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Resistance-Based Connectivity Model to Construct Corridors of the Przewalski's Gazelle (*Procapra Przewalskii*) in Fragmented Landscape

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Abstract: Habitat connectivity is indispensable for the survival of species that occupy a small habitat area and have isolated habitat patches from each other. At present, the development of human economy squeezes the living space of wildlife and interferes and hinders the dispersal of species. The Przewalski's gazelle (*Procapra Przewalskii*) is one of the most endangered ungulates, which has experienced a significant reduction in population and severe habitat shrinkage. Although the population of this species has recovered to a certain extent, human infrastructure severely hinders the gene flow between several patches of this species. Therefore, we used the maximum entropy (MaxEnt) model to simulate the habitat suitability of the Przewalski's gazelle. In addition, we combined habitat suitability and ecological characteristics of the species to obtain eight habitat patches. Finally, we used the least-cost path (LCP) and circuit theory based on the resistance model to simulate the landscape network of this species. The results showed that habitat patches and connectivity in the east of the Qinghai Lake were crucial to the communication between populations of the Przewalski gazelle, and our study provided important reference for the distribution of important habitats and the construction of corridor between patches. Our study aimed to provide habitat networks and maintain landscape connectivity for achieving the fundamental goal of protecting and revitalizing populations of the Przewalski's gazelle.

Keywords: Przewalski's gazelle; MaxEnt model; least-cost path model; circuit theory model; habitat patches; connectivity

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1. Introduction

Habitat fragmentation is considered to be one of the most important threats to biodiversity and seriously affects the sustained survival of species [1–3]. The transformation of the landscape by humans has caused the landscape to be scattered, and the habitat of the species has been divided into smaller and more isolated fragments. The habitat loss of species and the increase of isolation would change the structure and function of the remaining debris [4,5]. Habitat fragmentation often hinders the spread and movement of individuals, reduces gene exchange between groups, increases the risk of extinction due to inbreeding, and limits the ability of species to cope with long-term environmental changes [4,6–8]. Therefore, enhancement of habitat connectivity between populations or construction of ecological corridors can reduce the negative impact of habitat fragmentation and provide more opportunities for the sustained survival of small populations [9,10].

The Przewalski's gazelle (*Procapra Przewalskii*) is one of the most endangered large ungulates. It was widely distributed in northwestern China. After excessive illegal hunting, habitat loss and a series of human impacts, the habitat range shrank to the area around the Qinghai Lake, and the population declined significantly. The population size of this species was less than 300 in 1994 [11,12]. The Przewalski's gazelle has received the attention and protection of the Chinese government since 1990s, and the population has gradually increased [13,14]. Nevertheless, the human activities and infrastructure development have severely restricted the individual movement of the Przewalski's gazelle among several independent populations around the Qinghai Lake, which is very detrimental for the Przewalski's gazelle with low genetic diversity to maintain the long-term viability of the population [15]. Human interference, such as traffic facilities and residents, causes the dispersal of wildlife, especially the road has a significant negative impact on wildlife. Wildlife scientists have published studies on the impact of roads on wildlife [16,17]. Roads are considered to be extremely strong obstacles to wildlife. It causes the loss of species habitat and hinders the dispersal of species. It has also been pointed out by many studies that wildlife was killed by vehicles when crossing the road [18–20].

Currently, the establishment of ecological networks to enhance habitat connectivity has become one of the important strategies for protecting wildlife in fragmented habitats [21–23]. Various methods and software have been developed to build ecological networks [24]. Many researchers used graph theory for landscape ecological assessment and planning and the construction of ecological corridors [25,26]. At present, graph theory is regarded as a powerful and effective tool for landscape connection modeling, because it simplifies the landscape pattern into a functionally interconnected network and performs complex analysis of landscape connectivity [27–30].

The commonly used graph theory methods include resistance-based connectivity models, such as the least-cost path (LCP) model and the circuit theory model. These models can analyze the movement costs between patches, which are conducive to identify possible routes for species dispersal between habitat patches [31,32]. LCP model was proposed by Knaapen [33] and has been widely cited in the fields of species dispersal and landscape pattern analysis [31]. The LCP is a subset of cost distance analysis, and this model is based on a grid of cost surface to represent the difficulty of species crossing different parts of the landscape. The LCP represents the most efficient path from the starting cell to other cells [34], and it usually identifies one path with the lowest cumulative cost from the accumulated resistance of all units on the map. Circuit theory can convert the potential of landscapes and animals to move into electric current, voltage and resistance, thereby connecting landscape patterns with functional connection [35]. Methods based on circuit theory identified multiple movement paths [32]. The LCP has a strong correlation with circuit theory. It calculates the sum of the resistance values of the source and destination along the single path of least resistance. On the other hand, the circuit theory evaluates the "flow" through each map cell according to the resistance layer of the whole landscape between sources. In our study, we used both the LCP and circuit theory to simulate and evaluate the patch connectivity, providing information for a more comprehensive understanding of the landscape connectivity and corridor construction for the Przewalski's gazelle. In this study, we used the maximum entropy (MaxEnt) model to evaluate the habitat suitability, LCP model and circuit theory to evaluate the habitat connectivity of the Przewalski's gazelle. Our goals were to (1) simulate the habitat suitability of the Przewalski's gazelle and establish its distribution range, (2) assess the potential dispersal corridors for the connectivity of the entire patches of the Przewalski's gazelle and (3) provide a theoretical reference for habitat protection and population rejuvenation of the Przewalski's gazelle.

2. Materials and Methods

2.1. Study Area

The study area is located in the surrounding area of the Qinghai Lake in Qinghai Province, China. The area is located between the Qaidam Basin in the west of the Qinghai Province and the Huangshui Valley in the east, the source of several rivers in the south and the Qilian Mountains in the north. The altitude ranges between 2100 and 5300 m. The area has a plateau continental climate with strong sunshine and short frost-free season. Due to its abundant water resources, the area is rich in wildlife and plants, and is one of the regions with the richest biodiversity on the Tibetan Plateau.

2.2. Occurrence Data and Environment Variables

A total of 172 occurrence records were used in this study. Of these, 162 coordinate points were obtained by the field survey in 2018–2019, which were implemented by the Northwest Plateau Institute of Biology. All 162 coordinate points of the Przewalski's gazelle were recorded by GPS. The remaining ten points were collected from the literature [15]. We used the corresponding distribution map of the Przewalski's gazelle in the literature and imported into ArcGIS 10.2 for geo-referencing. Then, we randomly obtained coordinate points in the areas that have no records in our field surveys to supplement the distribution data (Figure 1).

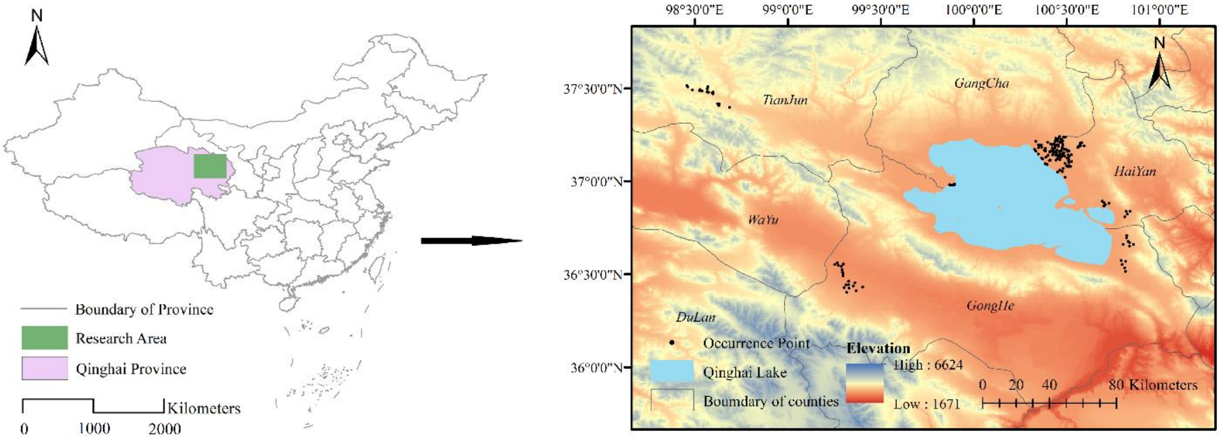

Figure 1. The occurrence data of the Przewalski's gazelle.

In our research, we collected a total of 78 environmental variables (Table S1), of which climate-related variables were obtained from the Global Climate Data (http://www.worldclim.com/), including 19 bioclimatic factors, monthly precipitation and average, minimum and maximum monthly temperature, and all have a spatial resolution of 1km. In addition, we obtained altitude and normalized difference vegetation index (NDVI) from the Geospatial Data Cloud (http://www.gscloud.cn/), and obtained population distribution data sets and vegetation types from the Resource and Environment Science and Data Center (http://www.resdc.cn/), and obtained land cover data and road data from the Geographic Information Monitoring Cloud Platform (http://www.dsac.cn/). The road data includes railways, highways, national highways, provincial roads and county roads. The 2019 point of Interest (Poi) related to human activities were obtained through the extraction of Chinese maps. We also used ArcGIS 10.2 software to extract slope, surface ruggedness, and terrain curvature data based on elevation data. Finally, we processed all layers to a resolution of 1 km.

In order to avoid the overlapping of information between environmental variables, we used SPSS22 to analyze the correlation of the 78 environmental variables and remove the environmental variables with high correlation ($p \geq 0.8$) [36]. The principle of selecting variables is that as many environmental variables as possible contain biological meaning, and the variables cover almost all environmental types. Finally, 15 environmental variables were used for modeling (Table 1).

Table 1. Environmental variables applied in the MaxEnt for evaluating the habitat suitability of the Przewalski's gazelle. Land cover and vegetation type are two categorical variables, and the rest are continuous variables.

Type	Variable	Description	Units
Terrain	Alt	Altitude	m
	Slop	Slope	°
	Cur	Terrain Curvature	m^{-1}
Climate	Bio2	Mean Diurnal Range (Mean of monthly (max temp–min temp))	°C
	Bio3	Isothermality (BIO2/BIO7) (×100)	%
	Bio8	Mean Temperature of Wettest Quarter	°C
	Bio15	Precipitation Seasonality (Coefficient of Variation)	%
	Bio19	Precipitation of Coldest Quarter	mm
	Prec3	March Precipitation	mm
Vegetation	Veg	Vegetation Type	-
	LC	Land Cover	-
	NDVI	Normalized difference vegetation index	-
Human Influence	Pop	Population Distance	m
	RD	Road Distance	m
	Poi	Distance of Point of Interest	m

2.3. Modelling Process

We used the MaxEnt model [37] to assess the distribution of the species. In the process of the MaxEnt modeling, occurrence data and environmental variables should be included in the model, and then the probability distribution map of species can be obtained. We used the MaxEnt model to get the large probability distribution of the Przewalski's gazelle, which is the mapping of the current environmental conditions. The prediction performance and stability of this model are better than other similar models [38,39]. Therefore, this model is often used to predict the suitability of species' habitats. Studies have shown that the use of optimized parameter settings has better prediction performance than the default parameters. Therefore, we adjusted the feature combination (FC) and the regularization parameters (RM) to obtain the best combination of parameters. We used ENMeval1.4.4 (an R package for estimating optimal model complexity for the Maxent model) to evaluate the value of the corrected Akaike information criterion (AICc) [40] under different parameter combinations, and then we selected the parameter with the smallest AICc value.

In the process of modeling, the occurrence data was randomly assigned as training and testing dataset (75% as training, 25% as test) and we ran the final model with 10 replicates in the MaxEnt. Then, we used the Jackknife test to get the contribution rate and importance of environment variables. Receiver operating characteristic curve (ROC) and area under ROC curve (AUC) value was regarded as the standard for evaluating qualitative characterization of the final species distribution model. AUC value of a model ranges from 0 to 1, and if the AUC value is between 0.9 and 1, the model accuracy can be judged as excellent [41].

2.4. Analysis of Habitat Patches and Connectivity

Patch represents a continuous area of space with all necessary resources for the persistence of a local population and separated by unsuitable habitat from other patches. Connectivity is the spatial continuity of a habitat or cover type across a landscape [42].

2.4.1. Habitat Patches

We obtained the suitability distribution map through the MaxEnt model, and its suitability index ranged from "0" to "1". Four categories of habitat suitability for the Przewalski's gazelle were classed, including no suitability (0–0.2), low suitability (0.2–0.4), medium suitability (0.4–0.6) and high suitability (0.6–1) [43,44]. The final distribution area of the species was determined based on two parts of the data. One part of the data came from the suitable habitat (≥0.2) evaluated by the MaxEnt model, guaranteeing free movement of species without serious obstacles, and the other part of the data was based on the movement characteristics of the Przewalski's gazelle. The Przewalski's gazelle has a strong running ability, but the migration distance of this species is very short (within 3–5 km), which is consistent with the behavior that we observed in recent years. Therefore, we took the distribution point of the Przewalski's gazelle as the center and obtained another distribution range of this species with a radius of 4 km. Finally, we applied ArcGIS 10.2 to superimpose the suitable habitat with the distribution range of 4 km radius and took the shared area as the final distribution area of the Przewalski's gazelle.

2.4.2. Connectivity Modeling

Resistance Surface Construction

Construction of landscape network (resistance surface) is a key part of establishing a connectivity model. The resistance value of the habitat represents the degree of obstacles to wildlife activities. The higher the resistance value, the less chance of wildlife passing through the area [45]. In this study, we converted the habitat suitability map into a resistance surface for species dispersal. As the distribution map was divided into four levels, we regarded the resistance of the most suitable area (≥0.6) as 1 (the lowest resistance value), and the resistance of other areas was transformed by the negative exponential function of suitability. The specific conversion formula is as follows [46,47]:

$$\text{Resistance} = e^{\frac{\ln(0.001)}{threshold} \times HSI} \times 1000 \tag{1}$$

In the formula, *threshold* = 0.6; *HSI* represents all habitat suitability index less than 0.6. The final resistance layer has a value range of 1–1000.

Besides this, we added the resistance layer of transportation facilities and residents. We used the empirical method and the distance between the distribution points of the Przewalski's gazelle and the human facilities to divide the critical resistance distance. We set the critical resistance value to 100 because this is the result of the transformation of the threshold value (*HSI* = 0.2) between suitable and unsuitable habitats. Therefore, the resistance value within the threshold distance was considered to be 100, and the other resistance values are considered to be 1.

The four resistance layers (road, railway, population and Poi) and the resistance layer transformed from the suitability distribution map were superimposed as the final resistance layer (Figure S2).

Connectivity Assessment Modeling

The LCPs represent the lowest edges of cumulative cost from the origin node to the destination node. In our study, the habitat patches of the Przewalski's gazelle were nodes of the network, the constructed resistance surface was the landscape surface for species dispersal, and the connections between two patches can be obtained by ArcGIS. We used the cost distance of spatial analysis tools in ArcGIS to calculate the cost distance raster and cost backlink raster of each node and then applied the cost path tool with the cost distance raster and cost backlink raster (calculated in the previous step) to obtain the LCP from each node to the other nodes.

$$MCR = fmin \sum_{j=n}^{i=m} D_{ij} \times R_i \tag{2}$$

MCR represents the minimum cumulative resistance. f is a monotonic increasing function, which indicates the positive correlation between the minimum cumulative resistance and the ecological process. D_{ij} represents the distance from node j to landscape node i. R_i represents the resistance coefficient of landscape unit i to species movement.

In the circuit theory model, we regarded the landscape layer as the conductive surface and the habitat patch as the node. Among them, the resistance value that promotes species dispersal was lower, while that hinders dispersal was higher [48]. Therefore, areas with high current flows are areas where animal movement is likely to be constrained. We used Circuitscape 5.0 (https://circuitscape.org/) to calculate the pairwise connections between nodes.

2.5. Analysis of the Importance of Corridors

The intensity of interaction between habitat patches can reflect the importance of potential migration corridors in the network. Based on the gravity model [49,50], quantitative assessment and identification of important ecological corridors were achieved.

$$G_{ij} = \frac{N_i N_j}{D_{ij}^2} = \frac{\left[\frac{1}{P_i} \times \ln(S_i)\right]\left[\frac{1}{P_j} \times \ln(S_j)\right]}{\left(\frac{L_{ij}}{L_{max}}\right)^2} = \frac{L_{max}^2 \ln(S_i S_j)}{L_{ij}^2 P_i P_j} \tag{3}$$

G_{ij} represents the interaction force between patches i and j, N_i and N_j represent the weight values of the two patches, D_{ij} represents the normalized value of the potential corridor resistance between patches i and j, and P_i represents the resistance value of patch i, S_i represents the area of patch i, L_{ij} is the cumulative resistance value of the corridor between patches i and j, and L_{max} represents the maximum cumulative resistance value of all corridors.

2.6. Patch-Based Indices

In graph-based connectivity analysis, habitat patches were used as modeling nodes. The importance of the analysis of patches is to identify habitats that are critical for maintaining landscape connectivity. In this study, we used the software Conefor 2.6 [51] to calculate connectivity integral index (*dIIC*) and patch importance value (*dPC*). These indicators were used to quantify the relative importance of habitat patches for overall network connectivity.

$$IIC = \frac{\sum_{i-1}^{n} \sum_{j-1}^{n} \left[(a_i a_j) / (1 + nl_{ij})\right]}{A_L^2} \tag{4}$$

$$dIICk\,(\%) = 100 \times \frac{IIC - IIC_{remove,k}}{IIC} \tag{5}$$

$$PC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_i \times a_j \times p_{ij}^{*}}{A_L^2} \tag{6}$$

$$dPCk\,(\%) = 100 \times \frac{PC - PC_{remove,k}}{PC} \tag{7}$$

In the above formula, n represents the total number of patches in the landscape, a_i and a_j represent the areas of patches i and j, nl_{ij} represents the number of connections between patches i and j, and A_L represents the area of the entire landscape; *IIC* is the connectivity index value of a certain landscape and $IIC_{remove,k}$ represents the overall index value of the remaining patches after removing a single patch; PC indicates the possible connectivity index of a patch in the study landscape, dPC_k indicates the importance of the patch and PC_{remove} indicates the possible connectivity index after removing the patch. We used Conefor 2.6 software to calculate *dIICk* and *dPCk*.

3. Results

3.1. Model Performance and Importance Variables

According to the AICc value and the smoothness of the response curves, the three characteristic parameters were linear (L), quadratic (Q), product (P) and RM = 1. The receiver operating characteristic (ROC) curve showed that the average AUC value of the Przewalski's gazelle obtained after 10 repetitions was 0.985 ± 0.008, indicating that the prediction result was excellent, and the model could produce more accurate results in assessing the habitat suitability of the Przewalski's gazelle [52] (Figure 2A).

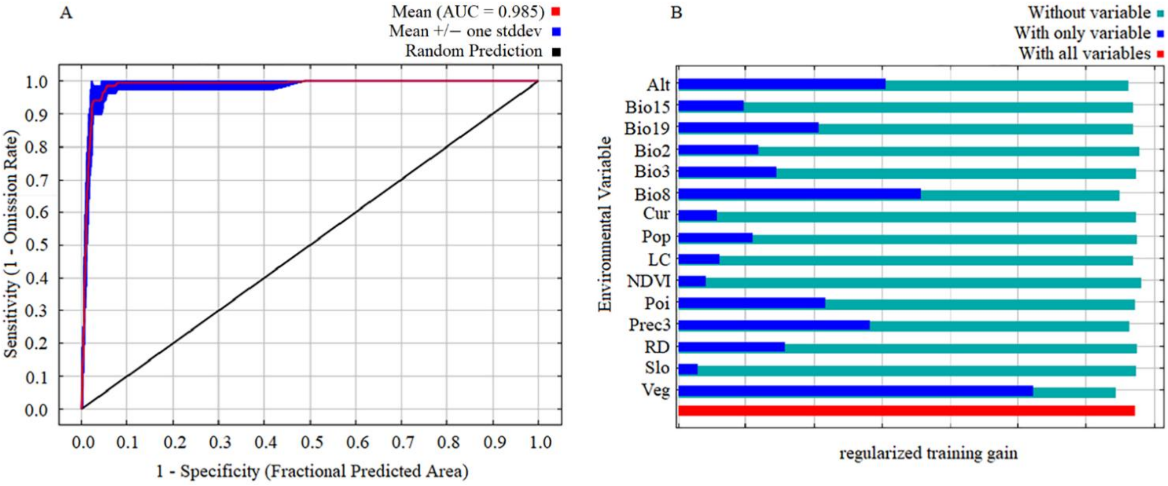

Figure 2. (**A**) Area under the curve (AUC) plot. AUC = 0.985 suggests the good performance of the model. (**B**) A Jackknife test result showing the relative contribution of predictor variables in predicting the potential habitat distribution.

According to the Jackknife test of variable importance, the main environmental variables affecting the distribution of the Przewalski's gazelle included climate factors (Bio3, Bio8, Bio19 and Prec3), altitude (Alt), vegetation type (Veg) and human influence (RD and Poi) (Figure 2B, Figure S1).

3.2. Distribution Area of the Przewalski's Gazelle

The habitat suitability distribution map of the Przewalski's gazelle obtained according to the MaxEnt model is shown in Figure 3A. In general, the suitable habitat area of the Przewalski's gazelle was very limited, and the most of the highly suitable habitat accounted for 0.46% of the total area of Qinghai Province, with the area of 3288.03 km^2; all suitable habitats accounted for 1.35% of the total area of Qinghai Province, with an area of 9744.06 km^2 (Table 2).

In addition, the habitat suitability distribution map was superimposed with the buffer area of 4 km radius of the distribution point (Figure 3B) to obtain eight distribution areas of the Przewalski's gazelle (Figure 3C). These eight areas could also be considered as habitat patches in the landscape ecology. The area range of these patches was 22.71–514.91 km^2. The Haergai-Ganzihe population had the largest patch area, and the Bird Island population had the smallest patch area (Table 3).

Table 2. Proportion and area of suitable/unsuitable habitats for the Przewalski's gazelle.

HabitatCategory	Suitability Score	Area (km^2)	Proportion of Qinghai Province (%)
High suitable habitat	4	3288.03	0.46
Moderate suitable habitat	3	1943.76	0.27
Low suitable habitat	2	4512.27	0.62
Unsuitable habitat	1	712,555.93	98.65

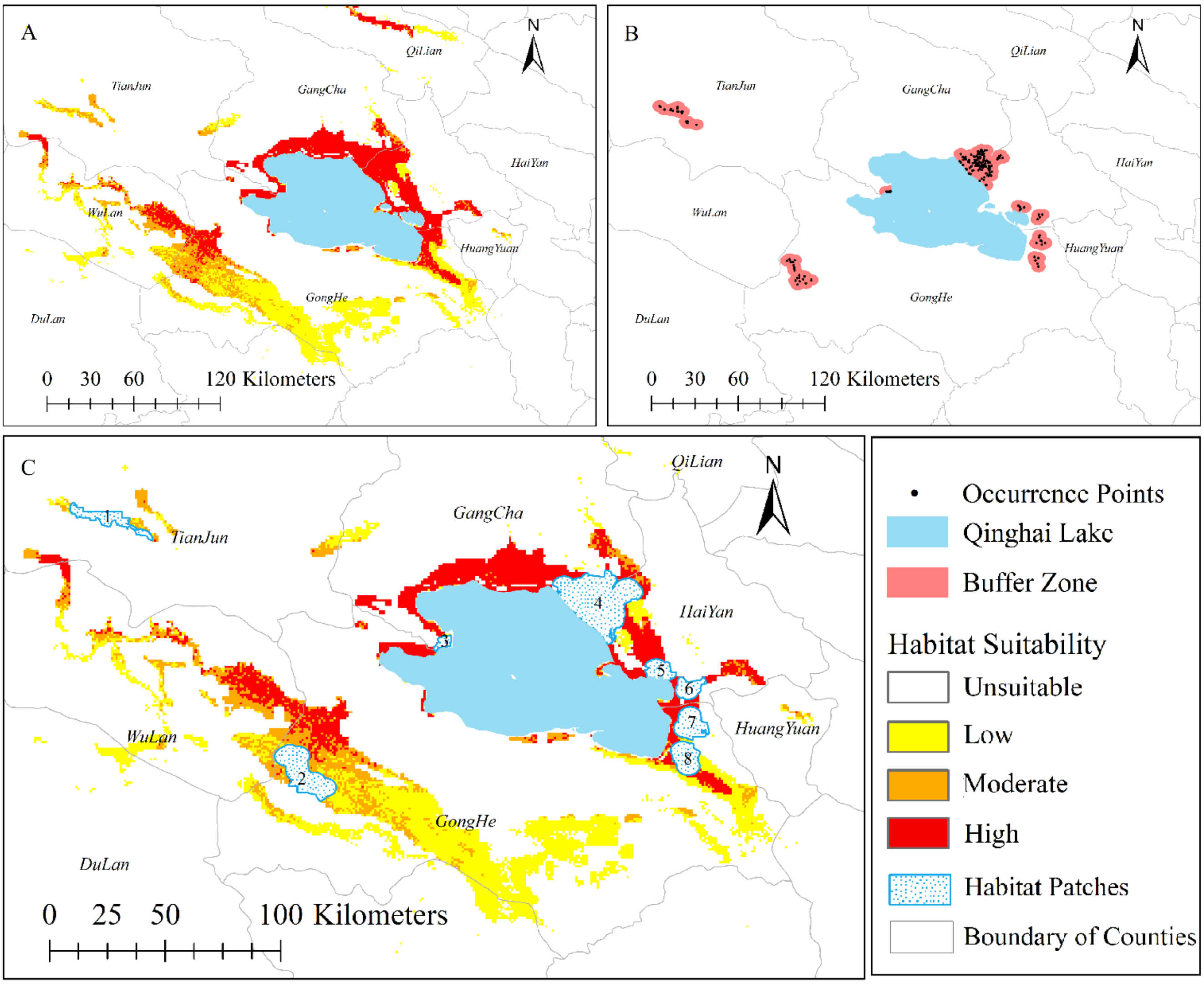

Figure 3. (**A**) Distribution map of habitat suitability predicted by the MaxEnt model; (**B**) The 4 km buffer zone formed by the distribution point as the center; (**C**) The final habitat patches formed by superimposing the suitable area and the buffer area of the distribution point.

Table 3. Area and importance indices of all patches.

Patch Code	Patches Description	Area (km^2)	*dIIC*	*dPC*
1	Tianjun	104.82	2.66	2.33
2	Wayu	247.66	14.84	13.03
3	Bird Island	22.71	0.12	0.11
4	Hargai-Ganzihe	514.91	64.16	56.33
5	Shadao	67.18	4.37	9.44
6	Hudong	66.94	7.49	15.98
7	Ketu	118.77	11.94	21.74
8	Yuanzhe	111.45	8.32	14.61

3.3. *LCP and Circuit Theory Models*

The LCP model simulated a total of 28 connections, which were formed between the habitat patches. To avoid overlapping pairwise linkages, we showed eight corridors with the lowest cost between pairs of patches and ensured that all habitat patches could be connected into a circular network (Figure 4A). The geographical distance between patch 4 and patches 5, 6, 7 and 8 was relatively the shortest, and the resistance between these patches was small. Therefore, the dispersal cost between these patches was low. Due to the long geographic distance and high resistance value between patches 1, 2 and other patches, the cost of their dispersal to other patches was relatively high. Of these, the path cost between patch 1 and the remaining seven patches was the highest. The results simulated by the circuit theory model were very similar to the LCP. The four patches on the east side of the Qinghai Lake had strong current values (Figure 4B), indicating that these areas are important to support dispersal opportunities for species. The least-cost path corresponds to the high-current area of circuit theory and vice versa. The simulation results of the LCP showed that the range of path cost was 0.71–156.21, and the range of path length was 13.84–207.47 km. The resistance distance range of circuit theory was 0.99–129.46, and the current value range was 0–7.30 (Table 4).

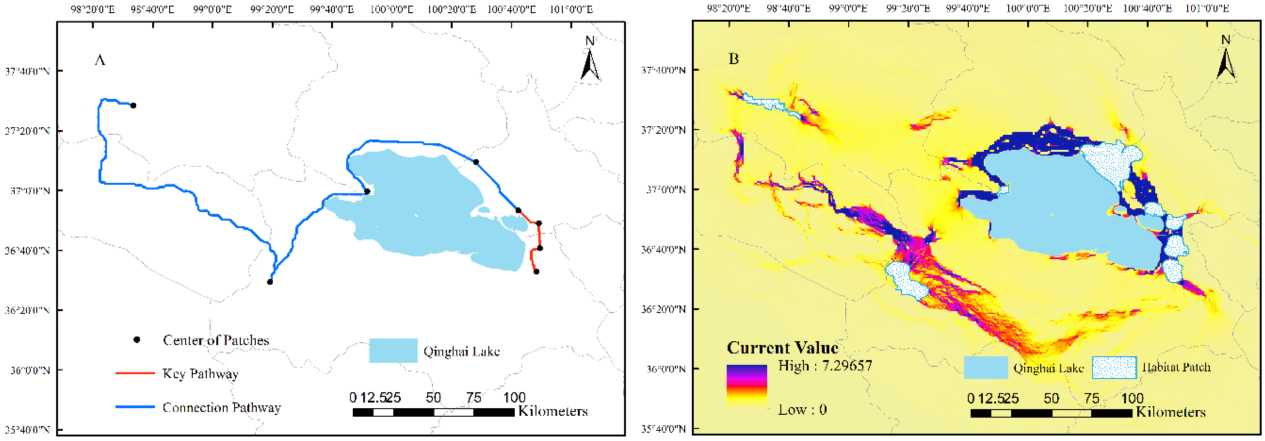

Figure 4. (**A**) The pathways between each patch simulated by the LCP model, the red lines represent important connection between patches; (**B**) The current diagram that representing the connectivity between patches simulated by the circuit theory model.

Table 4. Connectivity evaluation indicators of the two models. The resistance value generated by the circuit theory model, the path cost value and least-cost path length value generated by the LCP model between the eight patches. G_{ij1} represents the connection importance between the pair patches simulated by LCP, and G_{ij2} represents the connection importance between the paired patches simulated by the circuit theory.

Patches		**Resistance Value**	**Pathcost Value**	**LCP Length (km)**	G_{ij1}	G_{ij2}
From	**To**					
1	2	129.46	156.21	207.47	0.01	0.00
2	3	76.00	128.76	87.82	0.02	0.02
3	4	33.05	6.24	98.53	17.85	0.21
4	5	4.32	1.93	37.42	912.53	59.95
5	6	1.26	0.91	13.84	2526.46	438.50
6	7	0.99	0.71	15.70	2977.55	512.88
7	8	1.50	1.43	18.81	354.67	105.74

3.4. Patch-Based Indices and Importance of Corridors

According to the results of the gravity model, the interactions between habitat patches 4, 6, 7 and 8 were very strong. On the contrary, the interaction between patches 1 and 2 and other patches was very small (Table 4).

According to the results of patch importance analysis, patch 4 was the most important among all patches. The patch plays an important role in connectivity, and the patch has the largest area among all patches. Patch 3 had the smallest area, and the patch also had the lowest relative importance. Although the area of patch 1 was larger than that of patches 5 and 6, the dPC value showed that the relative importance of patches 5 and 6 was higher than patch 1 (Table 3).

In addition to the current distribution area of the species, more suitable habitats may be required as potential areas that species may also need to stay or rest during the long-distance dispersal. Therefore, we took the remaining areas with relatively high suitability ($HSI > 0.4$) as references for potential refuge available for the Przewalski's gazelle (Figure 5A). Also, we combined the simulated pathways with the current transportation facilities. The conflict between the road and the dispersal paths was very strong. There were 13 conflict points between roads with pathways and five conflict points between railways with pathways. The conflict points of diffusion pathways and roads are inevitable obstacles for species dispersal. Combined with the results of the importance analysis of patches and dispersal corridors, the corridors between patches 4, 5, 6, 7 and 8 should be considered as the main connecting routes (Figure 5B).

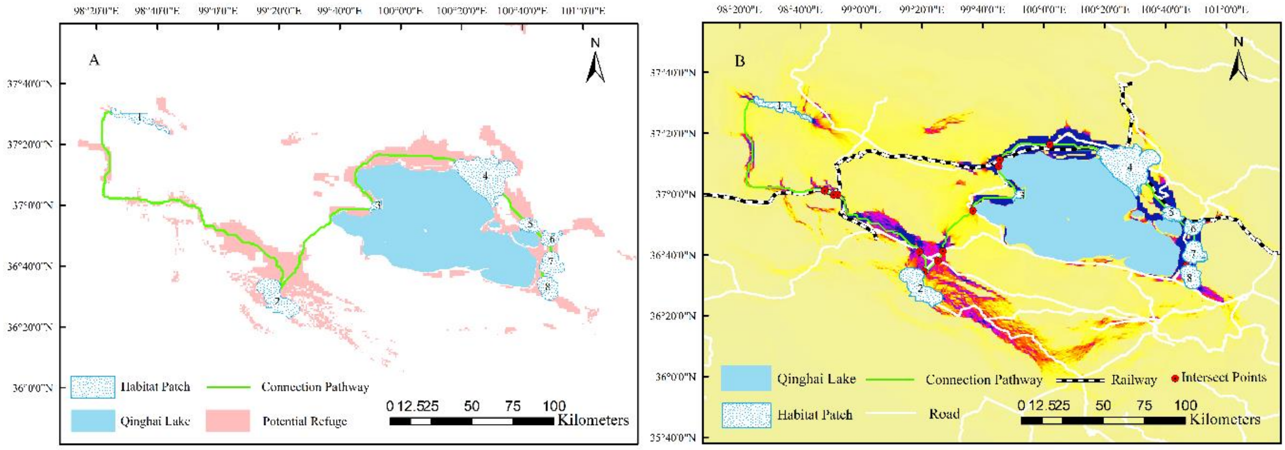

Figure 5. (**A**) Potential refuge area for Przewalski's gazelle; (**B**) Intersect points of the connectivity of the Przewalski's gazelle with transportation facilities (roads and railway).

4. Discussion

In our study, we chose environmental factors with a great biological significance to predict the spatial distribution of the Przewalski's gazelle. The prediction results of the MaxEnt model indicated that the potentially suitable habitat area of the Przewalski's gazelle predicted by the model was up to 9744.06 km^2, but the actual habitat area of the species was less than the predicted value. Therefore, to obtain a more realistic distribution range of the species, we reduced the predicted area of the Przewalski's gazelle based on the movement characteristics of the species.

We used both the LCP and the circuit theory models to simulate the potential corridors of the Przewalski's gazelle. The LCP model provided the only and least expensive path between the distribution areas. This method can obtain the connections between any two habitat patches, but the lowest cost path simulated may not be the exact path used by the species [53]. Wildlife does not plan the most labor-saving path like humans themselves. If the species follow the LCP, they may encounter smaller obstacles in migration, spend less travel time and increase survival because of the high possibility of obtaining optimized food [54]. Compared with the LCP model, the circuit theory model produces a non-linear path. This model can provide more migration options based on the assumption. It is in line with the behavioral characteristics of organisms [55]. According to the simulation results of the two simulation methods, the circuit theory is related to the LCP, because the area with the highest current generated by the circuit theory is the same as the lowest-cost path. The complementarity of the two methods can provide a better reference for corridor construction [56,57].

According to the analysis of path cost and resistance, the establishment of corridors is the easiest for the Przewalski's gazelle located in several patches in the east of the Qinghai Lake. Because both geographical distance and dispersal cost to other populations are minimal, the interactions between habitat patches 4, 5, 6, 7 and 8 are very strong, indicating that corridors provide more important linkages between these patches. Therefore, the connections between these patches should be given high priority. On the contrary, the interactions between patches 1 and 2 with other patches were very low because of long-distance and high dispersal cost. Therefore, it may not be the main consideration when restoring connectivity. The patch-based indices showed that patch 4 was identified as the most important patch due to its larger patch size compared to other patches. Patch 4 was indeed the patch with the largest area of the Przewalski's gazelle. Patch size is an important feature of landscape structure. It was reported that larger patches contained more resources, nutrients and energy than small patches and could support more species than small patches [42,58]. Except for the largest and smallest patches, the sub-large patches 1 and 2 did not have obvious advantages in all patches in our analysis. The reason may be that the importance of these two patches seems to be weakened by long-distance and high dispersal cost. When constructing dispersal corridors, it is necessary to consider the ways to cross obstacles (e.g., roads) to maintain the continuity of the corridors in addition to the cost and distance. Our results showed that the dispersal paths and densely distributed roads had several inevitable intersections, indicating that species may cross these intersections to communicate with the population. The highway has almost no fence. Thus, it is relatively easy to cross, but traffic congestion is a big hidden danger. Although there are culverts under the Qinghai-Tibet Railway, they may not be used by ungulates due to the narrow tunnels [59,60]. It is very important to ensure the connectivity of the intersection between important corridors and roads. According to the results, we should ensure the connectivity of the four patches located in the east of the Qinghai Lake.

At present, the survival of the Przewalski's gazelle in China still faces many challenges. Although the population of this species has increased year by year since 2000s due to the importance and protection of the species in recent decades, the research of the genetic structure of the Przewalski's gazelle based on mitochondrial and microsatellite methods published in 2003, 2011 and 2017 showed that the genetic diversity of this species was very low [15,61,62], and there was no trend of increasing with the increase of the number. In comparison, the genetic diversity of Tibetan antelopes (*Pantholops hodgsonii*) in China has improved significantly in 10 years of restoration [63]. Each independent population of the Przewalski's gazelle presented a strong systematic geographic structure. We believed that assessment of the connectivity between various patches and establishment of appropriate corridors could provide premises and opportunities for species to move and communicate smoothly. However, we cannot guarantee that species will migrate according to the route that was set up. Especially for those populations that are far away from other populations and have a high cost of dispersal, this may be the best prospect for promoting genetic exchanges between several populations.

Regarding the current habitat connectivity of the Przewalski's gazelle, we first recommend that corridors be established between the dispersed populations as soon as possible, especially the corridors between several key habitats in the eastern of the Qinghai Lake is crucial. At present, the most important issue in the process of constructing corridors is the solution of the conflict points between corridors and transportation facilities. We suggest that the problem of conflict points can be solved by establishing crossing passages similar to overpasses at these junctions, while increasing the number of railway culverts or widening the width and height of railway culverts, and the intersections between several important patches should be given priority. Since human activities squeeze the living space of the Przewalski's gazelle, it is necessary to expand the habitat area occupied by the Przewalski's gazelle. Human activities mainly include the construction of infrastructure and livestock grazing. A large number of livestocks took a lot of living space and competed with the Przewalski's gazelle for grassland resources [64]. Therefore, it is recommended to reduce grazing in the areas where the Przewalski's gazelle lives to ensure their food requirements. Finally, the wire fence in the habitat of the Przewalski's gazelle is also a big hidden danger for this species [65,66]. Due to a large number of wire fences and the wide range, we could not include this influencing factor in the analysis. In our field investigation in recent years, we found several dead Przewalski's gazelles on the wire fence as these species attempted to cross the fence. We could not ask the local residents to remove the wire fence because this involved the residents' pasture management and economic issues. Thus, we planned to use field investigations and drone tracking technology to carry out the corridor before the construction of the Przewalski's gazelle migration corridor. The direct monitoring can check the possible deviations of our simulated corridor during the actual construction process, and focus on the proposal to remove part of the small-scale wire fence for avoiding unnecessary losses caused by removing the fence. These protection tasks have become challenging due to economic conflicts and manpower consumption. However, the government and people are paying more and more attention to the protection of species at present, especially the protection of endangered species.

5. Conclusions

The Przewalski's gazelle is one of the world's most endangered large ungulate mammals. After experiencing a population bottleneck period, the population has been restored by the efforts of the government and protectors for nearly two decades. However, this species still faces strong interference from humans, and its genetic diversity is relatively low. Therefore, we used the MaxEnt model to predict the habitat suitability of the Przewalski's gazelle, and LCP and circuit theory models to simulate the dispersal path between several independent distribution areas. According to the results, areas with high suitability should be used as key protected areas for species. The migration corridors between simulated habitat patches can provide convenience and possibility for the exchange for several independent populations to communicate with each other. In addition, food competition and fence barriers between the Przewalski's gazelle and domestic animals should also be considered by the protectors.

Supplementary Materials: The following are available online at https://www.mdpi.com/2071-1050/13/4/1656/s1, Figure S1: Response curves of environmental variables with high contribution rate, Figure S2: The map of resistance surface, Table S1: All environmental variables and descriptions, Table S2: Correlation matrix of environmental variables selected for Maxent model of the Przewalski's gazelle. Positive and negative numbers represent positive and negative correlations, respectively.

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Abbreviations

NDVI	normalized difference vegetation index
MaxEnt	Maximum Entropy
HSI	habitat suitability index
FC	feature combination
RM	regularization parameters
ROC	Receiver operating characteristic
AUC	area under the receiver operating characteristic curve
AICc	corrected Akaike information criterion

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