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Research

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Abstract

Background

The main purpose of building national parks in China is to protect nationally representative natural ecosystems and maintain the integrity of their structures, processes, and functions. Landscape connectivity, as an important indicator to measure ecological processes, is of great significance to the migration and dispersal of species within a region. Based on the habitat characteristics of the target species, the study of landscape connectivity in Qianjiangyuan National Park, which aims to protect forest ecosystems, can provide a scientific basis for the optimization of its functional areas and the construction of biological corridors.

Results

The disturbed landscape of the study area is dominated by tea plantations and drylands, with central roads being an important factor affecting the overall landscape connectivity. In terms of the distribution of key habitat patches, the mountains have a high value. In terms of area, their size is not directly proportional to their importance for maintaining landscape connectivity in the region, but large area patches are generally of higher importance. In terms of distance, key habitats that are closer to each other have a stronger correlation and a greater possibility for species migration. Combined with the functional zoning of Qianjiangyuan National Park, the setting of strictly protected areas and recreational areas is reasonable, and traditional use areas and ecological conservation areas could be appropriately adjusted according to the distribution of key habitats. The important corridor in the middle of the ecological conservation area is crucial for the overall connectivity of the national park, and the connectivity between strict protected area will depend on successful protection of the ecological conservation area.

Conclusion

Based on the analysis of landscape connectivity in Qianjiangyuan National Park, we discussed the main factors that currently affect the landscape connectivity of this area, as well as the rationality

of the current setting of its functional zoning, and put forward some targeted suggestions for improving its connectivity.

Keywords: National park of China, Forest ecosystem, Landscape Connectivity, Morphological spatial pattern, Least-cost path method, Gravity model

Introduction

National parks are one of the most important types of protected area in China. Chinese government launched a pilot project to build Nation Park system in 2015 and completed the first batch, including 10 pilot national parks in 2020, with the main aim of protecting the integrity and authenticity of the natural ecosystem. Qianjiangyuan National Park, which focuses on the forest ecosystem, is one of the 10 existing pilots of the national park system in China and is in Zhejiang Province, one of China's most economically developed provinces. With rapid urban and rural development, rates of habitat loss and fragmentation have increased. In such circumstances, connectivity between habitat patches is becoming even more important, as it may be the only way to provide adequate habitat for wildlife populations (Jordán 2001).

Maintaining or restoring landscape connectivity is a widely recommended strategy for species conservation to face changing climate, as species are changing their distributions to adapt to emerging conditions (Magness et al. 2018). Landscape connectivity refers to the degree to which the landscape facilitates or impedes movement among source patches (Taylor et al. 1993) and is one of the most critical components of animal dispersal, population persistence, and maintenance of ecological function (Adriaensen et al. 2003). Landscape connectivity can be considered in terms of structural connectivity and functional connectivity, with the former referring to the apparent continuity that the landscape exhibits in space(Liu et al. 2019), which can be determined based on various types of maps, including satellite image maps, and the latter defining landscape continuity in terms of the characteristics of the ecological object or process under study(Wu 2007, Liu et al. 2020). Based on existing species-based studies of landscape connectivity, it is generally accepted that landscape connectivity plays an important role in biodiversity (He et al. 2018), which describes the role of the landscape in facilitating or hindering the dispersal of species between habitats (Cook 2002). Species characterized by low dispersal distances are more sensitive to landscape connectivity, and the barrier effect of specific land cover is species-specific (Minor

and Lookingbill 2010). Graph theory based approaches are widely used in different areas of landscape connectivity research, such as forests, protected areas, wildlife corridor design and ecological restoration (Machado et al. 2020).

In a study of agroecosystem connectivity focused on the Hazel Dormouse, Dondina et al. (2018) found that creating corridors on new pathways is more likely to improve connectivity in comparison with restoring or improving existing corridors (Dondina et al. 2018). Thus, the discovery of potential corridors between habitat patches based on target species can inform the development of conservation management plans for national parks.

In this study, we identified core habitats and corridors based on species' habitat and dispersal distances and assigned migration cost levels to target species' preferences for different landscape types. We selected two species under national protection in China at the first level as habitat representatives of the species in the region, and the final core habitat and potential corridors were obtained by overlaying the two species. This study attempts to analyze the current status of landscape connectivity in Qianjiangyuan National Park and to identify priority sites for ecological restoration and corridor construction to improve landscape connectivity in the study area and provide useful information for future national park planning and conservation management.

Study Area

Qianjiangyuan National Park is one of the first 10 pilot national parks in China and is located on the western border of Zhejiang Province, one of the most economically developed provinces in China (longitude 118°01'-118°37' East, latitude 28°54' North). 29°30'), at the junction of the three provinces of Zhejiang, Anhui, and Jiangxi (Fig. 1). The national park covers an area of approximately 252 km², consisting of the former Qianjiangyuan National Nature Reserve and Kaihua County Forestry Farm and the connecting area in between these regions, which includes 4 townships, including 19 administrative villages and 72 natural villages, with a total population of 9744. Qianjiangyuan National Park aims to protect the forest ecosystem and belongs to the low-elevation broad-leaved evergreen forest vegetation belt in the middle subtropical region, with five forest vegetation types distributed along the elevation gradient in the middle subtropical evergreen broad-leaved forest, evergreen deciduous broad-leaved mixed forest, coniferous broad-leaved mixed forest, coniferous forest, and subalpine wetlands. The composition of flora is

dominated by the typical East China flora, with transitional zone characteristics. The low elevation mid-subtropical broad-leaved evergreen forest in the national park is well preserved, representative, and typical; this type of ecosystem is rare in China and around in the world, giving it global conservation value.

Methods

Landscape distribution map of Qianjiangyuan National Park

We used high-resolution remote sensing images taken by China's Gaofen-1 (GF-1) satellite, which was successfully launched in 2013, as a data source. We selected high-resolution cloud-free remote sensing images (RS images) from March 2019 (resolution = 2 m, road area resolution = 0.8 m) based on the land cover characteristics of the study area. Based on ENVI 5.1 pre-processing of the images for geometric correction, full-color sharpening, cropping, and other pre-processing, followed by supervised classification and random sampling of the spots (381 sampling samples, sampling rate of 20%), the accuracy of the interpretation samples was tested by

Fig. 1 Location of Qianjiangyuan National Park

combining the Google Earth electronic map and field survey sample points. The accuracy of the interpretation layer and the image were checked for the degree of coincidence and missing

judgment and misjudgment. The interpretation accuracy was >95%, and the minimum feature of the map was 1000 m², which met the accuracy requirements of this study¹. The landscape of Qianjiangyuan National Park is classified into 24 categories based on the habitat type and land cover characteristics of the target species: natural arboreal forest, shrubland, bamboo forest, other woodland, natural grassland, nursery land, tea plantation, pond, dry land, bare land, highway, road land, bridge, trail, urban residential land, rural residential land, detached house, house under construction, land for hydraulic construction, ditch, other construction land, reservoir, river and lake.

Vegetation type distribution map of Qianjiangyuan National Park

The forest resources survey data for Qianjiangyuan National Park in 2017 were provided by the Zhejiang Forestry Resources Monitoring Center and used to determine the distribution of forest types, including broadleaf forest, coniferous forest, mixed coniferous forest, bamboo forest, shrubland, grassland, cultivated land, and non-forest land.

Habitat identification and dispersal distance threshold of target species

In this study, the analysis of landscape connectivity was based on the habitat characteristics of the target species in the study area. In landscape connectivity assessment, the selection and dispersal distance of the target species is crucial (Guo et al. 2018). The landscape connectivity of protected species can guide the management of protected areas. Dispersal distance is a key process in determining distance thresholds and is species-specific. There are two species in Qianjiangyuan National Park that are important for protection at the national level in China, namely Elliot's Pheasant (*Syrnaticus ellioti*) and the Black Muntjac (*Muntiacus crinifrons*), both of which are also CITES Appendix I listed species. In this study, a landscape connectivity analysis was conducted based on the dispersal distance threshold and habitat selections of these two species.

Elliot's Pheasant is a typical ground-dwelling forest resident bird that can inhabit broad-leaved forests, coniferous forests, bamboo forests, and short-term shrublands close to forests, with evergreen or deciduous broad-leaved forests being the most suitable habitat (Ding and Zhuge 1989). Li (1985) observed that the winter dispersal distance of Elliot's Pheasant can span two or three hills with a diameter of 1.5–2 km, while Shi and Zheng (1997) tracked the spring dispersal

¹ The remote sensing image interpretation and accuracy test of interpretation results in this study were commissioned by 21st Century Space Technology Co., LTD.

process over a long distance of more than 3 km using radio telemetry. Peng and Ding (2005) used telemetry to determine the spring breeding dispersal linear distance to be 1.5–2.1 km. Zhang (2015) used telescopes to observe and study the behavior of Elliot's Pheasant during wilderness training using radio telemetry tracking equipment, GPS, compass, telescopes, and other equipment, and an analysis of the behavior of Elliot's Pheasants released after wilderness training determined the dispersal distance to be 0.2–3.0 km. The habitat of the Black Muntjac includes broadleaf forest, mixed coniferous forest, coniferous forest, scrub, and bamboo forest, but mixed coniferous forest and broadleaf forest are preferred (Zheng et al. 2006). The dispersal distance of the Black Muntjac is poorly studied, and its activity patterns are territorial, generally involving movement within the domain, with some individuals moving up to 2.5–5.0 km (Sheng 1992; Wang 1990). Based on the literature described above, we set a dispersal threshold of 3.0 km for Elliot's Pheasant and 5.0 km for the Black Muntjac.

Landscape Fragmentation Analysis of Qianjiangyuan National Park

With reference to relevant studies (Bennett and Saunders 2010), natural arboreal forests, shrublands, natural grasslands, bamboo forests, other woodlands, bare lands, rivers, lakes and reservoirs in Qianjiangyuan National Park are classified as protected landscapes, whereas tea plantations, nursery lands, dry lands, highways, road lands, trails, bridges, ponds, ditches, rural residential lands, urban residential lands, detached houses, houses under construction, lands for hydraulic construction and other construction lands are classified as non-protected landscapes. The area percentage (P), area weighted mean plaque fractal dimension (AWMPFD), fragmentation index (F) and relative agglomeration (C') of protected landscape patches were calculated to analyze the spatial characteristics of protected landscape patches at the landscape level and as a whole. The formulae for calculating each landscape index are shown in Table 1.

Table 1. Landscape index calculation formulae

Landscape index	Abbreviation	Formula	Description
Percentage of protected landscape patch area	P	$\frac{\sum_{i=1}^n S_i}{A}$	Range: $0 \leq P \leq 1$; S_i is the area of the i -th protected landscape patch; A is the total area of the national park
Area weighted mean plaque fractal dimension (McGarigal 1994; Wu	AWMPFD	$\sum_{j=1}^n \left[\frac{2 \ln(0.25 P_{ij})}{\ln(a_{ij})} \left(\frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \right) \right]$	Range: $1 \leq \text{AWMPFD} \leq 2$; P_{ij} is the perimeter of the j -th patch of type i , a_{ij} is the area of the j -th patch of type i

2007)			
Fragmentation index	F	$1 - \sum_{i=1}^n \left(\frac{S_i}{\sum_{i=1}^n S_i} \right)^2$	Range: $0 \leq F \leq 1$; S_i is the area of the i -th protected landscape patch
Relative aggregation (Li and Reynolds 1993; Wu 2007)	C'	$1 + \frac{\sum_{i=1}^n \sum_{j=1}^n P_{ij} \ln(P_{ij})}{2 \ln(n)}$	Range: $0 \leq C' \leq 1$; P_{ij} is the perimeter of the j -th patch of the i -th type, n is the total number of patch types in the landscape

Fragmentation reduces patch area and increases the number of patches, so the average patch area decreases (Guo et al. 2018). Therefore, we used the average patch area to quantify fragmentation. The remote sensing images were cropped into grids (500 m × 500 m) using the Fishnet tool in ArcGIS. The area and number of patches in each grid were counted, and the average patch area was calculated to indicate the degree of fragmentation of the landscape.

Key habitat and Connectivity Analysis of Qianjiangyuan National Park

This study refers to the method of combining morphological spatial pattern analysis (MSPA) and the delta of the probability of connectivity (dPC) adopted by Guo et al. (2018) to identify the habitats in Qianjiangyuan National Park. First, according to the habitat types of Elliot's Pheasant and the Black Muntjac, as well as the relevant literature, the areas where vegetation, elevation, and slope matched the habitat selection of the two species, respectively, were selected as potential habitat areas in Qianjiangyuan National Park, and the study area was reclassified into foreground (potential habitat) and background (all other areas) to obtain a binary map of potential and non-potential habitat. A MSPA was then conducted in the GuidosToolbox software (<http://forest.jrc.ec.europa.eu/download/software/guidos/>) to reclassify the landscape into seven categories based on morphological features: core, islet, loop, bridge, perforation, edge, and branch (Soille and Vogt 2009). The edge width was set to five pixels, and "core" areas were extracted to identify habitats under the eight-neighbor rule. Unlike traditional methods that focus on the area or importance of individual patches without considering the overall landscape connectivity, this method provides four- or eight-neighbor rules because the connectivity analysis is performed on a raster grid, which allows for automatic classification based on pixel-level geometric concepts (Guo et al. 2018).

The probability of connectivity (PC) is an area-based functional connectivity method that is well suited to identify key elements that maintain overall habitat connectivity to quantitatively describe landscape connectivity and identify patches with important connectivity (Saura and Pascual-Hortal

2007). The delta of PC (dPC) can be used to calculate the contribution of each patch to the overall connectivity of the ecological network. The formula for the calculation is as follows:

$$PC = \frac{\sum_{i=1}^n \sum_{j=1, i \neq j}^n P_{ij}^* a_i a_j}{A_L^2} \quad (1)$$

$$dPC(\%) = \frac{PC - PC'}{PC} \times 100\% \quad (2)$$

where a_i and a_j refer to the area of habitat i and j , respectively; the strength of the connection between any pair of patches is denoted by P_{ij} , which describes the ease of dispersion between patches i and j ; and A_L refers to areas of the national park. Conefor Sensinode 2.6 software (<http://www.Conefor.org/>) was used to calculate dPC values. According to the different dispersal abilities of the target species, the dispersal distance thresholds were set at 3.0 km and 5.0 km for Elliot's Pheasant and the Black Muntjac, respectively. If the distance between two patches was within the threshold, we set 0.5 as the probability of dispersion between patches (Guo et al. 2015). Finally, the top 10 patches with the highest dPC values were selected as key habitats.

Potential Habitat Corridor Analysis of Qianjiangyuan National Park

Each pair of key habitats can be connected to each other by a least-cost path based on a least-cost model (Adriaensen et al. 2003). Least-cost paths are often used to optimize grid modules (Guo et al. 2018), and the grid's resistance value describes its facilitating or hindering effect on species dispersal processes. Resistance values are attached to each land cover cell to calculate the connectivity between two habitats (Grimm et al. 2008). Therefore, using cost-path analysis in ArcGIS to calculate the path of least resistance for organisms moving along key habitat patches, potential corridors between key habitats can be obtained.

Resistance values for different landscape types were key factors that influenced the results. Based on the published literature related to the habitat selection of Elliot's Pheasant and the Black Muntjac in the study area, the five resistance indicators of vegetation type, elevation, slope, distance from roads, and distance from settlements were selected to summarize the selection of different habitats by the target species in the literature and to assign habitat levels to them. The golden divide method (Zhang et al. 2014) was used to assign resistance coefficients to each habitat level, construct cost surfaces for different resistance indicators based on the resistance coefficients,

and superimpose the cost surfaces for each resistance indicator to construct a composite cost surface that was used in the least-cost path analysis to identify potential corridors for this study. We used the top 10 patches with the highest dPC values as key habitat areas and used the gravity model to identify general and important corridors in the potential corridors. The gravity model was used to quantitatively evaluate the interaction force between the source and the target (Sklar and Costanza 1991), with a greater force indicating a more important corridor. Therefore, the relative importance of the corridor was evaluated as follows.

$$G_{ab} = \frac{N_a N_b}{D_{ab}^2} = \frac{\left[\frac{1}{P_a} \times \ln(S_a) \right] \left[\frac{1}{P_b} \times \ln(S_b) \right]}{\left(\frac{L_{ab}}{L_{max}} \right)^2}$$

$$= \frac{L_{max}^2 \ln(S_a) \ln(S_b)}{L_{ab}^2 P_a P_b} \quad (3)$$

G_{ab} is the interaction force between core patches a and b , N_a and N_b are the weight values of the two patches, D_{ab} is the standardized value of the potential corridor resistance between patches a and b , P_a is the resistance value of patch a , S_a is the area of patch a , L_{ab} is the cumulative resistance value of the corridor between patches a and b , and L_{max} is the maximum value of the cumulative resistance of all the corridors in the study area.

In this study, we constructed an interaction matrix between 10 key habitats based on the gravity model, and corridors with an interaction force greater than 0.1 were extracted according to the matrix evaluation results as important corridors, with the rest designated as general corridors. The general corridors, important corridors and key habitats were superimposed to construct a network of key habitats and corridors in Qianjiangyuan National Park.

Results

Analysis of landscape fragmentation

The landscape type distribution map of Qianjiangyuan National Park was obtained after interpreting the high-precision remote sensing image to extract land cover information (Fig. 2). Table 2 shows the landscape classification results, in which natural arboreal forest is the largest, accounting for 78.37% of the total area of the national park, and other major landscape types include shrubs (accounting for 3.97%), bamboo forest (accounting for 2.85%), tea plantations

(accounting for 7.41%), and dry lands (accounting for 4.39%).

In the Qianjiangyuan National Park, natural arboreal forests, shrublands, natural grasslands, bamboo forests, other woodlands, bare lands, rivers, lakes and reservoirs are classified as protected landscapes, whereas tea plantations, nursery lands, dry lands, highways, road lands, trails, bridges, ponds, ditches, rural residential lands, urban residential lands, detached houses, houses under construction, lands for hydraulic construction, and other construction lands are classified as non-protected landscapes. The distribution of protected and non-protected landscapes is shown in Fig. 3. The average patch area of the protected landscapes was used to roughly simulate landscape fragmentation. As shown in Fig. 4, the central and outer edge portions of the national park are more severely fragmented in comparison with other areas. The four landscape indices calculated for the proportion of protected landscape area (P), area weighted mean plaque fractal dimension (AWMPFD), fragmentation index (F), and relative aggregation (C') are shown in Table 3.

Table 2. Area and proportion of different landscape categories of Qianjiangyuan National Park

Serial number	Landscape category	Area (km ²)	Proportion (%)
1	Natural arboreal forest	205.6821	78.3672
2	Tea plantation	19.43847	7.4063
3	Dry land	11.51652	4.3879
4	Shrubland	10.41074	3.9666
5	Bamboo forest	7.481252	2.8504
6	River	2.380823	0.9071
7	Reservoir	1.828854	0.6968
8	Highway	1.007906	0.3840
9	Rural residential land	0.973664	0.3710
10	Trail	0.586553	0.2235
11	Natural grassland	0.393852	0.1501
12	Bare land	0.264007	0.1006
13	Other forest land	0.107711	0.0410
14	Urban residential land	0.100458	0.0383
15	Nursery land	0.099273	0.0378

16	Road land	0.057231	0.0218
17	Other construction land	0.037765	0.0144
18	Detached house	0.035179	0.0134
19	House under construction	0.018213	0.0069
20	Pond	0.017469	0.0067
21	Lake	0.006537	0.0025
22	Land for hydraulic Construction	0.005876	0.0022
23	Ditch	0.004842	0.0018
24	Bridge	0.004084	0.0016
25	Aggregate	252.3800	100

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Fig. 2 Distribution of landscape categories in Qianjiangyuan National Park

Fig. 3 Distribution of protected and unprotected landscapes in Qianjiangyuan National Park

Fig. 4 Landscape fragmentation analysis of Qianjiangyuan National Park

251 **Table 3.** Landscape indexes in Qianjiangyuan National Park

Serial number	Landscape index	Result
1	Percentage of protected landscape area (P)	0.87
2	Area-weighted average plaque fractal dimension (AWMPFD)	1.38
3	Fragmentation index (F)	0.51
4	relative degree of aggregation (C')	0.69

Morphological spatial pattern analysis

Areas where land cover/vegetation type, elevation and slope conditions matched the habitat conditions were extracted based on the habitat characteristics of Elliot's Pheasant and the Black Muntjac (Table 4). The suitable (including most suitable, sub-preferred and generally suitable) vegetation types for Elliot's Pheasant are broad-leaved forest, coniferous forest, mixed forest, bamboo forest, shrub forest and farmland at an elevation of 200–1900 m, slope $\leq 50^\circ$, distance from roads > 700 m and distance from settlements > 700 m. Suitable vegetation types for Black Muntjac are broad-leaved forest, mixed-coniferous forest, coniferous forest and shrub forest, at altitudes ≥ 600 m, with slopes $\leq 45^\circ$, ≥ 50 m from roads, and ≥ 200 m from settlements. Areas that meet these habitat characteristics are shown in Fig. 5.

Table 4. Potential habitat range of Elliot's Pheasant and Black Muntjac

Species	Land cover type/vegetation	Altitude	Slope	Distance from road	Distance from residence
Elliot's Pheasant	Broad-leaved forests, coniferous forest, mixed forests, bamboo forests, shrub forests, farmland	200–1900 m	$\leq 50^\circ$	> 700 m	> 700 m
Black Muntjac	Broad-leaved forests, mixed forests, coniferous forests, shrub forests	≥ 600 m	$\leq 45^\circ$	≥ 50 m	≥ 200 m

(a) Suitable habitat for Elliot's Pheasant

(b) Suitable habitat for Black Muntjac

Fig. 5 Suitable habitat distribution for Elliot's Pheasant and Black Muntjac

GuidosToolbox (<https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/>) was applied to analyze the morphological features of the habitat map to reclassify the suitable habitats of Elliot's Pheasant and Black-fronted Muntjac into seven categories: core, edge, perforation, bridge, loop, branch, and islet(Vogt and Riitters 2017). In comparison with Elliot's Pheasant, the Black Muntjac had fewer patches and fewer areas due to its habitat requirements, but both species were found to be relatively evenly distributed.

The delta of the probability of connectivity analysis

(a) MSPA classification results for Elliot's Pheasant

(b) MSPA classification results for Black-fronted Muntjac

Fig. 6 Morphological spatial pattern analysis of Qianjiangyuan National Park

The core area from the morphological spatial pattern analysis was extracted, and the top 30 patches were selected in descending order according to the size of the area to generate the node files and link files required for the connectivity probability calculation, with different dispersal

distances considered in the calculation (Elliot's Pheasant = 3 km, Black Muntjac = 5 km). The delta of the probability of connectivity (dPC) for the 30 core patches was calculated using Conefor Sensinode2.6 software (<http://www.conefor.org/>) (Table 5). The top 10 patches with dPC values were selected as key habitat to obtain a map of key habitat importance ranking (Fig. 7).

Table 5. Top 10 core habitat dPC vs. area

Patch number	Elliot's Pheasant		Black Muntjac	
	dPC	Area (km ²)	dPC	Area (km ²)
1	65.07451	32.32	61.32844	30.31
2	64.90517	66.47	57.10925	31.92
3	62.79605	67.47	50.44735	17.66
4	8.635746	7.96	12.18496	5.57
5	2.794364	2.76	4.221646	1.99
6	2.608401	2.54	3.117111	0.22
7	1.600233	1.54	1.339277	0.64
8	1.405282	1.39	1.241377	0.72
9	0.704385	0.66	0.887261	0.01
10	0.688953	0.67	0.562306	0.35

Note: dPC is an indicator of importance for maintaining overall landscape connectivity

Analysis of potential habitat corridors

(a) Distribution of the patches with the top 10 dPC values for Elliot's Pheasant.

(b) Distribution of the patches with the top 10 dPC values for Black Muntjac.

Fig. 7 Map of the top 10 core habitat importance levels

The key habitat patches were transformed into particles, the minimum cost distance and cost back link between each particle were calculated, and then cost path analysis was performed. The cost raster data were crucial for this step, and the cost surface for each resistance indicator was constructed by determining the cost values of five resistance indicators: land cover/vegetation, elevation, slope, distance from road, and distance from residence (Fig. 8 and Fig. 9). Tables 6 and 7 show the resistance and costs for each resistance indicator set at different levels for Elliot's Pheasant and Black Muntjac, respectively, after reference to the relevant literature values (Guo et al. 2018). The final overlay yielded the respective cost raster data for Elliot's Pheasant and Black Muntjac (Fig. 10). Potential corridors between key habitats were obtained by cost-path analysis of 10 key habitats (Fig. 11).

Table 6. Resistance and cost values of each resistance indicator for Elliot's Pheasant

Rating	Vegetation	Altitude	Gradient	Distance from road	Distance from residence	Resistance	Cost value
Most suitable	Broadleaf forests, mixed forests	300–800 m	0–30°	>1800 m	>2200 m	0	1
Suboptimal	Coniferous forests, bamboo forests	200–300 m; 800–1000 m	30–40°	1000–1800 m	1500–2200 m	0.38	38
Generally appropriate	Shrublands, farm lands	1000–1900 m	40–50°	700–1000 m	700–1500 m	0.62	62
Unsuitable	others	<200 m; >1900 m	>50°	<700 m	<700 m	1	100

Table 7. Resistance and cost values of each resistance indicator for the Black Muntjac

Rating	Vegetation	Altitudes	Gradient	Distance from road	Distance from residence	Resistance	Cost value
Most suitable	Broadleaf forests, mixed forests	800–1000 m	0–30°	>600	>1000	0	1
Suboptimal	Coniferous forests, shrublands	600–800 m; 1000	30–45°	200–600	500–1000 m	0.38	38
Generally appropriate	—	—	—	50–200	200–500	0.62	62

Unsuitable	Bamboo forests, meadows, other	<600 m;	>45°	<50	<200 m	1	100
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Fig. 8 Cost surface of each resistance indicator for Elliot's Pheasant.

Fig. 9 Cost surface of each resistance indicator for the Black Muntjac.

Fig. 10 Cost raster maps of Elliot's Pheasant and the Black Muntjac in Qianjiangyuan National Park

(a) Key habitats and potential corridors of the Elliot's Pheasant. (b) Key habitats and potential corridors for the Black Muntjac.

Fig. 11 Distribution of key habitats and potential corridors in Qianjiangyuan National Park

Key habitat and important corridor network analysis

The interaction matrix between the 10 key habitats was constructed using a gravity model (Table 8, Table 9). According to the matrix evaluation results, corridors with an interaction force greater than 0.1 for Elliot's Pheasant were considered to be important corridors, and the rest were designated as general corridors (Fig. 12, Fig. 13). The key habitats and corridors of the two species were overlaid to construct a network of key habitats and corridors in Qianjiangyuan National Park (Fig. 14).

Table 8. Gravity model-based interaction matrix of key habitat interactions for Elliot's Pheasant.

Key Habitat Number	1	2	3	4	5	6	7	8	9	10
1		0.93	0.19	0.06	0.01	0.04	0.0050	0.01	0.0067	0.0034
2			0.48	0.12	0.02	0.07	0.0080	0.02	0.01	0.0053
3				0.10	0.02	0.06	0.0070	0.02	0.0092	0.0047
4					0.15	1.48	0.03	0.09	0.03	0.02
5						0.29	0.03	0.10	0.04	0.01
6							0.08	0.30	0.09	0.04
7								0.49	0.62	0.09
8									0.54	0.11
9										0.40
10										

304 **Table 9.** Gravity model-based interaction matrix of key habitat interactions for the Black Muntjac.

Key Habitat Number	1	2	3	4	5	6	7	8	9	10
1		0.08	0.29	0.26	0.09	0.04	0.02	0.06	0.03	0.03
2			0.06	0.18	0.23	0.09	0.04	0.12	0.04	0.03
3				0.39	0.10	0.04	0.03	0.07	0.04	0.03
4					0.39	0.15	0.07	0.21	0.08	0.06
5						4.23	0.64	2.94	0.22	0.18
6							0.91	9.34	0.17	0.14
7								2.64	0.19	0.16
8									0.33	0.28
9										10.00
10

305 **Fig. 12** Distribution of key habitats and corridors of Elliot's Pheasant in Qianjiangyuan National Park.

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Fig. 13 Distribution of key habitat and corridors of the Black Muntjac in Qianjiangyuan National Park.

Fig. 14 Network map of key habitats and corridors in Qianjiangyuan National Park

5 Discussion

According to the results of the study, landscape fragmentation in Qianjiangyuan National Park occurs in the northern and southern edges where human disturbance is concentrated, and in the

central part of the national park, where roads, settlements and cultivated land have a greater impact on fragmentation. The disturbed landscapes in the southern and northern edges are dominated by tea plantations, while the central disturbed landscapes are dominated by drylands, with tea plantations being the largest of all non-protected landscapes, followed by drylands. Appropriate vegetation restoration and reforestation efforts in these areas can help increase connectivity within Qianjiangyuan National Park.

The key habitats area of Qianjiangyuan National Park is 183.77 km², accounting for 72.92% of the total area of the park. In terms of the distribution of key habitats, mountains are of high importance in Qianjiangyuan National Park. The key habitat area of Elliot's Pheasant is relatively large and distributed in areas outside of the disturbed landscape; the Black Muntjac is influenced by habitat selection, and its key habitat area is smaller and mainly distributed in areas at higher elevations. The key habitats for both species assessed in this study are well-distributed. As shown in Table 5, the habitat patches that contributed most to maintaining landscape connectivity were not the largest area patches, and the size of the key habitat area for each target species was not proportional to its role in maintaining landscape connectivity in the national park, but the importance of large area patches was higher for both species, so the size of the key habitat was also important for maintaining landscape connectivity in the region. Due to the functional zoning of Qianjiangyuan National Park (Fig. 15), the combined area of the strict protected areas and ecological conservation areas accounts for 73.48% of the total area of the national park. The recreational areas are almost all within non-key habitats, which is reasonable, while about half of the traditional use areas belong to key habitats, especially the lower outer edges, in excessive human intervention during recreational activities should be avoided. Therefore, the zoning setting of Qianjiangyuan National Park is appropriate for habitat protection, but the scope of ecological conservation areas and traditional uses could be adjusted to better match the distribution of key habitats.

The corridors between key habitat patches with an interaction force greater than 0.1 were classified as important corridors based on the interaction matrix between the key habitats. Taking Elliot's Pheasant as an example, the interaction forces between key habitat areas 4 and 6, 1 and 2, and 7, 8 and 9 were highest, indicating that these patches in the study area were the most interconnected, the resistance overcome by the dispersal movement of species in these areas was

the least, the exchange and circulation of materials was the most convenient, and species migration was more likely. In contrast, the distance between key habitat patches 1, 2 and 3 and key habitat patches 7, 9 and 10 was farther and interactions were weak, indicating that these key habitat areas are weakly correlated and that species dispersal movements between them are less likely. Similarly, in the distribution of key habitats and corridors of the Black Muntjac, the strongest correlations were found between key habitat patches 9 and 10, 5 and 6, and 6 and 8, with less resistance to species dispersal and a higher probability of species migration. The distances between key habitat patches 1, 2 and 3 and habitat patches 7 and 10 were farther and the interactions were weaker.

The strict protected areas of Qianjiangyuan National Park are all located within large areas of habitat. Although there are strong interactions between a few small patches in the south and a high potential for species migration, these patches are small and are not key habitat areas that support the entire national park. In addition, based on the distribution of patches, fragmentation, and the distribution of corridors in Qianjiangyuan National Park, it is clear that the major roads in the central part of the national park are one of the most important causes of the overall landscape connectivity in the region, and the important corridors in the study show that linking the key patches in series helps to mitigate the impact of the roads and enhance the overall connectivity of the national park. Therefore, at the landscape scale, large habitat patches of high importance should be prioritized for protection and enhancing the construction and protection of corridors between these areas can promote habitat connectivity and species conservation in the study area. At the same time, small patch groups with low species migration potential should also be protected as a whole to avoid further fragmentation or even area loss; although these patches are far away and their area is small, protecting the corridors between these key habitat patches can improve the overall connectivity and network structure of the study area.

The distribution of potential corridors shows that there are a number of potential corridors in the center of Qianjiangyuan National Park that connect key habitats on both sides of the road, which indirectly suggests that central roads are one of the main causes of landscape fragmentation in the park as a whole. Roads have also been highlighted in other relevant studies as a major cause of landscape fragmentation and barriers to biological movement, resulting in reduced overall landscape connectivity for many native species (Crist et al. 2005). The ecological conservation

area is the most widely distributed area within Qianjiangyuan National Park, and the vast majority of potential corridors are located in this area, which is highly protected by strict Chinese laws and regulations, which favor the restoration of potential corridor areas. There are a number of more distinct potential corridors in the ecological conservation area that are important for improving the overall connectivity of the national park, and due to their location close to traditional use areas, i.e., human disturbances such as settlements and roads, it is also particularly important to consider enhancing conservation management in this area to increase its conservation intensity. Qianjiangyuan National Park has three separate strict protected areas located in the northern and southern regions of the park, so connectivity between these strict protected areas is dependent on successful protection of the conservation area, highlighting the importance of protecting the potential corridors in the central part of the park.

While this study used two relatively detailed habitat selections in the habitat corridor analysis and graded the resistance produced by different species based on landscape categories, it did not

Fig. 15. Functional zoning map of Qianjiangyuan National Park

consider the region's plant migration characteristics, the connectivity of aquatic organisms in the forest ecosystem, or the migration characteristics of the region's less studied and less data-accessible species, such as insects, amphibians, reptiles, etc. In addition, this study only analyzed and optimized connectivity recommendations within the study area, and further ecosystem integrity and connectivity analyses can be conducted in conjunction with surrounding potential habitat patches to make useful recommendations for range optimization in Qianjiangyuan National Park.

6 Conclusion

This study provides an index analysis and visualization simulation of landscape fragmentation in Qianjiangyuan National Park and identifies key habitats and important corridors in the study area in combination with the habitat characteristics of protected species in the region. We found that:

(1) Roads, settlements, and cultivated land have a significant impact on the landscape connectivity of Qianjiangyuan National Park, with roads being one of the main reasons for the fragmentation of the overall landscape. The construction of corridors to connect the habitat patches on both side of roads and appropriate vegetation restoration and reforestation of tea plantations and drylands in the study area will increase the landscape connectivity of Qianjiangyuan National Park.

(2) The key habitat patches distributed in the mountain land in the study area are of high importance. The area of each patch of key habitat is not proportional to its contribution to the landscape connectivity of Qianjiangyuan National Park, but the size of key habitats is also important for maintaining landscape connectivity. At the landscape scale, large habitat patches of high importance should be prioritized for protection to promote habitat connectivity and species conservation in the study area. At the same time, groups of small patches with a high potential for species migration should also be protected as a whole to avoid further fragmentation or even area loss.

(3) According to the results of this study, in the current functional zoning of Qianjiangyuan National Park, the location and scope of strict protected areas and recreational areas are relatively reasonable, and the scope of ecological conservation areas and traditional use areas could be adjusted to better match the distribution of key habitats. Special attention must be focused on protecting and managing ecological conservation areas because of the pressure of human

disturbance around the area. However, at the same time, there are several important corridors in the area, and the connectivity between the strictly protected areas depends on successful protection of the ecological conservation areas.

This study provides a reference for the next step of functional zoning optimization in the Qianjiangyuan National Park pilot, and the methodology of this study has the potential to be applied to connectivity optimization analysis in other forest ecosystem-type national parks.

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Declarations

Ethics approval and consent to participate

Not applicable.

Authors' contributions

GC planned the project. YP undertook most of the literature review and analyzed the data. YP and MM wrote the manuscript. RW and ZH contributed additional literature and contributed substantially to modifying the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

Figure 1

Location of Qianjiangyuan National Park Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Distribution of landscape categories in Qianjiangyuan National Park Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

Distribution of protected and unprotected landscapes in Qianjiangyuan National Park Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 4

Landscape fragmentation analysis of Qianjiangyuan National Park
Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

(a) Suitable habitat for Elliot's Pheasant

(b) Suitable habitat for Black Muntjac

Figure 5

Suitable habitat distribution for Elliot's Pheasant and Black Muntjac Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

(a) MSPA classification results for Elliot's Pheasant

(b) MSPA classification results for Black-fronted Muntjac

Figure 6

Morphological spatial pattern analysis of Qianjiangyuan National Park Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 7

Map of the top 10 core habitat importance levels (a) Distribution of the patches with the top 10 dPC values for Elliot's Pheasant. (b) Distribution of the patches with the top 10 dPC values for Black Muntjac. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 8

Cost surface of each resistance indicator for Elliot's Pheasant. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 9

Cost surface of each resistance indicator for the Black Muntjac. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

(a) Cost raster of Elliot's Pheasant.

(b) Cost raster of the Black Muntjac.

Figure 10

Cost raster maps of Elliot's Pheasant and the Black Muntjac in Qianjiangyuan National Park Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 11

Distribution of key habitats and potential corridors in Qianjiangyuan National Park (a) Key habitats and potential corridors of the Elliot's Pheasant. (b) Key habitats and potential corridors for the Black Muntjac. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 12

Distribution of key habitats and corridors of Elliot's Pheasant in Qianjiangyuan National Park. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 13

Distribution of key habitat and corridors of the Black Muntjac in Qianjiangyuan National Park. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 14

Network map of key habitats and corridors in Qianjiangyuan National Park Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 15

Functional zoning map of Qianjiangyuan National Park Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.