENG et al. 2017).

Ecological network

The Ecological Network (EN) was developed firstly in the 1970s and 1980s in some European countries. An ecological network is regarded as a coherent system of natural and/or semi-natural landscape elements that are configured and managed with the objective of maintaining or restoring ecological functions as a means to conserve biodiversity while also providing appropriate opportunities for the sustainable use of natural resources (BENNETT, WIT 2001, BENNETT 2004). An EN consists of core areas, corridors, buffer zones, nature restoration areas, and restoration areas (***Figure 3.1***) (BENNETT 1991, BISCHOFF, JONGMAN 1993)

Core areas: areas where the conserved features are (BIONDI et al. 2012), meeting the habitat and size needs of target species for their sustainable permanent occurrence and providing them with sufficient food supply, shelters, breeding, and dispersal conditions (DTP 2021c).

Corridors: functional linkage between core areas enabling dispersal and migration of species to flow gene and exchange species as well as involved interactions between ecosystems (BOUWMA et al. 2002).

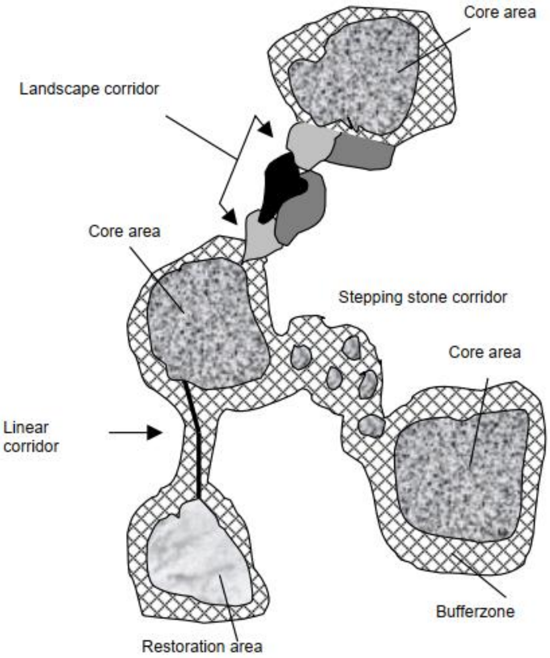


Figure 3.1: Structure of an ecological network (BOUWMA et al. 2002)

Buffer zones: IUCN defined a buffer zone as a peripheral zone to a protected area where restrictions are placed upon resource use or special development measures are undertaken to enhance the conservation value of the area (OLDFIELD 1988). The function of buffer zones is a shield around core areas to protect and safeguard core areas from negative influences from surrounding areas (BOUWMA et al. 2002, WORBOYS et al. 2010). A buffer zone should be multifunctional:

- to protect local traditional land use;
- to accomplish area requirements or shape irregularities of the core area;
- to set aside an area for manipulative research;
- to segregate core areas for nature conservation from other land uses such as agriculture, recreation, or tourism activities;
- to manage adverse effects by putting up a barrier for immediate protection;
- to locate developments that would have a negative effect on the core area (JONGMAN, TROUMBIS 1995, cited in JONGMAN, PUNGETTI 2004).

Restoration areas: restoration areas are the vital enlargement of existing areas for specified species or species groups to facilitate viable populations (BOUWMA et al. 2002, JONGMAN et al. 2006).

Stepping stones: Stepping stones function as habitat patches in the intervening space between core areas which are also called habitat islands to provide resources and refuge that assist animals to move through the landscape (JONGMAN et al. 2004, DTP 2021d).

Ecological security pattern

Since the 1990s, Professor Kongjian Yu of Peking University in China and his research team have put forward the theory and method of ecological security pattern (ESP) for the first time in the world. The team made the work in response to the severe contradiction in the relationship between man and land in China, and has continued to carry out national territorial research on multiple scales. The research on "ecological security pattern" clearly puts forward that the core solution to the various problems brought about by rapid urbanization is to establish a national land ecological security pattern and maintain the national land ecological security pattern at various scales. The definition of EPS is shown in 3.4.1.

3.2 Glossary of ecological connectivity network terms

(1) Species movements and related corridors

Home range is considered as the area traversed by the individual species' lives and moves on a periodic basis, such as food gathering, mating, and caring for the young (BURT 1943).

Movement is itself the product of evolutionary pressures contributing in many ways to the survival and the reproduction of animal species, animal species move through their home range, but may also move long distances from where they were born and their kin remain (BOUWMA et al. 2002; JONGMAN et al. 2004, JONGMAN, PUNGETTI. 2004). Species movements can be divided into three types (CAUGHLEY, SINCLAIR 1994), correspondingly, resulting in three kinds of corridors.

Local movement and movement corridor

Local movement is a movement within a home range and is on smaller scales (BOUWMA et al. 200, JONGMAN et al. 2004, JONGMAN, PUNGETTI 2004), resulting in a **movement corridor** that allows species to move within core areas for foraging, hiding from enemies, and optimizing living conditions (JONGMAN et al. 2004, JONGMAN, PUNGETTI 2004).

Dispersal and dispersal corridor

Dispersal is a movement of individuals from the place of birth to the site of reproduction, often away from their family group and usually without return to the place of birth (BOUWMA et al. 200, JONGMAN et al. 2004, JONGMAN, PUNGETTI 2004). Dispersal is a one-way permanent movement from a home range or birth place to a better living condition (RICKLEFS 1990).

Dispersal results in a dispersal corridor that allows for the movement of various species between high ecological value areas.

Migration and migration corridor

Migration is a movement back and forth regularly, usually seasonally, for example, species move from cold living conditions to warm living conditions in the winter period. Migration is a two-way long-distance movement for individual species from one area or climate to another (BOUWMA et al. 200, JONGMAN et al. 2004, JONGMAN, PUNGETTI 2004). Migration results in a migration corridor that allows species to move between areas of their permanent distribution.

(2) Several kinds of connectivity

There are several concepts of connectivity. WORBOYS et al (2010) defined four types of connectivity commonly used in conservation consideration: habitat connectivity, landscape connectivity, ecological connectivity, and evolutionary process connectivity for natural and semi-natural landscapes that interconnect and embed core areas.

Habitat connectivity. Habitat connectivity is the connectedness between suitable habitat patches for a particular species (FISCHER, LINDENMAYER 2007, LINDENMAYER, FISCHER 2013).

Landscape connectivity. Landscape connectivity is a human view of the connectedness of patterns of vegetation cover within a landscape (FISCHER, LINDENMAYER 2007, LINDENMAYER, FISCHER 2013).

Ecological connectivity. Ecological connectivity is the connectedness of ecological processes across many scales and includes processes relating to trophic relationships, disturbance processes, and hydro-ecological flows (FISCHER, LINDENMAYER 2007, LINDENMAYER, FISCHER 2013, SOULÉ et al. 2004, SOULÉ et al. 2006)

Evolutionary process connectivity. Evolutionary process connectivity identifies natural evolutionary processes including habitat selection, evolutionary diversification, genetic differentiation on a large scale and connectivity for gene flow, and range expansion (WORBOYS et al. 2010).

(3) Connectivity and connectedness

The main landscape functions for dispersal are connectivity and connectedness (JONGMAN et al. 2004).

Connectivity. Connectivity represents the functional ecological network, it is a parameter of landscape function, which measures the processes by which subpopulations of organisms are interconnected into a functional demographic unit (BAUDRY, MERRIAM 1998). Functional connectivity describes the ability of the animal to move among landscape elements (TAYLOR et al. 1993, WITH et al. 1997)

Connectedness. Connectedness represents the structural ecological network between elements of the spatial structure of a landscape and can be described from mappable elements (BAUDRY, MERRIAM 1998). Structural connectedness refers to the physical continuity of habitat across the landscape (CUSHMAN et al. 2010d) and describes the shape, size, and location of landscape features (BROOKS 2003).

3.3 Definition of ecological connectivity network in this dissertation

In the last two sections, I introduced the general concepts and key elements related to ECNs, here, based on the different definitions and different terms of ecological connectivity network (ECN), I summarized the definition of ECN in my dissertation. The concept of ECN should meet the environmental requirements both in China and in Hungary, so I extracted the "security network of natural and/or semi-natural landscape elements" in the definition. The structure of ECN should use internationally defined structures which are core areas, corridors, and buffer zones, because I used these keywords of structure repeatedly in the next chapters. The corridors I simulated in the next chapters are mainly for species movements and genetic transformation, so the concept of ECN should address this point. I used different mapping methods to simulate the detailed information about species' movements and corridors, so I will stress this point as well in the concluded concepts. In conclusion, ECN refers to a security, coherent, and functional network system of natural and/or semi-natural landscape elements that includes core areas, corridors, and buffer zones, providing detailed, comprehensive information about the relative strength of networks for species dispersal.

3.4 Historical development of ecological connectivity networks

(1) Historical development related to ecological connectivity networks in China

Despite being one of the largest nations in the world, with the world's largest population and one of the fastest-growing economies, there have been relatively few landscape-scale assessments of the structure, function, and optimality of ecological networks have been completed in China.

In 1979, **Three-North Shelterbelt Forest Program (TNSFP)** (Chinese: 三北防护林工程) (also known as the "Great Green Wall of China") was the first exploration of ecological construction to improve the desert environment and to decrease water and soil loss in China. This project was started in 1978 and will be completed in 2050 expectedly. The TNSFP refers to large-scale artificial forestry ecological projects constructed in China's Three North Regions (Northwest, North and. Northeast). Overall planning requirement of this program is to create a shelterbelt system that coordinates the development of agriculture, forestry, and animal husbandry, which are adopted by artificial afforestation, closing mountains to cultivate forests and grasses, creating forests to break wind and fix sand, and so on. This project has completely preserved afforestation for an area of 31.7429 million hectares until the end of 2020, which thoroughly changed the environments of human living, species movements, and afforestation situation.

After the 1990s, the Chinese government announced a set of urbanization policies that resulted in the creation of vast urban development, but also the first coordinated efforts to enhance green areas for health, aesthetic, and biodiversity values. These included initiatives such as Landscape Garden City, National Forest City, Ecological Garden City, and City in the Park. In recent years, national planning in China has increasingly considered the security and health of ecological processes to protect ecosystems systematically (PENG et al. 2018a).

Shanshui City (SSC) (Chinese: 山水城市)**.** The SSC was first proposed by Xuesen Qian in 1990, and it is a future city concept proposed on the basis of the traditional Chinese landscape view of nature and the philosophical view of the unity of man and nature. However, compared with other future urban theories, SSC is more of a conception, lacking a complete set of ideas and feasible solutions to solve modern urban problems.

Landscape Garden City (LGC) (Chinese: 园林城市). The selection activity of LGC was launched in 1992 by the Ministry of Housing and Urban-Rural Development in China. The LGC is proposed in the special environment of China, and it is closely related to traditional private gardens. Its predecessor is the SSC proposed by Xuesen Qian, which is somewhat similar to the "Garden City" proposed by European countries. They all emphasize the shaping of the urban landscape, just like painting, using artificial aesthetic taste to build every brick, every piece of grass, and every tree in the city. The LGC embodies the traditional Chinese aesthetic taste, while "Garden City" imprints the customs of European countries. The LGC takes a certain amount of green space as the basic organic linkage to make the urban physical environment have the best aesthetic and ecological effects by organizing and constructing various basic elements of urban space. There are 389 LGCs by 2019 in China.

National Forest City (NFC) (Chinese: 国家森林城市)**.** The NFC was proposed by the State Forestry Administration and the National Greening Council in 2004. The NFC refers to a city whose urban ecosystem is dominated by forest vegetation, and whose urban ecological construction achieves the integrated development of urban and rural areas. The purpose of the NFC is to let the forest enter the city and let the city embrace the forest. There are 219 NFCs by 2022 in China.

Ecological Garden City (EGC) (Chinese: 国家生态园林城市)**.** The EGC was launched by the Ministry of Housing and Urban-Rural Development in China in 2007. The EGC not only refers to a beautiful and clean environment and good landscaping, but also on the basis of garden city, using ecological principles, through planting trees, expanding forest area, increasing forest resources, protecting biodiversity, and improving urban ecological function, highlighting the ecological concept of the city. And to ensure that residents have a high degree of satisfaction with the city's ecological environment. There are 19 EGCs by 2019 in China.

City in the Park (CP) (Chinese: 公园城市)**.** The CP was proposed as a new concept and a new paradigm of urban development in 2018 by President Jinping Xi. The CP is a large system covering the whole city, and a city is a system of green buildings that grow out of the solitude of a park, rather than an island-style park. The CP was guided by the concept of ecological civilization, which deeply practices the concept of " Mountains of gold and silver are not as good as lucid waters and lush mountains ", builds a life community of mountains, rivers, forests, fields, lakes, and grass in the city from an ecological perspective, and deploys a high-quality green space system, and upgrades the "park in the city" to "City in the Park", forming a new pattern of harmonious development between man and nature.

Ecological security patterns (ESPs) (Chinese: 生态安全格局)**.** The concept of ESPs was firstly proposed in the 1990s and got started in 2007. The ESPs refer to landscape elements, spatial locations, and connections that are critical to maintaining the health and safety of ecological processes, including continuous and complete landscape patterns, wetland systems, natural forms of river systems, greenway systems, and the shelter forest systems built before in China. It is a multi-level, continuous, and complete network, including the macroscopic national ESP, the regional ESP, and the urban and rural microscopic ESP. The macroscopic national ESP corresponds to the national scale, the ESP is regarded as a permanent regional landscape to maintain natural ecological processes such as water conservation, flood regulation and storage, and biological habitat networks. It is used to protect the ecological security of cities and communities, and to define urban spatial development patterns and urban forms. The regional ESP corresponds to the regional and urban scales. The ESP can be implemented in the cities in the form of ecological infrastructure on this scale. On the one hand, it is used to guide the expansion of urban space, define the urban spatial structure, and guide the usage of surrounding land; on the other hand, ecological infrastructure can be extended to the interior of the urban structure and combined with various functions such as urban green space system, stormwater management, recreation, non-motor vehicle roads, heritage protection, and environmental education. The urban and rural microscopic ESP corresponds to the urban communities and scales. Ecological infrastructure as the limiting conditions and guiding factors of urban land development is implemented in the local urban facilities. Implementing the ESP makes ecosystem services benefit every urban resident.

Table 3.1: Historical development related to ecological connectivity networks in China (WANG et al. 2019)

Urban construction stage	**Proposal year**	**Implementation status**	**Keywords of the concept**

Three-North Shelterbelt Forest Program	1978	implemented in northwest, north and northeast China	Improve the Desert Environment, Decrease Water and Soil Loss
Shanshui City	1990	Only a vision, not implemented yet	Ancient poetry, Painting, and Classical Landscape
Landscape Garden City	1992	implemented in 345 cities and 7 districts until 2017 (Data source: Ministry of Housing and Urban-Rural Development)	Green Area Ratio
National Forest City	2004	implemented in 165 cities until 2018 (Data source: State Forestry Administration)	Forest and Tree
Ecological Garden City	2007	implemented 11 cities until 2017 (Data source: Ministry of Construction)	Urban Ecological Environment, Urban Living Environment and Urban Infrastructure
City in the Park	2018	Only a vision, not implemented yet	People-centered, Integration of Park System and Urban Spatial Pattern
Ecological security patterns	1990s	implemented in whole China	Health and Safety of Ecological Processes

(2) Historical development related to ecological connectivity networks in Western countries (Europe and America)

The ecological network developments in the USA and Europe have similar roots, but they went their own ways because of policy, geography, and scientific background. The development of the ecological networks in the US which is mostly called greenways aims to create a pathway or a corridor to connect the countryside, and in Europe which is called commonly ecological networks aims to conserve nature (JONGMAN, PUNGETTI 2004).

The first historical real greenway was built in the late 19th and early 20th centuries to create metropolitan systems for open spaces ((FABOS 1995, NEWTON 1971, ZUBE 1996, SMITH, HELLMUND 1993). Among these systems, the Boston Park System was the most important plan by Frederick Law Olmsted, Sr. (c. 1880s) who is the father of landscape architecture in the USA. The Boston Park System, known as the “Emerald Necklace”, is designed to link parks in Boston, Brookline, and Massachusetts, and to integrate the ecological corridors and the existing conservation areas.

The second historical greenway was built by Charles Eliot in the 1890s, named the Metropolitan Park System of Greater Boston. Eliot created a regional open system with five types of landscape elements which are ocean fronts, river estuaries, harbor islands, large forests, and small urban squares (JONGMAN, PUNGETTI 2004) to significantly expand Olmsted's Emerald Necklace.

The success of park systems in Boston raised the people's awareness of the greenways' significance. Benton MacKaye conceived the first idea to control urban sprawl which is called the metropolitan system of protected land (MACKAYE 1928). MacKaye's work expanded theoretically the concept of the urban park system from Olmsted and Eliot. The next significant development of the greenway concept is to insert ecological awareness into urban planning. Ian McHarg argued the major issue of landscape planning was the distribution pattern of protected lands, not the absolute or relative areas (MCHARG 1969).

Greenways was recommended as a new tool to go through the open spaces where they live and to connect the rural and urban spaces of American land use by the President's Commission on Americans Outdoors in the United States of America in 1987 (PCAO 1987)

The concept of ecological corridors was inspired by the concept of greenways in European countries, for example, the Habitats and Species Directive with **Natura 2000** (EC 2024) and the **Pan-European Ecological Network (PEEN)** (BENNETT 1998). **Ecological network** was recommended as a tool for the European conservation of species and habitat by Graham Bennett at the conference "Conserving Europe's Natural Heritage: Towards a European EN" in 1993 (BENNETT 1994).

Boardman divided the development of nature conservation into three periods. These three periods are (1) the origin of nature conservation (2) its consolidation and (3) nature conservation with landscape ecology-based (BOARDMAN 1981, JONGMAN 1995). European countries passed through these three periods of nature conservation at different levels.

At the end of the 19th century, the value of nature's beauty, the love of nature, and the awareness of outdoor recreation were addressed in literature, art, and architecture and created the foundation of nature conservation (JONGMAN 1995, HUXLEY 1946). In this period, the governments of the western countries insisted the development on nature conservation should not be interfered with. However, in the last decade of the 19th century, the organizations for bird conservation realized the significance of international cooperation, and they started to contact the whole Europe (JONGMAN 1995). In 1895, the first international conference on bird conservation was held in Paris, and in 1902, European countries signed the first international agreement on useful bird conservation (JONGMAN 1995, FERRERO-GARCÍA 2013). In the early 19th century, regional planning expanded from urban planning in Europe. The International Town Planning Conference in Amsterdam in 1924 (GEDDES 1924) aimed at regional plans, parks, and recreation which was a significant movement to insert the concept of regional planning into urban planning (JONGMAN 1995). The Second World War warned that nature conservation needs cooperation among governments, after the Second World War the International Union of the Protection of Nature

(IUPN; since 1959, International Union for Conservation of Nature (IUCN)) was found to improve the development of international cooperation in nature conservation (JONGMAN 1995). In the last decades of the 20th century, the development of organization and legislation documents on nature conservation can be seen as the development of cooperation of nature conservation within the European Union (EU) (JONGMAN 1995).

Despite the increase in international cooperation, habitat loss and habitat fragmentation of species were still the main topics among European countries.

Natura 2000 and Pan-European Ecological Network (PEEN) were created in this background. Natura 2000 is a network to provide core breeding and resting sites for rare and threatened species, and some rare natural habitats that are conserved in their own right. The goal of the Natura 2000 is to support the long-term sustainability of the most valuable and threatened species and habitats in Europe, listed under both the Birds Directive and the Habitats Directive. **Natura 2000** is the largest cooperated network of conservation areas in the world. It spans all 27 EU countries, both on land and at sea areas, and offers a haven for the most valuable and threatened species and habitats in Europe. The **Natura 2000** networks should be expanded the ecosystem integration so that species can go through the habitat fragmentation caused by land use changes (MACARTHUR, WILSON 1967, LEVINS 1969, RODOMAN 1974, PULLIAM 1988, BIONDI et al. 2012). In the 27 EU countries, the network needs to be expanded the value of ecology and politico-economy, this assignment can be achieved by the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) which was signed by 54 European countries to support the **Natura 2000** sites (JONES-WALTERS 2007, MÜCHER et al. 2009).

One of the most important tools of the PEBLDS is the PEEN. PEEN was developed in three subprojects: Central and Eastern Europe (BOUWMA et al. 2002), South-eastern Europe (BIRÓ et al.2006), and Western Europe (JONGMAN et al. 2006). The goals of PEEN were (1) to emphasize the development of ecological networks at a European level, (2) to identify the restoration areas, (3) to protect the ecosystem, habitats, species and landscapes in the whole Europe, and (4) to reduce the fragmentation caused by spatial and environmental changes.

3.5 Fragmentation analysis

There are two types of input in FRAGSTATS: vector images as input data and raster images as input data (MCGARIGAL 1995). The input data of raster images accepts 8- or 16-bit binary image files, ASCII image files, Erdas image files, Arc/Infor SVF files, and IDRISI image files (MCGARIGAL 1995). Here a few key terms are considered as prerequisites to the effective use of FRAGSTATS (MCGARIGAL 1995).

- **Landscape.** There are different concepts for landscape based on different topics. Considering the land as a mosaic of patches or landscape elements, the landscape is a "heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout" (FORMAN, GODRON 1986). Considering the wildlife perspective, a landscape is an area of land containing a mosaic of habitat patches, within which a particular "focal" or "target" habitat patch often is embedded (DUNNING et al. 1992). Considering the connectivity conservation perspective, landscape is the combination of plants, animals, ecosystems, and ecological processes that interact within an interconnected and functional ecological network for the long-term persistence of species (ERVIN et al. 2010).
- **Patch.** A mosaic of patches composes the landscape (URBAN et al. 1987). Considering an ecological view, patches refer to relatively discrete areas or periods of homogeneous environmental conditions (WIENS 1976). Considering the organism-centered perspective, patches represent the environmental units, and nonrandom distribution of resource utilization among environmental units practically (WIENS 1976).
- **Matrix.** Several types of landscape elements compose a landscape (MCGARIGAL 1995), and the matrix is the most connected and most extensive landscape element type to dominate the landscape function (FORMAN, GODRON 1986).
- **Scale.** From the ecological concept perspective, the spatial scale includes both extent and grain (FORMAN, GODRON 1986, TURNER et al. 1989, WIENS 1989). Extent is "the overall area encompassed by an investigation or the area included within the landscape boundary" (MCGARIGAL 1995). Grain is the size of the individual units of observation (MCGARIGAL 1995). Extent and grain define the upper and lower limits of resolution of a study and any inferences about scale-dependency in a system are constrained by the extent and grain of investigation (WIENS 1989). Here in this dissertation, in extent perspective, I used Luohe region, Luohe central area, Budapest agglomeration area and Budapest central area to be study area extent; In grain perspective, I used different resolutions of images to represent the different grain.
- **Landscape structure.** A landscape can be represented by both its composition and configuration (DUNNING et al. 1992, TURNER 1989). **Landscape composition** and **landscape configuration** are two foundational concepts in landscape ecology that describe the characteristics of patches and the spatial arrangement of those patches (DUNNING et al. 1992, TURNER 1989) within a landscape. **Landscape composition** reflects only the types and proportions of landscape components within the landscape but without reference to their spatial arrangement (GUSTAFSON 1998). Such as, a landscape may consist of

built-up area, road, water surface, farmland, green space and unused land. Landscape composition only calculates the percentage of land use type (MCGARIGAL 1995). **Landscape configuration** refers to the spatial characteristic and physical distribution of patches within a landscape (TURNER 2005). Such as, the shape, size, proximity, and arrangement of land use types. For example, a bigger size of green space may contain smaller or isolated green patches.

3.6 International Union for Conservation of Nature

The International Union for Conservation of Nature (IUCN; formally International Union for Conservation of Nature and Natural Resources (IUCN 2024a) was founded in 1948, and is now the largest and most diverse environmental network in all over the world (IUCN 2024b), and is an international organization working in nature conservation and sustainable use of natural resources.

IUCN Red List of Threatened Species, also called the IUCN Red List or Red Data Book, created in 1964, is the most comprehensive inventory of the conservation status of biological species in the world (IUCNRL 2023). It uses a set of accurate criteria to measure the extinction risk of species and subspecies.

Species are divided into nine groups by the IUCN Red List (IUCN-SPS 2017): extinct (EX), extinct in the wild (EW), critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), data deficient (DD) and not evaluated (NE) (***Figure 3.2***). The definition of these nine groups is shown in (IUCNSPC 2022).

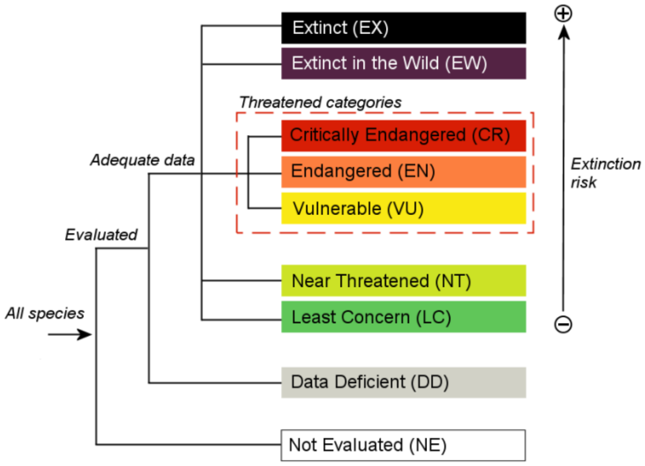


Figure 3.2: Structure of the IUCN Animal Threat Category List (IUCNSPC 2022)

3.7 Potential mammal species in study areas

Potential mammal species in Henan Province

I summarized the key mammal species in **Henan Province** from the book "The Forestry and Garden Chronicle in Luo city from 1986 to 2012" (CCM 2014), "China's Mammal Diversity and Geographic Distribution" (JIANG et al. 2015) and IUCN list like below **(*Table 3.2*)**.

Table 3.2: Key mammal species and their endangerment status, habitat, and dispersal ability in Henan Province (for detailed information see *Appendix 1*)

Scientific name	**English name**	**IUCN Animal Threat Category List**	**China Mammal Threat Category List**	**Habitat type**	**Dispersal distance (km)**
Panthera pardus	Leopard	VU	EN	Forest, Grassland, Savanna, Shrubland	**Male: 8.5 –13.5** **Female: 2.3 – 3.1**
Lutra lutra	Eurasian Otter	NT	EN	Wetlands, Forest, Grassland, Shrubland	**10 — 26**
Mustela eversmanii	Steppe Polecat	LC	VU	Grassland, Shrubland	**8**
Martes flavigula	Yellow-throated Marten	LC	NT	Forest, Shrubland	**10 — 20**
Sciurus vulgaris	Eurasian Red Squirrel	LC	NT	Forest	**1 — 16**

Potential mammal species in Hungary

I summarized the mammal species in **Hungary** from the book "Fajbook - Magyarország 100 legismertebb vadon élő állatfaja" (MÁTÉ et al. 2019), "Wild Animals (RSPB Pocket Nature)" (GIBSON 2010) and IUCN list like below **(*Table 3.3*)**.

Table 3.3: Potential mammal species and their endangerment status, habitat, and dispersal ability in Hungary (for detailed information see *Appendix 2*)

Scientific Name	**English Name**	**IUCN Animal Threat Category List**	**Habitat Type**	**Dispersal distance (km)**
Muscardinus avellanarius	Hazel Dormouse	**LC**	Forest	**1**
Nyctereutes procyonoides	Raccoon Dog	**LC**	Forest, Shrubland, Grassland	**5 — 30**
Vulpes vulpes	Red Fox	**LC**	Forest, Shrubland, Grassland	**132 — 1036**
Sus scrofa	Wild Boar	**LC**	Forest, Shrubland	**16.6**

3.8 Theories related to ecological connectivity networks

There are two theories used by mapping ecological connectivity networks.

(1) Circuit theory

Brad McRae defined circuit theory as an alternative and process-driven method to model gene flow and species movement (MCRAE 2006, MCRAE, BEIER 2007, MCRAE et al. 2008), and then MCRAE and others (2008) introduce the key concepts and metrics of circuit theory and how they could be used to model the connectivity. Circuit theory describes how well-connected habitat patches may be (RUDNICK et al. 2012). Well-connected habitat patches have wide, continuous habitats between them, while poor-connected habitat patches have constricted habitats between them (RUDNICK et al. 2012). Resistance distance and current density are the most commonly used metrics of circuit theory (DICKSON et al. 2019). Circuit theory uses the same resistance data with LCP analysis, and current density represents an estimate of movement probabilities of random walkers on corresponding graphs (***Figure 3.3***) (DICKSON et al. 2019, MCRAE et al. 2008). High current (yellow color) represents low resistance, and most paths are forced to pass through that area because of high resistance elsewhere, while low current (red color) represents high resistance, and paths can pass through other lower resistance areas (RUDNICK et al. 2012). Current maps are very useful for measuring connectivity and defining constrained areas (RUDNICK et al. 2012).

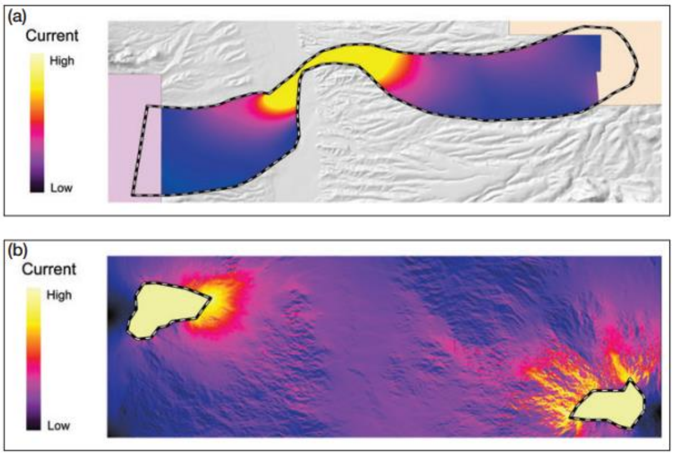


Figure 3.3: Current maps (RUDNICK et al. 2012) ((a) a landscape where analysis was constricted to a corridor; (b) a landscape where analysis was not constricted to a corridor)

(2) Graph theory

Graph theory is originally from the mathematic term which is described by means of a diagram including nodes and edges (BONDY, MURTY 1976). From a conservation perspective, graph theory combines with LCP analysis or circuit theory to enhance landscape connectivity assessment and modeling (RUDNICK et al. 2012). The landscape is composed of nodes (the center of habitat patches), edges (linear representations), patches, and corridors (linkages) in graph theory (***Figure 3.4***) (RUDNICK et al. 2012). This approach is specifically useful to model connectivity among large conservation set to identify isolated conservation set, evaluate multiple connections and measure the consequence of losing nodes (RUDNICK et al. 2012).

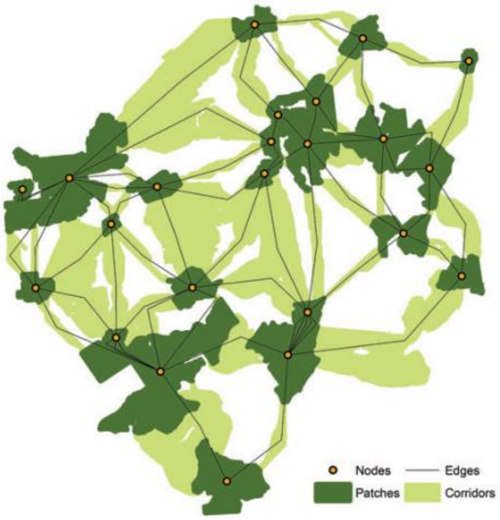


Figure 3.4: Graph theory (RUDNICK et al. 2012)

3.9 Mapping methods of ecological connectivity networks

3.9.1 Core areas identification

There are two criteria to evaluate the importance of core areas of green habitat:

(1) **The size of green space**, since species often have minimum patch area requirements to occupy and persist in a habitat patch.

(2) **Degree of Probability of Connectivity (dPC)** is identified as the probability that two animals randomly travel from each other (SAURA, PASCUAL-HORTAL 2007), representing habitat availability and connectivity (HOFMAN et al. 2018).

3.9.2 Resistance surface definition

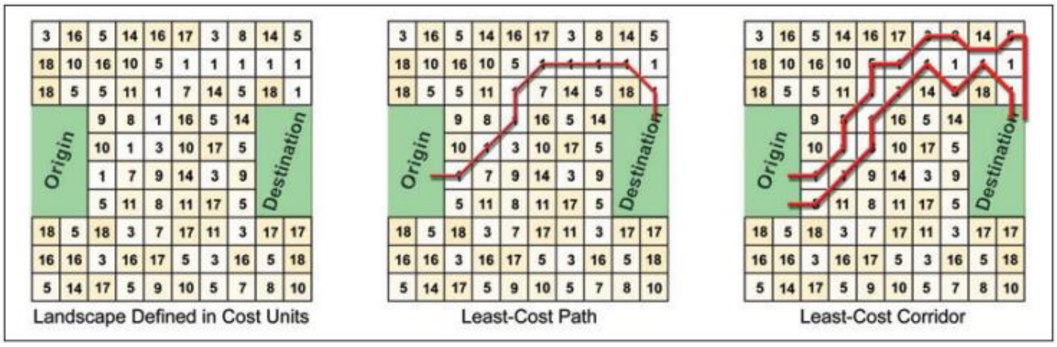
Resistance surfaces describe the difficulty that a species will experience in moving through different locations in the landscape in relation to things such as land use types, topography, barrier features, and other landscape characteristics that influence movement (CUSHMAN et al. 2006, PENG et al. 2018b). Low resistance promotes species' movements, and high resistance slows down or blocks species' movements.

Cumulative resistance surfaces are derived from resistance surfaces. Animals have costs when they move within and cross the landscape, thus cumulative resistance surfaces sum the resistance surface value and represent the movement cost of species from one source location to another. A high-cost distance value means that a given location in the landscape is relatively inaccessible from any source, while a low-cost distance value indicates functional proximity to source locations, based on cumulative resistance. The value of cumulative resistance was defined by the cost distance from core areas across the resistance map, which means the value of cumulative resistance was defined by the resistance and the distance from core areas to a random location. Areas near core areas and between two core areas generally had relatively low cumulative resistance.

3.9.3 Least-cost path analysis

Researchers (WALKER, CRAIGHEAD 1997, FERRERAS 2001, GRAHAM 2001, MICHELS et al. 2001, SCHADT et al. 2002, ADRIAENSEN et al. 2003) used least-cost path (LCP) analysis as the traditional method to map functional land-use-based ECN. LCP analysis is originated from graph theory and based on an algorithm of eight-neighbor-cell (ADRIAENSEN et al. 2003), which identifies the least costly route that species can move from one location to another (RUDNICK et al. 2012). In this method, every landscape unit (pixel) is assigned a cost value (also referred to as resistance) (RUDNICK et al. 2012, ADRIAENSEN et al. 2003) based on its facilitating/impeding effects of species' movement process, resulting in one single land cover type instead of landscape complexes from the scape perspective which represents only the cost of species movement, and landscape elements can get their accurate position and orientation (ADRIAENSEN et al. 2003). This value calculates the connectivity between a source cell and a target cell, and affects the actual energy transformation and future reproductive potential (ADRIAENSEN et al. 2003). Low cost/resistance promotes species movement, and high cost/resistance slows down species movement.

Like ***Figure 3.5***, species will find the lowest value to move from the origin place to the destination place, resulting in a one-cell size width path, and two paths compose a corridor to support species movements.



Landscape Defined in Cost Units

Least-Cost Path

Least-Cost Corridor

Figure 3.5: Least-cost path analysis (RUDNICK et al. 2012)

3.9.4 UNICOR cumulative resistant kernel analysis

The UNIversal CORridor and network simulation model (UNICOR) uses Dijkstra's algorithm (DIJKSTRA 1959) to solve the single source shortest path issue for species movement (LANDGUTH et al. 2012). It includes resistant kernel (RK) modeling (COMPTON et al. 2007) and factorial LCP modeling (CUSHMAN et al. 2009) for quantifying landscape connectivity (CUSHMAN et al. 2013b).

Detailed information about resistant kernel modeling

RK calculates all the expected densities of all sources for the whole study area, resulted in the expected density of the presence of species dispersal (RUDNICK et al. 2012). RK modeling has advantages in assessing ECN for multiple dispersal species (CUSHMAN, LANDGUTH 2012). First, it predicts the incidence function of the rate of expected movement from a defined set of source locations cumulatively through a landscape (CUSHMAN et al. 2013b) for every pixel in the study area to measure the resistance of the landscape, the nature of the dispersal function, and the dispersal ability of the species (RUDNICK et al. 2012) (CUSHMAN et al. 2012b), rather than only for a few selected "linkage zones" (COMPTON et al. 2007). Second, it can include scale dependency of dispersal ability to assess how species will be affected by landscape fragmentation under multi-dispersal scenarios (e. g. CUSHMAN et al. 2010 a, b, c). Third, it enables simulation through the vast geographical extents for multi-species (e.g., CUSHMAN et al. 2010a, c, 2011). The RKs are shown in ***Figure 3.6***.

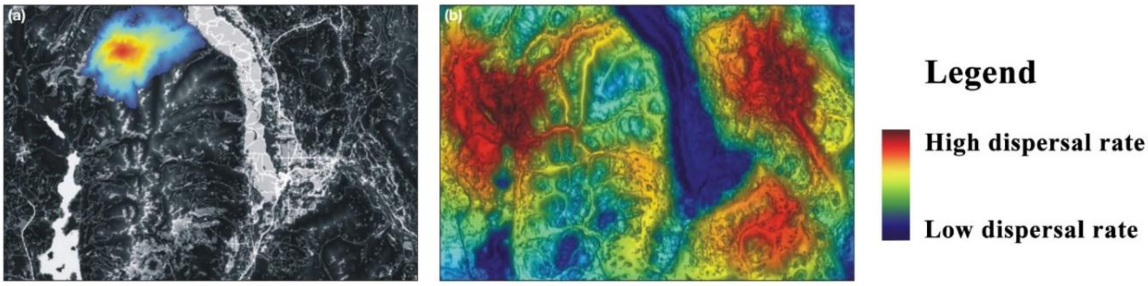


Figure 3.6: Resistant kernel analysis (RUDNICK et al. 2012) ((a) single kernel analysis (one-pixel source situation); (b) cumulative resistance surface for all kernels within the landscape (multi-pixel source situation). Red areas represent the areas with a high dispersal rate (low resistance), while the blue areas represent the areas with a low dispersal rate (high resistance).)

Detailed information about factorial least-cost path modeling

Factorial LCP modeling predicts movement corridors and corridor strength (CUSHMAN et al. 2013c) for species with multi-dispersal abilities. Factorial LCP analysis requires two input files: 1) a resistance surface, and 2) source point location for every pixel within the landscape. Resistance surface represents the difficulties for species movements, which point location defines the LCP between pairs of starting nodes and ending nodes (CUSHMAN et al. 2013b). Dijkstra's algorithm was applied to find optimal paths of species movement, calculated for every paired combination of starting and ending nodes (CUSHMAN et al. 2013b). Then these predicted LCPs were buffered based on kernel density estimations (e.g. CUSHMAN et al. 2009), and the Gaussian function was applied for the kernel density buffering (e.g. LI, RACINE 2007). Finally, the buffered LCPs were combined through summation (e.g. CUSHMAN et al. 2009) to produce ECNs between all pairs of starting points and ending points (CUSHMAN et al. 2013b).

Factorial least-cost path (LCP) modeling addresses one major limitation of traditional LCP which is limited to the prediction of connectivity between a single source and a single destination (RUDNICK et al. 2012). This provides a more comprehensive connectivity analysis for focal conservation areas. For example, LCP may calculate corridor connectivity between multiple sources and a single source (e.g. CUSHMAN et al. 2010b), or between multiple sources and multiple sources (e.g. CUSHMAN et al. 2009, CUSHMAN et al. 2011) among a complex landscape. Factorial LCP modeling combines a vast number of paths to show an ECN with the extent and strength of corridors across a huge and complex landscape, such as factorial LCP modeling to generate paths among a vast number of source points across a cost/resistance surface (***Figure 3.7***) (RUDNICK et al. 2012).

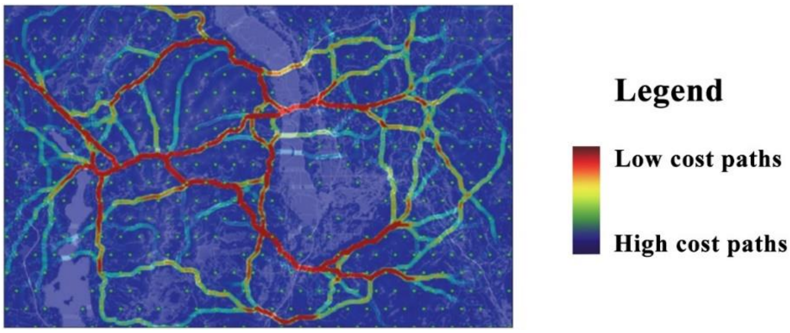


Figure 3.7: Factorial least-cost path analysis (RUDNICK et al. 2012) (The densities of paths are shown by a gradient color from blue to red, with red paths representing routes that are predicted paths between a higher amount of pairs of source and destination points. Green points represent source areas.)

4. MATERIALS AND METHODS

4.1 Study area

The study areas include Luohe city in China and Budapest in Hungary. Luohe city includes two sub-level areas which are Luohe Region (LR) and Luohe Central Area (LCA), Budapest includes two sub-level areas which are Budapest Agglomeration Area (BAA) and Budapest Central Area (BCA).

4.1.1 Luohe city

LR is located in the Central Plains of China which is in central Henan province (113º27’ – 114º16’E, 33º24’ – 33º59’N) (***Figure 4.1a***). The total municipal territory of LR is 2698 km^2, administering three districts (Yuanhui district, Yancheng district and Shaoling district) and two counties (Wuyang county and Linying county) (***Figure 4.1b***), spanning 76 km from east to west and 64 km from north to south. Luohe is about 140 km south of Zhengzhou (***Figure 4.1a***), the capital of Henan province. Luohe city is developed along the Sha and Li rivers which meet in the central area. It is an important transportation hub of the whole province and is located in the second circle of the Central Plains City Group Metropolitan Area which has the center in Zhengzhou city (***Figure 4.1a***).

LCA is situated in the south of LR, with a total area of 158 km^2, spanning 19 km from east to west and 10 km from north to south (***Figure 4.1b***).

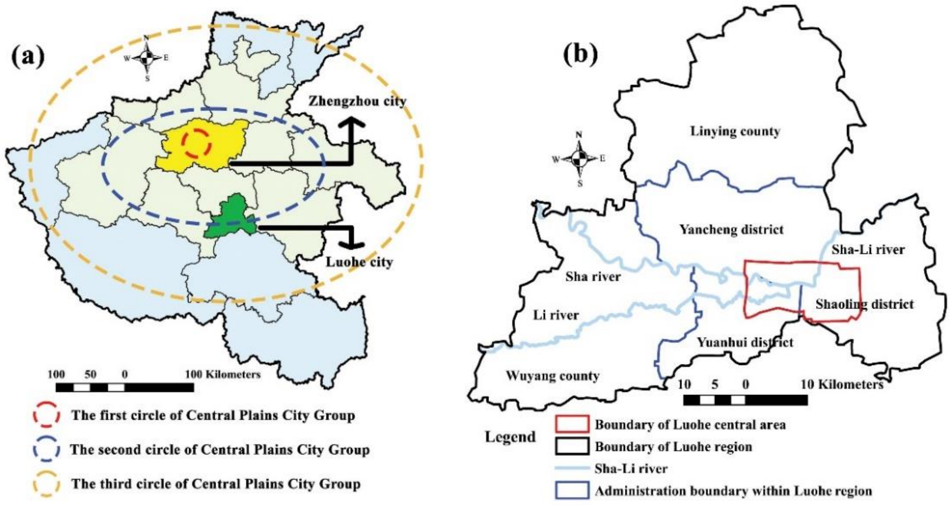


Figure 4.1: Luohe region location

(1) **Topography**

LR is located on the southwestern edge of the North China Plain, with the Funiu mountain in the west and the plain in the east. The elevation above sea level in the eastern part of LR is about 57 m, while the elevation above sea level in Linying county is the lowest, which is about 53 m, there is no hilly part within LR.

(2) **Green spaces**

Green spaces in LR involve urban parks, productive plantation areas, and green areas for environmental protection.

The total area of **urban parks** in LR is 788.84 ha **(*Table 4.1*)**. Among them, comprehensive parks provide complete facilities that are suitable for outdoor activities for the public, with an area of 109.51 ha. Community parks refer to a centralized green space with certain activities and facilities that serve the residents within a certain residential area, with an area of 19.37 ha. Special parks are parks with a specific content or form and certain recreational facilities, with an area of 10 ha, such as botanical gardens, zoos, children's parks, etc. Linear parks refer to long and narrow green spaces with certain recreation facilities along roads, city walls, and waterfronts, with an area of 633.06 ha. Roadside green space is a relatively independent piece of green space outside the urban road, like a green space cell in an urban area, with an area of 16.9 ha.

Table 4.1: Green spaces in Luohe region

Green space types		Area (ha)	Total area (ha)
Urban parks	Comprehensive parks	**109.51**	**788.84**
	Community parks	**19.37**	
	Special parks	**10.00**	
	Liner parks	**633.06**	
	Roadside green space	**16.90**	
Productive plantation areas	/	**285.70**	**285.70**
Green areas for environmental protection	/	**569.14**	**569.14**

Productive plantation areas refer to the nursery, flower garden, grass garden, and other gardens that provide nursery stock, flowers, and seeds for urban greening, and are the production base of urban greening. The total area of productive plantation area is 285.7 ha, accounting for 4.40% of the current urban construction land. The productive plantation area is large and can meet the needs of local seedlings.

Green areas for environmental protection refer to the green land set up to meet the city's requirements for hygiene, isolation, and safety. Its function is to protect or weaken natural disasters and urban public hazards to a certain extent, and it should not be used as an urban park. The main green area for environmental protection in Luohe city is distributed along railways and highways, with an area of 569.14 ha.

Generally speaking, the landscape in LR is a linear landscape of rivers and roads. The river landscape is formed by the Sha-Li river, the road landscape is formed by the transportation system.

(3) Water system

The 81 rivers in Luohe municipal territory belong to the Huai River system. The rivers are latitudinal from west to east and flow into the Huai River in Anhui Province. Main Rivers are the Sha river and Li river (***Figure 4.2***).

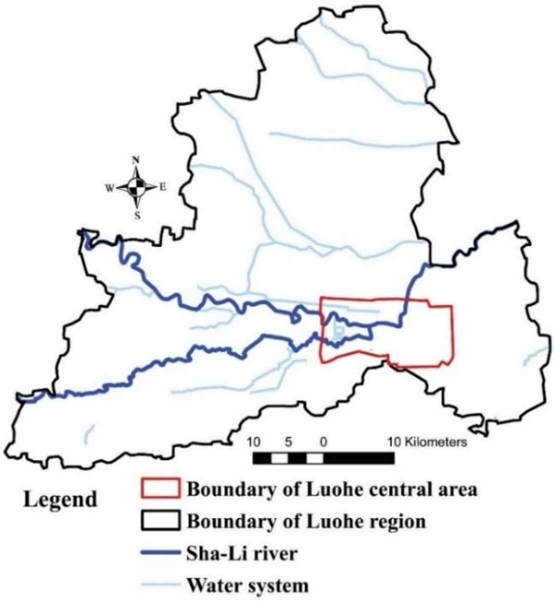


Figure 4.2: Water system in Luohe region (Source: OpenStreetMap)

(4) Transportation system

Luohe is a second-class transportation hub with a superior location and developed transport system. The four railways of Beijing–Guangzhou railway, Beijing–Guangzhou high-speed railway, Mengbao railway, and Luohe-Wugang railway meet in Luohe city, which is an important integrated passenger and freight railway cross hub in the central part of China and form a “double cross” structure of transportation (***Figure 4.3***).

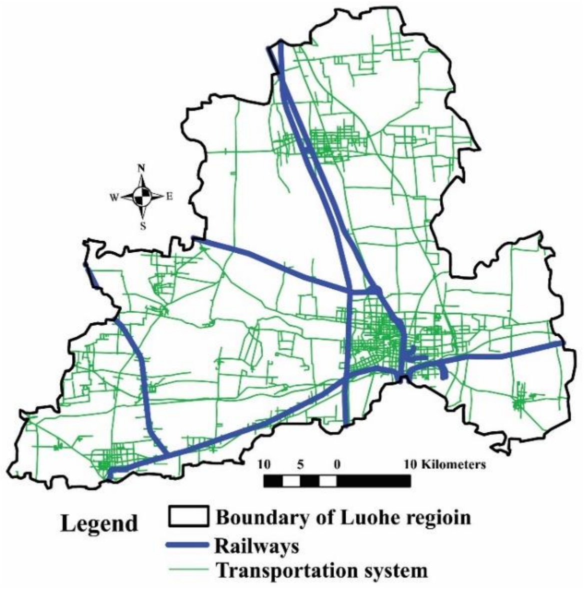


Figure 4.3: Transportation system in Luohe region (Source: OpenStreetMap)

4.1.2 Budapest

BAA is located in the middle part of Hungary (47.4979° N, 19.0402° E) (***Figure 4.4a***). The total area of BAA is 2539 km^2, spanning 60 km from east to west and 72 km from north to south. The Budapest region is the capital city of Hungary, which is a city and county as well. The Budapest region was divided into the Buda side in the west and the Pest side in the east by the Danube (***Figure 4.4b***).

BCA is situated in the heart of BAA, with a total area of 159 km^2, spanning 15 km from east to west and 17 km from north to south (***Figure 4.4b***).

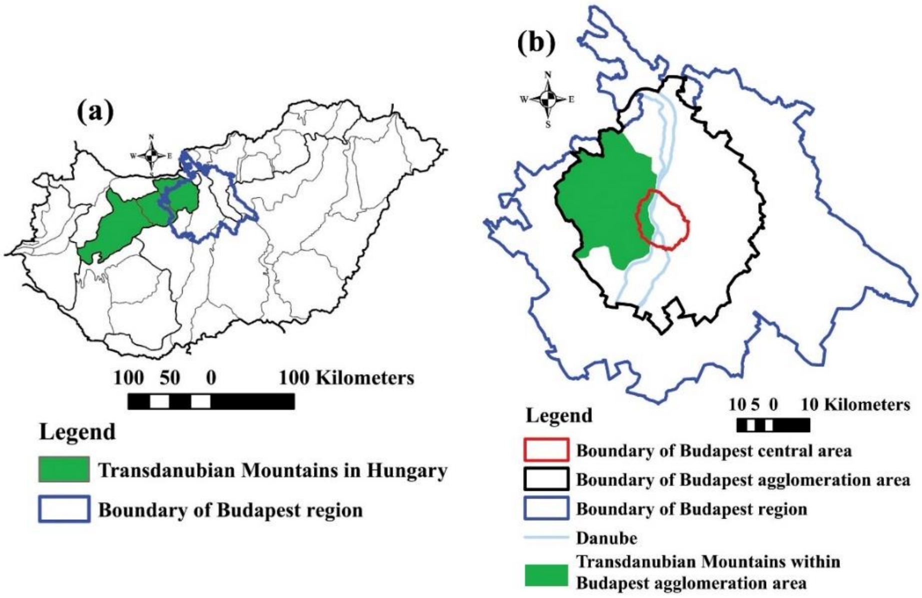


Figure 4.4: Budapest agglomeration area location

(1) Topography

The Budapest region is located on the ancient corridor connecting the Great Plain and the Transdanubia Mountains (Hungarian: Dunántúli-középhegység). The 159 km^2 area of Budapest is surrounded by the settlements of BAA. The Danube enters from the north to the south of the Budapest region and encircles a small number of islands in the middle of the Danube. The Danube separates the Budapest region into two different topography areas. The left side of the Danube contains a lot of hills and is very hilly, while the right side of the Danube contains an intensive residential area and is flat. The highest point is the Pilis with an elevation of 757 m, while the lowest point is the line of the Danube with an elevation of 96 m.

(2) Green spaces

Green spaces in BAA are complete and rich, which involve parks & gardens, islands, and mountains.

BAA has a lot of municipal parks which have a complex park system. Parks augmented the wealth of green space by ECNs containing forests, lakes, and rivers as natural areas, including the Botanical Garden and Budapest Zoo. The most popular parks are City Park and People’s Park.

The Danube encircles several islands which are the critical landscape of the Danube. Margaret island is a very popular recreational area for both tourists and locals with a lot of theme parks that provide a different experience for people and multi-functions where you can do sport or just relax.

The mountains provide a variety of outdoor activities and beautiful seasonal views. Normafa is frequently visited by locals with a lot of activities, including barbecue, ski run, hiking, etc. Buda Hills (Hungarian: Budai-hegység) and Pilis Mountains (Hungarian: Pilis) as parts of the Transdanubian Mountains contain a lot of forests that vastly protect wildlife that appeared in the region.

(3) Water system

The water system in BAA is distributed equally, and the main river is the Danube (***Figure 4.5***). The Danube originated in Germany and is an important waterway in this region from a trade and tour perspective.

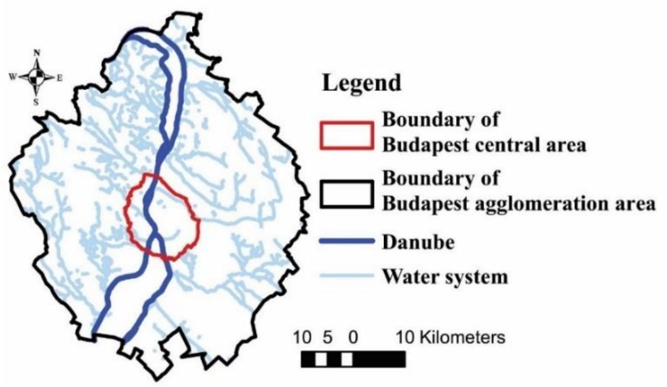


Figure 4.5: Water system in Budapest agglomeration area (Source: OpenStreetMap)

(4) Transportation system

The transportation system is very intensive and is similar to that in Paris, with several ring roads, and main roads radiating out from BCA (***Figure 4.6***). Railways are very central as many major European railways lead to Budapest.

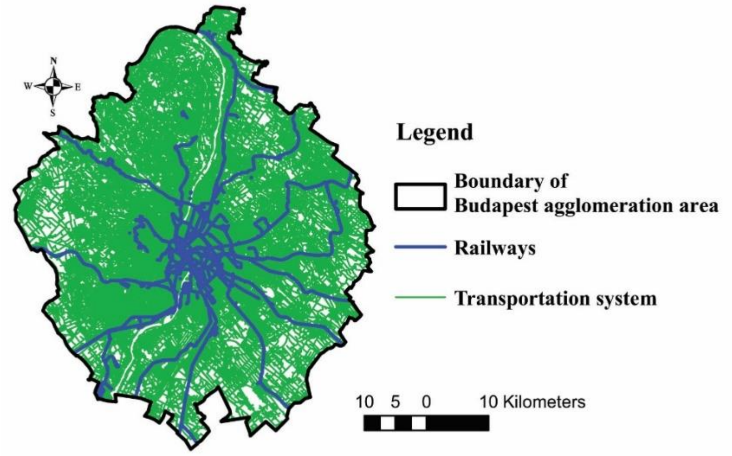


Figure 4.6: Transportation system in Budapest agglomeration area (Source: OpenStreetMap)

4.1.3 Comparison of Luohe region and Budapest agglomeration area

I compared the similarities and differences between the Luohe region (LR) and the Budapest agglomeration area (BAA) to illustrate the reason that I chose the study areas.

Similarities

(1) BAA has a territory area and population similar to LR (***Table 4.2***).

(2) Both of them have character rivers. BAA has the Danube (***Figure 4.5***), while LR has the Sha and Li rivers, which meet in the central area (***Figure 4.2***).

Table 4.2: Similarities between Luohe region and Budapest agglomeration area

Location	Area (km^2)	Population
Luohe region	2698	2 841 300 (2018)
Budapest agglomeration area	2539	2 457 787 (2007)
Luohe central area	158	950 000 (2020)
Budapest central area	159	810 214 (2019)

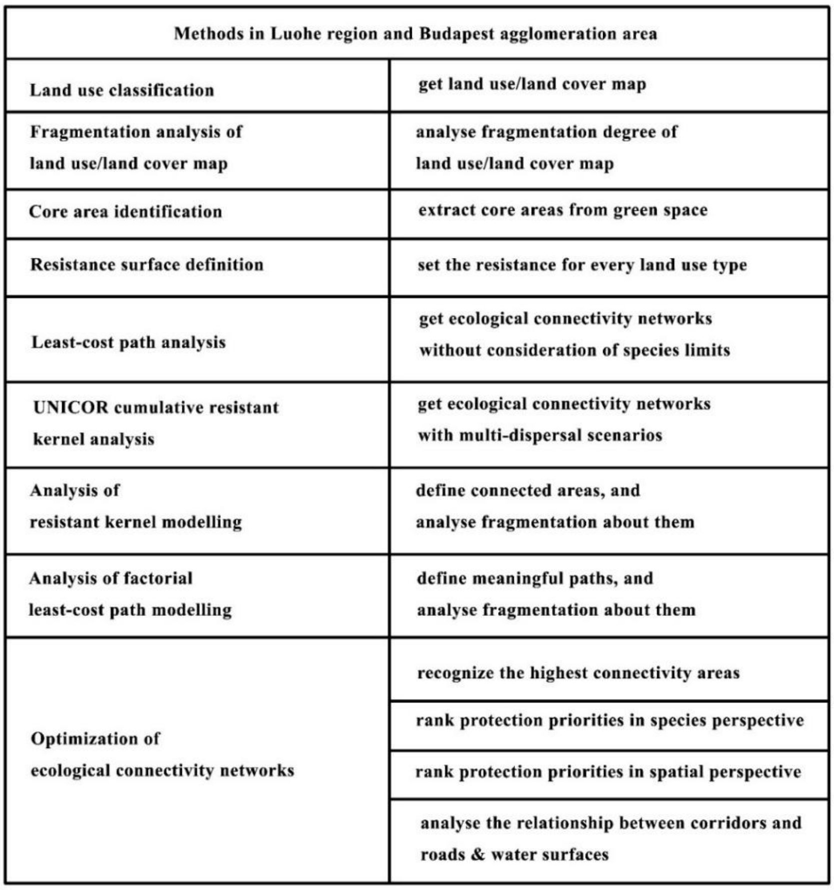
Differences

(1) Water direction. The water direction in LR is a latitudinal pattern (***Figure 4.2***), while the water direction in Budapest is a longitudinal pattern (***Figure 4.5***).

(2) Road direction. Road direction in LR (***Figure 4.3***) usually is from south to north and east to west, while road direction in BAA (***Figure 4.6***) is a radial pattern from center to outside of the city.

4.2 Ecological connectivity networks in Luohe region and in Budapest agglomeration area

In this section, I used the big areas of study areas which are the Luohe region and the Budapest agglomeration area to map the ecological connectivity network (***Figure 4.7***). First, I used supervised classification to classify the land use/land cover (LULC) map for these two study areas. Second, I did a fragmentation analysis to quantify the landscape structure and composition. Third, I used two mapping methods called least-cost path analysis and UNICOR cumulative resistant kernel analysis to simulate the ECN (WANG et al. 2021, WANG et al. 2022). Finally, I optimized the ECN based on the results of the analyses I did in the last steps.



Methods in Luohe region and Budapest agglomeration area	
Land use classification	get land use/land cover map
Fragmentation analysis of land use/land cover map	analyse fragmentation degree of land use/land cover map
Core area identification	extract core areas from green space
Resistance surface definition	set the resistance for every land use type
Least-cost path analysis	get ecological connectivity networks without consideration of species limits
UNICOR cumulative resistant kernel analysis	get ecological connectivity networks with multi-dispersal scenarios
Analysis of resistant kernel modelling	define connected areas, and analyse fragmentation about them
Analysis of factorial least-cost path modelling	define meaningful paths, and analyse fragmentation about them
Optimization of ecological connectivity networks	recognize the highest connectivity areas
	rank protection priorities in species perspective
	rank protection priorities in spatial perspective
	analyse the relationship between corridors and roads & water surfaces

Figure 4.7: Methods in Luohe region and in Budapest agglomeration area

4.2.1 Land use/land cover classification

In this section, firstly, I downloaded Landsat 8 images of LR and BAA on EarthExplorer – USGS to be basic data. Secondly, I classified land use types by using ENVI 5.3. Finally, I used FRAGSTATS to evaluate the structure and composition of the landscape in LR and BAA.

(1) Image acquisition

I downloaded two Landsat 8 images in LR on February 09, 2020 (Resolution: 30 m; XY Coordinate System: WGS 84 / UTM zone 50N) and on February 16, 2020 (Resolution: 30 m; XY Coordinate System: WGS 84 / UTM zone 49N), and one Landsat 8 image in BAA on April 20, 2020 (Resolution: 30 m. XY Coordinate System: WGS 84 / UTM zone 34N) on EarthExplorer – USGS. At that time the crops and green space in Henan province and Budapest were sprouted, with a distinctive light green color, and as the green area is characterized by high reflectance in the green wavelengths, it is possible to distinguish green space and farmland spectrally with other landscape elements with great accuracy. The acquisition time of two images in LR is proximal enough to ensure comparable landscape conditions on the two dates without substantial land use and land cover change.

(2) Image preprocessing

In ENVI 5.3, I used Radiometric Calibration and FLAASH Atmospheric Correction functions to normalize the original Landsat images in LR and in BAA. Because the whole LR involves two images, classification accuracy was not high at the edge of the maps when I mosaicked them. I classified them first and then mosaicked them to solve the edge problem.

(3) Classification

Luohe region. First, I selected three types of land cover of interest - water surface, green area (farmland and green space), and built-up area (built-up area and road), and performed a supervised classification to prepare land use/land cover (LULC) map using Support Vector Machine Classification in ENVI 5.3. Second, I clipped two images by using the boundary of LR and original Landsat images to produce the LULC classification of LR. Then I input two classification maps into ArcGIS 10.8.1 (ESRI 2020) to mosaic them using the Mosaic To New Raster function. Third, I used five Sentinel 2 images (resolution: 10 m) acquired on October 29, 2020, October 30, 2019, October 10, 2018, June 07, 2018, and June 12, 2018, to calculate the Normalized Difference Vegetation Index (NDVI) using the formula (band 8 - band 4) / (band 8 + band 4), then to calculate mean NDVI from NDVI values by using Mosaic To New Raster function. I then used the function of Reclassify to reclass the mean NDVI value, and defined the area where the mean NDVI value larger than 0.3 is green space. I then used Google Maps, Google Earth, and field trips to do manual corrections which correct the wrong classification by using visual interpretation. Finally, I summed the results of the second step and third step by using the Raster Calculator function in ArcGIS 10.8.1 to generate the land use types with water surface, farmland, built-up area (built-up area and road), and green space. Fourth, I downloaded OpenStreetMap (OSMDE 2018) to provide a road network map for the analysis, then buffered road width (***Table 4.3***) by measurement from actual Sentinel 2 imagery (resolution: 10m) on October 29, 2020. I overlaid the buffered roads onto the land use map using the Rasterize (overwrite with fixed value) function in Quantum Geographic Information System (QGIS) to extract roads from built-up areas. Finally, I produced a classified map of five land use types which are water surface, green space, farmland, built-up area, and road.

Table 4.3: Road width in Luohe region

Road type	Width (m)
Cycleway and footway	1
Living street, path, pedestrian, track, track grade1 and track grade2	3
Motorway and motorway link	40
Primary, primary link, trunk and trunk link	30
Rail and subway	18
Residential	8
Secondary, secondary link, unclassified, and unknown	20
Service and steps	2
Tertiary and tertiary link	16

Budapest agglomeration area. First, I selected three types of land cover of interest - water surface, green area (farmland and green space), and built-up area (built-up area and road), and performed a supervised classification to prepare the LULC map using Support Vector Machine Classification in ENVI 5.3. Second, I input six Landsat 8 images (resolution: 30 m) acquired on May 09, 2021, May 22, 2020, August 21, 2018, May 30, 2017, August 29, 2015, and July 12, 2015 to calculate NDVI using the formula (band 5 - band 4) / (band 5 + band 4), then to calculate the mean NDVI, maximum NDVI and minimum NDVI from NDVI values by using Mosaic To New Raster function in ArcGIS 10.8.1. Third, I used the function of Reclassify to reclass the mean NDVI value, the area where the mean NDVI value is larger than 0.4 is green space. Meanwhile, a lot of farmlands were mis-defined into the built-up area as Budapest has no exact harvest seasons, so the NDVI value of farmland that is empty at that time is lower than 0.4. Fourth, I summed the results of the first step and third step by using the Raster Calculator. Fifth, I calculated the NDVI difference value (maximum NDVI - minimum NDVI) by using Raster Calculator function in ArcGIS 10.8.1, the area where the NDVI difference value is larger than 0.246709 is farmland. Sixth, I used Google Maps, Google Earth, Urban Atlas, and field trips to do manual corrections which correct the wrong classification by using visual interpretation. Finally, I got the four land use types which are farmland, water, green space, and built-up area (built-up area and road). Seventh, I downloaded OpenStreetMap to provide a road network map in BAA, then buffered road width (***Table 4.4***) by measurement from actual Sentinel 2 imagery (resolution: 10m) on September 19. 2020. I overlaid the buffered roads onto the land use map using the Rasterize (overwrite with fixed value) function in QGIS to extract roads from the built-up area, and then I clipped the overlaid results by using the boundary of BAA. Finally, I produced a classified map of five land use types which are water surface, green space, farmland, built-up area, and road.

Table 4.4: Road width in Budapest agglomeration area

Road type	Width (m)
Bridleway, service and tram	4
Cycleway, footway	2
Light rail, secondary link, tertiary link	10
Living street	14
Miniature railway, narrow gauge, path	3
Motorway and trunk	38
Motorway link, trunk link, unclassified, unknown, primary link, residential	12
Pedestrian	6
Primary	40
Rail	15
Secondary	30
Steps	1.2
Subway	0
Tertiary	16
Track, track grade1, track grade2, track grade3, track grade4, track grade5	8

(4) Accuracy assessment

I selected 500 ground truth points on Sentinel 2 imagery (Resolution: 10 m) acquired June 01, 2020, of LR and 500 ground truth points acquired September 19, 2020, of BAA to test the classification accuracy by using the function of Confusion Matrix Using Ground Truth ROIs in ENVI 5.3.

(5) Fragmentation analysis

FRAGSTATS (MCGARIGAL et al. 2002, 2012) is used to quantify the landscape structure and composition. FRAGSTATS calculates three levers of metrics: patch metrics, class metrics, and landscape metrics. The descriptions of these metrics are below:

Percentage of Landscape (PLAND) is the most universal, straightforward, and fundamental measure of landscape composition, and is not affected by the spatial structure or composition of landscape patches in any way (CUSHMAN, MCGARIGAL 2008). PLAND measures the proportional abundance of a particular patch type in the landscape, and is suggested in every landscape pattern analysis (CUSHMAN et al. 2008).

Patch Density (PD) is a limited but fundamental metric to measure the spatial density of landscape patches (CUSHMAN et al. 2008). Technically, the landscape becomes more fragmented as the PD increases.

Edge Density (ED) represents the edge length on a hectare area basis to compare landscapes of different sizes. It can reflect landscape fragmentation as well to some degree.

Radius of Gyration_Area-Weighted Mean (GYRATE_AM) or correlation length measures landscape continuity or patch structural connectedness that represents the average traversability of the landscape for an organism that is confined to move within a single patch (CUSHMAN et al. 2010a); specifically, it calculated the average distance one organism can move from a random starting point in a random direction to any ending point within one patch (CUSHMAN, MCGARIGAL 2019).

Aggregation Index (AI) measures aggregation and the frequency that the patch types appear on the map.

Largest Patch Index (LPI) measures the proportion of the total area composed of the largest patches.

Number of Patches (NP) is a simple metric to measure the extent of subdivision or fragmentation of the patch type (MCGARIGAL et al. 2002),

Patch Area_Area-Weighted Mean (AREA_AM) measures the area-weighted mean patch area of all the patches within land use/land cover (LULC) classes.

I calculated several landscape metrics in FRAGSTATS (MCGARIGAL et al. 2002, 2012) to assess quantitatively the structure and composition of the LULC map and habitat loss and fragmentation of landscape in LR and BAA. I chose the Percentage of Landscape (PLAND), Patch Density (PD), Edge Density (ED), Radius of Gyration_Area-Weighted Mean (GYRATE_AM) or correlation length (CUSHMAN et al. 2013a), and Aggregation Index (AI). These metrics were chosen given past research that demonstrated their utility in species–environment relationship modeling (CUSHMAN et al. 2016, GRAND et al. 2004), connectivity, and gene flow modeling (CUSHMAN et al. 2012a, 2013a).

4.2.2 Core areas identification and prioritization

I used two criteria to select core areas in LR and in BAA.

(1) **The size of green space.** I reclassified the land use types by using the "Reclassify" function in ArcGIS 10.8.1. I binarized the value of green space as two as foreground, the value of other land use types is one as background, and other land use types as background which the value is one in these two study areas. I then input the data into GuidosToolbox and conducted Morphological Spatial Pattern Analysis (MSPA). Morphological Spatial Pattern Analysis (MSPA) of GuidosToolbox (SOILLE, VOGT 2009, VOGT et al. 2007) was used to extract core areas. The green space was divided into seven classes – Core, Islet, Perforation, Edge, Loop, Bridge, and Branch. The core is defined as areas of a large extent of green space, the islet is defined as the isolated pixels unconnected from any other pixels, the bridge and loop are connectors linking core areas, edge and perforation are the outer and inner boundaries of habitat patches, the branch is connector linking one end to a habitat patch (CARLIER, MORAN 2019, SOILLE, VOGT 2009). Then I chose class metrics of PD, PLAND, GYRATE_AM, ED, and AI to measure the spatial pattern of each type of green space. Among them, I extracted Core as core areas, then I selected all Cores with areas greater than 50,000 m^2 in LR and with areas greater than 250 000 m^2 in BAA to have a similar amount of core in both study areas for inclusion in the next analysis, as BAA has mountain areas while LR only has normal parks which makes the core area I chose in BAA is larger than that in LR.

(2) **Degree of Probability of Connectivity (dPC).** I used Conefor 2.6 (BODIN, SAURA 2010, SAURA, TORNÉ 2009) to identify the important nodes, and chose core areas whose dPC is larger than 2 to represent the important nodes for the connectivity network across the two study areas. Then I calculated landscape metrics of PD, GYRATE_AM, ED, and AI to measure the landscape pattern of important nodes in these two study areas.

4.2.3 Resistance surface definition

Based on the experts' opinion of relative resistance values of different land cover types for the movement of animal species, I set the resistances of green space, farmland, water surface, built-up area, and road to 1, 30, 80, 100, and 100 respectively. Green space as habitat patches has a minimum cost for movement. Farmland has quite a low cost as it has vegetation that probably can provide a source for species. Water likely is high resistant to all species that don't fly and don't swim. Built-up area and road have the highest resistance as barriers for species. However, the resistance value for land cover can be defined based on different parameters (e.g., LULC, slope, and elevation (CUSHMAN et al. 2006)).

4.2.4 Least-cost path analysis

Here I divided it into two ways to accomplish LCP analysis in LR and in BAA.

(1) LCP analysis by "cost path". "Cost path" maps one-cell size raster LCP between core areas by using the centroids of the important core areas and resistant surface. The input data are the resistance map and the centroids of important core areas. There are two steps to accomplish LCP in ArcGIS 10.8.1 by using "cost distance" and "cost path". First, I used the resistance surface and the centroids of important core areas by "cost distance" function to get the direction map and the cumulative resistance map or cost distance map (CUSHMAN et al. 2010b) which measures the lowest cost of movement on resistance map (ADRIAENSEN et al. 2003). To accomplish it, I converted important core areas into points by using the function of Feature To Point, then I paired all centroids of the core areas like 1 & (2-n), 2 & (3-n), … (n-1) & n (***Figure 4.8***). This analysis measures the direction map and the cumulative map for all pairs of centroids of the core areas within the spatial extent of the resistance surface (CUSHMAN et al. 2009). Next, I performed the "cost path" by using the direction map and the cost distance map to calculate LCPs for every pair of the centroid of the core area. Finally, I got paths for the whole core area in these two study areas by adding all pairs' paths by using the Mosaic To New Raster function in ArcGIS 10.8.1. These LCPs record the cheapest paths from a single location to the rest of the source location.

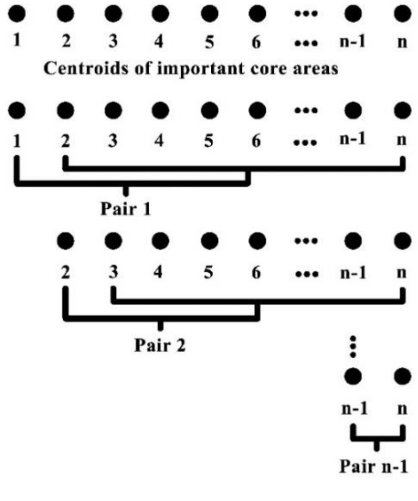


Figure 4.8: Pairs of centroids of important core areas

(2) LCP analysis by Linkage Mapper which is an add-on function in ArcGIS 10.8.1. Linkage Mapper (GALLO, GREENE 2018) maps vector least-cost corridors between core areas by using core areas and resistant surface as input data. LCP analysis identifies the lowest cost routes that animal species would move in the region between pairs of core areas, of which can be a patch, park, or conservation area (RUDNICK et al. 2012). I used important core areas and the resistance surface as inputs into the Linkage Mapper Tool by using the function of Build Network and Map Linkages to predict the cumulative resistance surface and LCPs among the important core areas in these two study areas. Note that every pair of core areas is connected by LCP as I did not set the limitations of cumulative resistance surface for the species (HORMAN et al. 2018).

4.2.5 UNICOR cumulative resistant kernel analysis

Here I used the same input data for modeling RK and factorial LCP. I considered the species dispersal abilities for both modeling, which is critical for the precise prediction for the pattern of landscape-scale connectivity (CUSHMAN et al. 2013b, 2016). There were three input files that needed to be prepared before running UNICOR.

(1) Resistance surface. The resistance surface represents the unit cost of each cell when species move on it (LANDGUTH et al. 2012). I converted the TIFF files of the resistant surfaces in these two study areas into ASCII files of the resistant surfaces by using the Raster to ASCII function in ArcGIS 10.8.1.

(2) Source points. Points locations define the starting and ending points of paths linking pairs of individuals (LANDGUTH et al. 2012). I converted important core areas into raster data with 100 m resolution in LR and with 200 m resolution in BAA to have similar amounts of pixels of core areas, then converted raster data into points, and finally, used the Add XY Coordinates function to get the location of source points.

(3) Main parameters in the RIP file. First, I set the dispersal distance to reflect species-specific differences in dispersal abilities based on the mean resistance. The mean resistance is around 40 in LR and around 35 in BAA, so I used 40 000, 80 000, 160 000, 320 000, 640 000, and 1 280 000 cost units in LR and 35 000, 70 000, 140 000, 280 000, 560 000, and 1 120 000 cost units in BAA to represent the dispersal thresholds 1 km, 2 km, 4 km, 8 km, 16 km, 32 km respectively (MATEO-SÁNCHEZ et al. 2014), which follows power two scaling to span the scale of the study area and the potential dispersal ability of most native species. In this way, I evaluated the general sensitivity of ecological network predictions to dispersal for species associated with green space. Second, I used the Gaussian function (CUSHMAN et al. 2009, PINTO, KEITT 2009, KASZTA et al. 2018) to smooth output paths. Third, I set all_paths as Edge_Type for RK modeling, while threshold as Edge_Type for factorial LCP.

4.2.5.1 Analysis of resistant kernel modeling

The RKs represent the connectivity of species' movement (COMPTON et al. 2007). A high value indicates a high rate of expected movement through that location in the landscape given the source point distribution, density, resistance of the landscape, and dispersal ability of the species. A low value indicates low expected rates of movement (e.g., CUSHMAN et al. 2012b, KASZTA et al. 2019, 2020a). The process of getting standardized value is to put different variables on a common scale which allows you to compare scores between different types of variables (PHILLIPS 2017, 74. FROST 2024). I modeled RKs with multi-dispersal thresholds and calculated the standardized values of RKs to explore the relationship between landscape connectivity and species dispersal ability.

I defined the connected areas and unconnected areas for study areas by using RK maps. Areas with the RK value above 0 represent **connected areas**, and areas with the RK value equal to 0 represent **unconnected areas** (WASSERMAN et al. 2013). I then turned the RK into binary form, with the value 1 where the areas are connected areas and with the value 0 where the areas are unconnected areas. I chose PLAND, GYRATE_AM, PD, and largest patch index (LPI) (CUSHMAN et al. 2012a, WASSERMAN et al. 2012) in FRAGSTATS (MCGARIGAL et al. 2002, 2012) to evaluate the landscape configuration of connected areas.

4.2.5.2 Analysis of factorial least-cost path modeling

Factorial LCPs represent the most optimal potential routes that species would move in connecting all pairs of source points at a given dispersal threshold and on a given resistance surface (CUSHMAN et al. 2009). The number of factorial LCPs increased as the connectivity increased. The factorial LCPs also have a measure of strength that represents the expected relative centrality of each location in the connectivity network, which is related to the rate at which a species would move through that location in the network if moving optimally as a function of resistance among pairs of source points. I modeled factorial LCPs with multi-dispersal thresholds to explore the relationship between corridor strength and species dispersal ability.

Factorial LCPs depict the spatial pattern and strength of corridors. It is necessary to evaluate the meaningful connections (MACDONALD et al. 2018). I extracted factorial LCPs above 0 as **meaningful paths**, while factorial LCPs equal to 0 represent **unmeaningful paths**. Then I turn the factorial LCP into binary form, with the value 1 for meaningful paths and with the value 0 for unmeaningful paths. I used the same class metrics in FRAGSTATS (MCGARIGAL et al. 2002, 2012) to evaluate the landscape configuration of meaningful paths.

4.2.6 Optimized ecological connectivity networks

Prioritizing ECN in spatial perspective and in species perspective could help planners to optimally arrange green spaces to maximize their ecological resilience and minimize their financial cost (e.g., KASZTA et al. 2019, 2020b).

(1) High connectivity area identification. I used RStudio to calculate the 75th percentile of every RK surface (***Table 4.5 and 4.6***) in these two study areas. I then used the value of the 75th percentile of every RK surface to get the binary form of every RK surface by using the "Reclassify" function, which the value above the 75th percentile of every RK surface is 1, the value under and equal to the 75th percentile of every RK surface is 0. Finally, I intersected all the kernels above the 75th percentile of every RK surface in ArcGIS 10.8.1 to get the highest connectivity areas in LR and in BAA.

Table 4.5: 75th percentile of resistant kernels in Luohe region

Dispersal threshold (km)	**1**	**2**	**4**	**8**	**16**	**32**
75%	0	29.395559	96.27360	326.8150	591.4744	732.7372

Table 4.6: 75th percentile of resistant kernels in Budapest agglomeration area

Dispersal threshold (km)	**1**	**2**	**4**	**8**	**16**	**32**
75%	62.96472	287.97766	499.95474	645.14317	718.57129	755.28565

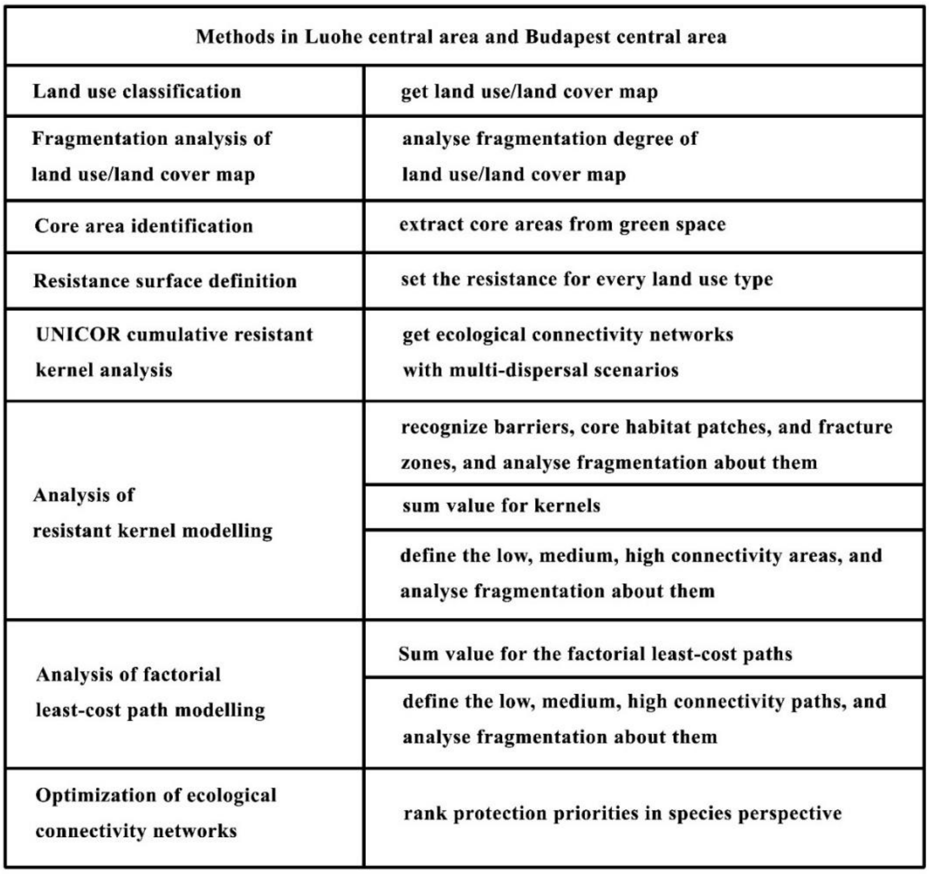
(2) Optimization of ecological connectivity network in species perspective. I used RK modeling and factorial LCP modeling to rank protection priorities in these two study areas by considering species' dispersal limits.

(3) Optimization of ecological connectivity network in spatial perspective. I intersected LCPs by Linkage Mapper with a 2 km threshold scenario to get the first protection priority, intersected LCPs by Linkage Mapper with the 8 km threshold scenario to get the second protection priority, removed core areas from the 8 km threshold scenario to get the third protection priority in LR. I buffered 60m of the first protection corridors, the second protection corridors, and the third protection corridors, and then intersected them with land use classification, I got the intersected land use types within the buffered corridors in LR. I intersected LCPs by Linkage Mapper with a 4 km threshold scenario to get the first protection priority, LCPs by Linkage Mapper were the second protection priority in BAA. I buffered 60m of the first protection corridors and the second protection corridors, and then intersected them with land use classification, I got the intersected land use types within the buffered corridors in BAA.

(4) The relation of the least-cost path by Linkage Mapper with road and water surface. I intersected the least-cost paths by Linkage Mapper with roads and water surfaces. Then I calculated the whole length of LCPs, the length of intersection for LCPs and roads, and the length of intersection for LCPs and water surfaces. Finally, I got the intersection pattern of LCPs with roads and water surfaces.

4.3 Ecological connectivity networks in Luohe central area and in Budapest central area

In this part, I used UNICOR cumulative RK analysis to simulate ECN with multi-dispersal scenarios in LCA and in BCA (***Figure 4.9***). I defined barriers, core habitat patches, and fracture zones for these two study areas. Meanwhile, I also identified low connectivity areas, medium connectivity areas, high connectivity areas, low connectivity paths, medium connectivity paths, and high connectivity paths for these two study areas. Finally, I ranked the protection priority in species perspective.



Methods in Luohe central area and Budapest central area	
Land use classification	get land use/land cover map
Fragmentation analysis of land use/land cover map	analyse fragmentation degree of land use/land cover map
Core area identification	extract core areas from green space
Resistance surface definition	set the resistance for every land use type
UNICOR cumulative resistant kernel analysis	get ecological connectivity networks with multi-dispersal scenarios
Analysis of resistant kernel modelling	recognize barriers, core habitat patches, and fracture zones, and analyse fragmentation about them
	sum value for kernels
	define the low, medium, high connectivity areas, and analyse fragmentation about them
Analysis of factorial least-cost path modelling	Sum value for the factorial least-cost paths
	define the low, medium, high connectivity paths, and analyse fragmentation about them
Optimization of ecological connectivity networks	rank protection priorities in species perspective

Figure 4.9: Methods in Luohe central area and in Budapest central area

4.3.1 Land use/land cover classification

In this section, firstly, I used an unmanned aerial vehicle image in the LCA and Urban Atlas Land

Cover/Land Use 2018 (vector), Europe, 6-yearly (EEAGDC 2020) in the BCA to be the basic data. Secondly, I classified land use types by using a visual interpretation method in the LCA and by using the Reclassify function in ArcGIS 10.8.1 in the BCA. Finally, I did fragmentation analysis by using the FRAGSTATS to quantify the landscape structure and composition in the LCA and the BCA.

(1) Image acquisition

Luohe central area. The basic data used in this part is mainly an unmanned aerial vehicle (UAV) image of LCA (Resolution: 0.09 m. Projected Coordinate System: WGS_1984_Transverse_Mercator), and the image acquisition time is in March 2016. At this time, the leaves of large-size and medium-size deciduous trees and shrubs have not fully grown yet, all types of land use can be identified by visual recognition, which can more accurately determine the boundary of the land use type. Topographic map (1: 10 000), general urban planning of Luohe city (2005-2020), and Google map were used as auxiliary data sources for the manual interpretation of UAV image.

Budapest central area. I downloaded the LULC vector data of Budapest from Urban Atlas Land Cover/Land Use 2018 (vector), Europe, 6-yearly.

(2) Classification

Luohe central area. First, I performed geometric correction and crop of the UAV image in ArcGIS 10.8.1, combined with field investigation and verification, and applied a visual interpretation method to extract vector data of LULC type. Second, I performed topology correction to correct the overlapping area and gap area. Finally, I divided LULC into six categories based on the classification criteria of land use status (GAQSIQ, SAC 2017), permeability, utilization types, and performance features of the land: **green space, water surface, farmland, built-up area, road,** and **unused land**.

Budapest central area. I clipped Urban Atlas 2018 of Budapest by the boundary of BCA, I then used Google Maps, Google Earth, and field trips to do manual corrections. Based on the original LULC types (***Table 4.7***), I then reclassified the LULC map into six classes which are **built-up area, farmland, green space, road, unused land, and water surface**.

Table 4.7: Land use types in Budapest central area

Original land use types	**New land use types**
Construction sites, continuous urban fabric (S.L.: > 80%), discontinuous dense urban fabric (S.L.: 50% - 80%), industrial, commercial, public, military and private units, port areas, sports and leisure facilities, mineral extraction and dump sites.	Built-up area

Arable land (annual crops).	Farmland
Forests, green urban areas, pastures, discontinuous very low density urban fabric (S.L.: < 10%), discontinuous low density urban fabric (S.L.: 10% - 30%), discontinuous medium density urban fabric (S.L.: 30% - 50%).	Green space
Fast transit roads and associated land, other roads and associated land, railways, associated land.	Road
Land without current use.	Unused land
Water.	Water surface

(3) Fragmentation analysis

I used class metrics of PLAND, PD, ED, GYRATE_AM and AI by using FRAGSTATS to analyze the landscape structure and composition in LCA and BCA.

4.3.2 Core areas identification and prioritization

I used the same criteria with the LR and BAA to identify core areas in Luohe central area and Budapest central area.

(1) **The size of green space.** I extracted Core as core areas, then I selected all Core with areas greater than 5 000 m^2 in LCA and in BCA for the next analysis.

(2) **Degree of Probability of Connectivity (dPC).** I chose core areas whose dPC is larger than 2 to be the important nodes for LCA and BCA. Then I analyzed the fragmentation degree of important nodes in these two study areas.

4.3.3 Resistant surface definition

I converted vector land use data in LCA and in BCA into raster data with 30 m resolution, I then set the resistances of green space, farmland, water surface, built-up area, road, and unused land to 1, 30, 80, 100, 100 and 30 respectively.

4.3.4 UNICOR cumulative resistant kernel analysis

UNICOR cumulative RK analysis considers the species' limits to map ECN, I used the UNICOR (LANDGUTH et al. 2012) to perform RK modeling (COMPTON et al. 2007) and factorial LCP modeling (CUSHMAN et al. 2009) in this part's analysis.

There were also three input files like in the LR and BAA did, but the detailed information was different in this part's analysis.

(1) Resistant surface. I did the same process for LCA and BCA like in the LR and BAA.

(2) Source points. I converted important core areas into raster data with 100 m resolution in LCA and with 200 m resolution in BCA, and got the locations of source points.

(3) RIP file. The mean resistance is around 60 in LCA and around 90 in BCA, so I used 2 000, 4 000, 8 000, 16 000, and 32 000 in LCA and 3 000, 6 000, 12 000, 24 000, and 48 000 in BCA to represent the dispersal thresholds 1 km, 2 km, 4 km, 8 km, 16 km respectively (Mateo Sánchez et al. 2014). I did the same rest of the processes in LCA and BCA like in LR and BAA.

4.3.4.1 Analysis of resistant kernel modeling

RK modeling represents the rate of expected movement for every pixel in the region (CUSHMAN et al. 2012b). I analyzed the RKs like below:

(1) I defined **barriers**, **core habitat patches**, and **fracture zones** by using RKs. Areas where the RKs were zero represent **barriers** (CUSHMAN et al. 2013b). Areas where the RK values greater than 10% of the highest recorded for the scenarios represent **core habitat patches** (CUSHMAN et al. 2013b). Areas where the RK is larger than zero and smaller than 10% of the highest recorded value for the scenarios represent **fracture zones** (CUSHMAN et al. 2013b). I then used FRAGSTATS (MCGARIGAL et al. 2002, 2012) to calculate the PLAND, GYRATE_AM, LPI, and NP (CUSHMAN et al. 2013b) to evaluate the structure of barriers, core habitat patches, and fracture zones. Finally, I intersected all barriers, all core habitat patches, and all fracture zones of all scenarios to get the intersected barriers, intersected core habitat patches, and intersected fracture zones respectively of the study area extent.

(2) Sum value for kernels. I calculated the sum value across pixels for kernels by summing all the “added paths.txt” files in MATLAB.

(3) I calculated the RKs and standardized values in LCA and BCA like in LR and BAA.

(4) Percentile value for kernels. I set all the 0 values from all kernels into no data in ArcGIS 10.8.1 by using the SetNull function to extract all the RKs above 0. I then used the “quantile” function of Zonal Statistics as Table in ArcGIS Pro to get the 25th, 50th, and 75th percentile of every RK surface for all the RKs above 0 (***Table 4.8 and 4.9***). I chose the middle scenario whose dispersal threshold is 4 km to apply all the scenarios to do the next analyses. I then used the 25th, 50th, and 75th percentile values of the 4 km dispersal distance for all the kernels to convert into binary formats. Accordingly, for kernels, I used the values of 25th=0.764188, 50th=1.909388, 75th=4.101338 in LCA and 25th=0.958184, 50th=2.503188, 75th=6.045926 in BCA.

I defined areas with the 25th percentile of RKs above 0 at 4 km scenario as **low connectivity areas**, areas with the 50th percentile of RKs above 0 at 4 km scenario as **medium connectivity areas**,

areas with the 75th percentile of RKs above 0 at 4 km scenario as **high connectivity areas** for all the scenarios. I chose PLAND, LPI, AREA_AM, and GYRATE_AM to evaluate the fragmentation degree of low, medium, and high connectivity areas.

Table 4.8: Percentile value of the resistant kernels above 0 in Luohe central area

Dispersal threshold (km)	25th	50th	75th
1	0.541785	1.650294	3.322078
2	0.848916	1.797454	3.522836
4	0.764188	1.909388	4.101338
8	1.131409	3.154824	6.357412
16	1.701604	6.38536	12.38550

Table 4.9: Percentile value of the resistant kernels above 0 in Budapest central area

Dispersal threshold (km)	25th	50th	75th
1	1.197256	2.712456	4.473187
2	0.823291	2.892574	4.363335
4	0.958184	2.503188	6.045926
8	0.97409	2.540129	6.233785
16	0.819829	1.824452	4.819077

4.3.4.2 Analysis of factorial least-cost path modeling

Factorial LCP modeling predicts the movement corridors of species with different dispersal limits (Cushman et al. 2013c). I analyzed the factorial LCPs like below:

(1) Sum value for the factorial LCPs. I used the same methods to sum the factorial LCPs like summing RKs.

(2) I simulated the factorial LCPs with different dispersal thresholds.

(3) Percentile value for factorial LCPs. I used the same methods to get the 25th, 50th, and 75th percentile of every factorial LCP for all paths above 0 (***Table 4.10 and 4.11***). I then used the 25th, 50th, and 75th percentile values of the 4 km dispersal distance for all the paths. For paths, I used the values of 25th=2, 50th=5, 75th=12 in LCA and 25th=1, 50th=2, 75th=5 in BCA. I defined paths with the 25th percentile of factorial LCPs above 0 at 4 km scenario as **low connectivity paths** for

all the scenarios, paths with the 50th percentile of factorial LCPs above 0 at 4 km scenario as **medium connectivity paths** for all the scenarios, paths with the 75th percentile of factorial LCPs above 0 at 4 km scenario as **high connectivity paths** for all the scenarios. I chose the same indices to evaluate the low, medium, and high connectivity paths.

Table 4.10: Percentile value for the factorial least-cost paths above 0 in Luohe central area

Dispersal threshold (km)	25th	50th	75th
1	1	3	5
2	1	3	5
4	2	5	12
8	3	12	24
16	10	24.5	51

Table 4.11: Percentile value for the factorial least-cost paths above 0 in Budapest central area

Dispersal threshold (km)	25th	50th	75th
1	1	2	4
2	1	2	4
4	1	2	5
8	1	2	5
16	2	3	6

4.3.5 Optimized ecological connectivity networks

I used RK modeling and factorial LCP modeling to rank protection priorities in the LCA and the BCA in species perspective.

5. RESULTS

5.1 Results in Luohe region and Budapest agglomeration area

5.1.1 Land use/land cover classification

Classification in Luohe region (*Figure 5.1*). The classification results showed that built-up areas were mainly in LCA, north of LR, and southwest of LR.

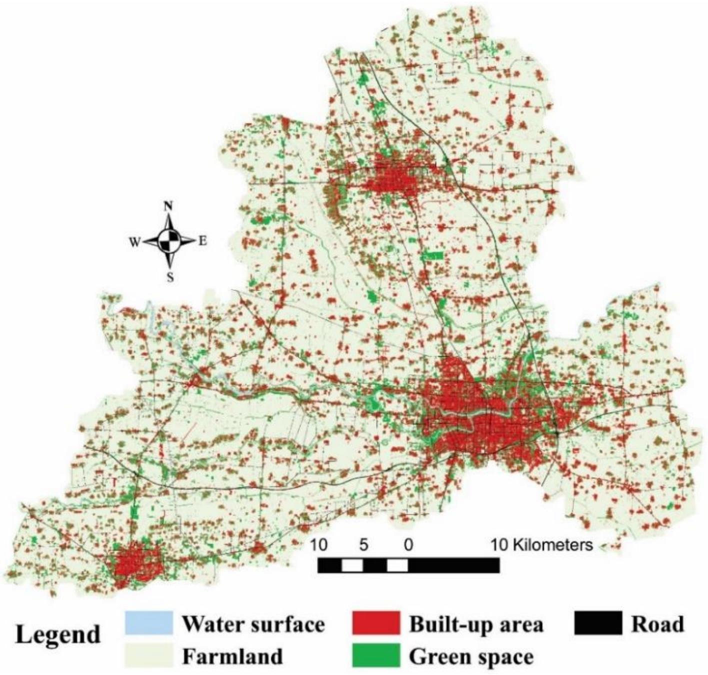


Figure 5.1: Land use/land cover classification in Luohe region

Accuracy assessment in Luohe region (*Table 5.1*). The overall accuracy of land use classification in LR was 99.3941%, with a Kappa Coefficient of 0.9867. This illustrates the land use classification was precise and sufficient for the remaining analyses in this study.

Table 5.1: Accuracy assessment of land use classification in Luohe region

Class	Commission (%)	Omission (%)	Producer Accuracy (%)	User Accuracy (%)
Water surface	0.16	3.12	96.88	99.84
Farmland	0.12	0.03	99.97	99.88
Built-up area	1.09	1.90	98.10	98.91
Green space	8.95	0.43	99.57	91.05
Road	4.03	1.38	98.62	95.97

Fragmentation analysis in Luohe region (*Table 5.2*). PLAND value of farmland was the largest among land use types. With more than 70% of total land, farmland is the main matrix land use that will dominate the structure and function of this regional landscape, and likely affect the regional ECN. The PD and ED values of green space were quite large, the GYRATE_AM value of green space was the smallest, and the AI value of green space was quite low as well. Collectively, these metrics indicate that green space in LR is limited in extent and highly fragmented.

Table 5.2: Fragmentation indices of land use classification (class metrics) in Luohe region

Class	PLAND (%)	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Water surface	0.6599	0.6420	2.7780	1096.1017	67.3099
Farmland	71.4652	4.7907	62.7221	7032.1139	93.3500
Built-up area	14.5615	5.5365	51.4971	417.9396	73.5571
Green space	11.2809	13.4535	61.7345	220.6607	58.9615
Road	2.0325	1.9101	14.3381	9879.7820	47.2090

Classification in Budapest agglomeration area (*Figure 5.2*). The classification results showed that built-up areas were mainly in BCA.

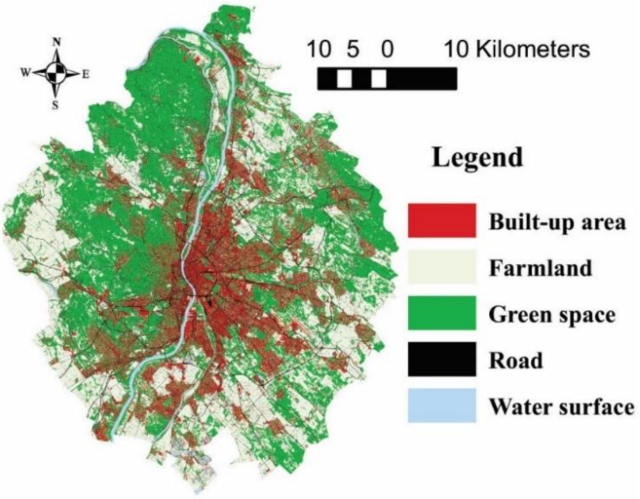


Figure 5.2: Land use/land cover classification in Budapest agglomeration area

Accuracy assessment in Budapest agglomeration area (*Table 5.3*). The overall accuracy of land use classification in BAA was 97.0466%, with a Kappa Coefficient of 0.9545. This showed the classification is highly successful and robust for use as the basis of the rest of the analysis.

Table 5.3: Accuracy assessment of land use classification in Budapest agglomeration area

Class	Commission (%)	Omission (%)	Producer Accuracy (%)	User Accuracy (%)
Water surface	0.06	4.84	95.16	99.94
Farmland	4.22	0.16	99.84	95.78
Built-up area	0.18	18.56	81.44	99.82
Green space	1.69	0.10	99.90	98.31
Road	2.33	0.59	99.41	97.67

Fragmentation analysis in Budapest agglomeration area (*Table 5.4*). PLAND of farmland with more than 30% was lower than that in LR, PLAND of green space with more than 40% was higher than that in LR. Farmland and green space will dominate the structure and function of landscape, and likely influence the ECN in this area with more than 70% of total land. The PD value of green space was quite small, the ED and the GYRATE_AM values of green space were the largest, the value of green space was medium, and the AI value of green space was quite high.

Table 5.4: Fragmentation indices of land use classification (class metrics) in Budapest agglomeration area

Class	PLAND (%)	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Water surface	2.5555	0.3749	3.8250	3513.1888	88.8099
Farmland	32.5831	17.8021	88.2130	1460.3330	79.6413
Built-up area	13.8503	7.5247	77.0404	1025.0158	58.3644
Green space	41.3341	7.9973	98.6398	5087.1341	82.0589
Road	9.6770	31.0952	95.1637	4960.3590	26.1898

5.1.2 Core area identification and prioritization

(1) The size of green space

MSPA analysis in LR (***Figure 5.3***) indicated that Core is 1.62%, Islet is 4.60%, Perforation is 0.01%, Edge is 2.28%, Loop is 0.29%, Bridge is 0.64%, Branch is 1.83% of the extent of the analysis area. The highest ratio of Islet showed that 4,60% of green space is isolated. The Bridge and the Loop ratio showed that 0.64% + 0.29% of the areas connect the core area. The Edge and the Perforation ratio showed that 2.28% + 0.01% of green space are the outer and inner boundaries of habitat patches. The Branch ratio showed that 1.83% of green space only connects one end to a habitat patch. 166 core areas were selected by MSPA analysis to calculate the dPC value.

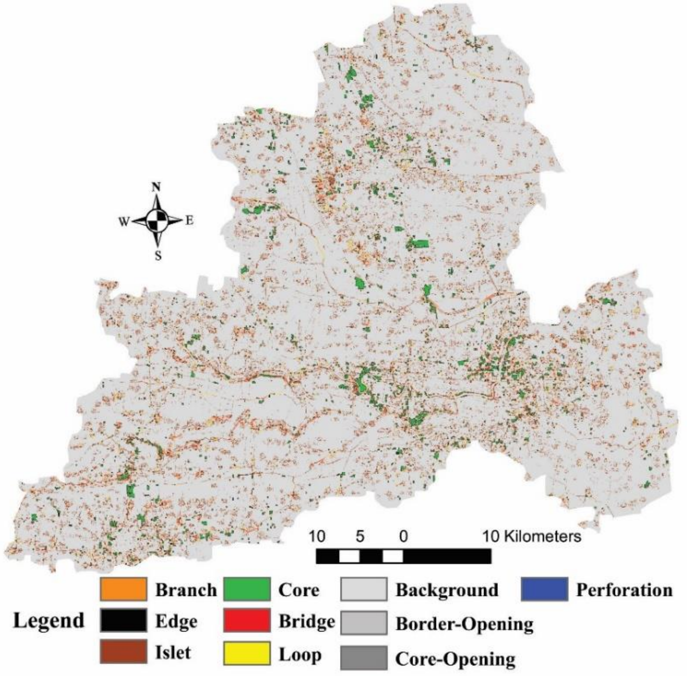


Figure 5.3: MSPA results of Luohe region

MSPA analysis in BAA (***Figure 5.4***) showed Core comprises 17.91% of landscape extent; Islet, indicating isolated green space, accounts for 2.83%; Perforation and Edge (inner and outer green space boundary) are 2.33% and 10.66% respectively, Loop and Bridge (areas connecting green space patches) are 0.76% and 3.42% respectively, and Branch (linkages between main core areas) is 3.41%. 200 core areas were selected to do the next analysis.

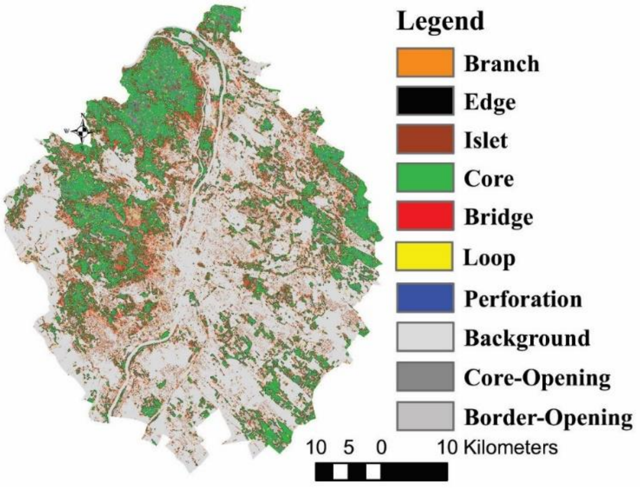


Figure 5.4: MSPA results of Budapest agglomeration area

(2) Degree of Probability of Connectivity (dPC)

Conefor analysis in LR showed there are 17 core areas with a value of dPC greater than 2, which were chosen for the first protection order, and there were 166 – 17 = 149 core areas to be the second protection order. The core areas were located equally in LR, and there were 25 core areas in the LCA (***Figure 5.5***).

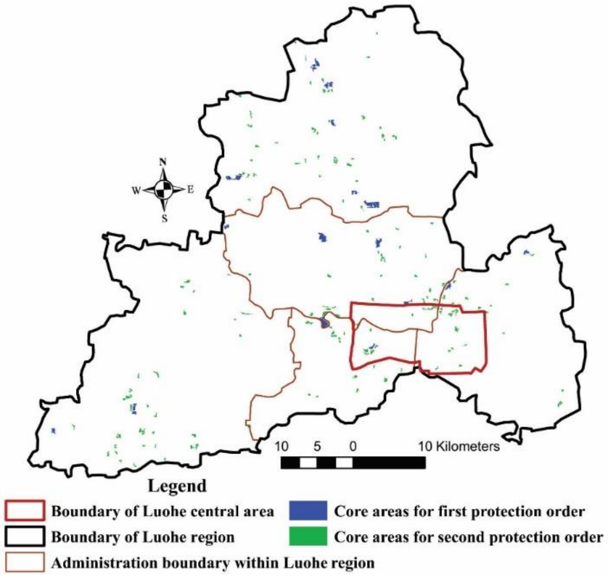


Figure 5.5: Location of core areas of Luohe region

23 important core areas were the first protection order in BAA, and 200 – 23 = 177 core areas were the second protection order. The core areas were mainly located northwest of BAA, and there were three core areas located in the BCA (***Figure 5.6***).

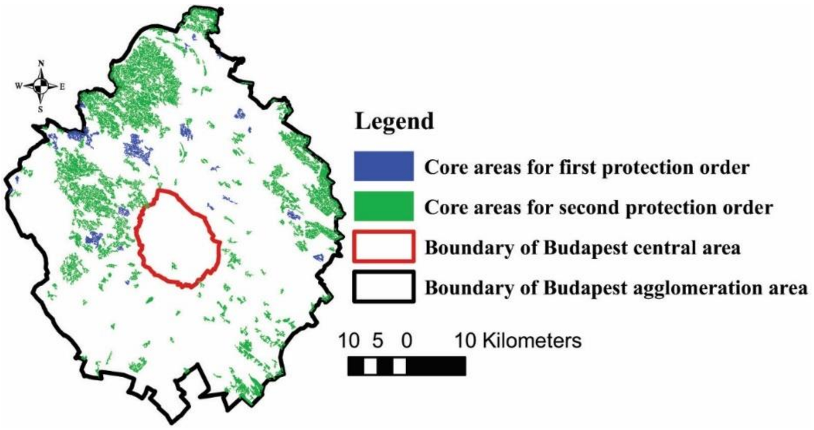


Figure 5.6: Location of core areas of Budapest agglomeration area

(3) Fragmentation analysis of MSPA analysis and Conefor analysis

After selecting green space core areas using Conefor2.6, I reanalyzed fragmentation on this subset in LR (***Table 5.5 and 5.6***). The PD and ED decreased, and the GYRATE_AM and AI increased for the core area green space subset compared to the full green space mosaic. This shows that raw green space has many more and smaller patches of higher diversity, and that the final core areas have more homogeneous patches of larger size. This shows our selection was successful in identifying the largest and most aggregated patches of green space for conservation and management focus.

Table 5.5: Fragmentation indices of MSPA results (class metrics) in Luohe region

TYPE	PLAND (%)	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core	14.3945	12.8775	53.0681	161.7088	72.5641
Islet	40.7735	111.6520	0.0000	58.3012	38.7592
Perforation	0.1292	0.1512	0.6210	47.6718	51.6827
Edge	17.2781	17.7702	69.0268	102.2059	45.2838
Loop	3.3243	2.9935	10.0559	93.7360	40.2398
Bridge	7.8694	4.6627	24.7567	146.5773	44.7810
Branch	16.2310	42.9009	25.0110	56.8387	39.1550

Table 5.6: Fragmentation indices of important core areas (landscape metrics) in Luohe region

TYPE	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core Areas	2.0700	0.0000	393.6200	92.0921

I reanalyzed fragmentation on MSPA results and important core areas in BAA (***Table 5.7 and 5.8***). The PD, ED and AI of the core area green space showed the same trend with that in LR. This shows our selection was robust for the next analysis.

Table 5.7: Fragmentation indices of MSPA results (class metrics) in Budapest agglomeration area

TYPE	PLAND (%)	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core	43.3248	8.8117	99.8174	1312.3942	82.6735
Islet	6.8504	17.9512	0.0000	53.6479	39.5114
Perforation	4.2330	6.1917	24.8417	55.5321	41.4380
Edge	18.4467	26.3427	96.0497	95.6447	39.7212
Loop	4.7323	7.4741	21.7666	61.2493	39.1548
Bridge	14.1529	7.1406	50.0962	197.8831	45.2237
Branch	8.2600	30.0212	22.4432	44.5156	31.6361

Table 5.8: Fragmentation indices of important core areas (landscape metrics) in Budapest agglomeration area

TYPE	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core Areas	0.7939	0.0000	952.4004	87.3854

5.1.3 Resistance surface

Areas of high resistance in LR were mostly located in LCA, the northern part of the residential area, and the southwestern part of the residential area, while areas with low resistance in LR were mainly concentrated in the surrounding areas of LR (***Figure 5.7***). Areas of high resistance in BAA were mainly concentrated in the central part of BAA, while areas with low resistance in BAA were mostly situated in the northwestern areas of BAA which is the mountain area (***Figure 5.8***).

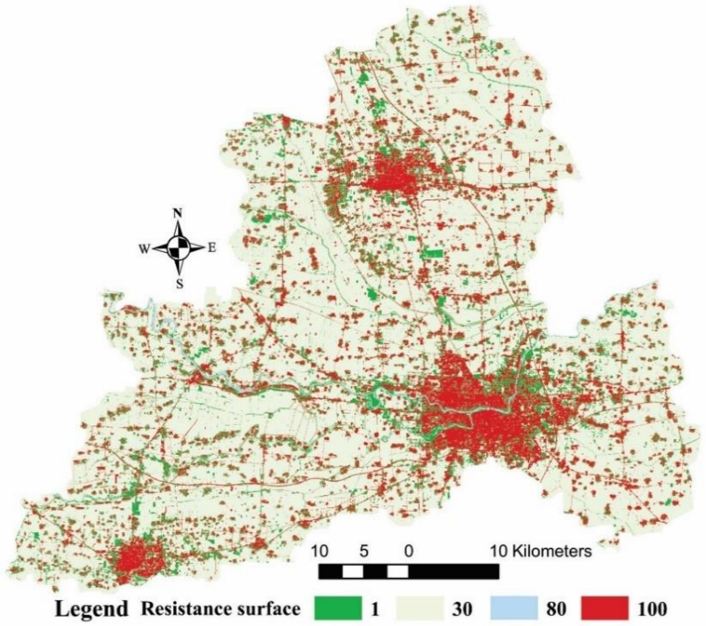


Figure 5.7: Resistance surface in Luohe region

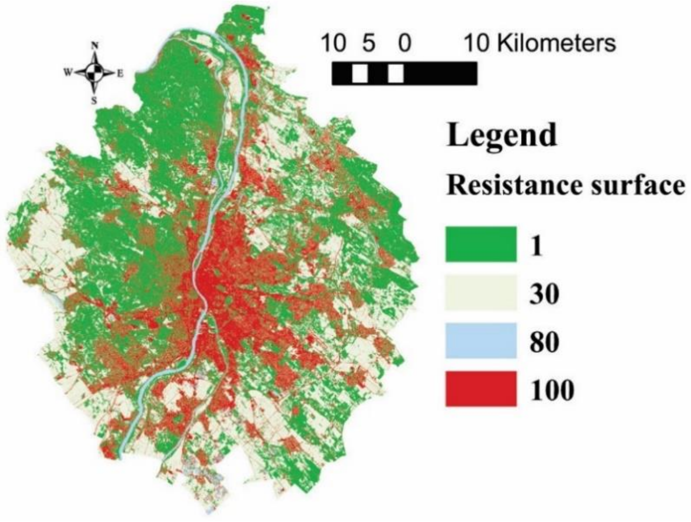


Figure 5.8: Resistance surface in Budapest agglomeration area

5.1.4 Least-cost path analysis results

Least-cost path results in Luohe region

The cumulative resistance surfaces in the northeastern and southeastern parts of the LR were high since these areas were far away from core areas. The patterns of cumulative resistance surfaces by cost distance and by Linkage Mapper were the same, and the values of cumulative resistance surfaces in these two ways were similar (***Figure 5.9 and 5.10***).

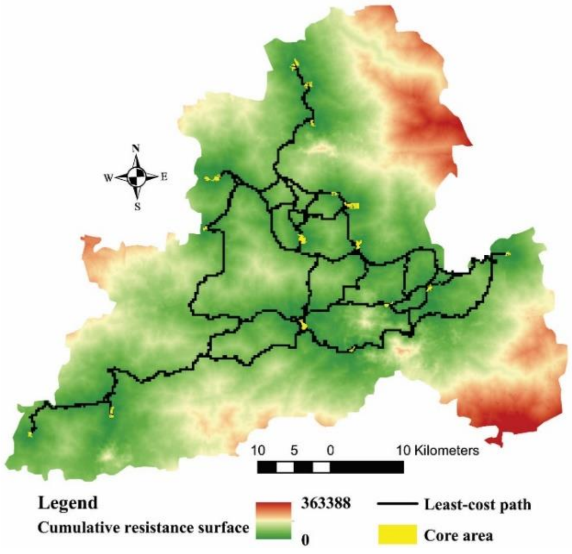


Figure 5.9: Least-cost path analysis by cost path

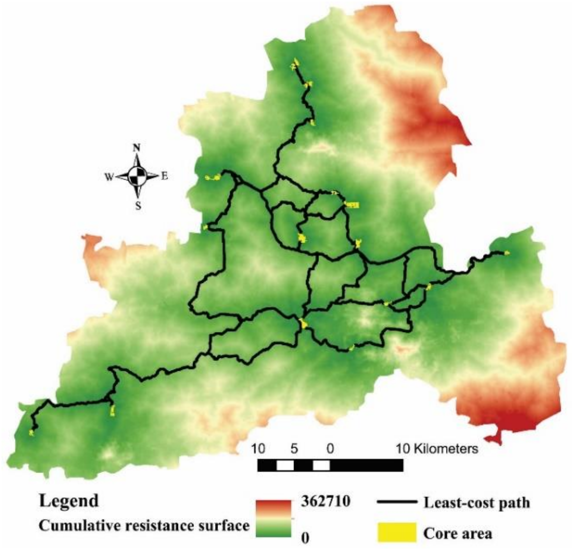


Figure 5.10: Least-cost path analysis by Linkage Mapper

The LCPs by cost path produce raster corridors, while the LCPs by Linkage Mapper produce vector corridors (***Figure 5.9 and 5.10***) between pairs of source points at a given dispersal distance. The patterns of LCPs by cost path and by Linkage Mapper were similar because they input similar files of resistance surfaces and core areas. The number of LCPs by cost path was more than that by Linkage Mapper because cost path can generate duplicated corridors. They do not show the corridor strength, and pass through all the core areas and LCA. That means LCP analysis only considered the landscape configuration effects and did not consider species' dispersal limits.

Least-cost path results Budapest agglomeration area

The areas in the northeastern and northwestern parts have very low cumulative resistance surfaces because of mountain areas in the BAA. The cumulative resistance surface in the central part was high since the area in the central part had high resistance and was far away from core areas as well. The patterns of cumulative resistance surfaces in these two ways were the same, and the values of cumulative resistance surfaces were similar (***Figure 5.11 and 5.12***).

The LCPs by cost path and by Linkage Mapper (***Figure 5.11 and 5.12***) showed the same spatial pattern without the corridor strength as in LR. The number of LCPs by cost path was more than that by Linkage Mapper like in LR. LCPs passed through all the core areas, but did not pass through the BCA. I will analyze the reason why there are no LCPs in the central area in 5.2.4.

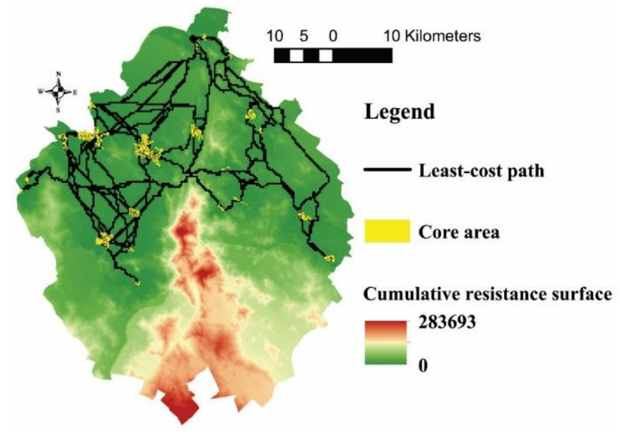


Figure 5.11: Least-cost path analysis by cost path

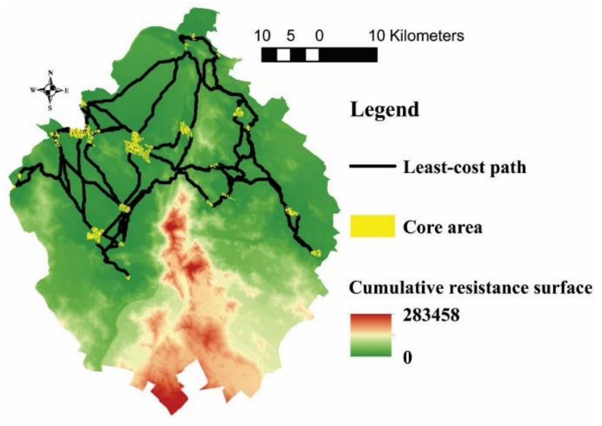


Figure 5.12: Least-cost path analysis by Linkage Mapper

5.1.5 UNICOR cumulative resistant kernel analysis

5.1.5.1 Analysis of resistant kernel modeling

Luohe region.

The values of the RKs (***Figure 5.13***) increased rapidly and the standardized values (***Figure 5.14***) decreased rapidly with dispersal thresholds of ≤ 2 km; species in these scenarios showed generally low connectivity in most of the areas. That means species in these scenarios which are dependent on greenspace for habitat, will experience fragmentation of their populations across the LR.

The values of the RKs (***Figure 5.13***) increased moderately and the standardized values (***Figure 5.14***) decreased moderately with dispersal thresholds of 4 km and 8 km. Species in these scenarios showed a network of connectivity with multiple pathways connecting the interior of the study area.

That means species whose dispersal or migration distance is between 4 km and 8 km and which are dependent on greenspace for habitat would be affected intermediately with strong connectivity in the core network of central green space but limited longer distance connectivity, particularly to the northeast and southeast corners of the study region.

Finally, the values of the RKs (***Figure 5.13***) increased slightly and the standardized values (***Figure 5.14***) decreased slightly with dispersal thresholds ≥ 16 km. Species in these scenarios showed high connectivity levels and appeared fairly insensitive to current configurations of human development in the study area. That means species whose dispersal abilities are ≥ 16 km which are dependent on greenspace for habitat would be affected slightly by the location and configuration of green space patches given their ability to integrate and move between patches through high dispersal.

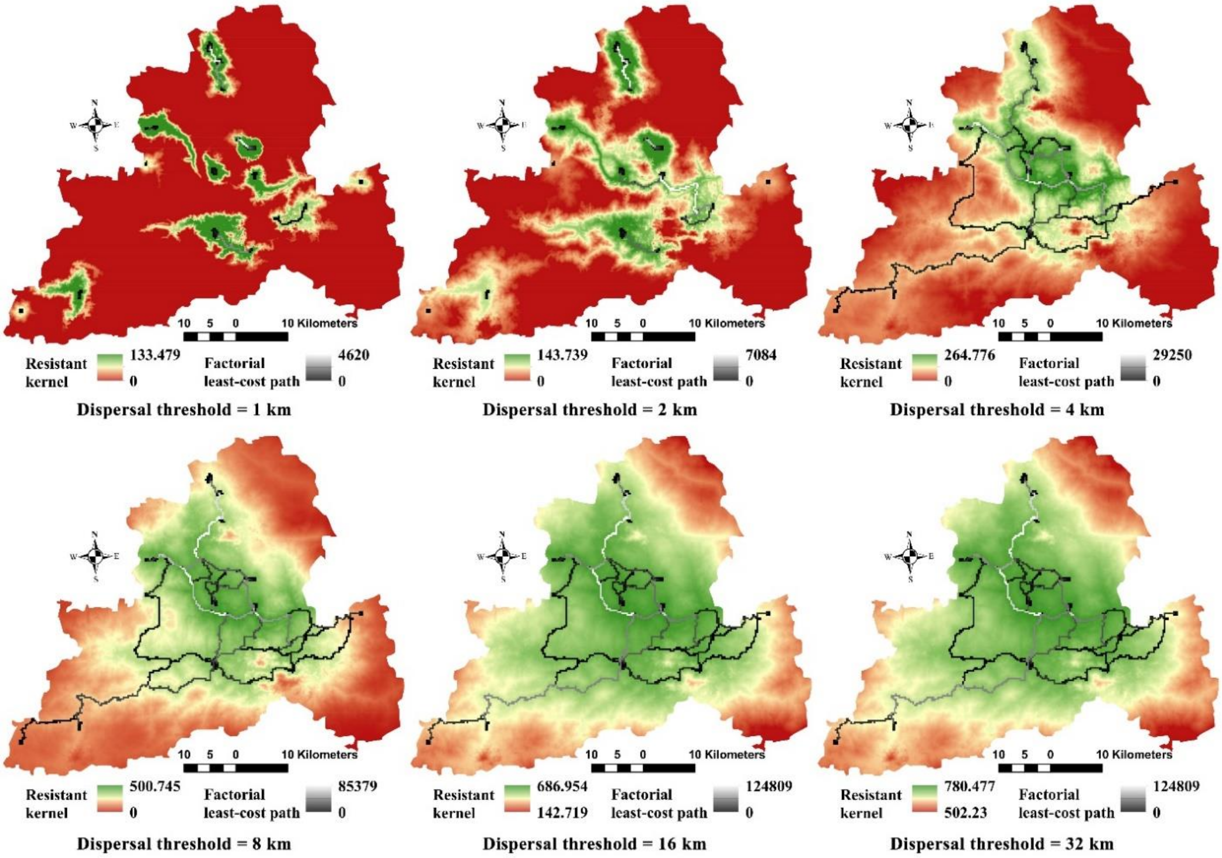
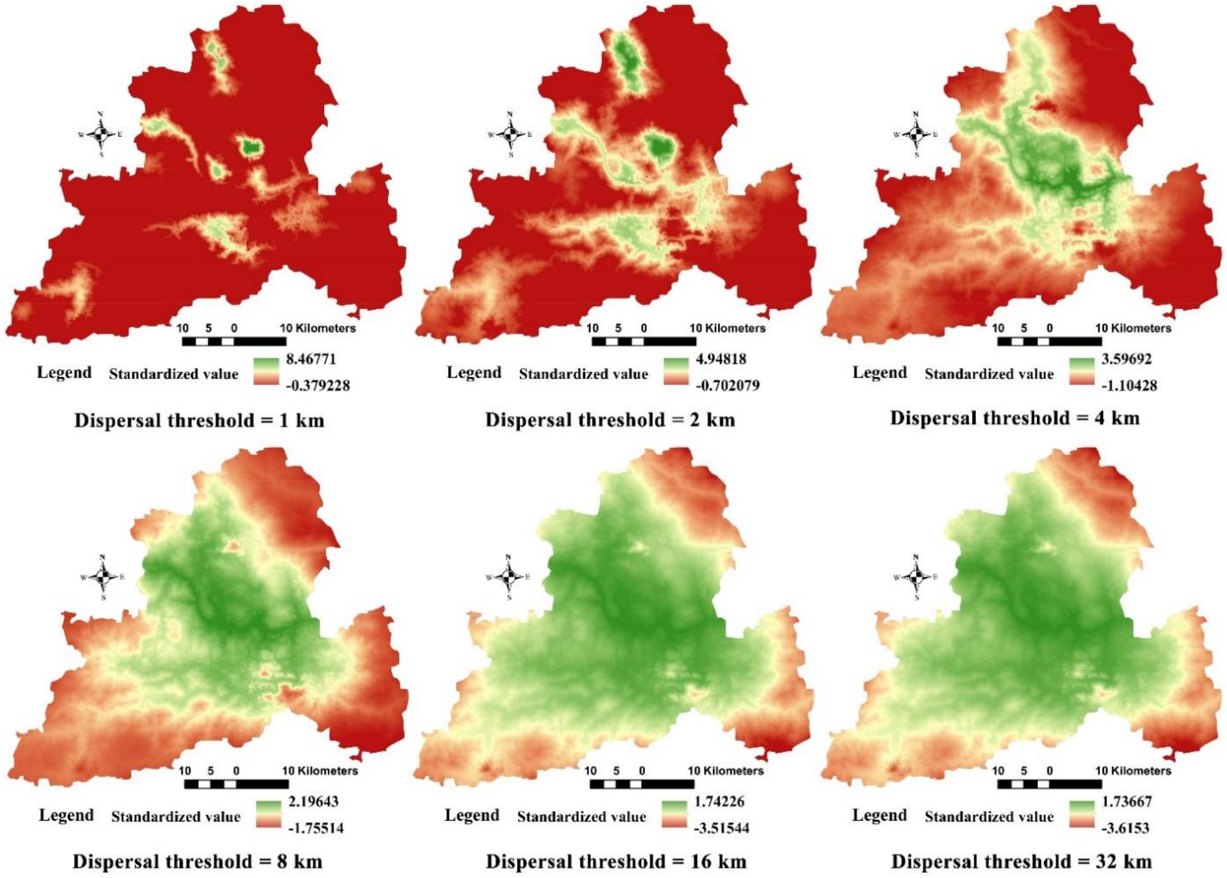


Figure 5.13: UNICOR cumulative resistant kernel analysis in Luohe region



Dispersal threshold = 1 km

Dispersal threshold = 2 km

Dispersal threshold = 4 km

Dispersal threshold = 8 km

Dispersal threshold = 16 km

Dispersal threshold = 32 km

Figure 5.14: Standardized value of the resistant kernel in Luohe region

Fragmentation analysis of resistant kernel modeling (*Table 5.9*). PLAND of connected areas with dispersal thresholds of ≤ 2 km were small and increased rapidly, which means species in these scenarios had very vulnerable connected areas. PLAND of connected areas with dispersal thresholds of 4 km and 8 km increased moderately, which means species in these scenarios had a moderate size of connected areas and was a strong system for species' movement. PLAND of connected areas with dispersal thresholds ≥ 16 km was 100, which means species in these scenarios could move anywhere in the study area extent. LPI and GYRATE_AM of connected areas showed the same trend with PLAND, which proved the results of kernel analysis. PD of connected areas was a little lower with dispersal thresholds of 1 km, PD of connected areas stayed unchanged with dispersal thresholds ≥ 2 km. That means the connected areas for all the scenarios were aggregated and the fragmentation degree was low.

Table 5.9: Fragmentation indices of connected areas in Luohe region

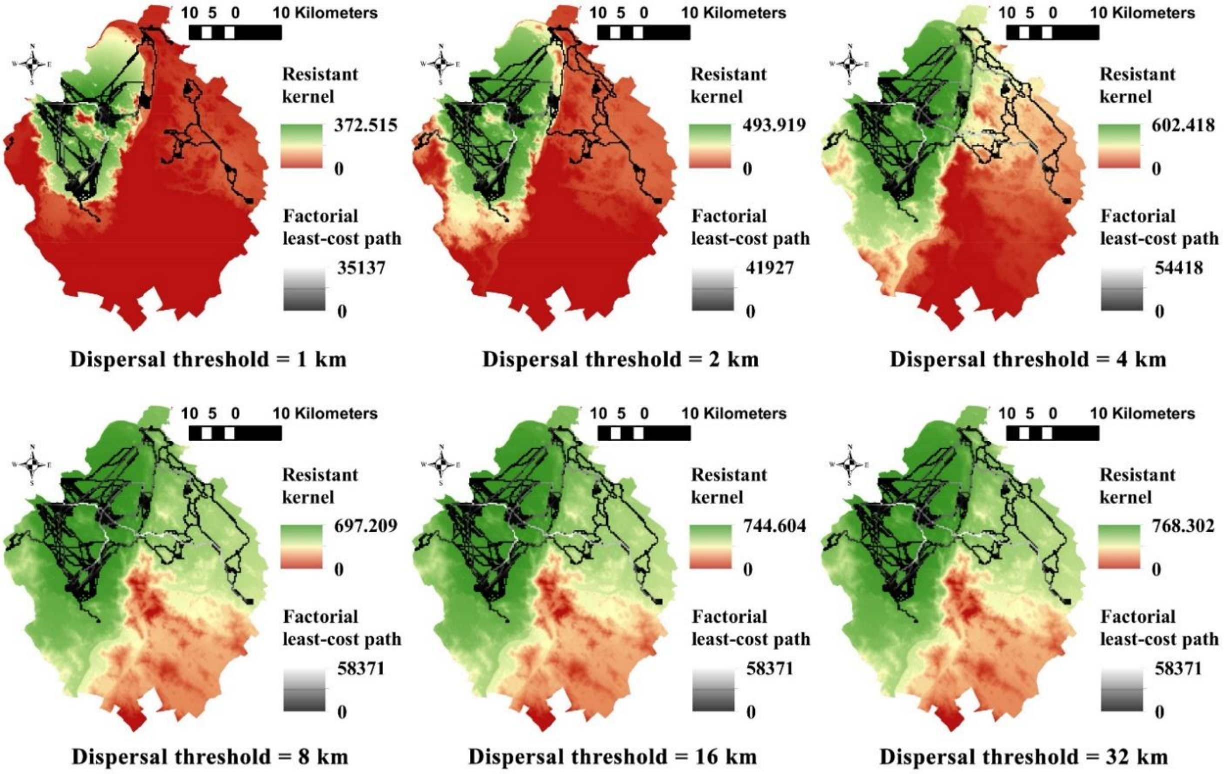
Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	GYRATE_AM
1	22.3453	0.0033	6.4078	4818.2554
2	54.2653	0.0004	54.2653	19002.3629
4	86.1563	0.0004	86.1563	20425.2913
8	99.8812	0.0004	99.8812	21920.4930

16	100.0000	0.0004	100.0000	21937.4785
32	100.0000	0.0004	100.0000	21937.4830

Budapest agglomeration area.

Generally speaking, the values of RKs and the standardized values showed different patterns from those in LR as the percentage of land use types are different. The values of the RK (***Figure 5.15***) increased dramatically and the standardized value (***Figure 5.16***) decreased dramatically with dispersal thresholds of ≤ 4 km; species in these scenarios showed high connectivity in the northwestern part of BAA and low connectivity in most of the areas. That means species in these scenarios were very sensitive to the interaction between dispersal ability and the structure of landscape resistance, will move smoothly in the northwestern part, and experience fragmentation of their populations in other parts of BAA.

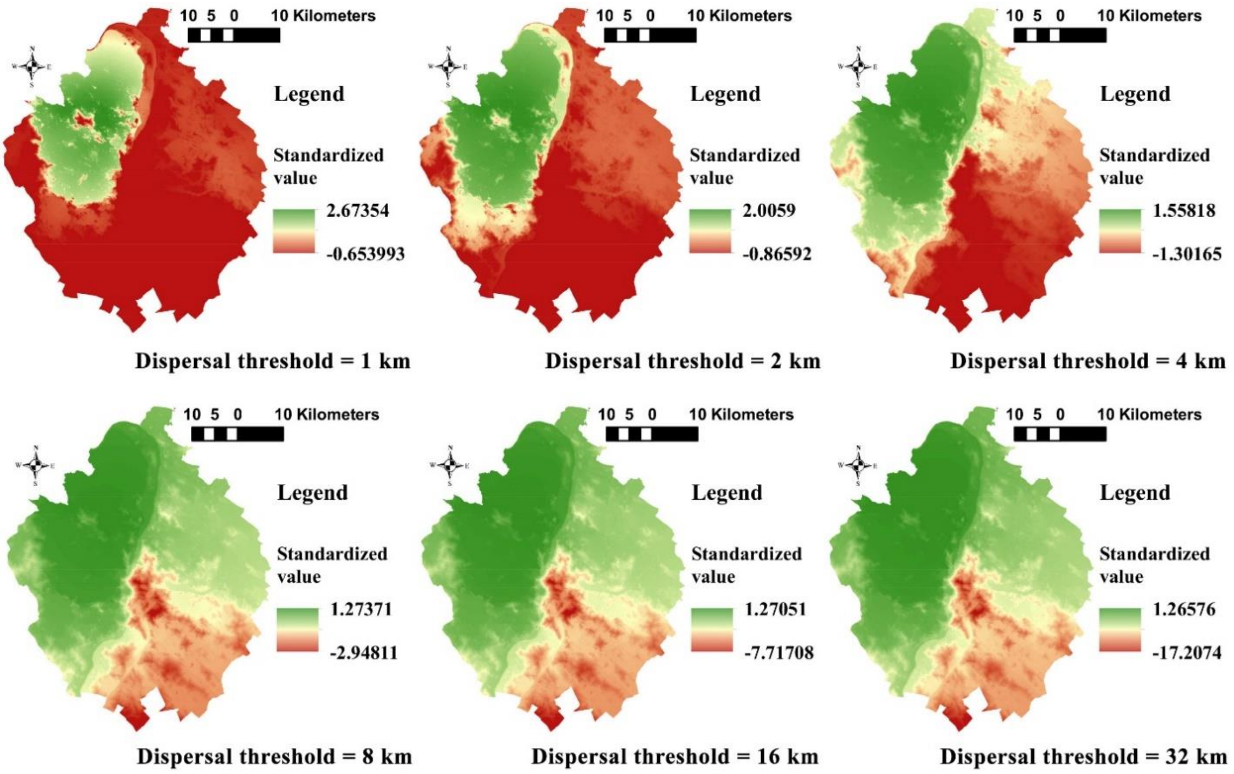
The values of the RKs (***Figure 5.15***) increased slightly and the standardized values (***Figure 5.16***) decreased slightly with dispersal thresholds ≥ 8 km. Species in these scenarios showed a network of connectivity with multiple pathways connecting the northern part of the study area. That means species whose dispersal or migration distance ≥ 8 km would move smoothly in the northern part of the study area and be affected slightly by strong connectivity. Species in these scenarios showed high connectivity levels but still were fragmented in the southern and middle parts of BAA. That means species in these scenarios would be affected slightly in the northern part of BAA, but still limited in the southern and middle parts of BAA.



Dispersal threshold = 1 km **Dispersal threshold = 2 km** **Dispersal threshold = 4 km**

Dispersal threshold = 8 km **Dispersal threshold = 16 km** **Dispersal threshold = 32 km**

Figure 5.15: UNICOR cumulative resistant kernel analysis in Budapest agglomeration area



Dispersal threshold = 1 km Dispersal threshold = 2 km Dispersal threshold = 4 km

Dispersal threshold = 8 km Dispersal threshold = 16 km Dispersal threshold = 32 km

Figure 5.16: Standardized value of the resistant kernel in Budapest agglomeration area

Fragmentation analysis of resistant kernel modeling (*Table 5.10*). PLAND of connected areas with dispersal thresholds of ≤ 4 km increased dramatically, which means species in these scenarios had very vulnerable connected areas. PLAND of connected areas with dispersal thresholds ≥ 8 km stayed unchanged and almost reached 100, which means species in these scenarios could move in most places in the study area extent. LPI and GYRATE_AM of connected areas showed the same trend with PLAND. PD of connected areas stayed unchanged with changes of dispersal thresholds. The illustration of fragmentation analysis of connected areas showed a similar trend with RK modeling, which also proved the results of RK modeling.

Table 5.10: Fragmentation indices of connected areas in Budapest agglomeration area

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	GYRATE_AM
1	61.3893	0.0004	61.3893	17158.2605
2	74.5271	0.0004	74.5271	18070.8578
4	94.0101	0.0004	94.0101	19147.1031
8	99.9965	0.0004	99.9965	19252.0385
16	99.9966	0.0004	99.9966	19252.0647
32	99.9966	0.0004	99.9966	19252.0647

5.1.5.2 Analysis of factorial least-cost path modeling

Luohe region.

Multi-dispersal scenarios have the same corridor patterns, but very different network extents and linkage (***Figure 5.13***). This means that different dispersal abilities do not influence the corridor patterns, but strongly affect how extensive and interlinked the corridor network is. The pattern is primarily driven by the source points and the resistance layer, which are consistent among scenarios. The strength, extent, and connectivity of the network are primarily driven by dispersal ability.

The number and strength of paths increased dramatically with dispersal thresholds of ≤ 2 km, with the network highly limited and localized around clusters of core patches. The number and strength of paths increased moderately at dispersal thresholds of 4 km and 8 km. The number and strength of paths stayed unchanged at dispersal thresholds of ≥ 16 km (***Figure 5.13***). This means species with short dispersal ability are very sensitive to network breakage and fragmentation.

The spatial patterns of factorial LCPs with dispersal thresholds of ≤ 2 km were different compared with other scenarios, while the spatial patterns of factorial LCPs at dispersal thresholds of 4 km and 8 km and at dispersal thresholds of ≥ 16 km were similar with different corridor strength which passed through all the core areas in the study area extent (***Figure 5.13***).

Fragmentation analysis of factorial least-cost path modeling (*Table 5.11*). PLAND of meaningful paths with dispersal thresholds of ≤ 2 km were small and increased dramatically, which means species in these scenarios had very vulnerable paths. PLAND of meaningful paths with dispersal thresholds of 4 km and 8 km increased moderately, which means species in these scenarios had a moderate connection system for species' movement. PLAND of meaningful paths with dispersal thresholds ≥ 16 km stayed unchanged, which means species in these scenarios simulated the general factorial LCPs in LR extent. LPI and GYRATE_AM of meaningful paths showed the same trend with PLAND, it proved the results of factorial LCPs. PD of meaningful paths decreased dramatically with dispersal thresholds of ≤ 2 km, and stayed unchanged with dispersal thresholds of ≥ 4 km. That means the meaningful paths were highly fragmented with dispersal thresholds of ≤ 2 km, and were aggregated with dispersal thresholds of ≥ 4 km.

Table 5.11: Fragmentation indices of meaningful paths in Luohe region

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	GYRATE_AM
1	0.3191	0.0041	0.0705	1447.9346
2	0.3651	0.0033	0.1245	3256.5647
4	0.6556	0.0004	0.6556	15145.0745
8	0.7273	0.0004	0.7273	15432.1732
16	0.7276	0.0004	0.7276	15428.7652
32	0.7276	0.0004	0.7276	15428.7652

Budapest agglomeration area.

The number and strength of paths (***Figure 5.15***) increased dramatically with dispersal thresholds of ≤ 4 km, with the network highly limited and localized around northwestern mountain areas. The pattern of factorial LCP with the dispersal threshold of 1 km was different from other scenarios, and the patterns of factorial LCPs with the dispersal threshold of 2 km started to connect the northwestern and the northeastern parts of the BAA. That means species with the dispersal threshold of 1 km only can smoothly move in the northwestern part of the BAA. The number, strength, and pattern of paths stayed unchanged with dispersal thresholds ≥ 8 km.

Fragmentation analysis of Factorial least-cost path modeling (*Table 5.12*). The PLAND of meaningful paths increased dramatically with dispersal thresholds of ≤ 4 km, while it remained unchanged with dispersal thresholds ≥ 8 km. LPI and GYRATE_AM of meaningful paths showed the same trend with PLAND. PD of meaningful paths was the largest with the dispersal threshold of 1 km, and stayed unchanged with dispersal thresholds of ≥ 2 km. That means the meaningful paths were highly fragmented with the dispersal threshold of 1 km, and were aggregated with dispersal thresholds of ≥ 2 km.

Table 5.12: Fragmentation indices of meaningful paths in Budapest agglomeration area

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	GYRATE_AM
1	2.0290	0.0012	1.7549	9209.7451
2	2.3502	0.0004	2.3502	11551.4151
4	2.6580	0.0004	2.6580	11912.6576
8	2.7267	0.0004	2.7267	11994.5351
16	2.7267	0.0004	2.7267	11994.5351
32	2.7267	0.0004	2.7267	11994.5351

Generally speaking, the values of RKs and the number and strength of factorial LCPs (***Figure 5.13, 5.15***) increased in extent and strength as the dispersal thresholds increased. This shows a scale-dependent effect on network connectivity as a function of dispersal ability, as seen in other studies (CUSHMAN et al. 2016) in which below a certain threshold of dispersal ability the network becomes rapidly attenuated and fragmented.

5.1.6 Optimization of ecological connectivity network

Optimized ecological connectivity network in Luohe region

(1) High connectivity area identification. The overlapping areas of all the kernels above the 75th percentile of every RK surface were mostly in the Yancheng district which is the central part of LR as the core areas were located equally in the study area extent (***Figure 5.17***).

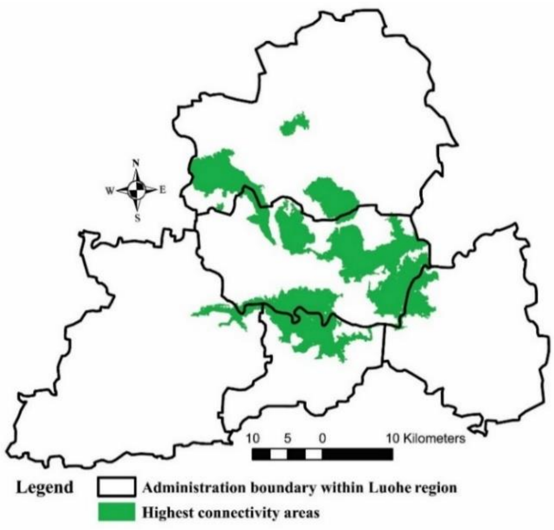


Figure 5.17: Highest connectivity areas

(2) Optimization of ecological connectivity network in species perspective. Based on the change trends of the values of RKs and standardized values of the RKs and the number and strength of factorial LCPs, species with dispersal abilities of ≤ 2 km are the first-order conservation, species with dispersal abilities of 4 km and 8 km are the second-order conservation, and species with dispersal abilities of ≥ 16 km are the third-order conservation.

(3) Optimization of ecological connectivity network in spatial perspective (*Figure 5.18*). The land use type ratio within the corridor buffer (***Table 5.13***) showed most corridors are along green space and farmland.

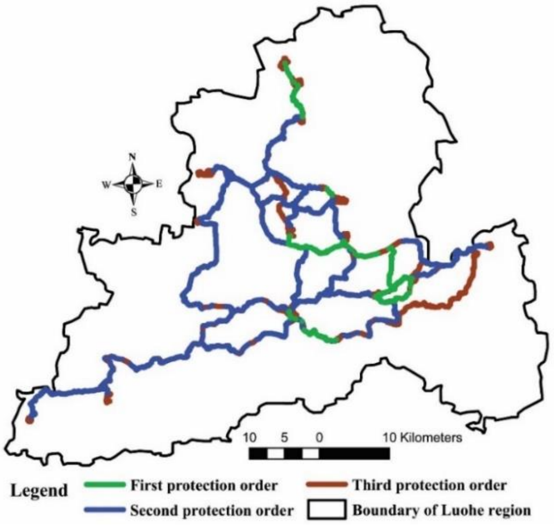


Figure 5.18: Protection priority rank in spatial perspective of Luohe region

Table 5.13: Land use type ratio within the corridor buffer in Luohe region

Land use types	The ratio (%) of first protection priority	The ratio (%) of second protection priority	The ratio (%) of third protection priority
Water surface	2.93	1.74	1.55
Farmland	33.1	35.81	28.56
Built-up area	7.83	8.28	6.2
Green space	53.37	51.97	62
Road	2.77	2.2	1.69

(4) The relation of the least-cost path by Linkage Mapper with linear elements (road and water) (*Figure 5.19*). The whole length of LCP by Linkage Mapper is 1 099 748 m in LR. The length of intersection for LCP by Linkage Mapper and road is 75 869 m, accounting for 6.90 % of the whole LCP length. The length of intersection for LCP by Linkage Mapper and water is 67 360 m, accounting for 6.13 % of the whole LCP length. The spatial patterns of the intersection of LCP by Linkage Mapper, road, and water are the same as with general ECN (LCP by Linkage Mapper).

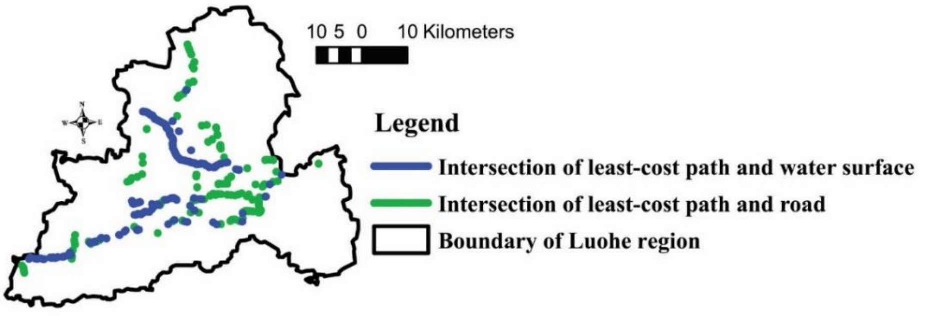


Figure 5.19: Intersection of least-cost path by Linkage Mapper with road and water surface

Optimized ecological connectivity network in Budapest agglomeration area

(1) High connectivity area identification. The overlapping areas of all the kernels above the 75th percentile of every RK surface were located in the Pilis Mountains which is the northwestern part of the study area and Buda Hills which is the western part of the study area (***Figure 5.20***) as Buda side is mostly hilly area.

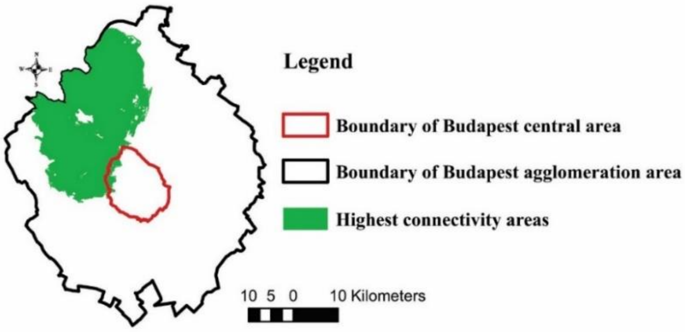


Figure 5.20: Highest connectivity areas

(2) Optimization of ecological connectivity network in species perspective. Species with dispersal abilities of ≤ 4 km are the first-order conservation, and species with dispersal abilities of ≥ 8 km are the second-order conservation.

(3) Optimization of ecological connectivity network in spatial perspective (*Figure 5.21*). The land use type ratio within the corridor buffer (***Table 5.14***) showed most corridors are along green space, while the ratio of corridors along green space was higher than that in LR, the ratio of corridors along farmland was much lower than that in LR. This was likely defined by the percentage of green space and farmland in landscape configuration.

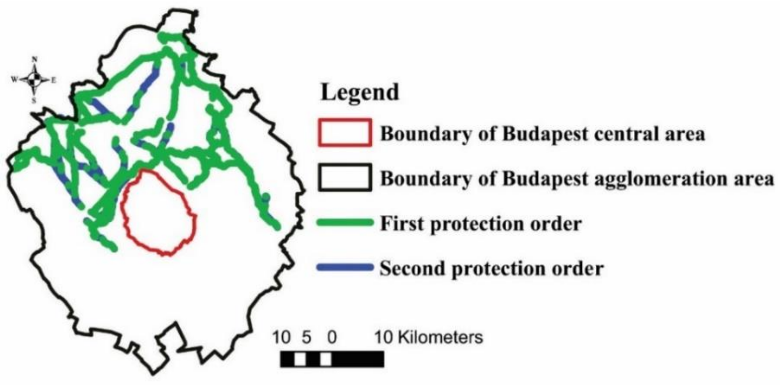


Figure 5.21: Protection priority rank in spatial perspective of Budapest agglomeration area

Table 5.14: Land use type ratio within the corridor buffer in Budapest agglomeration area

Land use types	**The ratio (%) of first protection priority**	**The ratio (%) of second protection priority**
Water surface	1.33	0.98
Farmland	7.85	6.34
Built-up area	1.60	1.30
Green space	83.98	86.54
Road	5.24	4.84

(4) The relation of the least-cost path by Linkage Mapper with linear elements (road and water) (*Figure 5.22*). The whole length of LCP by Linkage Mapper is 461 789 m in BAA. The length of intersection for LCP by Linkage Mapper and road is 252 246 m, accounting for 54.62 % of the whole LCP length. The length of intersection for LCP by Linkage Mapper and water is 23 189 m, accounting for 5.02 % of the whole LCP length. The spatial patterns of the intersection of LCP by Linkage Mapper, road, and water are the same as with general ECN (LCP by Linkage Mapper).

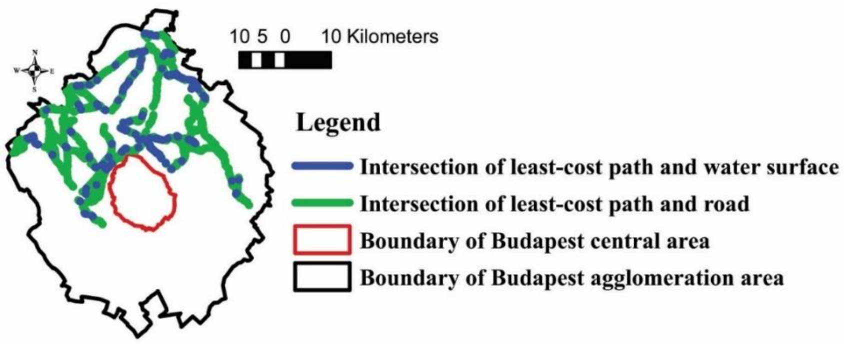


Figure 5.22: Intersection of least-cost path by Linkage Mapper with road and water surface

5.2 Results in Luohe central area and Budapest central area

5.2.1 Land use/land cover classification

Classification in Luohe central area (*Figure 5.23*). The classification results showed that built-up areas were in the center of LCA.

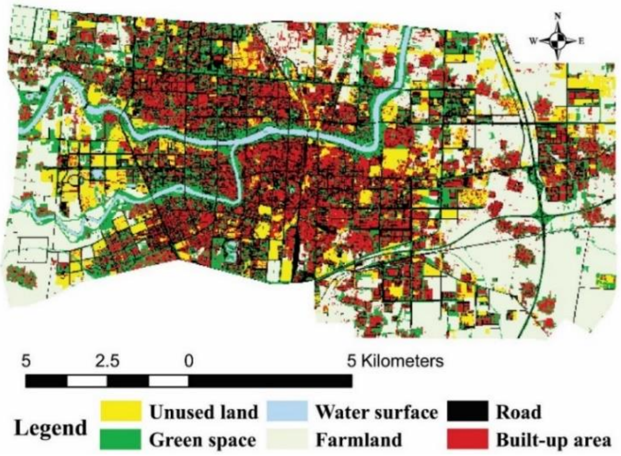


Figure 5.23: Land use/land cover classification in Luohe central area

Fragmentation analysis in Luohe central area (*Table 5.15*). According to the fragmentation analysis of land use classification, the PLAND value of farmland was the largest among land use types but was much lower than that in LR. There are no obvious dominant land use types, likely other landscape elements will also affect the ECN modeling. The PD and ED values of green space were quite large, and the GYRATE_AM and AI were quite low as well. Collectively, these metrics indicate that green space in LCA is highly fragmented.

Table 5.15: Fragmentation indices of land use classification (class metrics) in Luohe central area

Class	PLAND (%)	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Water surface	2.9170	2.4381	10.0768	590.2446	75.0099
Farmland	28.7765	1.9569	42.6726	739.5054	88.8379
Built-up area	21.0314	19.2582	113.2788	149.5855	59.7984

Green space	17.5598	21.5064	106.3976	211.7585	54.4968
Road	19.4002	18.4096	121.2544	2428.0796	53.0876
Unused land	10.3151	4.0530	34.9383	172.5047	74.9652

Classification in Budapest central area (*Figure 5.24*). The classification results showed that built-up areas were the main LULC type in BCA.

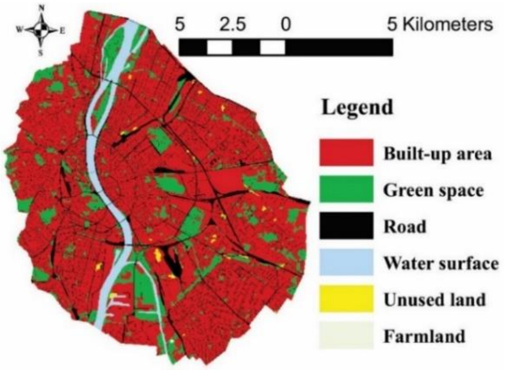


Figure 5.24: Land use/land cover classification in Budapest central area

Fragmentation analysis in Budapest central area (*Figure 5.16*). PLAND of built-up area was the largest among land use types. It means the built-up area is the main matrix land use with approximately 70% of the total land that will dominate the structure and function of landscape in BCA, and likely affect the pattern of ECN. PLAND of built-up area was much higher than that in LCA, which means the landscape in BCA is much more fragmented than that in LCA. While the PLAND of farmland was the smallest, which was the opposite situation with LCA. The PD, ED, GYRATE_AM, and AI values of green space were medium. It means the green space in BCA is highly fragmented.

Table 5.16: Fragmentation indices of land use classification (class metrics) in Budapest central area

Class	**PLAND (%)**	**PD (number / 100 ha)**	**ED (m / ha)**	**GYRATE_AM**	**AI (%)**
Water surface	5.0356	0.0252	5.7950	2196.0158	92.1903
Farmland	0.0148	0.0063	0.0492	58.8155	95.1220
Built-up area	68.5942	0.4730	108.9184	2505.7497	88.1164
Green space	13.3557	2.1379	30.7098	340.0591	82.8853
Road	12.5543	36.5458	103.0118	1044.9509	37.8380
Unused land	0.4455	0.1892	1.6895	92.3909	74.1573

5.2.2 Core area identification and prioritization

(1) The size of green space

MSPA analysis in LCA (***Figure 5.25***) indicated that Core is 1.26%, Islet is 7.80%, Perforation is 0.00%, Edge is 3.05%, Loop is 0.68%, Bridge is 1.64%, Branch is 3.14% of the extent of the analysis area. The highest ratio of Islet showed that 7.80% of green space is isolated. The Bridge and the

Loop ratio showed that 1.64% + 0.68% of the area connects the core area. The Edge and the Perforation ratio showed that 3.05% + 0.00% of green space are the outer and inner boundaries of habitat patches. The Branch ratio showed that 3.14% of green spaces only connect one end to a habitat patch. 97 core areas were selected by MSPA analysis to calculate the dPC value.

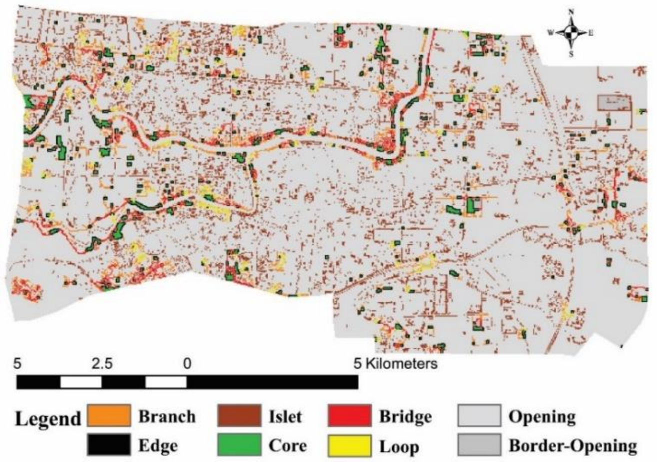


Figure 5.25: MSPA results of Luohe central area

MSPA analysis in BCA (***Figure 5.26***) showed Core comprises 5.95% of landscape extent; Islet, indicating isolated green space, accounts for 1.09%; Perforation and Edge (inner and outer green space boundary) are 0.16% and 4.33% respectively, Loop and Bridge (areas connecting green space patches) are 0.21% and 0.35% respectively, and Branch (linkages between main core areas) is 1.28%. 108 core areas were selected by MSPA analysis to calculate the dPC value.

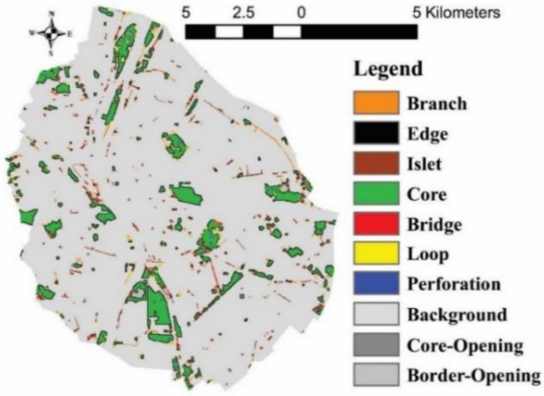


Figure 5.26: MSPA results of Budapest central area

(2) Degree of Probability of Connectivity (dPC)

Conefor analysis in LCA showed there are 32 core areas with a value of dPC greater than 2, which were chosen for the first protection order, and there were 97 – 32 = 65 core areas to be the second protection order. The core areas were located equally in LCA (***Figure 5.27***).

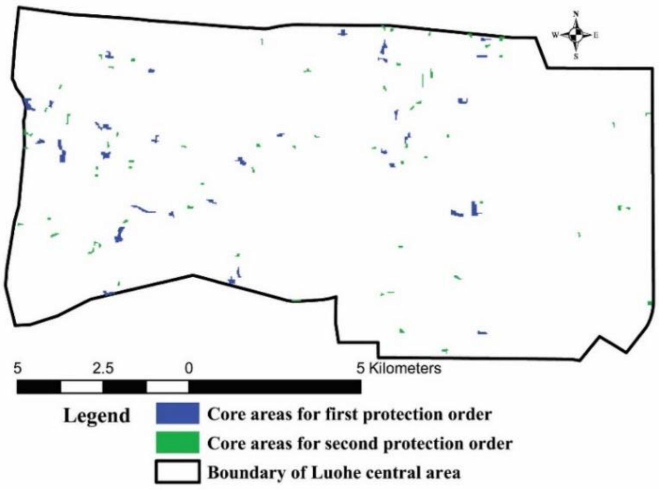


Figure 5.27: Location of core areas of Luohe central area

25 important core areas were selected in BCA with a value of dPC greater than 2, and 108 – 25 = 83 core areas were the second protection order. Core areas were located equally in BCA (***Figure 5.28***).

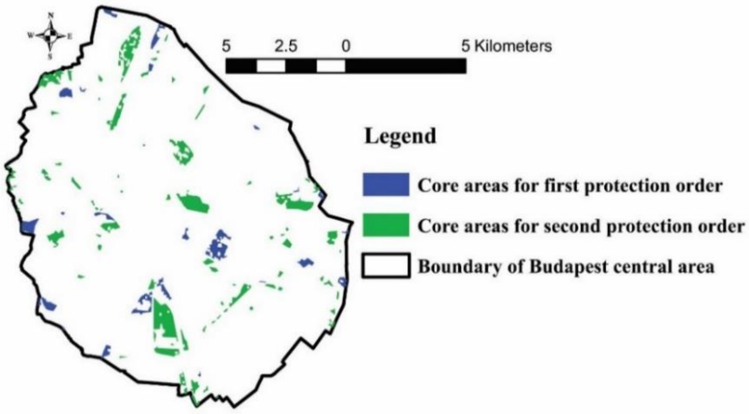


Figure 5.28: Location of core areas of Budapest central area

(3) Fragmentation analysis of MSPA analysis and Conefor analysis

After selecting green space core areas using Conefor, I reanalyzed fragmentation on this subset in LCA (***Table 5.17 and 5.18*)**. The ED decreased, and the GYRATE_AM and AI increased for the core area green space subset compared to the full green space mosaic. This shows our selection was successful to do the next analysis.

Table 5.17: Fragmentation indices of MSPA results (class metrics) in Luohe central area

TYPE	PLAND (%)	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core	7.1927	13.8848	42.2279	66.6716	56.2831
Islet	44.3929	115.0457	0.0000	66.3382	38.7611
Edge	13.6389	18.9339	58.1432	72.2032	42.9297
Loop	4.5896	3.2097	10.8843	110.8794	42.7689

Bridge	12.2984	6.1670	35.0763	156.9079	45.1301
Branch	17.8876	47.8576	29.5260	56.3836	38.7658

Table 5.18: Fragmentation indices of important core areas (landscape metrics) in Luohe central area

TYPE	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core Areas	34.8981	0.0000	99.9425	75.3532

I reanalyzed fragmentation on MSPA results and important core areas in BCA (***Table 5.19 and 5.20***). The PD and ED decreased, AI of the core area green space was larger than that in the whole landscape. This shows our selection was robust enough to support the next analysis.

Table 5.19: Fragmentation indices of MSPA results (class metrics) in Budapest central area

TYPE	PLAND (%)	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core	45.5265	11.8162	98.9336	263.2202	83.8614
Islet	7.2684	11.5232	0.0146	61.2148	53.9678
Perforation	1.0635	1.3183	5.6542	50.9792	49.5575
Edge	29.4076	21.3375	108.7039	165.9803	48.5023
Loop	3.2343	5.3222	13.6521	52.8333	43.8250
Bridge	5.1503	6.3475	20.6539	82.1861	45.0549
Branch	8.3494	26.5132	15.3220	48.6255	40.5442

Table 5.20: Fragmentation indices of important core areas (landscape metrics) in Budapest central area

TYPE	PD (number / 100 ha)	ED (m / ha)	GYRATE_AM	AI (%)
Core Areas	10.1937	0.0000	227.1033	91.7083

5.2.3 Resistance surface

High resistance areas were mostly concentrated in the central part of LCA, while low resistance areas were located in the edge areas of LCA because of the surrounding of farmland (***Figure 5.29***). Areas in BCA were full of high resistance areas, and only some green spaces and farmland as low resistance areas were distributed equally in the BCA (***Figure 5.30***). This situation will definitely impede the ECN mapping in this area.

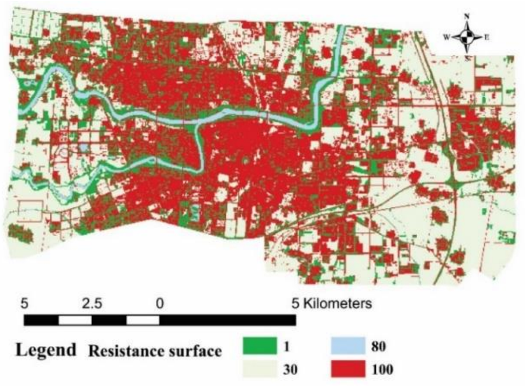


Figure 5.29: Resistance surface in Luohe central area

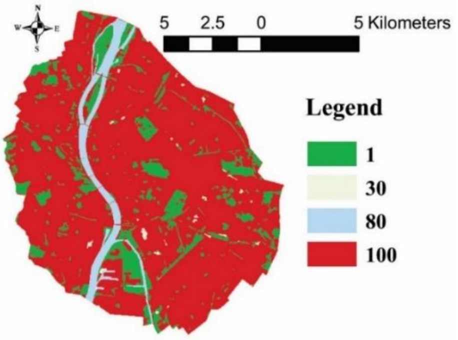


Figure 5.30: Resistance surface in Budapest central area

5.2.4 UNICOR cumulative resistant kernel analysis

5.2.4.1 Analysis of resistant kernel modeling

(1) Identification of extent and connectivity of habitat

Results in Luohe central area.

Barriers analysis (*Figure 5.31 and 5.32*). Barriers were defined by the resistance of land use and the distance between core areas and the targeted location. The resistance of land use and the distance between core areas and the targeted location defined areas of the barriers. After intersecting all the barriers for all the scenarios, the barrier areas of numbers 1, 2, 3, 4, and 6 were defined by the high resistance of built-up areas in these areas. The barrier areas of numbers 5 and 7 were defined by the distance between core areas and these locations which were mostly farmland in these areas.

Fragmentation analysis of barriers (*Table 5.21*). PLAND of barriers decreased gradually as dispersal thresholds increased, meaning that the areas where species could not move or appear were reduced because their dispersal ability was expanding. As dispersal thresholds increased, both the LPI and GYRATE_AM decreased, indicating that the barriers became fragmented. The NP of barriers increased with dispersal thresholds ≤ 4 km and decreased with dispersal thresholds ≥ 8 km.

Fracture zones analysis (*Figure 5.31 and 5.32*). Fracture zones connected barriers and core habitat patches. There were no intersected areas for fracture zones as they were usually linear areas, but there were plenty of blank areas between barriers and core habitat patches.

Fragmentation analysis of fracture zones (*Table 5.22*). The PLAND, LPI, and GYRATE_AM of fracture zones exhibited an opposite trend compared to barriers; they increased as dispersal thresholds increased. This implies that the fracture zones became more aggregated as the species' dispersal ability increased. The NP of fracture zones increased with dispersal thresholds ≤ 2 km and decreased with dispersal thresholds ≥ 4 km.

Core habitat patches analysis (*Figure 5.31 and 5.32*). Core habitat patches represent the highest connectivity area. These areas were in the same location as the core areas.

Fragmentation analysis of core habitat patches (*Table 5.23*). PLAND and LPI of core habitat patches showed the same trend with fracture zones as they represent the predicted connectivity areas. GYRATE_AM of core habitat patches increased with dispersal thresholds ≤ 8 km and decreased with dispersal thresholds at 16km. The NP of core habitat patches decreased with dispersal thresholds ≤ 8 km and increased with dispersal thresholds at 16 km.

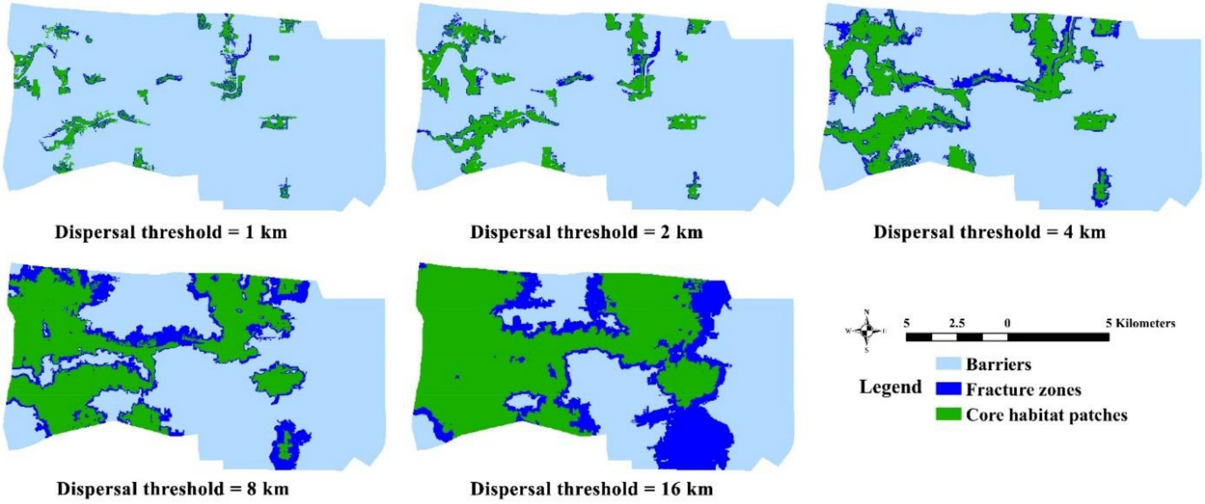


Figure 5.31: Habitat connectivity for the resistant kernels in Luohe central area

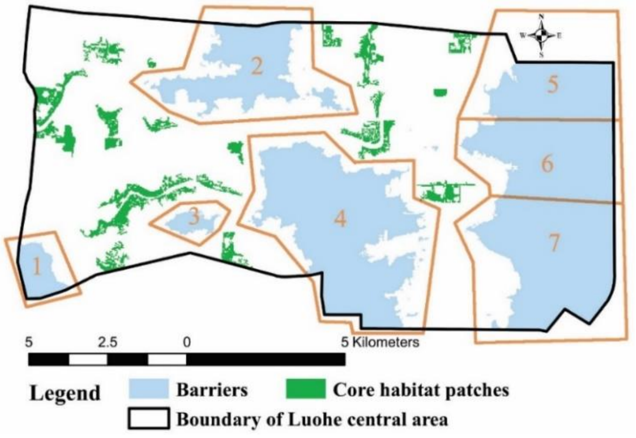


Figure 5.32: Intersections of habitat connectivity in Luohe central area

Table 5.21: Fragmentation indices of barriers in Luohe central area

Dispersal threshold (km)	PLAND (%)	NP	LPI (%)	GYRATE_AM
1	93.1087	87.0000	92.8140	5391.7403
2	88.3387	95.0000	87.9169	5340.8664
4	76.9629	116.0000	71.2548	4578.0246
8	58.7266	78.0000	44.5478	3253.2658

16	19.6960	61.0000	13.2190	2520.9074

Table 5.22: Fragmentation indices of fracture zones in Luohe central area

Dispersal threshold (km)	PLAND (%)	NP	LPI (%)	GYRATE_AM
1	2.1522	372.0000	0.2582	196.9798
2	2.8834	492.0000	0.2508	214.4430
4	6.6468	368.0000	1.0504	564.6197
8	12.4273	110.0000	5.0846	1811.9282
16	43.6530	1.0000	43.6530	4486.7831

Table 5.23: Fragmentation indices of core habitat patches in Luohe central area

Dispersal threshold (km)	PLAND (%)	NP	LPI (%)	GYRATE_AM
1	4.7392	25.0000	0.4434	380.0559
2	8.7779	17.0000	2.0724	816.0539
4	16.3902	12.0000	5.2453	1203.2896
8	28.8461	6.0000	18.6450	2043.6510
16	36.6510	44.0000	19.1215	1930.1650

Results in Budapest central area.

Barriers analysis (*Figure 5.33 and 5.34*). Overlapping barriers were defined by the high resistance of built-up areas only in BCA.

Fragmentation analysis of barriers (*Table 5.24*). PLAND of barriers in BCA was larger than that in LCA at the same dispersal threshold level which was caused by the high PLAND of built-up area in BCA. PLAND of barriers in BCA decreased with the dispersal thresholds increased, which means species with large dispersal ability can move more areas than those with small dispersal ability. NP of barriers fluctuated with dispersal threshold changes. LPI and GYRATE_AM of barriers decreased with the dispersal thresholds increased.

Fracture zones analysis (*Figure 5.33 and 5.34*). There were small amounts of intersected areas for fracture zones, and there were plenty of blank areas between barriers and core habitat patches.

Fragmentation analysis of fracture zones (*Table 5.25*). PLAND, LPI, and GYRATE_AM of fracture zones showed the same increase trend with fracture zones in LCA. It means the fracture zones were more aggregated as well in BCA. The NP of fracture zones fluctuated with dispersal threshold changes.

Core habitat patches analysis (*Figure 5.33 and 5.34*). These areas were in the same location as the core areas.

Fragmentation analysis of core habitat patches (*Table 5.26*). PLAND of core habitat patches showed the same trend as that in LCA. It was lower than that in LCA at the same dispersal threshold level. That means high resistance areas of the built-up areas affected the species' movements. NP of core habitat patches stayed unchanged with the dispersal threshold $\leq$ 8 km. LPI and

GYRATE_AM of core habitat patches in BCA were higher than that in LCA with the dispersal threshold of 1 km, and lower than that in LCA with other dispersal thresholds, because the dense built-up area affected the largest patches of high connectivity areas and the continuity of high connectivity areas.

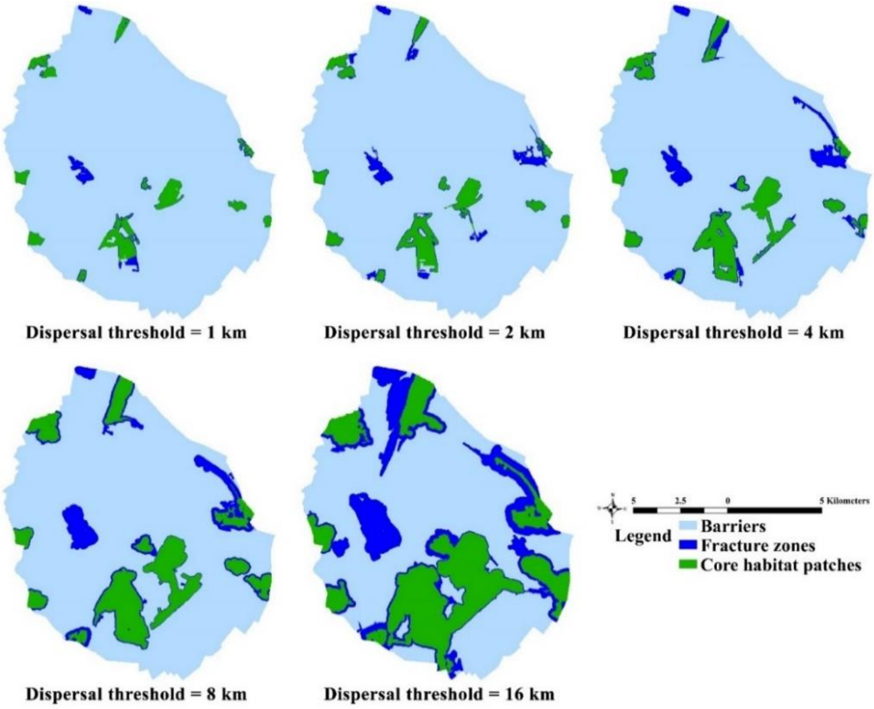


Figure 5.33: Habitat connectivity for the resistant kernels in Budapest central area

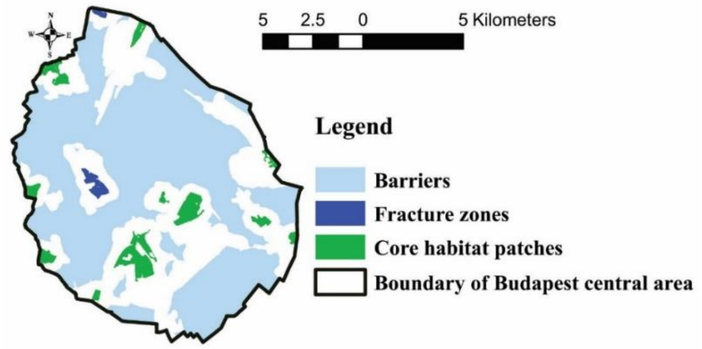


Figure 5.34: Intersections of habitat connectivity in Budapest central area

Table 5.24: Fragmentation indices of barriers in Budapest central area

Dispersal threshold (km)	PLAND (%)	NP	LPI (%)	GYRATE_AM
1	94.2232	18.0000	94.0506	4831.5390
2	91.6237	21.0000	91.4483	4826.1600
4	86.8713	19.0000	86.7675	4813.8906
8	79.4281	9.0000	79.4134	4808.1983
16	58.5395	17.0000	47.4082	3485.2609

Table 5.25: Fragmentation indices of fracture zones in Budapest central area

Dispersal threshold (km)	PLAND (%)	NP	LPI (%)	GYRATE_AM
1	1.5359	240.0000	0.5296	284.6625
2	3.0689	101.0000	0.7112	424.0622
4	4.9130	133.0000	1.4014	711.7907
8	7.2060	41.0000	1.8043	888.4777
16	17.5098	23.0000	4.6825	1862.7833

Table 5.26: Fragmentation indices of core habitat patches in Budapest central area

Dispersal threshold (km)	PLAND (%)	NP	LPI (%)	GYRATE_AM
1	4.2409	11.0000	1.3599	462.4484
2	5.3074	11.0000	1.9076	540.9975
4	8.2157	11.0000	2.7641	760.1147
8	13.3659	11.0000	3.9742	864.8060
16	23.9507	8.0000	13.9664	1569.2006

(2) Resistant kernel evaluation

Luohe central area.

Sum value for the resistant kernel. RKs represent landscape connectivity (COMPTON et al. 2007). The sum value for RK represents the whole connectivity of the landscape in every scenario. The whole connectivity of every scenario increased dramatically with dispersal thresholds increased (***Figure 5.35***). That means the connectivity was very sensitive to the species' dispersal ability.

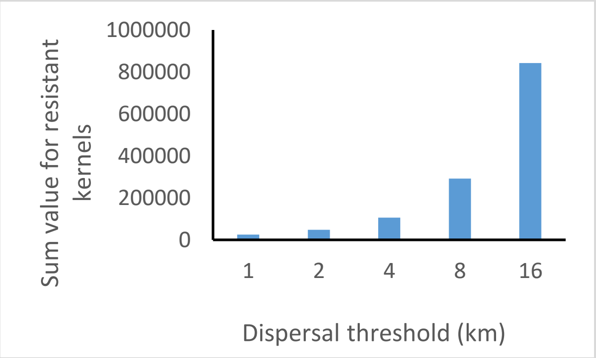


Figure 5.35: Sum value for resistant kernels in Luohe central area

Resistant kernel modeling. The values of the RKs (***Figure 5.36***) increased slightly and smaller increase than that in LR and the standardized values (***Figure 5.37***) decreased slightly and smaller decrease than that in LR with dispersal thresholds of ≤ 2 km, as LCA has more high resistance areas including built-up area and road than that in LR, and high resistance areas impede species' movement. That means the functional connectivity networks of species with dispersal abilities ≤ 2 km were very sensitive to the interaction between dispersal ability and landscape resistance.

The value of the RK (***Figure 5.36***) and the standardized value (***Figure 5.37***) were moderate with dispersal thresholds of 4 km, but the values of RKs were much lower than that in LR as the connectivity in LCA was lower than that in LR.

The values of the RKs (***Figure 5.36***) increased rapidly and the standardized values (***Figure 5.37***) decreased moderately with dispersal thresholds ≥ 8 km. That means species with dispersal abilities ≥ 8 km were still sensitive to landscape configuration.

Generally speaking, high connectivity areas were mostly located along the Sha-Li river for all scenarios as there are plenty of parks along the Sha-Li river.

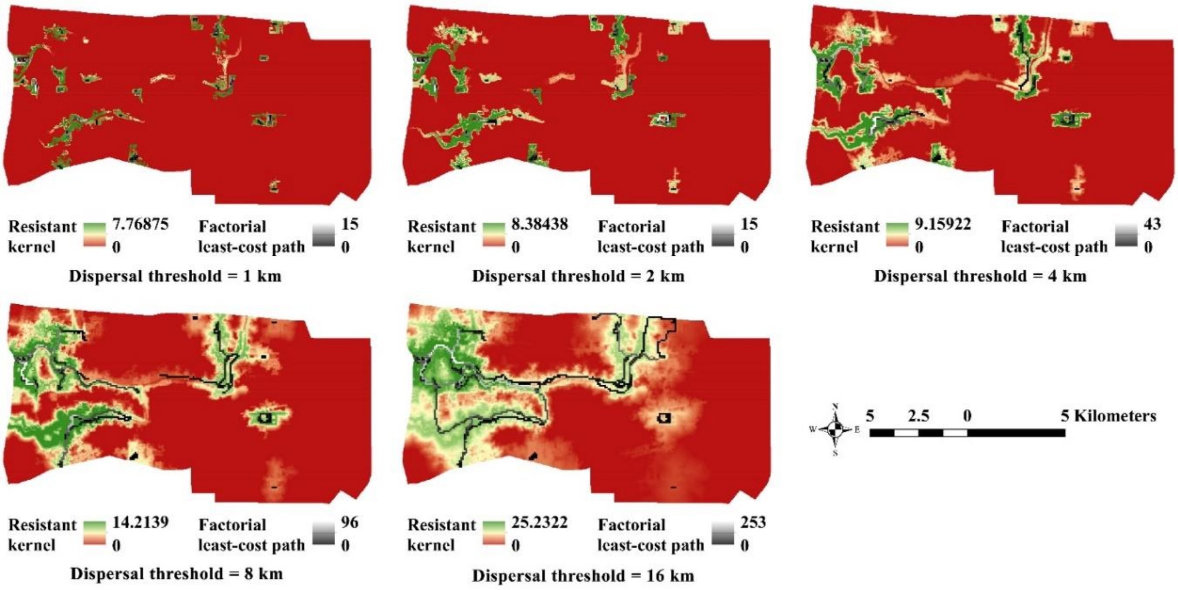


Figure 5.36: UNICOR cumulative resistant kernel analysis in Luohe central area

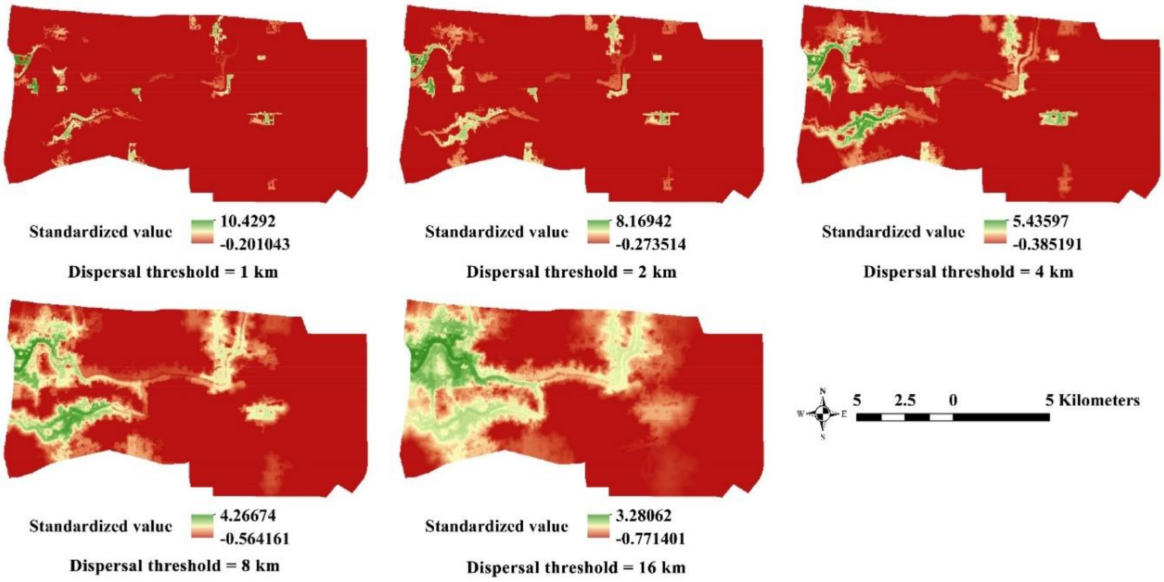


Figure 5.37: Standardized value of the resistant kernel in Luohe central area

Fragmentation analysis of resistant kernel modeling (*Table 5.27, 5.28 and 5.29*). The values of PLAND, LPI, AREA_AM, and GYRATE_AM increased for all connectivity areas except the AREA_AM and GYRATE_AM decreased with the dispersal thresholds ≥ 8 km for low connectivity areas. PD decreased for all connectivity areas with the dispersal threshold increased except the PD decreased with the dispersal thresholds ≥ 8 km for low connectivity areas. That means the predicted connectivity increased with the dispersal threshold increased.

Table 5.27: Fragmentation indices of low connectivity areas

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	4.7586	0.1583	0.4440	40.4710	379.7884
2	9.0224	0.1077	2.0946	190.2796	816.7272
4	17.2771	0.0697	5.5770	613.5194	1217.1720
8	33.9831	0.0317	29.1430	3975.6092	3609.2103
16	45.4375	0.2976	21.6789	2515.3487	2045.6826

Table 5.28: Fragmentation indices of medium connectivity areas

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	2.9358	0.1457	0.3642	35.4632	367.6539
2	5.4482	0.1203	1.3571	103.5934	545.3003
4	11.5188	0.0760	3.6682	397.0181	1048.3907
8	26.2961	0.0380	17.5911	2105.8072	2057.0948
16	46.3756	0.0127	46.2884	7295.5418	4553.2493

Table 5.29: Fragmentation indices of high connectivity areas

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	1.2733	0.0697	0.2479	22.2032	244.8479
2	2.3271	0.0633	0.5905	58.7469	462.5557
4	5.7594	0.0570	1.7686	196.2179	795.2474
8	17.0696	0.0317	7.2208	852.2473	1400.7946
16	38.1267	0.0127	36.0680	5405.4060	3865.3259

Budapest central area.

Sum value for the resistant kernel modeling (*Figure 5.38*). The sum value for RK represents the whole connectivity of every scenario in BCA. The whole connectivity of every scenario increased steadily with dispersal thresholds increased, and the sum values of RKs in BCA were bigger than that in LCA with the dispersal thresholds ≤ 2 km and smaller than that in LCA with the dispersal thresholds ≥ 4 km as the landscape was highly fragmented because of the high ratio of built-up area and road in BCA.

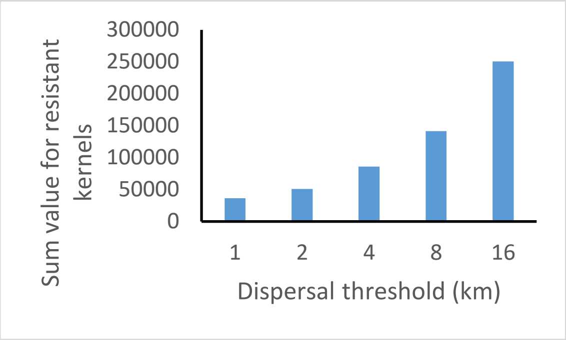


Figure 5.38: Sum value for resistant kernels in Budapest central area

Resistant kernel modeling.

The values of the RKs (***Figure 5.39***) increased moderately and the standardized values (***Figure 5.40***) decreased moderately with dispersal thresholds of ≤ 2 km, and smaller changes than that in BAA as BCA has more high resistance areas including the built-up area and road than that in BAA. That means species with dispersal abilities ≤ 2 km had very vulnerable connected areas.

The values of the RKs (***Figure 5.39***) increased slightly and the standardized values (***Figure 5.40***) decreased slightly with dispersal thresholds of 4 km and 8 km. That means species with dispersal distances at 4 km and 8 km would be affected intermediately by landscape configuration.

The value of the RK (***Figure 5.39***) was the largest and the standardized value (***Figure 5.40***) was the smallest with dispersal threshold of 16 km. That means species with dispersal abilities at 16 km were not highly sensitive to landscape configuration.

Generally speaking, the connectivity in BCA was higher than that in LCA with dispersal abilities of ≤ 2 km, and the connectivity in BCA was lower than that in LCA with dispersal thresholds ≥ 4 km. That means the high resistance areas make species with short dispersal abilities have higher connectivity and make species with long dispersal abilities have lower connectivity.

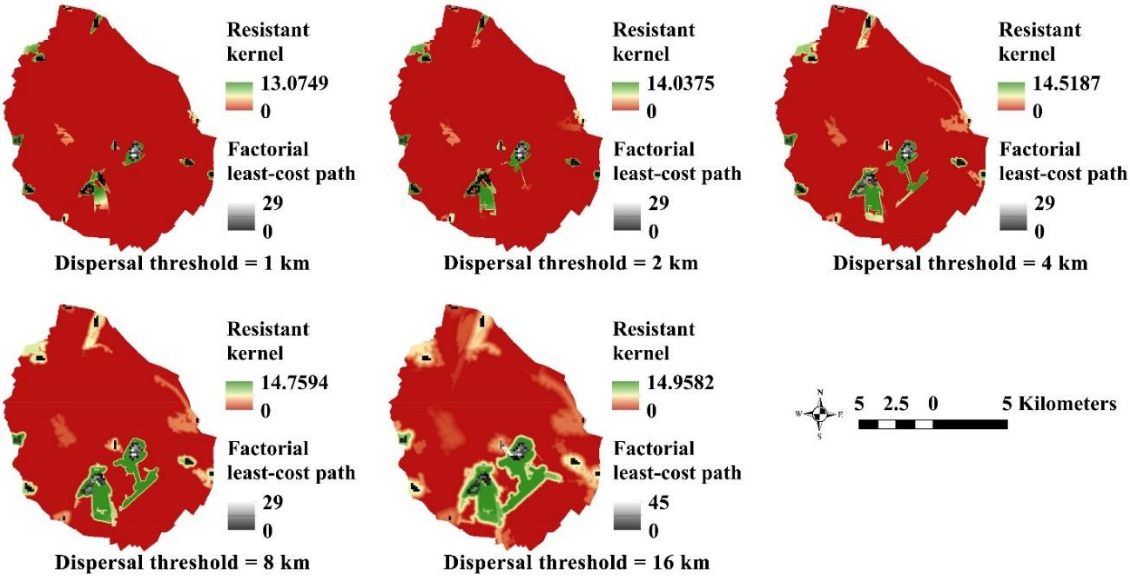


Figure 5.39: UNICOR cumulative resistant kernel analysis in Budapest central area

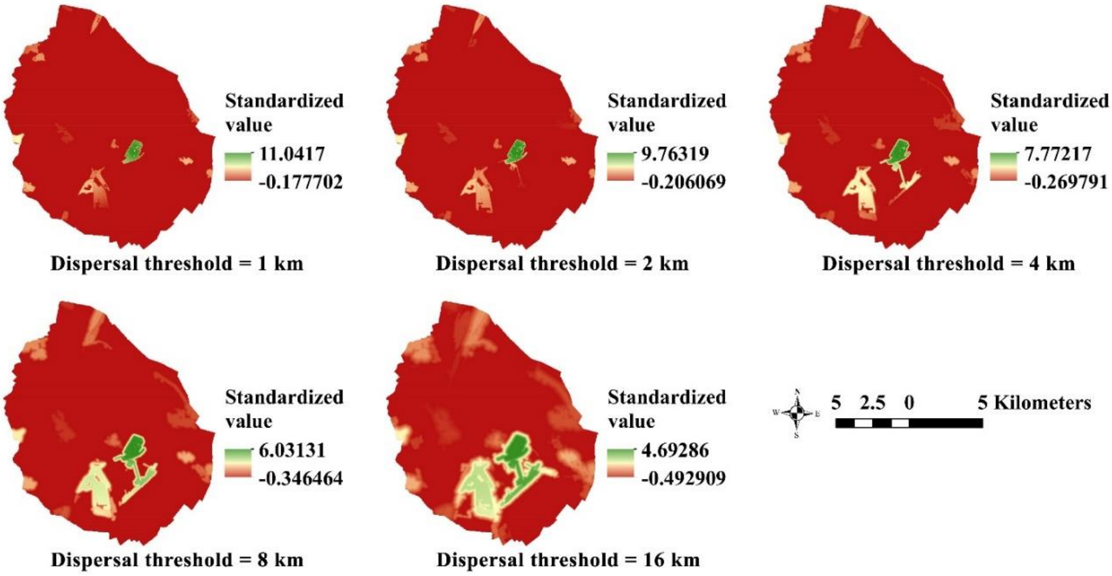


Figure 5.40: Standardized value of the resistant kernel in Budapest central area

Fragmentation analysis of resistant kernel modeling (*Table 5.30, 5.31 and 5.32*).

The values of PLAND, LPI, AREA_AM, and GYRATE_AM increased for all connectivity areas. That means the predicted connectivity of connected areas increased with the dispersal threshold increased. PD stayed unchanged for low connectivity areas with the dispersal threshold ≤8 km. PD generally decreased but stayed unchanged with 2 km ≤ the dispersal threshold ≤8 for medium connectivity areas. PD vibrated for the high connectivity areas with the dispersal threshold increased.

Table 5.30: Fragmentation indices of low connectivity areas

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	4.5440	0.0820	1.5058	127.1292	474.4158
2	5.7802	0.0820	1.9826	166.5877	546.2347
4	9.8464	0.0820	2.8725	254.9593	742.9597
8	15.6555	0.0820	4.1581	386.1136	881.3554
16	29.4891	0.0568	15.5585	1490.3055	1616.1224

Table 5.31: Fragmentation indices of medium connectivity areas

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	3.0842	0.0631	0.7969	72.5368	382.4588
2	4.5605	0.0568	1.7164	157.6967	537.4976
4	6.5640	0.0568	2.4082	249.0320	746.8687
8	10.3986	0.0568	3.6898	399.0167	907.3238
16	17.7737	0.0378	12.3732	1424.0692	1630.9046

Table 5.32: Fragmentation indices of high connectivity areas

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	0.8536	0.0126	0.6635	88.4912	401.4554
2	1.0988	0.0126	0.8763	117.9669	442.1414
4	3.2823	0.0189	1.5393	228.5507	764.7667
8	5.2853	0.0189	2.5189	379.0383	995.0486
16	8.7226	0.0126	8.4149	1289.0008	1884.5205

5.2.4.2 Analysis of factorial least-cost path modeling

Luohe central area.

Sum value for the factorial least-cost path (*Figure 5.41*). Factorial LCP represents the minimum cost routes for all pairs of source points (CUSHMAN et al. 2009). The sum value for factorial LCP represents the whole corridor strength of every scenario. The whole corridor strength of every scenario increased dramatically with dispersal thresholds increased as the RK did. That means the corridor strength was very sensitive to the species' dispersal ability.

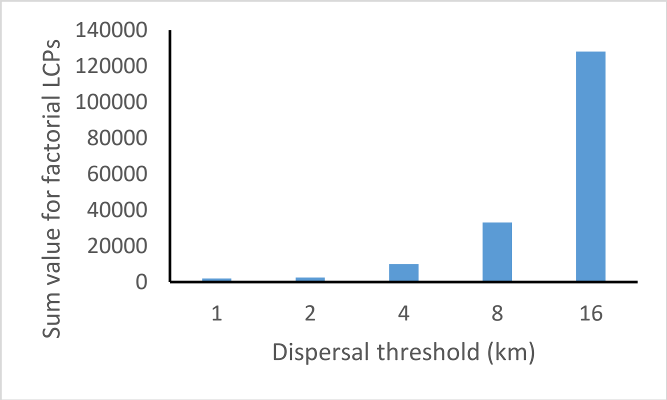


Figure 5.41: Sum value for factorial least-cost paths in Luohe central area

Factorial least-cost path modeling. The number of factorial LCPs stayed unchanged (***Figure 5.36***) and the strength of factorial LCPs (***Figure 5.41***) increased slightly with dispersal thresholds of ≤ 2 km and were lower than those in LR. That means the ECN of species with dispersal abilities ≤ 2 km were not so sensitive to the landscape configuration because of high resistance areas including built-up areas and roads which was proved in RK modeling in LCA and in BCA as well.

The number and strength of factorial LCP (***Figure 5.36 and 5.41***) were moderate with dispersal threshold of 4 km which were much lower than that in LR as the connectivity in LCA was lower than that in LR.

The number and strength of factorial LCPs (***Figure 5.36 and 5.41***) increased largely with dispersal thresholds ≥ 8 km. That means species with dispersal abilities ≥ 8 km were sensitive to landscape configuration.

Generally speaking, the change trends between factorial LCP modeling and RK modeling were synchronous in the same level of species' dispersal limits.

Fragmentation analysis of factorial least-cost path modeling (*Table 5.33, 5.34 and 5.35*). The values of PLAND, LPI, AREA_AM, and GYRATE_AM increased for all factorial LCPs with the dispersal thresholds increased. That means species could have more optimal potential routes to move with the dispersal thresholds increased. PD decreased for low connectivity paths; PD increased with the dispersal threshold of ≤ 4 km and decreased with the dispersal threshold of ≥ 8 km for medium connectivity paths; PD increased with the dispersal threshold of ≤ 8 km and turned to be smaller at the dispersal threshold of 16 km for high connectivity paths.

Table 5.33: Fragmentation indices of low connectivity paths

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	0.1698	0.2660	0.0456	3.0449	151.9883
2	0.2069	0.2596	0.0484	4.2290	182.0018
4	0.4702	0.2090	0.1402	13.2529	521.3010
8	0.8663	0.1203	0.4024	42.7672	1158.7549
16	1.6249	0.0570	1.5714	240.1774	3822.0846

Table 5.34: Fragmentation indices of medium connectivity paths

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	0.0450	0.1583	0.0085	0.8601	74.9673
2	0.0638	0.2027	0.0148	1.1571	95.1208
4	0.3112	0.2090	0.1020	10.0681	474.0638
8	0.7210	0.1520	0.3710	40.3477	1169.5981
16	1.4882	0.1077	1.4443	221.3712	3896.5980

Table 5.35: Fragmentation indices of high connectivity paths

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM

1	0.0034	0.0317	0.0011	0.1200	15.0000
2	0.0148	0.0570	0.0091	0.9346	75.1571
4	0.1522	0.1773	0.0490	3.8080	291.4553
8	0.4753	0.1900	0.1932	19.0949	853.9616
16	1.2003	0.0823	0.8635	105.7781	1823.3899

Budapest central area.

Sum value for the factorial least-cost path (*Figure 5.42*). The whole corridor strength of every scenario increased steadily with dispersal thresholds increased as the RK did. The corridor strength was not so sensitive to the species' dispersal ability ≤ 2 km in BCA as that in LCA because of the higher ratio of built-up areas and roads in BCA, which also proved the high resistance surface will not affect short-distance dispersal thresholds when the high resistance surface dominate the landscape configuration.

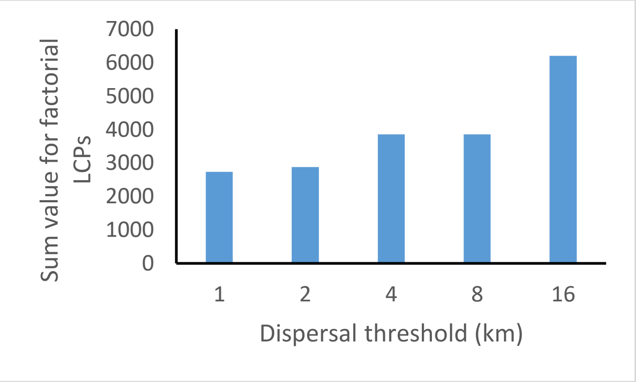


Figure 5.42: Sum value for factorial least-cost paths in Budapest central area

Factorial least-cost path modeling (*Figure 5.39 and 5.42*). The number of factorial LCPs stayed unchanged, and the strength of factorial LCPs increased slightly with dispersal thresholds of ≤ 2 km. The number and strength of factorial LCPs stayed unchanged with dispersal thresholds of 4 km and 8 km. The number and strength of factorial LCP was the largest with the dispersal threshold of 16 km.

Generally speaking, the change trends between factorial LCP modeling and RK modeling were synchronous in the same level of species' dispersal limits in BCA as well. A higher ratio of built-up area and road impedes species' movement and makes the species with short-distance dispersal abilities not so sensitive to landscape configuration.

Fragmentation analysis of factorial least-cost path modeling (*Table 5.36, 5.37 and 5.38*). The values of PLAND and GYRATE_AM increased generally for all factorial LCPs with the dispersal thresholds increased, only stayed unchanged with the dispersal thresholds of 4 km and 8 km. The values of LPI for all factorial LCPs stayed unchanged with dispersal thresholds of ≤ 8 km, and turned bigger with dispersal threshold of 16 km. The values of AREA_AM for the low connectivity paths generally increased, and only stayed unchanged with the dispersal thresholds of 4 km and 8 km. The values of AREA_AM for the medium connectivity paths decreased with dispersal thresholds of ≤ 2 km, stayed unchanged with the dispersal thresholds of 4 km and 8 km, and turned bigger with dispersal threshold of 16 km. The values of AREA_AM for the high connectivity paths decreased with dispersal thresholds of ≤ 2 km, stayed unchanged with the dispersal thresholds of 4 km and 8 km, and turned bigger with the dispersal threshold of 16 km.

Table 5.36: Fragmentation indices of low connectivity paths

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	0.3360	0.1198	0.1652	15.2957	243.8583
2	0.3644	0.1135	0.1652	17.1620	320.8098
4	0.4058	0.1135	0.1652	19.3518	328.2964
8	0.4058	0.1135	0.1652	19.3518	328.2964
16	0.4819	0.1072	0.2497	27.8198	393.9087

Table 5.37: Fragmentation indices of medium connectivity paths

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	0.1884	0.2396	0.1198	12.3972	211.7942
2	0.2066	0.2270	0.1198	11.7074	226.5416
4	0.2622	0.1955	0.1198	14.8227	333.5635
8	0.2622	0.1955	0.1198	14.8227	333.5635
16	0.3457	0.1892	0.2038	23.7117	407.3679

Table 5.38: Fragmentation indices of high connectivity paths

Dispersal threshold (km)	PLAND (%)	PD (number / 100 ha)	LPI (%)	AREA_AM	GYRATE_AM
1	0.0692	0.0883	0.0585	7.8639	227.1420
2	0.0715	0.1135	0.0585	7.6171	220.4073
4	0.1357	0.1261	0.0585	7.3096	291.9051
8	0.1357	0.1261	0.0585	7.3096	291.9051
16	0.1941	0.1135	0.1186	13.8100	392.1961

5.2.5 Optimized ecological connectivity networks

Protection priority in species perspective in Luohe central area

Based on the change trends of the values of RKs and the standardized values of RKs and the number and strength of factorial LCPs, species with dispersal abilities of ≤ 2 km are the first-order conservation, species with dispersal ability of 4 km are the second-order conservation, and species with dispersal abilities of ≥ 8 km are the third-order conservation.

Protection priority in species perspective in Budapest central area

Species with dispersal abilities of ≤ 2 km are the first-order conservation, species with dispersal abilities of 4 km and 8 km are the second-order conservation, and species with dispersal ability of 16 km are the third-order conservation.

6. DISCUSSION

My main results showed the differences in the predictions produced by cumulative resistant surface, resistant kernel, least-cost path and factorial least-cost path; The connectivity, assessed both by the factorial least-cost path, and resistant kernel methods, was highly sensitive to dispersal ability. An important product of our analysis is a quantitative and objective prioritization of ecological connectivity network design and protection importance. Moreover, I identified four aspects to discuss: (1) I compared the mapping methods of ecological connectivity networks. (2) I showed the setting principles of the dispersal thresholds. (3) I explained the green spaces along rivers in these two study areas. (4) Finally, I summarized the scope and limitations of this dissertation.

6.1 Comparison of mapping methods

(1) **Core area and source points.** LCP analysis used individual habitat patches as core areas or linkage zones, resulting in the selection of 17 and 23 core areas as sources in LR and BAA respectively for the LCP to produce simplified ECNs. UNICOR analyses converted habitat patches into sets of source points, which has the major advantage of weighting core areas proportional to their size (or the population size of the species that they support). This resulted in the conversation of the 17 core areas into 875 source points with 100 m resolution in LR, the 23 core areas into 794 source points with 200 m resolution in BAA, the 32 core areas into 103 source points with 100 m resolution in LCA, and the 25 core areas into 64 source points with 200 m resolution in BCA. UNICOR analysis predicted the routes of highest potential connectivity linking all pairs of source points, greatly improved the utility of LCP analysis by enabling it to account for the density and distribution of a source population and the dispersal ability of the species in predicting spatially synoptic patterns of ECN strength, as distribution and density of the source population being modeled have dominant effects on predictions of connectivity (e.g., CUSHMAN et al. 2013b, 2016, 2018).

(2) **Cumulative resistant surface and resistant kernel.** Cumulative resistant surfaces only reflect the total cost of species movement across the landscape from source locations. This is limited given that it doesn't account for the density of source points for the dispersal ability of the species. RK analysis (COMPTON et al. 2007) greatly improves this by explicitly combining the influences of both dispersal ability and the density and distribution of the source population, resulting in the calculation of the incidence function of expected movement rates through every cell in the landscape (e.g., CUSHMAN et al. 2014, KASTZA et al. 2018). It resolved the limitations of traditional cost-distance and cumulative resistance analysis by enabling explicit accounting for the

influences of spatially varying distribution and density of the focal species population as well as the critical influences of its dispersal ability. Similar to CUSHMAN et al. (2016) and (2013b), my results showed a very strong dependence on the predicted extent and connectivity of the ECN depending on the dispersal threshold employed in RK analysis. Importantly, my results show that species with dispersal abilities ≤ 2 km cannot traverse among green area patches across most of the landscape in LR, BAA, LCA, and BCA; the connectivity of the green area network increases rapidly and non-linearly with increasing dispersal ability (like seen by CUSHMAN et al. 2016 for lions in Southern Africa) in the areas where the ratio of high resistance surface is not high, such as LR and LCA; the connectivity of ECN increases steadily and no-linearly with increasing dispersal ability in the areas where the ratio of high resistance surface is high, such as BAA and BCA.

(3) **Least-cost path and factorial least-cost path.** LCPs were raster paths by cost path and vector paths by Linkage Mapper that only showed the spatial pattern of ECNs without the corridor strength. LCPs showed the optimal network of linkages among the source locations and passed through all the core areas because they do not consider species' dispersal limits. Factorial LCPs, in contrast, provide much richer information including the strength of corridors and the influence of dispersal threshold on the extent and strength of the corridor network, accounting for the distribution and density of the source population, the dispersal ability of the species and the resistance of the landscape. Different dispersal abilities had the same pattern of corridors, but the extent and connectivity of the network were highly sensitive to dispersal ability. Depending on dispersal ability, factorial LCPs did not connect all the source pixels because of the high density of built-up areas but passed through the central area in the LR thanks to the green space along the rivers. Factorial LCPs did not connect all the source pixels and did not pass through the central area in the BAA because there were only a few core areas in the BCA.

(4) Given the above comparisons I strongly favor the combined use of factorial LCP and RK analysis over traditional cumulative resistance and LCP analyses (for example implemented by cost path or by Linkage Mapper) given they provide much more biologically rigorous, scale-dependent predictions that account for the density and distribution of the source population, the dispersal ability of the species and the resistance of the landscape. When applied in combination these two methods enable rigorous prediction of the most important core areas and the strongest corridor linkages among them given particular distributions and dispersal abilities of the target organisms. This combined approach has been used productively in the United States (CUSHMAN et al. 2013b, 2014), Africa (CUSHMAN et al. 2016, 2018), Southeast Asia (KASTZA et al. 2020a) and Western Asia (KHOSRAVI et al. 2018, ASHFRADZADEH et al. 2020).

6.2 The setting principles of the dispersal thresholds

The longest dispersal threshold I set was 32 km in LR and in BAA based on the change trend of factorial LCP modeling and the spanning areas of them, which span 76 km from east to west and 64 km from north to south in LR, and 60 km from east to west and 72 km from north to south in BAA. The corridor strength and the spatial patterns of factorial LCPs stayed unchanged with dispersal thresholds ≥ 16 km, therefore, there is no necessity to explore a larger dispersal threshold than 32 km at the region level. The longest dispersal threshold I set was 16 km in LCA and in BCA based on the spanning areas of them, which span 19 km from east to west and 10 km from north to south in LCA and 15 km from east to west, and 17 km from north to south, therefore, there is no necessary to explore much larger dispersal threshold than 16 km in the central area level. Different scales might have different change trends in different study areas which contain different LULC types, this is why I only chose the study area extents to do analysis.

6.3 Green spaces along rivers

There are plenty of green spaces along the Sha-Li river (***Figure 6.1***). With a high density of residential communities along the Sha-Li river, these green spaces greatly fulfill the requirements for entertainment, communication, and interaction for human beings.

Figure 6.1: Green spaces along Sha-Li river

Banks of the Danube – the World Heritage site (***Figure 6.2***). The castle and beautiful buildings along the banks of the Danube exhibit a strong architectural unity with the rows of residential homes on the Danube embankment (WHB 1995-2018. They preserve the characteristics of the architectural heritage created by consecutive layers of historical periods (UNESCOWHC 1992-

2024). There is a scarcity of green space along the Danube to protect the architecture view of the banks of the Danube (***Figure 6.3***), and large trees may obstruct the city views of buildings along the Danube.

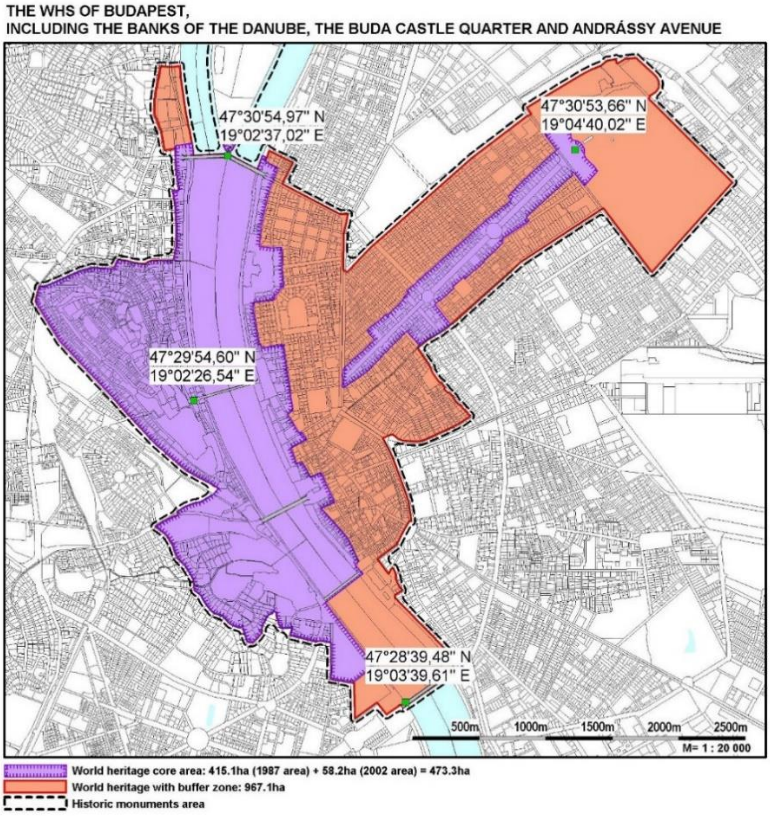


Figure 6.2: World Heritage sites of Budapest (UNESCOWHC 2008)

Figure 6.3: City view along the Danube

6.4 Scope and limitations

(1) The analysis produced here identifies the most critical, scale-dependent linkages among the main green-space core areas in the LR, BAA, LCA, and BCA and prioritizes them based on their importance. This provides an unprecedented quantitative means to guide landscape planning to promote ecological sustainability, human health, and biodiversity in urban landscapes. This analysis evaluated connectivity in a synoptic (CUSHMAN et al. 2014), scale-dependent (CUSHMAN et al. 2016) manner. Several recent research efforts have shown that scale-dependent

synoptic analysis is critical to providing rigorous predictions of functional connectivity and evaluation of ECN (e.g., CUSHMAN et al. 2013c, 2014, 2016, 2018, KASATA et al. 2018, KHOSRAVI et al. 2018, ASHFRADZADEH et al. 2020). This is a strength of my analysis. I based my analysis on a classified land use map that was extremely accurate, which is also a strength. However, the functional connectivity of ecological processes or biological processes is not the same as the structural connectivity of a LULC map. My analysis assumed expert values for the resistance of different land use classes, which is not ideal and may not reflect the actual resistance experienced by different organisms (e.g., MATEO-SÁNCHEZ et al. 2015a, b, SHIRK et al. 2010, WASSERMAN et al. 2010, ZELLER et al. 2018). And it assumes that LULC is the main determinant of the resistance surface, which can only be used for rough estimations. It would be desirable, therefore, to conduct empirical optimization of both the distribution and density of the source populations of species of interest (given the dominant effect this has on connectivity predictions; e.g., CUSHMAN et al. 2013b), the resistance of the landscape for their movement (e.g., CUSHMAN et al. 2006, CUSHMAN, LEWIS 2010), and their dispersal abilities (e.g., CUSHMAN et al. 2014, 2016). This would best be done through extensive biodiversity monitoring networks deployed across the green-space network (e.g., LUCID et al. 2018, 2019, 2021, ROBINSON et al. 2017), coupled with telemetry studies of dispersal in focal taxa (e.g., CUSHMAN, LEWIS 2010, ELLIOT et al. 2014) or landscape genetics (e.g., CUSHMAN et al. 2006, SHIRK et al. 2010, WASSERMAN et al. 2010, MATEO-SÁNCHEZ et al. 2015b, ZELLER et al. 2018). These datasets and connectivity analyses based on them would allow for data-driven assessment of ECN effectiveness, as has been done for several species in the United States (e.g., WASSERMAN et al. 2012, 2013, CUSHMAN et al. 2009, 2012b, 2013c) and Europe (RUIZ-GONZÁLEZ et al. 2014). In the present, however, the current analyses provide a robust and informative assessment of the patterns of ECN connectivity in a synoptic, scale-dependent manner, enabling localization and prioritization of land use actions to enhance the extensiveness, strength, and resilience of the green space network in the LR, BAA, LCA, and BCA.

(2) The resolution of the Landsat 8 images I used is low. Higher-resolution satellite images do not necessarily provide a better land use classification (IRONS et al. 1985), but increase the internal variability within the same LULC type (CARLEER et al. 2005, CUSHNIE 1987, WOODCOCK, STRAHLER 1987, APLIN et al. 1997, THOMAS et al. 2003). This might reduce the accuracy of land use classification (IRONS et al. 1985) in LR and in BAA. In future research, I should employ high-resolution images to examine how image resolution affects land use classification results. I defined five classes of land use for general species in LR and in BAA, however, I will further specify green space types (e.g. forest, grassland, shrubland, orchard, urban green area) based on specific species in future in-depth research.

(3) Running UNICOR analysis requires a substantial amount of installed RAM. I currently have

128 GB of installed RAM, which can efficiently handle 17 core areas with 875 source points at a 100 m resolution in LR, and 23 core areas with 794 source points at a 200 m resolution in BAA. If analysis requires running data for additional core areas with higher resolutions, it is advisable to upgrade the installed RAM accordingly.

(4) Road coverage on OpenStreetMap. I applied the same filters for the road data in OpenStreetMap, but observed different road densities in LR **(*Figure 4.3*)** and in BAA **(*Figure 4.6*)**. Two main reasons account for this disparity: 1) OpenStreetMap coverage is significantly better in BAA compared to LR. 2) Data availability on OpenStreetMap is much higher in BAA due to China's stringent national security concerns, restricting the capture of extensive data from China. Consequently, the intersection of LCP in LR is less accurate than the reality.

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

(1) Cost-distance or cumulative resistance methods that do not account for source point distribution and density or the dispersal ability of the species are also very limited and potentially misleading. Resistant kernel modeling, such as those implemented in UNICOR, resolves the limitations of traditional cost-distance and cumulative resistance analysis by enabling explicit accounting for the influences of spatially varying distribution and density of the focal species population as well as the critical influences of its dispersal ability.

(2) The LCP analysis provided a simple and easy-to-understand illustration of potential paths connecting habitat patches, but grossly underpredicted areas where the species may be used for movement because the results only contained very narrow paths and lacked the consideration of species' dispersal limit. Factorial LCP analysis, such as those implemented in UNICOR, greatly improves the utility of LCP analysis by enabling it to account for the density and distribution of a source population and the dispersal ability of the species in predicting spatially synoptic patterns of ECN strength.

(3) The combination of factorial LCP and RK analysis jointly provides complementary and synergistic information that provides a strong suite of methods for comprehensive assessment of ECN extensiveness, effectiveness, and prioritization of landscape scenarios to optimize ECN in the future.

(4) RK analysis predicted the density of dispersal movement across the landscape, revealing that the extensiveness of kernel connectivity was highly dependent on dispersal ability. For small dispersal abilities of ≤ 2 km in LR, LCA, and BCA, and dispersal abilities of ≤ 4 km in BAA, high levels of fragmentation were observed. As dispersal ability increased, kernel connectivity produced broader extents of interconnected habitat.

(5) Factorial LCPs predict the routes of the highest potential connectivity linking all pairs of source points, revealing the optimal network of linkages among the source locations. Different dispersal abilities exhibit the same pattern of corridors, but the extent and connectivity of the network are highly sensitive to dispersal ability. Depending on dispersal ability, factorial LCPs in LR, BAA, LCA, and BCA do not connect all ecological nodes due to the high density of built-up areas. Factorial LCPs in LR pass through the LCA, and factorial LCPs in LCA eventually connect the west and northeast parts, thanks to the green spaces along the rivers. Factorial LCPs in BAA pass through the northwest part, where the mountain area is located. However, factorial LCPs in BCA

face significant restrictions due to the high density of built-up areas.

(6) The mapping of core habitat patches, barriers, and fracture zones in LCA and BCA indicates that all species are restricted from moving extensively within the study area extend due to the high density of built-up areas.

7.2 Planning recommendations

(1) Recommendations in Luohe region

Species with dispersal abilities of ≤ 2 km which is the first-order conservation in species perspective were very vulnerable. In future planning, planners should consider species of short dispersal abilities and build stepping stones strategically across the region to enable linkage among the green space network to meet their biodiversity requirements, such as additional roadside green spaces, residential area green spaces, transport corridors, and river corridors.

Species with dispersal abilities of 4 km and 8 km which is the second-order conservation were moderately sensitive, planners should build parks or gardens in the areas where linkage is most limited between the core areas to protect species with medium dispersal abilities in future planning.

Species with dispersal abilities of ≥ 16 km, which is the third-order conservation could move smoothly in the study area extent, planners could choose a few conservation areas with complete ecosystem functionality to conserve long-distance dispersal species. Species with large dispersal ability, however, generally also have larger body sizes and lower population densities, so their ability to persist is likely limited by the small extent and generally small size of green space patches. For these species with high vagility but large habitat area requirements, conservation strategies should focus on increasing the extent of green space as much as possible with less concern about where it is located.

In the southeastern and the northeastern parts of the region, the connectivity is the lowest at all dispersal scenarios (***Figure 5.13 and 5.14***), because of limited green space in these intensively agricultural areas, and because built-up areas of LCA and Linying county may act as movement barriers inhibiting species to move to the southeast and northeast. Planners should consider more about how to increase the connectivity in intense built-up areas. In the central area, there is still high connectivity even if there is the most intense built-up area, the plenty of green space along the Sha-Li river in the central area results in the consequences.

(2) Recommendations in Budapest agglomeration area

Species with dispersal abilities of ≤ 4 km which is the first-order conservation were very sensitive, planners should consider species of short dispersal abilities in northeastern, southeastern, and southwestern parts of the BAA and build small parks in these areas.

Species with dispersal abilities ≥ 8 km which is the second-order conservation would move smoothly in the northern part of the study area, planners should build parks or gardens in the southern and middle parts of BAA where linkage is most limited between the core areas and protected the existing high connectivity northern part of BAA to protect medium dispersal abilities' species in future planning.

The northwestern part of BAA had high connectivity with dispersal thresholds ≤ 4 km because there are Buda Hills and Pilis Mountains in that area. The southern and middle parts of BAA had low connectivity with dispersal thresholds ≥ 8 km because there are farmlands in the southern part of BAA and built-up areas in the middle part of BAA. Planners should consider carefully to build green space in the southern and middle parts of BAA to enhance the integral connectivity of the whole area.

(3) Recommendation of protection priority in spatial perspective in Luohe region and Budapest agglomeration area

First protection priority is very urgent and important to protect as most species pass through these areas, planners should firstly preserve these areas if there is a budget in urban planning. And then planners should preserve other areas based on the protection priorities correspondingly.

(4) Recommendations in Luohe central area

Recommendations in barrier. Planners should build small green areas along the roads and residential areas to enhance the ratio of green space in these areas in **barrier** 1, 2, 3, 4, and 6. Planners should build productive plantation areas to provide the diversity of species in **barrier** 5 and 7. Meanwhile, planners also need to consider building green areas for environmental protection along the highway in **barrier** 7 (***Figure 5.31 and 5.32***).

Recommendations in fracture zones. Planners should build small linear green areas in dense residential areas for short-distance dispersal species, and build parks in medium residential areas for medium-distance dispersal species, and build conservation areas for long-distance dispersal species as **fracture zones** to connect barriers and core habitat patches.

Recommendations in core habitat patches. Planners should build buffer zones of green space to protect existing high connectivity areas.

High connectivity areas were mostly located along the Sha-Li river for all scenarios. Planners should protect the existing park system along the Sha-Li river and enhance the connectivity in other areas.

(5) Recommendations in Budapst central area

Recommendations in barrier. Planners should build small parks in dense residential areas to meet short-distance dispersal species in **barriers** areas.

Recommendations in fracture zones. Planners should build more linear green areas along rivers and roads compared to the situation in LCA to increase the ratio of green space as much as possible in dense residential areas in **fracture zones**.

Recommendations in core habitat patches. Planners should build buffer zones of green space to protect existing high connectivity areas in **core habitat patches**.

8. NEW SCIENTIFIC RESULTS

Thesis 1: Different mapping methods resulted in different core areas, resistant surfaces, and corridors

The LCP analysis provided a simple and easy-to-understand illustration of potential paths without the consideration of species limits; UNICOR analysis considered the species' limitations to model enriched information of corridors for multi-dispersal thresholds. **I have determined that UNICOR analysis is more suitable for the illustration of corridor strength which assesses the sections of pathways differently, pixel by pixel.**

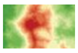
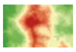
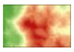
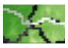
a) **Different source parameters (*Table 8.1*).** LCP analysis only takes into account resistance surfaces and core areas when predicting connectivity. In contrast, UNICOR analysis goes further by considering the distribution and density of the source population, as well as the dispersal limits of the species. This enhancement allows for the utilization of novel methodologies in analyzing ECN.

b) **Different resistance surface outcomes (*Table 8.1*).** The outcomes of resistance surfaces, including cumulative resistance surfaces and RKs, highlight how UNICOR analysis improves the understanding of connectivity by additionally considering the species' limitations. It provides a more detailed view compared to the LCP analysis.

c) **Different corridors (*Table 8.1*).** The analyses of LCPs and factorial LCPs provide a more comprehensive understanding of corridors by considering not just the spatial patterns but also the corridor strength. The extent and strength of the corridors for multi-dispersal thresholds add depth to the analysis.

Overall, these elements illustrate advancements in refining methodologies, understanding ecological connectivity, and offering a more detailed insight into corridors.

Table 8.1: Comparison of mapping methods (small Figures here from ***Figure 5.11, 5.12, 5.15***)

Comparison items	**LCP analysis by cost path**	**LCP analysis by Linkage Mapper**	**UNICOR**
Source parameter	The central point of core area polygon 	Core area polygon 	The set of source points of core area pixels 
Resistance surface outcome	Whole cost map (Cumulative resistance surface) 	Whole cost map (Cumulative resistance surface) 	Connectivity map (Resistant kernel) 
Corridor type	Raster corridor without corridor strength 	Vector corridor without corridor strength 	Raster corridor with corridor strength 

Thesis 2: Different ratios of the highest resistance surfaces (including built-up areas and roads) affected the whole landscape connectivity distinctly for species with different dispersal abilities, and also affected the ratio of low, medium, and high connectivity areas and low, medium, and high connectivity paths differently

The lower ratio of the impervious surfaces affected the whole connectivity largely, and the higher ratio of the impervious surfaces affected the whole connectivity intermediately. **I have defined that the different ratios of the highest resistance surfaces affected the whole landscape connectivity distinctly for species with different dispersal abilities, and also affected the ratio of low, medium, and high connectivity areas and low, medium, and high connectivity paths differently.**

a) **Impact of different ratios of the highest resistance surfaces on landscape connectivity between Luohe city and Budapest city.** The results reveal that in both Luohe City and Budapest City, a higher ratio of the highest resistance surfaces is associated with lower landscape connectivity. The ratio of the highest resistance surfaces in LR and BAA was lower than that in LCA and BCA, respectively. Correspondingly, the landscape connectivity in LR and BAA was higher than that in LCA and BCA at the same dispersal threshold. This proves that the higher the ratio of impervious surfaces, the lower the landscape connectivity. The summed values of RKs and factorial LCPs in the BCA are higher than that in the LCA with dispersal abilities ≤ 2 km, and the summed values of RKs and factorial LCPs in the LCA are higher than that in the BCA with dispersal abilities ≥ 4 km. This relationship is notably influenced by the ratio of built-up areas and roads, which is below 50% in LCA and above 80% in BCA.

b) **Impact of different ratios of the highest resistance surfaces on the ratio of low, medium, and high connectivity areas and low, medium, and high connectivity paths.** The ratio of low and high connectivity areas in the BCA was lower than that in the LCA with all the dispersal thresholds except medium connectivity areas with dispersal threshold of 1 km. The ratio of low, medium, and high connectivity paths in LCA was lower than that in BCA with dispersal thresholds ≤ 2 km. The ratio of low, medium, and high connectivity paths in LCA was higher than that in the BCA with dispersal thresholds ≥ 4 km.

In summary, the findings provide evidence about the complex interplay between the highest resistance surfaces and landscape connectivity, highlight the importance of considering urban characteristics (such as built-up areas and roads) when studying and planning landscape connectivity in urban environments.

Thesis 3: Landscape fragmentation largely affected landscape connectivity for species with different dispersal abilities

Landscape fragmentation decreased, and landscape connectivity increased with the dispersal thresholds increased. The number of connected areas and meaningful paths increased dramatically with short-dispersal abilities, and stayed stable with large-dispersal abilities. **I have defined that landscape fragmentation largely affected landscape connectivity for species with different dispersal abilities.**

a) **Relationship between landscape fragmentation and landscape connectivity in LR.** Values of PLAND, LPI, and GYRATE_AM of connected areas and meaningful paths increased dramatically with dispersal abilities of ≤ 2 km, these three values increased moderately with dispersal abilities at 4 km and 8 km, and these three values stayed unchanged with dispersal abilities ≥ 16 km.

b) **Relationship between landscape fragmentation and landscape connectivity in BAA.** The values of PLAND, LPI, and GYRATE_AM of connected areas and meaningful paths increased dramatically with dispersal abilities of ≤ 4 km, and these three values stayed unchanged with dispersal abilities of ≥ 8 km.

These conclusions collectively indicate how landscape fragmentation affects landscape connectivity among different species with multi-dispersal abilities in both the connected areas and meaningful paths. Lower dispersal abilities lead to fragmented and vulnerable connected areas and paths, while higher dispersal abilities result in highly connected areas and more aggregated paths. The fragmentation indices across different dispersal thresholds further enhance these findings, contributing to a better understanding of species movement and landscape connectivity.

Thesis 4: The landscape connectivity defined the protection priority in species perspective

Different species have different dispersal abilities, and the patterns of ECN are different for species with different dispersal abilities. **I have determined that species' dispersal ability defined the predictable connectivity of ECN, and the connectivity defined the protection priority in species perspective.**

> **Hierarchy of conservation prioritization based on the dispersal abilities in different regions.** Protection priority in species perspective only considers the species dispersal ability. Across these study areas, there's a consistent trend of categorizing species with short dispersal abilities (≤ 2 km) as first-order conservation priorities. The hierarchy shifts based on the specific dispersal abilities observed in LR, BAA, LCA, and BCA, with higher dispersal abilities resulting in species being placed in second or third-order conservation priorities. The conservation prioritization hierarchy differs between regions, indicating that the conservation status in species perspective varies based on the local landscape context and the range of dispersal abilities observed in those areas.

These conclusions emphasize the importance of defining conservation strategies in species perspective within specific geographical regions. Understanding the hierarchical importance of conservation prioritization based on species' movement capacities aids in establishing effective conservation plans based on the unique characteristics of each area.

Thesis 5: The connectivity defined the protection priority in spatial perspective

LCPs illustrate the general spatial pattern of ECN, while factorial LCPs represent spatial pattern of ECN for species with different dispersal abilities. The determination of protection priorities in spatial perspective involves intersecting LCPs with factorial LCPs. **I have determined that the connectivity defined the protection priority in spatial perspective.**

> The determination of protection priorities in spatial perspective takes into account not only the species' dispersal abilities but also the spatial pattern of ECN. Intersecting LCPs with factorial LCPs for species with short dispersal abilities results in the first protection priority. These networks are deemed the most crucial and urgent for addressing the spatial movement needs of species, as they are expected to be heavily utilized by a majority of species. On the other hand, LCPs alone, factorial LCPs alone, or the intersection of LCPs with factorial LCPs for species with large dispersal abilities result in the identification of second or third protection priorities. These networks are considered less important and less urgent to protect, as only a small number of species are expected to utilize them.

These conclusions highlight the establishment of protection priorities based on the usage of ECN in spatial perspective. It emphasizes the urgency and importance of protecting these identified networks, varying based on the expected species movement and the impact of different dispersal scenarios on their habitat utilization.

Thesis 6: The spatial arrangement of land use/land cover types significantly affected ecological connectivity networks and the highest connectivity areas

Corridors passed through the lowest resistance surface and avoided the highest resistance surface. The location of the highest connectivity areas was in the areas with the cluster of core areas. **I have defined that the location of the lowest resistance surface (core areas) and the highest resistance surface (built-up areas) significantly affected the spatial pattern of ecological connectivity networks and the spatial distribution of the highest connectivity areas.**

a) **The relationship between core areas & built-up areas and the spatial pattern of ECN.** In LR, core areas were evenly distributed throughout the entire area, while built-up areas were primarily concentrated in LCA, and in the northern and southwestern residential areas. Despite the high density of built-up areas in LCA, the LCPs traversed this area due to the presence of 25 core areas here, indicating the importance of these core areas for connectivity. In BAA, core areas were distributed around the edge of the area, and built-up areas were mainly located in BCA. However, despite the high density of built-up areas in BCA, the LCPs did not pass through this area due to the three core areas present there.

b) **The relationship between core areas & built-up areas and spatial distribution of highest connectivity areas.** In LR, the highest connectivity areas were concentrated in the Yancheng district. This spatial distribution correlates with the even distribution of core areas across the region, emphasizing their influence on connectivity. In BAA, the highest connectivity areas were located in the Pilis Mountains and Buda Hills. These areas exhibit the highest connectivity due to the natural landscape elements and the presence of core areas contributing to the connectivity.

These conclusions highlight the significant influence of core areas in facilitating connectivity, even in areas with high densities of built-up regions. They also emphasize the spatial disparities in ECN, which are influenced by the spatial distribution of core areas and built-up areas across the study areas.

Thesis 7: Linear elements of the landscape (water surfaces and roads) contributed to the spatial pattern of the ecological connectivity networks

After 1990, the Chinese government implemented policies aimed at improving ecosystem management and conservation, leading to the establishment of extensive green spaces along transportation and riparian corridors (PENG et al, 2017). These efforts contributed to shaping the landscape and potentially influenced the formation of ECNs. Budapest, as a capital city in the European Union, made substantial efforts to integrate local parks or gardens into the Pan European Ecological Network, indicating deliberate steps toward establishing a connected ECN within the city. The pattern of the intersection of LCPs with roads and water surfaces is the same with the pattern of LCPs in both the LR and the BAA. **I have determined that linear elements of the landscape (water surfaces and roads) contributed to the spatial pattern of the ecological connectivity networks.**

a) **Ratio of intersected LCPs with roads and water surfaces.** In LR, the ratio of intersected LCPs and roads (6.90%) was higher than that of intersected LCPs and water surfaces (6.13%). This suggests a relatively higher contribution of roads to the formation of LCPs in LR. However, in BAA, the contribution of roads to LCPs was significantly higher, with a much larger ratio of intersected LCPs and roads (54.62%) compared to water surfaces (5.02%). This highlights the dominant contribution of roads to the spatial pattern of ECN in BAA.

b) **Similarity between the intersection spatial pattern of LCPs with roads & water surfaces and general ECNs spatial patterns.** The spatial pattern observed in the intersection of LCPs with roads and water surfaces mirrors the overall spatial pattern of general ECNs (LCPs by Linkage Mapper) in both LR and BAA. This suggests that linear landscape elements contribute to the broader connectivity spatial patterns observed in the ECNs.

These conclusions indicate that governmental policies and deliberate urban planning efforts contribute to the establishment of ECNs, with linear landscape elements like roads significantly contributing to the formation of ECNs in study areas. The similarity between the intersection spatial pattern of LCPs with roads & water surfaces and general ECNs spatial patterns underscores their contribution to the overall ECNs within these landscape elements.

Thesis 8: Species' dispersal ability defined the resistant kernel connectivity, and factorial LCP connectivity had the same differences with resistant kernel connectivity

Species with small dispersal abilities had low kernel connectivity, while those with large dispersal abilities had high kernel connectivity. **I have determined that species' dispersal ability defined the resistant kernel connectivity, and factorial LCP connectivity had the same differences with resistant kernel connectivity.**

a) **Kernel connectivity and factorial LCP connectivity in LR and in BAA.** In LR, the values of the RKs increased rapidly with dispersal thresholds of ≤ 2 km, increased moderately with dispersal thresholds of 4 km and 8 km, and increased slightly with dispersal thresholds ≥ 16 km. Factorial LCPs had the similar change trend with the values of RKs, except they remained unchanged with the dispersal thresholds of ≥ 16 km in LR. In BAA, the values of RKs increased dramatically with dispersal thresholds of ≤ 4 km, and increased slightly with dispersal thresholds ≥ 8 km. Factorial LCPs had the similar change trend with the values of RKs, except they remained unchanged with dispersal thresholds ≥ 8 km. The ratio of connected areas and meaningful paths had the same differences with factorial LCPs both in LR and in BAA.

b) **Kernel connectivity and factorial LCP connectivity in LCA and in BCA.** In LCA, the values of the RKs increased slightly with dispersal thresholds of ≤ 2 km, was moderate with dispersal threshold of 4 km, and increased rapidly with dispersal thresholds ≥ 8 km. Factorial LCPs, and ratios of fracture zones, core habitat patches, low, medium, and high connectivity areas, and connectivity paths had the same differences with the values of RKs in LCA. In BCA, the values of the RKs increased moderately with dispersal thresholds of ≤ 2 km, increased slightly with dispersal thresholds of 4 km and 8 km, and was the largest with dispersal threshold of 16 km. Factorial LCPs had similar differences except they stayed unchanged with dispersal thresholds of 4 km and 8 km. The ratios of fracture zones, core habitat patches, low, medium, and high connectivity areas had the same differences with the values of RKs, and low, medium, and high connectivity paths had the same differences with factorial LCPs in BCA.

The analysis yielded several notable change trends within various scenarios regarding connectivity and dispersal abilities. It illustrates that resistant kernel connectivity increases with increasing dispersal abilities, and factorial LCP connectivity also increases alongside the resistant kernel connectivity.

9. SUMMARY

The main goal of my dissertation is to map ecological connectivity networks (ECNs), and to compare the differences among mapping methods and several parameters, encompassing the following key points:

(1) I introduced the significance of ecological connectivity networks in light of habitat fragmentation and loss, emphasizing their critical role. By addressing the challenges of planning ECNs in China and Hungary, I highlighted the importance of my research in resolving these planning issues.

(2) I identified gaps in current research regarding mapping methods and the unique aspects of the study areas. This led to the establishment of research goals based on the topic's importance and the specific study areas. Then I formulated research questions and hypotheses aligning with these goals.

(3) In the chapter on literature review, 1) I covered various concepts (parkways, green belt, greenways, green infrastructure, ecological corridor, ecological network, and ecological security pattern) related to ecological connectivity networks, outlining their historical development. 2) I compiled keywords associated with species movement, connectivity, and technical aspects. 3) Based on these concepts and keywords, I developed a specific definition of ecological connectivity networks for my dissertation. 4) I introduced the historical development of ecological connectivity networks both in China and in western countries. 5) I conducted a comprehensive review of fragmentation analysis, an essential analytical method used to quantify the structure and composition of landscapes. Given that my primary focus was on simulating ecological connectivity networks based on species movements. Furthermore, I introduced 6) the International Union for Conservation of Nature and 7) the key mammal species both in Hungary and in Henan province. 8) Lastly, I detailed the theories and mapping methods utilized to simulate and represent ecological connectivity networks, offering insights into the methodologies employed to model these intricate ecological systems.

(4) I modeled the general ECN by LCP analysis and the multi-scenario of ECN related to species dispersal abilities by UNICOR analysis in LR and BAA. I identified high-connectivity areas, established protection priorities, and investigated the relationship between ECNs and linear elements in these regions. Additionally, I presented the outcomes of UNICOR cumulative resistant kernel analysis in the LCA and the BCA. Furthermore, I conducted resistance kernel modeling and factorial LCP modeling to gain detailed insights into the structure of ecological connectivity networks.

(5) My conclusions highlighted the distinct advantages of LCP analysis in illustrating simple and easy-to-understand potential paths between habitat patches without considering species limits. In contrast, UNICOR analysis provided a comprehensive system of ECN to explore the multi-scenarios of species dispersal abilities. I proposed recommendations for planners based on these findings, advocating the establishment of stepping stones in predicted connectivity networks to aid species with short-distance dispersal abilities. For species with medium-distance dispersal abilities, I suggested the creation of parks or gardens, while emphasizing the need for fewer but larger conservation areas to protect species with long-distance dispersal abilities.

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APPENDIX

Appendix 1: Key mammal species and their endangerment status, habitat, and dispersal ability in Henan Province

Scientific name	English name	Chinese name	Hungarian name	IUCN Animal Threat Category List	China Mammal Threat Category List	Habitat type
Moschus berezovskii	Forest Musk Deer	林麝	Apró pézsmaszarvas	EN	CR	Forest, Shrubland
Cuon alpinus	Dhole	豺	Ázsiai vadkutya/Dól	EN	EN	Forest, Grassland, Shrubland
Neofelis nebulosa	Clouded leopard	云豹	Ködfoltos párduc	VU	CR	Forest, Shrubland
Panthera pardus	Leopard	金钱豹	Leopárd	VU	EN	Forest, Grassland, Savanna, Shrubland
Naemorhedus griseus	Chinese Goral	中华斑羚	Kínai gorál	VU	VU	Shrubland, Forest
Hydropotes inermis	Chinese Water Deer	河麂	Kínai víziőz	VU	VU	Wetlands, Grassland, Shrubland, Forest
Arctonyx collaris	Greater Hog Badger	猪獾	Örvös sertésborz	VU	NT	Forest, Grassland, Shrubland, Savanna
Catopuma temminckii	Asiatic Golden Cat	金猫	Ázsiai aranymacska	NT	CR	Forest, Shrubland, Savanna, Grassland
Lutra lutra	Eurasian Otter	水獭	Európai vidra	NT	EN	Wetlands, Forest, Grassland, Shrubland
Capricornis milneedwardsii	Chinese Serow	中华鬣羚	Kínai széró	NT	VU	Shrubland, Forest
Trogopterus xanthipes	Complex-toothed Flying Squirrel	复齿鼯鼠	Trogopterus xanthipes	NT	VU	Forest
Nyctalus aviator	Japanese Large Noctule	大山蝠	Kelet-ázsiai koraidenevér	NT	NT	Forest
Canis lupus	Gray Wolf	狼	Szürke farkas	LC	VU	Forest, Shrubland, Grassland, Wetlands
Mustela eversmanii	Steppe Polecat	艾鼬	Molnárgörény	LC	VU	Grassland, Shrubland
Viverra zibetha	Large Indian Civet	大灵猫	Indiai cibetmacska	LC	VU	Forest, Shrubland
Viverricula	Small Indian	小灵猫	Kis	LC	VU	Forest, Shrubland, Grassland, Savanna,

indica	Civet		cibetmacska			Wetlands
Prionailurus bengalensis	Leopard Cat	豹猫	Leopárdmacska	LC	VU	Grassland, Wetlands, Shrubland, Forest
Muntiacus reevesi	Reeves' Muntjac	小麂	Kínai muntyákszarvas	LC	VU	Forest, Grassland, Shrubland
Pteromys volans	Siberian Flying Squirrel	小飞鼠	Szibériai repülőmókus	LC	VU	Forest
Mogera wogura	Japanese Mole	小缺齿鼹	Japán vakond	LC	NT	Grassland, Forest, Shrubland
Scaptochirus moschatus	Short-faced Mole	麝鼹	Rövid arcú vakond	LC	NT	Grassland
Vulpes vulpes	Red Fox	赤狐	Vörös róka	LC	NT	Shrubland, Grassland, Wetlands, Forest
Nyctereutes procyonoides	Raccoon Dog	貉	Nyestkutya	LC	NT	Forest, Grassland, Shrubland
Martes flavigula	Yellow-throated Marten	黄喉貂	Sárgatorkú nyest	LC	NT	Forest, Shrubland
Melogale moschata	Small-toothed Ferret-badger	鼬獾	Pézsma borznyest	LC	NT	Forest, Shrubland, Grassland
Meles leucurus	Asian Badger	狗獾	Kínai borz	LC	NT	Shrubland, Grassland, Forest
Paguma larvata	Masked Palm Civet	果子狸	Álcás pálmasodró	LC	NT	Forest, Shrubland
Capreolus pygargus	Siberian Roe Deer	狍	Szibériai őz	LC	NT	Wetlands (inland), Forest, Grassland, Shrubland
Sciurus vulgaris	Eurasian Red Squirrel	松鼠	Európai mókus	LC	NT	Forest

Appendix 2: Potential mammal species and their endangerment status, habitat, and dispersal ability in Hungary

Scientific name	English name	Hungarian name	IUCN Animal Threat Category List	Habitat type
Mustela lutreola	European Mink	Európai nyérc	CR	Wetlands
Oryctolagus cuniculus	European Rabbit	Üregi nyúl	EN	Forest, Savanna, Shrubland, Grassland
Spermophilus citellus	European Souslik	Közönséges ürge	EN	Grassland
Sorex alpinus	Alpine Shrew	Havasi cickány	NT	Forest, Grassland
Lutra lutra	Eurasian Otter	Európai vidra	NT	Wetlands
Neomys fodiens	Eurasian Water Shrew	Közönséges vízicickány	LC	Forest, Grassland, Wetlands
Neomys anomalus	Southern Water Shrew	Miller-vízicickány	LC	Wetlands
Crocidura leucodon	Bicolored Shrew	Mezei cickány	LC	Shrubland, Grassland
Crocidura suaveolens	Lesser Shrew	Keleti cickány	LC	Shrubland, Grassland
Myotis daubentonii	Daubenton's Myotis	Vízi denevér	LC	Forest, Shrubland, Wetlands
Myotis mystacinus	Whiskered Myotis	Bajuszos denevér	LC	Forest, Shrubland, Grassland
Myotis brandtii	Brandt's Myotis	Brandt-denevér	LC	Forest, Shrubland, Grassland, Wetlands
Myotis myotis	Greater Mouse-eared Bat	Közönséges denevér	LC	Forest, Shrubland
Sorex araneus	Common Shrew	Erdei cickány	LC	Forest, Shrubland, Wetlands
Myotis nattereri	Natterer's Bat	Horgasszőrű denevér	LC	Forest, Shrubland, Grassland, Wetlands
Myotis emarginatus	Geoffroy's Bat	Csonkafülű denevér	LC	Shrubland, Grassland
Nyctalus noctula	Noctule	Rőt koraidenevér	LC	Forest, Wetlands
Nyctalus leisleri	Lesser Noctule	Szőröskarú koraidenevér	LC	Forest, Shrubland
Eptesicus serotinus	Serotine	Közönséges késeidenevér	LC	Forest, Savanna, Shrubland, Grassland, Wetlands, Introduced vegetation
Eptesicus nilssonii	Eptesicus nilssonii	Északi késeidenevér	LC	Forest, Wetlands
Vespertilio murinus	Particoloured Bat	Fehértorkú denevér	LC	Forest, Grassland
Pipistrellus pipistrellus	Common Pipistrelle	Közönséges törpedenevér	LC	Forest, Shrubland, Wetlands

Pipistrellus nathusii	Nathusius' Pipistrelle	Durvavitorlájú törpedenevér	LC	Forest, Wetlands
Pipistrellus kuhlii	Kuhl's Pipistrelle	Fehérszélű törpedenevér	LC	Artificial/Terrestrial
Hypsugo savii	Savi's Pipistrelle	Alpesi törpedenevér	LC	Forest, Shrubland, Grassland, Wetlands
Plecotus auritus	Brown Long-eared Bat	Barna hosszúfülű-denevér	LC	Forest, Shrubland
Nannospalax leucodon	Lesser Mole Rat	Nyugati földikutya	LC	Grassland
Castor fiber	Eurasian Beaver	Közönséges hód	LC	Forest, Shrubland, Wetlands
Myocastor coypus	Coypu	Nutria	LC	Wetlands
Ondatra zibethicus	Muskrat	Pézsmapocok	LC	Wetlands
Arvicola amphibius	European Water Vole	Közönséges kószapocok	LC	Forest, Grassland, Wetlands
Arvicola scherman	Montane Water Vole	Arvicola scherman	LC	Grassland
Myodes glareolus	Bank Vole	Vöröshátú erdeipocok	LC	Forest, Shrubland
Microtus agrestis	Field Vole	Csalitjáró pocok	LC	Forest, Shrubland, Grassland, Wetlands
Microtus oeconomus	Root Vole	Északi pocok	LC	Wetlands
Microtus subterraneus	European Pine Vole	Közönséges földipocok	LC	Forest
Muscardinus avellanarius	Hazel Dormouse	Mogyorós pele	LC	Forest
Glis glis	Edible Dormouse	Nagy pele	LC	Forest, Shrubland
Dryomys nitedula	Forest Dormouse	Erdei pele	LC	Forest, Shrubland
Apodemus agrarius	Striped Field Mouse	Pirókegér	LC	Forest, Grassland, Wetlands
Apodemus sylvaticus	Long-tailed Field Mouse	Közönséges erdeiegér	LC	Forest, Shrubland, Grassland
Apodemus flavicollis	Yellow-necked Field Mouse	Sárganyakú erdeiegér	LC	Forest
Rattus rattus	House Rat	Házi patkány	LC	Shrubland
Micromys minutus	Eurasian Harvest Mouse	Törpeegér	LC	Forest, Wetlands
Canis aureus	Golden Jackal	Aranysakál	LC	Forest, Shrubland, Grassland, Wetlands
Canis lupus	Grey Wolf	Szürke farkas	LC	Forest, Shrubland, Grassland, Wetlands

Nyctereutes procyonoides	Raccoon Dog	Nyestkutya	LC	Forest, Shrubland, Grassland
Procyon lotor	Northern Raccoon	Mosómedve	LC	Forest
Mustela eversmanii	Steppe Polecat	Molnárgörény	LC	Shrubland
Neovison vison	American Mink	Amerikai nyérc	LC	Forest, Shrubland, Wetlands
Mustela erminea	Stoat	Hermelin	LC	Forest, Shrubland, Grassland, Wetlands
Mustela nivalis	Least Weasel	Menyét	LC	Forest, Shrubland, Grassland, Wetlands
Martes martes	Pine Marten	Nyuszt	LC	Forest, Shrubland
Lynx lynx	Eurasian Lynx	Eurázsiai hiúz	LC	Forest, Shrubland, Grassland
Dama dama	Fallow Deer	Európai dámvad	LC	Forest, Shrubland, Grassland
Capreolus capreolus	European Roe Deer	Európai őz	LC	Forest, Shrubland, Grassland
Meles meles	Eurasian Badger	Eurázsiai borz	LC	Forest, Shrubland, Grassland
Mustela putorius	Western Polecat	Közönséges görény	LC	Forest, Shrubland, Grassland, Wetlands
Cricetus cricetus	Common Hamster	Mezei hörcsög	LC	Shrubland, Grassland
Ursus arctos	Brown Bear	Barna medve	LC	Forest, Shrubland, Grassland, Wetlands, Introduced vegetation
Sciurus vulgaris	Eurasian Red Squirrel	Európai mókus	LC	Forest
Martes foina	Beech Marten	Nyest	LC	Forest, Shrublan
Lepus europaeus	European Hare	Mezei nyúl	LC	Forest, Shrubland, Grassland
Rattus norvegicus	Brown Rat	Vándorpatkány	LC	Artificial/Terrestrial
Microtus arvalis	Common Vole	Mezei pocok	LC	Forest, Shrubland, Grassland
Vulpes vulpes	Red Fox	Vörös róka	LC	Forest, Shrubland, Grassland
Erinaceus roumanicus	Northern White-breasted Hedgehog	Keleti sün	LC	Forest
Cervus elaphus	Red Deer	Gímszarvas	LC	Forest, Shrubland, Grassland
Sus scrofa	Wild Boar	Vaddisznó	LC	Forest, Shrubland
Felis silvestris	European Wildcat	Vadmacska	LC	Forest, Shrubland, Grassland, Wetlands
Talpa europaea	European Mole	Közönséges vakond	LC	Forest, Shrubland, Grassland