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Identifying Connectivity Conservation Priorities among Protected Areas in Qinling-Daba Mountains, China

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Abstract: Mountain biodiversity is under unprecedented threat due to climate change and excessive human activity. Although protected areas (PAs) are the cornerstone of nature conservation, it is increasingly hard for isolated PAs to maintain the species and ecological processes they depend on in the long term. Linking nature reserves to form a large and connected conservation network is regarded as the optimal measure, but research in this field is lacking in China. We mapped PAs in the Qinling-Daba Mountains in China and identified corridors among PAs and the corridors’ key nodes using a least-cost analysis and circuit theory to model an ecological connectivity conservation network for the region. The results showed that this large ecological network has 46 habitat patches connected by 88 corridors, with 69 pinchpoints, 86 barriers and 37 stepping stones in and around the corridors. In this study, 34.86% of suitable habitats have little or no protection and, in the future, these areas should be developed with caution, with more emphasis on protecting their ecological connectivity. This study used connectivity analysis to construct large ecological corridors based on PAs, providing a framework for connectivity conservation at the biogeographic scale and a scientific reference for further, subsequent conservation actions.

Keywords: ecological corridor; connectivity conservation; protected area; connectivity modelling; large-scale corridor; Qinling-Daba Mountains

1. Introduction

Mountains, characterised by wide environmental gradients, host unusual biodiversity and endemicism [1–3]. Mountain ecosystems are fragile and threatened by the combined effects of climate change and excessive human activities [4,5]. Protected areas (PAs) are the cornerstone of conservation [6,7], and mountains account for 32.4% of the world’s PAs [8]. However, isolated PAs may not provide the species movements or flows of ecological materials needed to maintain genetic and species diversity, making it difficult to maintain available populations over the long term [7,9,10]. Linking PAs into large, connected conservation networks and restoring ecological connectivity among them are considered effective ways to complement and promote existing, natural conservation systems, especially in mountainous areas [11–13]. Large-scale ecological networks span multiple ecological, climatic and altitudinal gradients [14,15], providing chances for species’ long-distance dispersal and adaptation in response to climate change and other environmental changes [16–18].

Since they were first proposed by Wilson and Willis in 1975 [19,20], connectivity corridors have gone from being controversial [21–23] to widely recognised [24–26], and several frameworks and models for assessing connectivity have been proposed [27–29]. Two primary approaches have been used: the traditional species-specific (‘fine filter’) approaches
and those based on ecological integrity as a proxy (‘coarse filter’) [30]. Focal-species approaches [31,32] have been successfully used for decades. However, they become difficult and less representative when used at large scales, and the required field surveys are time consuming and costly [30,33,34]. In response to these limitations, coarse-filter methods based on ecological integrity or naturalness [35,36] have become a recognised alternative. These are not limited to specific species or habitats, are independent of vegetation type and attempt to provide a coarse filter for species and processes sensitive to human interference, individually or combined with species-based approaches in large connectivity initiatives [35,37].

In terms of connectivity modelling, widely used models include graph theory [38], the least-cost model (LCM) [39] and circuit theory [40]. Graph theory is used to measure structural (physical) connectivity at a wide range of spatial scales [41,42], but may overestimate the actual connectivity between habitat patches because it is based on Euclidean distances and ignores the influence of landscape barriers on movement [43]. Both the LCM and circuit theory are based on graph theory’s structure, but differ in assumptions about species movement behaviours [44]. The LCM is the most popular model for its simple algorithm and efficiency in identifying the least-cost path between patches [29]. While circuit theory is helpful in mapping suboptimal paths and identifying potential bottlenecks, when used at large scales, the calculation of a circuit-density map is complex and time consuming [40]. Combining these methods can compensate for the shortcomings of the individual methods, and may be the most informative way to identify corridors [43].

In China, ecological conservation has always been highly valued, and more than 10,000 nature reserves have been established nationwide, accounting for over 20% of the terrestrial area [45]. However, the PAs are mostly too small, isolated and poorly designed, severely constraining their protective efficiency. In recent years, the integration and optimisation of natural PAs and the construction of large-scale ecological corridors have been promoted by the Chinese government and scholars [46]. However, there is still no genuine PA network in China [47], and few studies have focused on this issue. Previous research involved only one kind of species [48], ignored human interference [49] or failed to identify conservation priorities and corridors [50].

Located in central China, the Qinling-Daba Mountains (hereinafter the ‘Qinba Mts’) serve as a natural corridor connecting the Qinghai–Tibet Plateau and the eastern plain, which is of great significance for the dispersal, intersection, diversification and specialisation of biological species in China [51]. As a result of increasing human interference, the corridor effect of the Qinba Mts has almost disappeared. Therefore, taking this geographically complete area as the study area, we aimed to model ecological connectivity between PAs, map the potential PA conservation network and identify connectivity priorities using circuit theory, which will provide scientific references and suggestions for the upcoming Qinling National Park and a technical framework for large-scale conservation network construction in other regions.

2. Materials and Methods

2.1. Study Area and Data Sources

The Qinba Mts, composed of the Qinling Mountains and the Daba Mountains, are located at longitudes 102°–114° E and latitudes 31°–36° N, covering a total area of about 30.60 × 10^4 km^2 [52]. The mountains stretch over 1000 kilometres in an east–west direction, encompassing 155 counties, 31 cities and 6 provinces of central China (Figure 1). The terrain declines from west to east, with an altitude span of more than 5000 metres. As the north–south transitional zone in China, steep elevational gradients and the complex climate make it a biodiversity hotspot; it is a key habitat for rare animals, such as the Giant Panda (Ailuropoda melanoleuca), the Golden Snub-nosed Monkey (Rhinopithecus roxellanae) and the Crested Ibis (Nipponia nippon). Thus, this area is one of the most important and concerning areas for biodiversity in China; it contains the Minshan zone, Baihuixiang zone and Qinling zone of the Giant Panda National Park (GPNP) and the whole Shennongjia National Park
As there was no exact list of PAs in the Qinba Mts, we collected basic information about the nature reserves, national parks and national forest parks, and we geographically vectorised the boundaries of these nature reserves one by one. For analysis purposes, the following operations were performed on these nature reserves: (1) those aimed at wildlife and forest ecosystem protection and larger than 2000 hectares were screened and retained; (2) those with an inter-patch Euclidean distance of less than 3 km were treated as one patch; (3) a few nature reserves without boundary information were simplified as circular areas of equal size; and (4) those with overlapping boundaries were fused into one patch, with those included within the national parks being based on the national park boundaries. As a result, 99 nature reserves were retained, including 52 at the national level, 45 at the provincial level and 2 at the city and county level. After merging the boundaries of adjacent PAs, 46 habitat patches with a total area of $44.50 \times 10^3$ km² were finally created, accounting for 14.55% of the total study area (Figure 2).

Figure 1. Geographic location of the Qinba Mts.

Several datasets were used in our study. (1) The Globeland30 Land Use/Land Cover Dataset, with a 30 m spatial resolution (http://globeland30.org, (accessed on 7 March 2022)), provided land cover information; (2) the PAs in this paper were mainly obtained from the World Database on Protected Areas (https://www.protectedplanet.net/en, (accessed on 7 March 2022)), the Platform of Nature Reserve Specimen Resource in China (http://www.papc.cn, (accessed on 7 March 2022)), relevant literatures and government reports; (3) Road maps came from 1:250,000 National Basic Geographic Information data in 2019 (https://www.webmap.cn, (accessed on 7 March 2022)), the Platform of Nature Reserve Specimen Resource in China (http://www.papc.cn, (accessed on 7 March 2022)), relevant literatures and government reports; (4) population density data came from the 2020 Worldpop Database (https://www.worldpop.org, (accessed on 7 March 2022)), measuring population per square kilometre, with a resolution of 1 km. All data used the same projection system (Albers conical equal area), with a resolution of 500 m.

2.2. Core Area Identification

As there was no exact list of PAs in the Qinba Mts, we collected basic information about the nature reserves, national parks and national forest parks, and we geographically vectorised the boundaries of these nature reserves one by one. For analysis purposes, the following operations were performed on these nature reserves: (1) those aimed at wildlife and forest ecosystem protection and larger than 2000 hectares were screened and retained; (2) those with an inter-patch Euclidean distance of less than 3 km were treated as one patch; (3) a few nature reserves without boundary information were simplified as circular areas of equal size; and (4) those with overlapping boundaries were fused into one patch, with those included within the national parks being based on the national park boundaries. As a result, 99 nature reserves were retained, including 52 at the national level, 45 at the provincial level and 2 at the city and county level. After merging the boundaries of adjacent PAs, 46 habitat patches with a total area of $44.50 \times 10^3$ km² were finally created, accounting for 14.55% of the total study area (Figure 2).
2.3. Resistance Surface Construction

In connectivity modelling, the resistance surface describes the difficulty of species movement among patches in different habitats [44], and resistance estimation is usually achieved by parameterising environmental variables through ‘resistance’ or ‘cost’ [29]. To compare environmental factors of different sources, these variables are commonly separated into several categories. In this study, we classified the degree to which the landscape impedes biological or ecological processes under five categories (habitat, suitable matrix, moderate matrix, unsuitable matrix and barrier), and the selected environmental variables—land cover, population density and distance from road—were also classified under five categories correspondingly (Table 1) [53,54]. The resistance values were based on the maximum type of resistance after the superposition of each element.

Table 1. Classification and assignment of environmental variables.

| Resistance Tier       | LUCC                          | Human Density | Distance from Road |
|-----------------------|-------------------------------|---------------|--------------------|
|                       |                               |               | National Road      | Provincial Road | County Road | Township Road |
| Habitat               | Woodland, shrubbery, wetlands | 0–10          | >2000              | >1500          | >1000       | >500         |
| Suitable Matrix       | Grass, bare ground, ice and snow | 10–50        | 1500–2000          | 1000–1500      | 500–1000    | -            |
| Moderate Matrix       | Water                         | 50–100        | 1000–1500          | 500–1000       | -           | -            |
| Unsuitable Matrix     | Farmland                      | 100–500       | 500–1000           | 0–500          | 0–500       | 0–500        |
| Barrier               | Artificial surface            | >500          | 0–500              | -              | -           | -            |

In modelling resistance surface, there is often a lack of biological movement information. Expert opinion is mostly used to compensate for this lack but may bring a certain degree of uncertainty, and sensitivity analysis is needed to explore the influence of parameter values based on expert opinion [29,37,55]. In this study, four approaches were used to model resistance surfaces, namely, the basic model ([1,3,5,7,9]), the linear model ([1,25,50,75,100]), the contrasting model ([1,10,25,50,100]) and the highly contrasting model ([1,25,100,500,1000]) (Figure 2). We assessed the effect of the four models on a least-cost paths (LCPs) simulation by comparing their Spearman’s rank coefficient index (SRI) and then determined the optimal model.

2.4. Ecological Corridors and Key Nodes

Mapping ecological corridors and identifying the key nodes of corridors require a lot of decisions and assumptions and may produce various results. The Linkage Mapper...
toolbox based on ArcGIS (Esri, Redlands, CA, USA) was used to map least-cost corridors, identify key nodes with the Circuitscape plug-in and assess the connectivity priority of PAs.

2.4.1. Ecological Corridor Identification

A least-cost analysis was used to model the LCPs of species by calculating the minimum cumulative cost of species moving from the ‘source’ through heterogeneous landscapes to a certain point. This method used a cost-weighted distance (CWD) to measure the difficulty for individuals to move between habitats [56]. The basic formula [57] used was:

\[ \text{LCD} = f_{\min} \sum_{i=1}^{n} (D_{ij} \times R_i), \]  

where \( \text{LCD} \) is the least-cost distance of a species from its ecological source to any landscape patches; \( f \) is an unknown but monotonically increasing function; \( \min \) indicates the minimum cumulative resistance from different sources for unit \( i \); \( D_{ij} \) represents the spatial distance from the source \( j \) to the cell \( i \); \( R_i \) is the resistance of patch \( i \); and \( n \) and \( m \) are the number of sources and patches, respectively.

In this step, we ensured that connections between two source patches did not pass through other patches. After receiving the LCPs, Linkage Mapper subtracted the least-cost path distance from the raw corridors to obtain the normalised minimum cost corridor, \( \text{NLCC}_{AB} = \text{CWD}_A + \text{CWD}_B - \text{LCD}_{AB} \), where \( \text{CWD}_A \) and \( \text{CWD}_B \) are the cost-weighted distances from the core areas A and B, respectively, and \( \text{LCD}_{AB} \) is the cost-weighted distance accumulated moving along the ideal LCP. That is, for LCPs, the NLCC values are zero.

2.4.2. Key Nodes Identification Based on Circuit Theory

A connectivity model based on circuit theory abstracts the heterogeneous landscape as a circuit composed of a series of nodes and resistors [38]. According to Ohm’s law in physics, the current through a conductor is proportional to the voltage between the two points. The current \( I \) is expressed as: \( I = \frac{V}{R_{\text{eff}}} \), where \( V \) is the voltage measured across the conductor, and \( R_{\text{eff}} \) is the effective resistance of the conductor, also known as the resistance distance. Reducing with increasing connection pathways, \( R_{\text{eff}} \) is considered an indicator of spatial isolation among the nodes.

Pinchpoints, also called bottlenecks, are locations where the loss of a small area can disproportionately impair connectivity. These were identified by Circuitscape in the previously mapped corridors [58]. To identify the pinchpoints of the entire network, we used the ‘All-to-one’ Circuitscape mode to calculate current flow centrality. This mode ties one core area to the ground and injects a current into the remaining cores, iterating across all cores. The generated current map with high current density shows pinchpoints important for maintaining the entire network connection.

Barriers are defined as landscape features that hinder biological movement between ecologically important areas, the removal or restoration of which could significantly improve connectivity [58]. Barrier detection may identify recovery opportunities that probably maximise the benefits of connectivity protection and may also reveal unpractical modelled corridors. The improvement score of barrier removal is \( \Delta \text{LCD} = \text{LCD} - \text{LCD}' \). LCD is the minimum cumulative resistance along the LCP from one patch to another, and \( \text{LCD}' \) is the lowest cost distance after obstacle clearance (resistance is changed to 1). Dividing \( \Delta \text{LCD} \) by the search diameter gives the connectivity benefit per unit restored; dividing \( \Delta \text{LCD} \) by \( \text{LCD} \) gives the proportional improvement relative to the unrestored effective distance [40].

Centrality is a measure of the importance of links (corridors) or core areas in maintaining the entire network connectivity. When assessing centrality, each core area is treated as a node and each link is assigned a resistance equal to the CWD of the corresponding least-cost corridor; one node is then injected with a 1 Amp current and the other to ground, and the centrality score is the final cumulative current values from each core and the links.
after all core pairs are iterated [59]. The bigger the value, the more important the core area is for maintaining the overall connectivity of the entire habitat network.

3. Results
3.1. Spatial Pattern of Ecological Resistance

In the Qinba Mts, ecological resistance can be separated into five levels, from low to high: habitats, suitable matrixes, moderate matrixes, unsuitable matrixes and barriers (Figure 3). Habitats and suitable matrixes (collectively called ‘suitable habitat’) occupy $52.63 \times 10^3$ km$^2$ and $98.52 \times 10^3$ km$^2$, respectively, accounting for 17.20% and 32.20% of the study area, covering almost all protected natural areas. These areas mainly include the Dieshan Mountains and Minshan Mountains in the west, the Qinling Mountains in Shaanxi, the hinterland of the Micang Mountains and Daba Mountains in the south, the Shennongjia Mountains in the southeast and the Funiu-Xiong’er Mountains in the northeast. Moderate matrixes are scattered throughout, accounting for 12.46% of the study area. Unsuitable habitats have a wide range, mainly in the areas with low altitude and high population density, such as those in Hanzhong City and Ankang City in Shannxi Province, Luoyang and Zhengzhou in Henan Province (Songshan area) and Longnan City and Dingxi City in Gansu Province, accounting for 32.11% of the total area. Barriers, the areas with the highest resistance level, are mainly found in the buffer zones of artificial land and national roads, accounting for only 6.02% of the study area.

[Figure 3. Ecological resistance in the Qinba Mts. The upper bar diagram from left to right shows the three environmental variables: land cover (L.UCC), population density and distance to road.]

In general, ecological resistance in the Qinba Mts is consistent with the spatial pattern of the PAs. For the PAs, the habitats and suitable areas take up $21.62 \times 10^3$ km$^2$ and $16.82 \times 10^3$ km$^2$, respectively, together accounting for 86.38%; the proportions of the corresponding resistance levels are 41.08% and 17.07%, respectively, indicating that a large proportion of suitable habitat patches are still unprotected. Areas of the remaining three resistance levels account for 4.19%, 8.69% and 0.74% of protected patches, respectively, suggesting that a few PAs may be disturbed by surrounding human activities to some extent. Meanwhile, in specific nature reserves, modest human activity is a cause for biological conservation. For example, in the Hanzhong Crested Ibis Nature Reserve, local pesticide-free paddy fields are a major feeding place for the Crested Ibis, indicating a harmonious coexistence between human and birds. In this case, the situation will be treated differently.
3.2. LCPs and Sensitivity Analysis

When modelling LCPs, we hoped that they could avoid urban areas, residential areas, industrial zones, transport infrastructure and agricultural land as much as possible. According to the results of the four sensitivity models, there are 110, 102, 100 and 96 LCPs, respectively (Figure 4). That is, the lower the sensitivity, the more LCPs were modelled and the greater the probability that LCPs would pass through unsuitable habitats, suggesting that some LCPs may be unreliable. However, for the highly contrasting model, some LCPs appear to be too curved to be efficient. The spatial pattern of the LCPs mapped by the four models have strong consistency, as did the relative values of the CWD. LCPs were separated into five categories by CWD. The smallest are mainly in the Minshan area and the border zone between Shaanxi Province and Gansu Province. The largest are linkages between the Qinling Mountains and the Daba Mountains; and the Xinkailing Mountains with the Huashan Mountains and Wudang Mountains.

According to Table 2, LCPs based on the basic model have more than 50% overlap with those based on the linear model and contrasting model, while the overlap with the highly contrasting model is significantly smaller. The LCPs resulting from the linear model have the highest overlap with the contrasting model, at 0.71. In terms of the SRIs, all the correlation coefficients between the four models almost exceeded 70%; that is, the four models generally have strong correlations with each other. These figures indicate that the least-cost corridors in our study have some robustness to the four sensitivity models. Therefore, in light of the actual situation of the Qinba Mts, and in order to make the corridors pass through habitat areas as much as possible, we finally chose the contrasting model to map our ecological corridors, abandoning LCPs with the largest 10% CWD (the dark red paths in the lower left panel of Figure 4) and those through highly human-disturbed towns. Finally, we obtained 88 LCPs based on the contrasting resistance model, connecting all the PAs of the Qinba Mts into a connected whole.

![Figure 4](image-url)
Table 2. Sensitivity analysis of LCPs based on the four sensitivity models.

|                | Linear |              |                  | Highly Contrasting |                  |
|----------------|--------|--------------|------------------|-------------------|------------------|
|                | Overlap| SRI          | Overlap          | SRI               | Overlap          | SRI               |
| Basic          | 0.56   | 0.81         | 0.52             | 0.78              | 0.37             | 0.68              |
| Linear         | 1      | 1            | 0.71             | 0.96              | 0.50             | 0.85              |
| Contrasting    |        |              | 1                | 1                 |                  |                  |
| Highly Contrasting |      |              |                  |                   |                 |                  |

3.3. Ecological Corridors and Key Nodes

When identifying pinchpoints of ecological corridors based on circuit theory, we set the CWD cut-off values to 20 km, 50 km, 80 km, 100 km, 150 km and 200 km, respectively. According to Figure 5, current density in corridors decreases as the CWD cut-off increases, while the location of relatively high current density areas remains almost unchanged, i.e., the position of pinchpoints does not vary with the corridor width. In the Qinba Mts, the current density map presents a pattern that is ‘small at the two ends and large in the middle’. Areas with high current density, namely pinchpoints, are mainly distributed in the connections such as the Qinling Mountains–Funiu Mountains, Qinling Mountains–Xinkailing Mountains, the interior of Micang Mountains and the Micang Mountains–Daba Mountains. Therefore, protecting or restoring connectivity of pinchpoints in these corridors could help to functionally connect all PAs in the Qinba Mts, achieving ecological connectivity across the whole mountainous region.

![Figure 5. Patterns of current density between protected areas in the Qinba Mts (the green polygons represent the PA patches).](image-url)

In barrier detection analysis, we calculated the maximum improvement value (IV_Max), the percent of maximum improvement value (IV_Max_Pct), the sum improvement value (IV_Sum) and the percentage of sum improvement value (IV_Sum_Pct) (Figure 6). The patterns of IV_Max and IV_Sum have a high degree of similarity, with the high values scattered in corridors between PAs in the northern Longnan City, the western Hanzhong City, the Funiu Mountains, the Jingshan Mountains and elsewhere. That is, these areas are subject to strong anthropogenic disturbance, which has a substantial hindering effect on ecological connectivity. The main difference between the two maps is in the connections of PAs in the eastern part of the study area, such as the corridors between the Funiu Mountains and the Danjiang Wetland, Shennongjia Mountains and Wudang Mountains, suggesting that some of the barriers are shared by multiple corridors. The distribution of IV_Max_Pct...
and IV_Sum_Pct are almost completely consistent, mainly in the corridors in the Longnan–Tianshui area, the Funiu Mountains and the Jingshan Mountains, which probably should be given the highest priority of connectivity conservation. Above all, we found that the Longnan–Tianshui area in the western Qinling Mountains, Funiu Mountains and Jingshan Mountains in Hubei Province play a particularly important role in the improvement of connectivity in the whole region, which should receive more attention.

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Figure 6. Patterns of barrier improvement values and barrier improvement rates of the Qinba Mts (the green polygon areas represent the PAs).

3.4. Pattern of Ecological Network

To map ecological corridors, we chose 80 km as the CWD cut-off, covering most of a region’s suitable habitat areas and well demonstrating the connectivity protection needs between the PAs. Meanwhile, to highlight connectivity priority areas in the mapped corridors, we took the pinchpoints and barriers as the two largest of the five categories divided by the Jenks natural breaks method. The national forest parks retain a relatively intact ecosystem while providing recreation opportunities, so we believe they could function well as stepping stones in the ecological network, and we simplified them as circular areas with the size equal to their actual areas. Thus, in combination with the results of the centrality analysis, we were able to use the PAs in the Qinba Mts to map the ecological network pattern.

The ecological network has 46 core patches and an area of $44.50 \times 10^3$ km$^2$, dominated by the national parks and their adjoining nature reserves, connected by 88 corridors with a total area of $66.75 \times 10^3$ km$^2$, accounting for 36.36% of the study area, covering 73.60% of the suitable habitat. In the corridor area, there are 69 pinchpoints (about $2213.26$ km$^2$), mostly located in corridors between the Qinling Mountains and the Funiu Mountains, Micang Mountains and Daba Mountains; 86 barriers, with an area of $2629.66$ km$^2$, are mainly located in the northwest Longnan City and corridors between the Qinling Mountains and Micang Mountains; Qinling Mountains and Xiong’er Mountains; and the Funiu Mountains and Danjiang Wetland. As elements to make corridors more effective, we filtered 37 national forest parks as potential stepping stones, with a total area of $4373.46$ km$^2$, playing a vital role in achieving the whole ecoregion’s effective connectivity (Figure 7).
4. Discussion

4.1. Effect of the Resistance Assignment on Corridor Modelling

Landscape resistance should ideally be assessed on the basis of field and experimental data. However, collection of such data is limited by capital, technology and time, and, thus, reliance on expert opinion is common and likely to continue in the future [29,54]. The sensitivity of LCPs to the relative value of resistance varies with the degree of landscape fragmentation and the number of suitable habitats [60]. In the same landscape, simulation results for network connectivity lie mainly in differences in relative resistance values for environmental factors rather than in the absolute magnitude of resistance values; LCPs are more sensitive to differences between moderate habitat and barriers than between habitat and moderate habitat [55]. Chen [61] suggested that resistance assignments can be made according to the study area’s actual situation and the study’s purpose, for example, assigning values for a moderate matrix close to the values of habitat could better identify stepping stones. In this study, when considering resistance assignments of different sensitivities, we referred to the schemes of WHCHG [37] and Chen [61] and proved that the LCPs between PAs in the Qinba Mts are robust to different sensitivity models, which is consistent with the results of the above scholars’ studies.

When constructing the resistance surface, this paper used the method based on ecological integrity to assess the habitat suitability of the Qinba Mts. The results showed that the suitable habitat covers the vast majority (86.38%) of the existing PAs, consistent with the PAs’ spatial distribution. To obtain the final resistance surface, we superimposed the resistance of environmental factors and took the maximum values. The resulting ecological resistance value may be large, given the conservative approach, but it well highlights the area with the best ecological integrity and authenticity in the Qinba Mts. Some scholars [49,50] chose ecosystem service as a proxy for resistance surface, not taking into account that biodiversity hotspots (ecological integrity) may not be consistent with ecosystem service hotspots [62], identifying an unreasonable range of ecological sources and affecting the accuracy of their ecological decisions.

4.2. Suggestions for Ecological Connectivity Conservation

In light of the results of the above analysis, we make a number of recommendations for ecological connectivity conservation in the Qinba Mts.

Establish an ecological network with national parks as the core while integrating all the natural PAs. According to the centrality analysis, the extensive national parks are obviously the centre of the entire ecological network; thus, integration and optimisation of other...
nature reserves and enhancement of their ecological connectivity with the national parks are vital for promoting the migration and dispersal of rare species and the flow of ecological processes to truly achieve long-term conservation. In addition, habitats around the national parks that are not included in the protection system, such as the border area between Baoji in Shaanxi and Tianshui in Gansu, the eastern part of SNP, are important buffer zones for the national park. These are crucial for the conservation effect of the national park and the connectivity of the whole region and need to be protected as a priority.

Break down administrative limits and carry out conservation measures with ecogeo-graphic units as a whole. A complete mountain range is often split into multiple nature reserves due to administrative divisions, and, even though the boundaries of these reserves are connected, most of their core areas are not, which seriously limits the ecological integrity and connectivity of habitat patches [48]. In particular, in mountain ranges at the borders of provincial administrative units, such as the Micang Mountains at the border between Shaanxi and Sichuan, the corridors between nature reserves are high-frequency areas where wildlife may occur, and inter-governmental cooperation is needed to enhance ecological connectivity.

Maintain and restore key connectivity areas and strengthen the protection of stepping-stone corridors. For the pinchpoints in the corridors, more attention should be paid to the maintenance or promotion of their ecological environment and to avoiding development activities. For barriers, moderate ecological restoration or wildlife corridors can be built to improve connectivity after a scientific assessment. In particular, stepping stones can be used as the middle station and shelter for wildlife migration among habitat patches; they play a role that cannot be ignored, especially those around the pinchpoints. For example, the three national forest parks of Louguantai, Taiping and Zhuque are important stepping stones between the Qinling Area of GPNP and Niubeiliang National Nature Reserve; the other three national forest parks from west to east, Zhongnanshan, Wangshunshan and Shaohuashan, make it possible to connect the Niubeiliang Reserve with the Xiaoqinling Reserve for a corridor up to 157.28 km in length.

Integrate connectivity protection into regional ecological conservation planning and land-use planning. About 70% of the suitable habitat is still not included in current conservation systems, accounting for 34.86% of the total study area. At present, nature reserves in the Qinba Mts have reached a high level in terms of number and scale, and it is obviously extremely hard to convert these areas strictly into PAs. This would not only cost a great deal of human and financial resources but would also exacerbate the shortage of construction land in the region, to the detriment of sustainable, regional economic and social development. Therefore, these areas should be developed carefully, with a focus on protecting their ecological connectivity, to achieve a harmonious coexistence between man and nature.

5. Conclusions

Across the Qinba Mts, we identified potential corridors and their key nodes by assessing the connectivity between PAs, as well as filtered habitat patches that can serve as stepping stones, thus, creating an ecological connectivity conservation network. This large-scale network, with the Minshan and Baishuijiang areas, the Qinling area of GPNP and the SNP as the core, integrates the natural PAs in the research area and provides a framework for the Qinba Mts to become an ecologically connected whole. Corridors modelled in this study are of great significance for breaking down the limitations of traditional conservation systems, helping organisms adapt to climate change and realising the long-term protection of species and ecological processes.

This study has a relatively rough resolution and is still vague in details; so, subsequent analysis is required to combine the habitat needs and distribution pattern of species in the region on a finer scale. It is certain that this analysis at the whole ecoregional scale provides candidate positions for finer-scale ecological corridor modelling and analysis and provides scientific references for the latter.
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