# Ecological Connectivity Networks for Multi-dispersal Scenarios Using UNICOR Analysis in Luohe Region, China

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**Abstract:** Habitat loss and fragmentation are increasingly disrupting natural ecosystems across the world, especially in areas that have experienced extensive recent anthropogenic land use change. Evaluating multi-dispersal scenarios of ecological connectivity networks provides an important means to evaluate how dispersal ability influences the prediction of optimal ecological networks. Few examples exist of the dependence of connectivity networks on the scale of dispersal ability used in the analysis. In this study, we performed supervised classification to map land use types using Landsat 8 imagery, then used Morphological Spatial Pattern Analysis and Conefor to identify important core areas for biodiversity, and finally used UNICOR to simulate the resistant kernel and factorial least-cost path connectivity networks. Our main results show: (1) Species with dispersal abilities of ≤ 2 km showed generally low connectivity in most areas, with core areas of high connectivity mainly in Luohe central area, Linying county and Wuyang county, and major corridors were restricted within the Luohe central area, Linying county and Wuyang county. Species with dispersal abilities of 4 km and 8 km showed a network of connectivity with multiple pathways connecting the interior of the study area. Finally, species with dispersal abilities of ≥ 16 km showed high connectivity levels and appeared fairly insensitive to current configurations of human development in the study area. (2) Intensely developed areas may be obstructing species movements into the southeastern and northeastern parts of the region. The green space along roads and rivers may facilitate movement and promote connectivity. In future planning, planners should consider ways to enhance ecological connectivity networks, such as identified in this study, for conserving species with limited dispersal range.

**Keywords:** Ecological network, dispersal ability, resistant kernel, factorial least-cost path

## 1 Introduction

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. 2018, UPADHYAY et al. 2017). In effect, landscape fragmentation and degradation cause habitat loss and impact the movement of species (CLOSSET-KOPP et al. 2016). Thus, maintaining landscape connectivity and mitigating the fragmentation of habitat may be critical for ecological processes such as gene flow, dispersal and migration (RUDNICK et al. 2012). Ecological Networks (ENs) 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

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flow, migration, dispersal of species (RICOTTA et al. 2000). Therefore, an optimized ecological network (EN) spatial pattern is of great significance for the sustainable development of urban and rural ecosystems (RUIZ-GONZÁLEZ et al. 2014).

While 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 2020, ASHRAFZADEH et al. 2020), relatively few have explicitly evaluated the sensitivity of these network predictions to the dispersal ability of focal organisms. This is particularly important, 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, 2013a and 2016, RIORDAN et al. 2016, MACDONALD et al. 2018).

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 completed in China. In 1979, Three-North Shelterbelt 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 which 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. In recent years, national planning in China has increasingly considered the security and health of ecological processes to protect ecosystems systematically (PENG et al. 2018).

Luohe city was designated a National Landscape Garden City in 2002 and 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 focus of 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. To provide this critical information, we applied the UNIversal CORridor and network simulation model (UNICOR) (LANDGUTH et al. 2012) to map the ecological connectivity networks for multi-dispersal scenarios in Luohe region, 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. We have three goals: (1) to map and compare resistant kernel maps at multi-dispersal scenarios, (2) to map and compare factorial least-cost paths at multi-dispersal scenarios, and (3) to rank conservation orders of ecological connectivity network.

## 2 Study Area

Luohe region is located in central Henan province (113°27′ – 114°16′E, 33°24′ – 33°59′N) and is characterized by varied topography of plateau and hills in the west and lower riverine valleys in the east. The total municipal territory of Luohe region is 2617 km$^2$, including

Yuanhui district, Yancheng district, Shaoling district, Wuyang county and Linying county (Figure 1), spanning 76 km from east to west and 64 km from north to south. Luohe city is developed along Sha and Li rivers which meet in the central area.

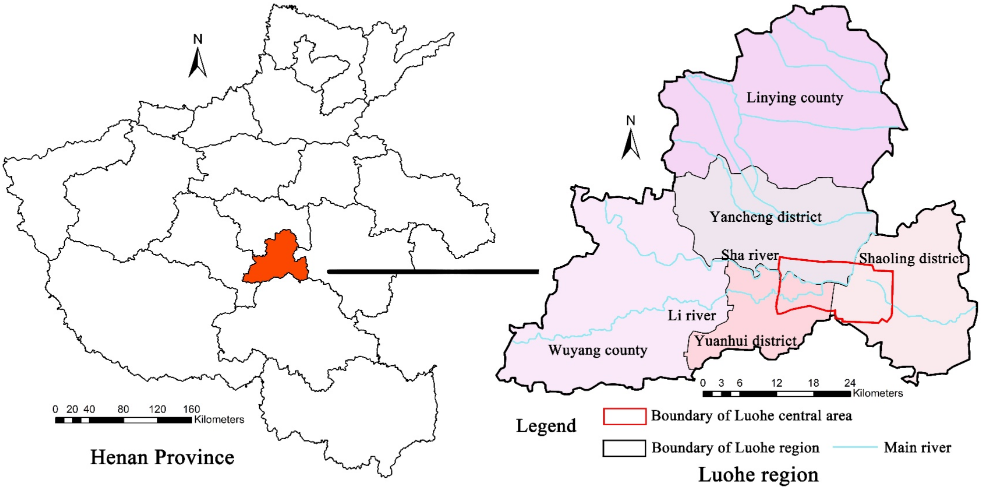

**Fig. 1:** Location of Luohe region within Henan Province

# 3 Methods

## 3.1 Multi-dispersal Scenarios and Ecological Source Selection

We evaluated connectivity network predictions across seven dispersal thresholds, including 1 km, 2 km, 4 km, 8 km, 16 km, 32 km, 64 km (MATEO SANCHEZ et al. 2013), 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, we evaluated a general sensitivity of ecological network predictions to dispersal for species associated with green space.

## 3.2 Remotely Sensed Image Acquisition and Preprocessing

1) **Image acquisition.** We downloaded two Landsat 8 images on June 14, 2019 and July 7, 2019 (Resolution: 30 m; Coordinate system: WGS_1984_UTM_zone_50N and WGS_1984_UTM_zone_49N respectively) from EarthExplorer – USGS (INTERNET 1. 2021). At that time the wheat in Henan province was fully mature, with a distinctive yellow color, and as green space is characterized by high reflectance in the green wavelengths, it is possible to distinguish green space and farmland spectrally with great accuracy.

2) **Image preprocessing.** In ENVI 5.3, we used Radiometric Calibration and FLAASH Atmospheric Correction functions to produce two maps, then clipped them using the boundary of the Luohe region. Because the whole Luohe region involves two images, classification accuracy was not high at the edge of the maps when we mosaicked them. Classifying them first then mosaicking them solved the problem.

3) **Classification.** We selected five types of the land cover of interest – green space (e. g. forest, grassland, shrubland, orchard, urban green area), farmland, water surface, road and built-up area (AQSIQ, SAC. 2017), and performed a supervised classification to prepare land use/land cover (LULC) map using Support Vector Machine Classification in ENVI, then we input two classification maps into ArcGIS to mosaic them using Mosaic To New Raster function (Figure 2).

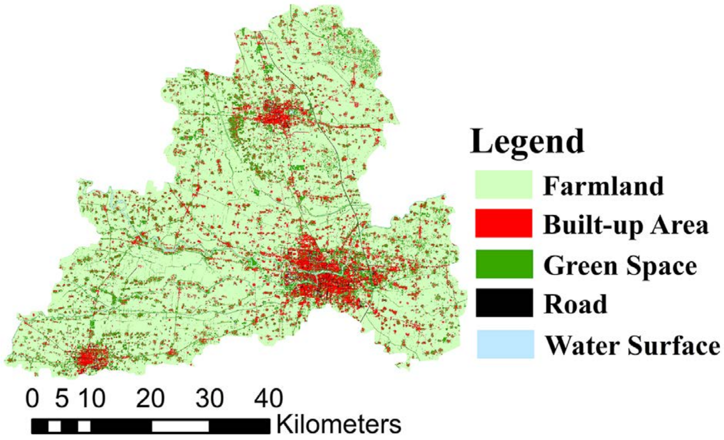

**Fig. 2:** LULC classification of Luohe region

4) **Accuracy assessment.** We chose 100 ground truth points on a Sentinel-2 image (Resolution: 10 m) on September 30, 2019, to test the accuracy of classification using the Confusion Matrix Using Ground Truth ROIs function in ENVI.

5) **Fragmentation analysis.** Calculated five class metrics including Patch Density (PD), Percentage of Landscape (PLAND), Radius of Gyration_Area-Weighted Mean (GYRATE_AM), Edge Density (ED), and Aggregation Index (AI) in Fragstats (McGarigal et al. 2002 and 2012) to quantify the structure and composition of the land use mosaic. These metrics were chosen given past research that demonstrated their utility in species environment relationship modeling (Grand et al. 2004, Chambers et al. 2016), and connectivity and gene flow modeling (Cushman et al. 2013b and 2012b). The ecological meaning of these metrics can be found in (Cushman & McGarigal 2008, Cushman et al. 2008, Cushman & Mcgarigal 2019).

## 3.3 Identifying and Ranking Core Areas

We used 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. To accomplish this, we reclassified the land use types in ArcGIS. We set the value of green space is two as foreground, the value of other land use types is one as background, then input the data into GuidosToolbox and conducted Morphological Spatial Pattern Analysis (MSPA) (Soille & Vogt 2009). The green space was divided into seven classes – core, branch, edge, islet, bridge, loop and

perforation. The core is defined as areas of large extent of green space, the islet is defined isolated pixels unconnected 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 (SOILLE & VOGT 2009, CARLIER & MORAN 2019). Then we chose class metrics of PD, PLAND, GYRATE_AM, ED, AI to measure the spatial pattern of each type of green space. Among them, we extracted Core as core areas, then we selected all core with areas greater than 50,000 $m^2$ for inclusion in the next analysis.

2) Degree of Probability of Connectivity (dPC), representing habitat availability and connectivity (HOFMAN et al. 2018). We used Conefor 2.6 to identify the important nodes, and chose core areas whose dPC is larger than 1 to represent the important nodes for the connectivity network across the Luohe region. Then we calculated landscape metrics of PD, GYRATE_AM, ED, AI to measure the landscape pattern of important nodes.

## 3.4 Ecological Connectivity Network Mapping and Evaluating

The UNIversal CORridor and network simulation model (UNICOR) (LANDGUTH et al. 2012) includes two approaches for quantifying landscape connectivity. The first approach is resistant kernel modeling (COMPTON et al. 2007). Resistant kernel modeling predicts the incidence function of the rate of expected movement from a defined set of source locations cumulatively through a landscape (CUSHMAN et al. 2012a) for every pixel in the study area, rather than only for a few selected “linkage zones” (COMPTON et al. 2007). The second approach is factorial least-cost path modeling (CUSHMAN et al. 2009). Factorial least-cost path modeling predicts movement corridors and corridor strength (CUSHMAN et al. 2013c) for species with multi-dispersal abilities.

1) Resistance Surface. Based on the literature review (YIN et al. 2011, JIANG et al. 2016) and the purposes of this study, we set the resistance values of green space, water surface, farmland, road, built-up area is 1, 10, 30, 90, and 100 respectively.

2) Source points. We extracted centroids of the important nodes from Conefor to be the source points.

3) Resistant kernel modeling and factorial least-cost path modeling. We input resistance surface and points location in UNICOR and predicted resistant kernel and factorial least-cost path networks for each dispersal ability threshold.

4) Ecological connectivity network evaluation. We used the function of Raster Calculator in ArcGIS to standardize values of resistant kernels in order to compare the differences of multi-dispersal scenarios. We overlapped the resistant kernel & factorial least-cost path and main road & main river to show the location of the paths.

# 4 Results

## 4.1 Land Use Classification

Accuracy assessment (Table 1) showed the overall accuracy is 92.1478%, with a Kappa Coefficient of 0.8806. This shows the classification is highly successful and robust for use as the basis of the rest of the analysis.

## 4.2 Definition and Rank of Core Areas

MSPA analysis (Figure 3) indicated that Core is 1.4%, islet is 4.65%, perforation is 0.01%, Edge is 2.85%, loop is 0.37%, bridge is 1.18%, branch is 2.77% of the extent of the analysis area. The highest ratio of islet showed that 4,65% of green space is isolated. The core ratio showed that 1.4% of the area is core areas. The bridge and the loop ratio showed that 0.37% + 1.18% of area connect the core area. The edge and the perforation ratio showed that 2.85% + 0.01% of green space are the outer and inner boundaries of habitat patches. The branch ratio showed that 2.77% of green space only connect one end to a habitat patch.

Conefor analysis showed there are 80 core areas which a value of dPC greater than 1, which were chosen for the first protection order. Through MSPA analysis we chose 96 core areas which have areas larger than 50,000 m$^2$. Based on these two criteria, there were 96 – 80 =16 core areas to be the second protection order. Most of the core areas are located in Luohe central area, Linying county and Wuyang county (Figure 4).

**Table 1:** Accuracy assessment of land use classification (Overall Accuracy = 92.1478%, Kappa Coefficient = 0.8806)

| Class | Commission (Percent) | Omission (Percent) | Prod. Acc. (Percent) | User Acc. (Percent) |
|---|---|---|---|---|
| **Farmland** | 3.88 | 0 | 100 | 96.12 |
| **Built-up Area** | 16.07 | 7.84 | 92.16 | 83.93 |
| **Green Space** | 26.47 | 28.57 | 71.43 | 73.53 |
| **Road** | 4.55 | 46.15 | 53.85 | 95.45 |
| **Water Surface** | 6.74 | 2.35 | 97.65 | 93.26 |

## 4.3 Fragmentation Analysis

Fragmentation analysis of land use types is reported in Table 2. The PLAND revealed that the proportion of land use types in descending order of extent is: farmland > green space > built-up area > water surface > road. This showed that the Luohe region has farmland-dominated land use. The PD and ED of green space are 12.3583 and 70.1397 respectively, showing that green space in the region is highly fragmented. AI of green space is larger than road and water surface, showing that green space is more aggregated than these highly heterogeneous cover types.

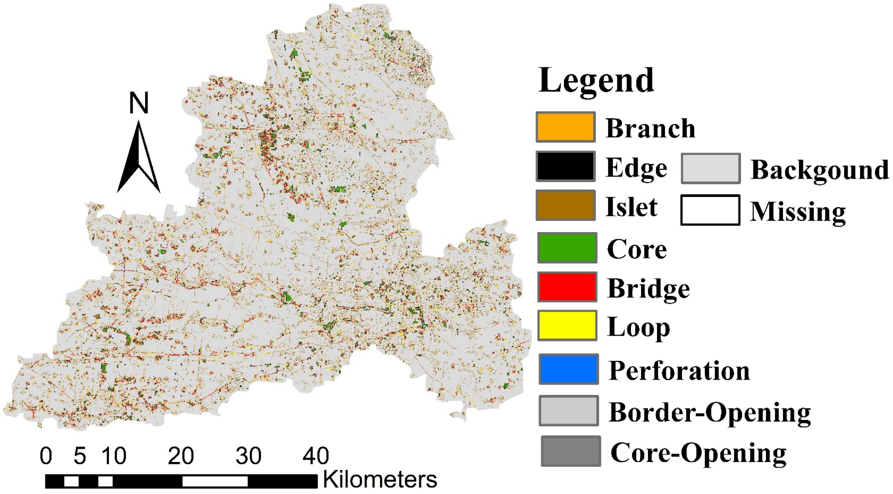

**Fig. 3:** MSPA results of Luohe region

After selecting green space core areas using Conefor, we reanalyzed fragmentation on this subset (Tables 3 and 4). The PD and ED decreased, 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 a higher diversity of types, 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.

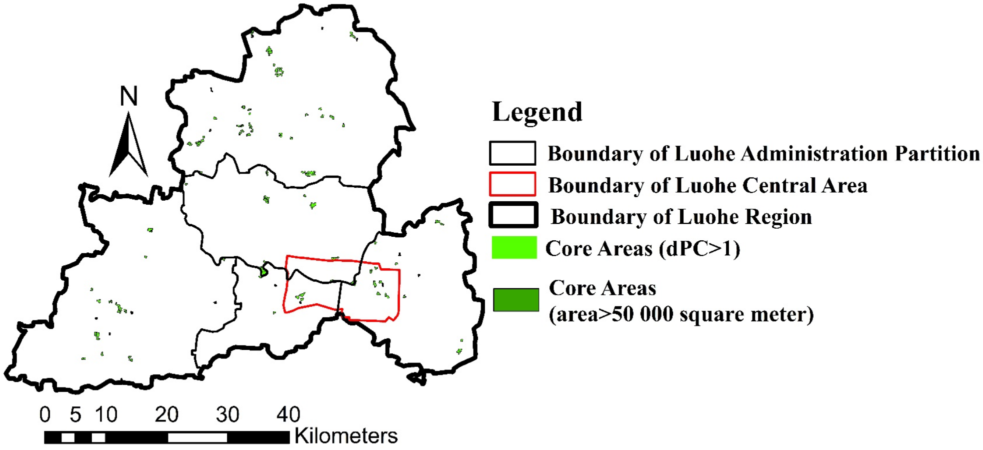

**Fig. 4:** Location of core areas of Luohe region

**Table 2:** Fragmentation analysis of land use types (class metrics)

| Class | PLAND | PD | ED | GYRATE_AM | AI |
|---|---|---|---|---|---|
| **Farmland** | 75.2578 | 4.3621 | 70.2955 | 8906.892 | 92.9359 |
| **Built-up Area** | 9.3464 | 4.807 | 36.0924 | 600.3523 | 71.152 |
| **Green Space** | 13.2222 | 12.3583 | 70.1397 | 280.5806 | 60.2107 |
| **Road** | 0.768 | 1.9858 | 6.1258 | 118.3107 | 40.3934 |
| **Water Surface** | 1.4057 | 2.2244 | 7.3363 | 3327.675 | 59.9499 |

**Table 3:** Fragmentation analysis of MSPA results (class metrics)

| TYPE | PLAND | PD | ED | GYRATE_AM | AI |
|---|---|---|---|---|---|
| **Loop** | 3.5063 | 3.0822 | 10.2066 | 101.7828 | 42.4706 |
| **Islet** | 35.137 | 86.1615 | 0 | 63.0258 | 41.3329 |
| **Branch** | 20.9781 | 52.6468 | 33.3189 | 68.7404 | 40.739 |
| **Edge** | 17.4077 | 22.713 | 76.018 | 75.5529 | 43.0736 |
| **Core** | 10.5946 | 15.7893 | 53.9287 | 101.939 | 61.986 |
| **Bridge** | 12.3253 | 6.9406 | 39.3989 | 154.3613 | 45.8415 |
| **Perforation** | 0.0509 | 0.0504 | 0.253 | 56.3837 | 51.2 |

**Table 4:** Fragmentation analysis of core areas (landscape metrics)

| TYPE | PD | ED | GYRATE_AM | AI |
|---|---|---|---|---|
| **Core Areas** | 7.9146 | 0 | 225.3534 | 84.2022 |

## 4.4 Resistant Kernel Evaluation

Resistant kernel (Figure 5) values are the spatial incidence function of the expected density of movement through each cell in the landscape by dispersing organisms with the specified dispersal ability, moving from the specified source cells, and responding to the specified resistance surface (Cushman et al. 2012a). Generally speaking, the resistant kernel increased with the dispersal threshold increased. The values of the resistant kernel (Figure 5) and standardized value (Figure 6) changed dramatically with dispersal thresholds of ≤ 2 km; species with dispersal abilities of ≤ 2 km showed generally low connectivity in most of areas (Figure 5 and 6), with core areas of high connectivity mainly in Luohe central area, Linying county and Wuyang county. That means species with dispersal abilities ≤ 2 km, and which are dependent on greenspace for habitat, will experience fragmentation of their populations across the Luohe region. In future planning in the Luohe region, 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.

The values of the resistant kernel (Figure 5) and standardized value (Figure 6) have a moderate increase with dispersal thresholds of 4 km and 8 km. Species with dispersal abilities of 4 km and 8 km 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 southwest corners of the study region. Planners should build parks or gardens in the areas where linkage is most limited between the core areas to protect medium dispersal abilities' species in future planning.

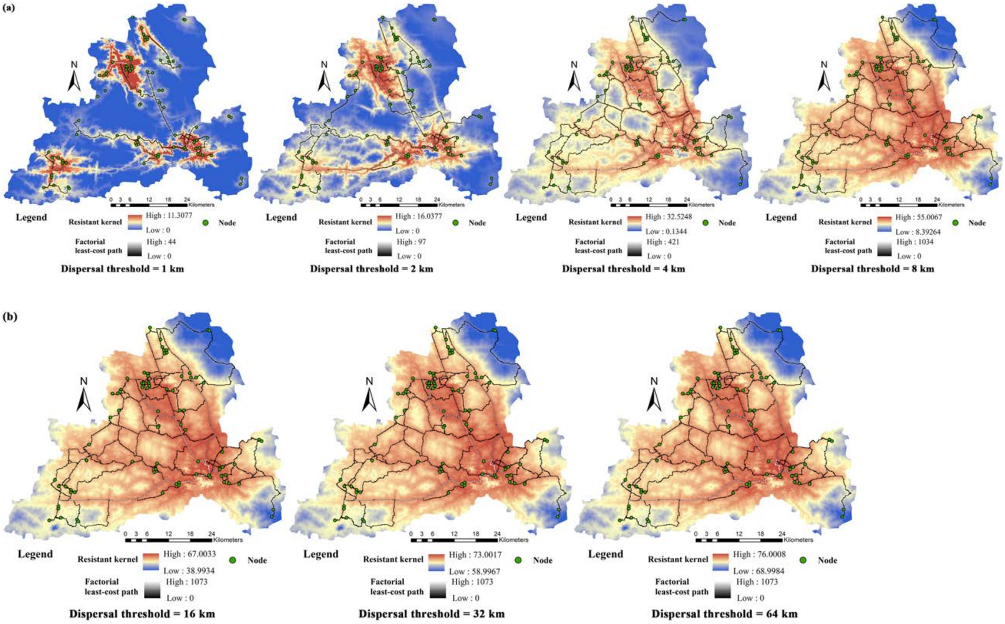

**Fig. 5:** Comparison of resistant kernel and factorial least-cost path

Finally, the value of the resistant kernel (Figure 5) increased slowly and the standardized value (Figure 6) almost did not change with dispersal thresholds ≥ 16 km. Species with dispersal abilities of ≥ 16 km 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. 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), because of limited green space in these intensively agricultural areas, and because built-up areas of Luohe central area 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.

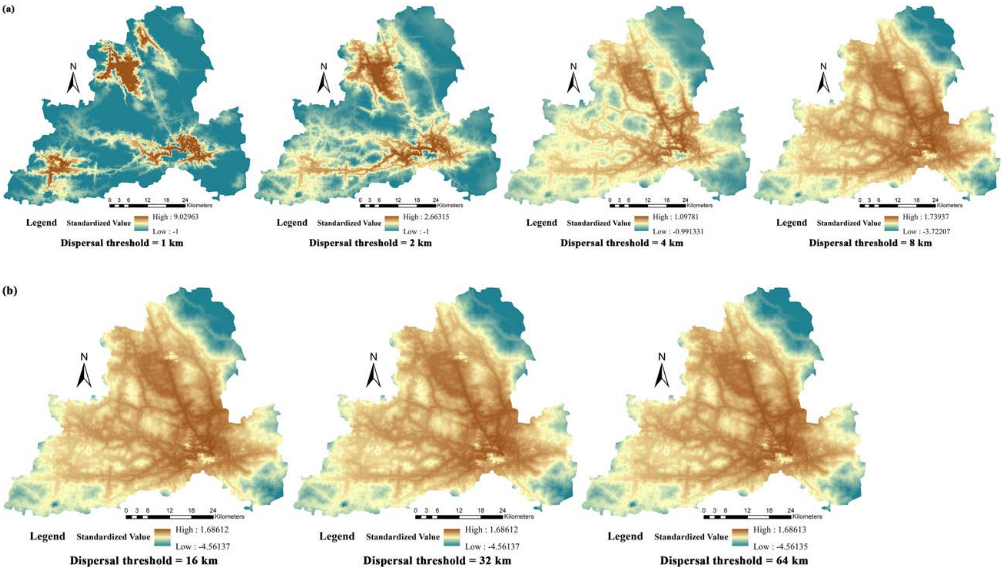

**Fig. 6:** Comparison of the standardized value of the resistant kernel

## 4.5 Factorial Least-Cost Path Evaluation

Multi-dispersal scenarios have the same corridor patterns, but very different network extents and linkage (Figure 5). 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 changed 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 stayed approximately the same at dispersal thresholds of 4 km and 8 km. The number and strength of paths changed relatively little as well at dispersal thresholds of ≥ 16 km. This means species with short dispersal ability are very sensitive to network breakage and fragmentation, and planners must carefully plan networks of stepping stone green space patches along the routes of most important connectivity among core areas of green space.

## 4.6 Overlapping Map Evaluation

Main roads and rivers passed through high connectivity areas, and most Factorial least-cost paths are aligned with main roads and rivers (Figure 7). This reflects past urban design applications in which planners concentrated on the creation of green space along roads and rivers based on national policies. This showed that not only land use type influences the species' dispersal, but also national policies about the green space construction. It reminds planners to build more green space combined with other landscape elements, for instance, river corridors and transport corridors.

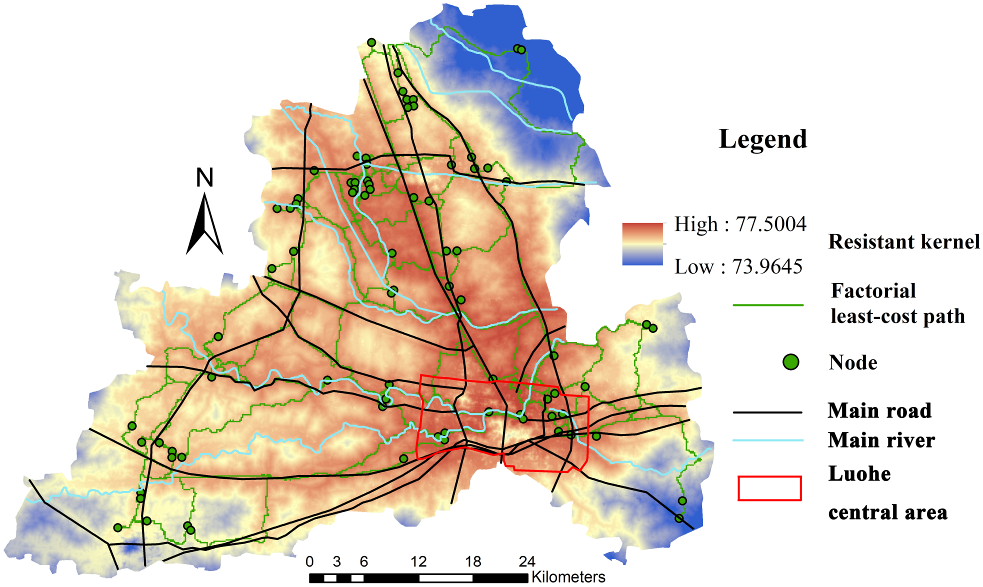

**Fig. 7:** Overlapping map of main road & main river and resistant kernel & factorial least-cost path

## 5 Discussion

Our overall goal in this study was to assess the pattern of green network connectivity in the Luhoe region across a range of dispersal abilities. Our main result is that connectivity, assessed both by the factorial least-cost path and resistant kernel methods, was highly sensitive to dispersal ability, with strong threshold effects below 4 km dispersal distance at which the connectivity of the system broke down dramatically. Conversely, above 8 km dispersal ability, the network appeared highly connected across the full region. Moreover, we identified three hypotheses to discuss.

1) **Hypothesis 1: Kernel connectivity will increase with dispersal ability.** Kernel connectivity represents the predicted spatially-explicit dispersal rates across the study area extent (CUSHMAN et al. 2010b). As expected, species with small dispersal abilities of ≤ 2 km have low kernel connectivity, which changed dramatically from the larger dispersal abilities. Species with large dispersal abilities are predicted to have high kernel connectivity and the value of that stayed stable above dispersal ability of 16 km. These results suggest that planners should rank the conservation order based on the study results: species with dispersal abilities of ≤ 2 km are the first protection order, species with dispersal abilities of 4 km and 8 km are the second protection order, species with dispersal abilities of ≥ 16 km are the third protection order in Luohe region.

2) **Hypothesis 2: Symmetry of thresholds of kernel connectivity and factorial least-cost path connectivity.** Factorial least-cost path 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). Our analysis showed

that the number and strength of paths changed dramatically with dispersal abilities of ≤ 2 km, and the number and strength of paths stayed stable with large dispersal abilities, showing the same dispersal threshold sensitivity as the kernel connectivity analysis. That means the change of the factorial least-cost path is synchronous with the change of the kernel connectivity. These results remind planners to improve connectivity through building more green space concentrated in areas predicted to be important linkages based on both kernel and factorial least-cost path methods, across the full range of dispersal abilities.

3) **Hypothesis 3: Most ecological connectivity networks are along with roads and rivers.** After 1990, the Chinese government launched policies to improve ecosystem management and conservation, resulting in the creation of extensive green space along transportation corridors and riparian corridors (PENG et al. 2017). Luohe city reflects this characteristic; most ecological connectivity networks are along roads and rivers. It reminds planners that future green space should be created in other landscape contexts, particularly in areas of the landscape with low human activity levels and disturbance to promote the existence and movement of species sensitive to human disturbance.

4) **Scope and limitations.** The resolution of Landsat 8 images is low, which might affect the results of the land use classification and MSPA analysis. In future research, we should use high-resolution images to compare how the resolution of images affects the results. We defined five classes of land use for general species, we will specify the green space types (e. g. forest, grassland, shrubland, orchard, urban green area) based on the exact species in the future deep research. There might be some errors because of the number of ground points we chose, we should choose more points in the next study.

## 6 Conclusion and Outlook

In UNICOR analysis, we had three conclusions based on the results and goals:

1) Resistant kernel analysis predicted the density of dispersal movement across the landscape, and showed that the extensiveness of kernel connectivity was highly dependent on dispersal ability. At small dispersal abilities of ≤ 2 km there were high levels of fragmentation, and as dispersal ability increased kernel connectivity produced broader extents of interconnected habitat.

2) Factorial least-cost paths predicted the routes of highest potential connectivity linking all pairs of source points. This shows the optimal network of linkages among the source locations. Different dispersal abilities have the same pattern of corridors, but the extent and connectivity of the network are highly sensitive to dispersal ability. Depending on dispersal ability, least-cost paths do not connect all the ecological nodes because of the high density of built-up areas, but the paths pass through the central area thanks to the green space along the rivers.

3) Conservation order based on the results. We recommend planners should build plenty of stepping stones located in breakages in our predicted connectivity network of additional roadside green spaces, residential area green spaces, transport corridor, river corridor to protect species with dispersal ability of ≤ 2 km, which is the first conservation order. Planners should build some parks or gardens with city features to protect species with

dispersal ability of 4 km and 8 km, which the second conservation order. Planners should build fewer but larger conservation areas in areas of low human activity and disturbance to protect species with dispersal ability of ≥ 16 km, which is the third conservation order.

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