

IDENTIFICATION OF ECOLOGICAL CORRIDORS AND NODES FOR BLACK-AND-WHITE SNUB-NOSED MONKEY (*Rhinopithecus bieti*) IN SOUTHWEST CHINA

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ABSTRACT

The black-and-white snub-nosed Monkey (*Rhinopithecus bieti*, BWSM), a critically endangered species in Southwest China, faces severe threats from habitat loss, fragmentation, and migration barriers. Establishing and maintaining ecological corridors is crucial for its conservation. This study utilized the current distribution range of the BWSM as ecological source areas and employed the Linkage Mapper tool combined with the gravity model to extract ecological corridors and nodes, classify corridor hierarchies, and assess resistance factors. The key findings include the following: (1) Twenty-eight ecological source patches were identified, showing an island-like distribution with protection gaps; (2) Migration resistance followed a spatial pattern of south > north > central; (3) Thirty-five ecological corridors were extracted, including 10 first-level, 19 second-level, and 6 third-level corridors, predominantly oriented north-south. Additionally, 45 barrier points and 41 pinch points were identified, both of which exhibited discrete distributions. First-level corridors presented no barriers, while barrier and pinch points accounted for 41.1% and 30.24% in second-level corridors, and 58.9% and 69.76% in third-level corridors, respectively; (4) Land cover, residential areas, and road networks were the primary resistance factors affecting ecological corridors, while water systems and elevation had minimal influence. Secondary and tertiary corridors face migration obstructions due to fragmented vegetation, extensive residential development, and dense road networks. These findings provide a scientific basis for prioritizing the restoration and construction of ecological corridors to enhance habitat connectivity for BWSM conservation.

Keywords: Black-and-white snub-nosed monkey (BWSM); ecological corridor; ecological node; Linkage Mapper; Gravity Model.

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INTRODUCTION

The Black-and-White snub-nosed monkey (*Rhinopithecus bieti*, BWSM) is a rare and endangered species endemic to China. It is listed as a national first-class key protected animal and is included on the Red List of Threatened Species by the International Union for Conservation of Nature (IUCN). In recent years, with the continuous strengthening of conservation efforts, the BWSM population has increased from fewer than 2,000 to more than 3,800, and the number of groups has risen from 17 to 24 groups (Ren *et al.*, 2016). However, due to the combined impacts of climate change and human activities, more than 30% of the BWSM suitable vegetation types —such as dark coniferous forests and coniferous-broadleaf mixed forests have been lost (Li *et al.*, 2017). The BWSM's habitat continues to shrink and become increasingly fragmented (Yan, 2015; Zhao *et al.*,

2019a; Zhao *et al.*, 2019b). Moreover, the habitat patches were relatively isolated and lacks connecting ecological corridors (Su *et al.*, 2019), which decreases habitat connectivity (Su *et al.*, 2019; Zhao *et al.*, 2019a), which severely impedes gene flow between populations, causes inbreeding and population degradation, and increases the risk of extinction (Xia *et al.*, 2020). Establishing ecological corridors to facilitate dispersal and gene exchange among populations, and to enhance ecosystem connectivity, has therefore become a crucial strategy for the conservation of BWSM (Hou *et al.*, 2021).

However, existing domestic and international research on BWSM has primarily focused on species distribution (Fu *et al.*, 2019; He *et al.*, 2021), habitat suitability (Liu *et al.*, 2020; Liu *et al.*, 2021; Xiao *et al.*, 2022; Zhu *et al.*, 2022; Zhu *et al.*, 2023; Shen *et al.*, 2023), and landscape connectivity analysis (Li *et al.*, 2018; Li *et al.*, 2017; Zhang *et al.*, 2016; Clauzel *et al.*,

2015b), while systematic identification of ecological corridors remains relatively limited. Currently, commonly used corridors identification models include Minimum Cumulative Resistance (MCR) model, circuit theory model, patch gravity model, and ant colony optimization model. The MCR model efficiently identifies optimal migration paths but struggles to define corridor width and multipath diffusion (Yu, 1998). The circuit theory model simulates multipath diffusion and can identify key nodes and barrier points, though it also faces challenges in defining corridor width (McRae *et al.*, 2008). The patch gravity model quantifies interaction intensity between habitat patches, but cannot specifically identify corridors or their widths (Guo *et al.*, 2021). The ant colony model optimizes source selection and supports multipath identification, but requires strict parameter thresholds (Zhao *et al.*, 2021). In light of these limitations, integrating multiple models to leverage their respective advantages has become a recent research trend. For example, Yao *et al.* (Yao *et al.*, 2023) combined the MCR and gravity models to enhance the objectivity and rationality of ecological assessments. He *et al.* (He *et al.*, 2022) integrated the MaxEnt model with the Least-Cost Path (LCP) method to identify ecological corridors for Indo-Pacific humpback dolphins in Xiamen Bay. Teng *et al.* (Teng *et al.*, 2022) used the MaxEnt model coupled with the MCR model to identify potential ecological corridors for red deer in the southern section of the Greater Khingan Mountains. Shen *et al.* (Shen *et al.*, 2024) employed an integrated approach of MaxEnt, LCP and the LSCorridors model to delineate critical bird corridors in Jiangsu Province. However, no similar integrated approaches have yet been applied to the distribution range of the BWSM.

This study aims to integrate MaxEnt model with MCR, circuit theory, patch gravity model, and utilize the Linkage Mapper tool to identify ecological corridors and

nodes among BWSM groups. It further classifies corridor levels and applies GIS spatial analysis to determine resistance factors, ultimately proposing corresponding management strategies. The goal is to provide decision support and theoretical guidance for corridor planning and for ecological conservation and restoration of BWSM habitats.

MATERIALS AND METHODS

Study area: The BWSM is found in a narrow region between the Jinsha River and the Lancang River, located at the intersection of Sichuan, Yunnan, and the Tibet Autonomous Region in China. This species inhabits the Yunling Mountains of the Hengduan Mountain range on the southern edge of the Himalayas. Based on prior studies and considering the current population activity range and nature reserve boundaries of BWSM, the study area is defined as $25^{\circ} 60' - 29^{\circ} 72' N$ and $98^{\circ} 33' - 100^{\circ} 04' E$, encompassing a total area of 22,381.45 km². This region falls within the Three Parallel Rivers area of China. The administrative regions included, from north to south, Markam County in the Tibet Autonomous Region, along with Deqin, Weixi, Yulong, Lanping, Yunlong, and Jianchuan Counties in Yunnan Province (Figure 1). The terrain exhibits a gradient from high elevations in the north to lower elevations in the south, with altitudes ranging from 1,200 to 5,500 m, resulting in a relative height difference of about 4,300 m. The river network is dense, and the climate predominantly features a subtropical and temperate plateau monsoon climate. The annual average temperature varies from $-2^{\circ} C$ to $19^{\circ} C$, while the annual precipitation ranges from 260 to 950 mm. The primary vegetation types present include coniferous forest, broad-leaved forest, coniferous-broadleaf mixed forest, and meadows and shrubs.

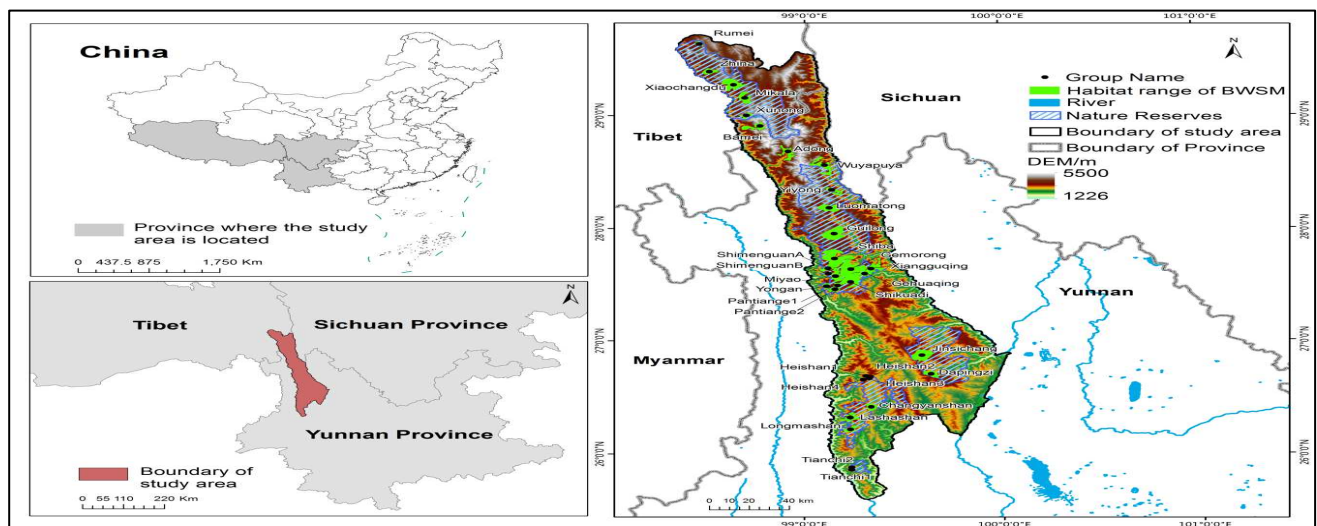


Figure 1: Location of the study area

by the author's team (Shi *et al.*,2025). The spatial reference of each data point is uniformly set to WGS_1984_UTM_Zone_47N, and the pixel size of the raster data is uniformly resampled to 30 m * 30 m.

Research Methods: In the study area, the habitat range of the BWSM was designated as the ecological source, and the MaxEnt model was employed for habitat suitability analysis to generate a resistance surface. The Linkage tool was then used to identify potential ecological corridors and nodes, followed by the gravity model to classify corridor levels. Finally, GIS tools were used to assess the impacts of land use, residential areas, roads, and water systems on the ecological corridors and nodes. (Figure 2).

Data Sources and Preprocessing: This study incorporates data on the natural environment, human disturbances, distribution data of the BWSM, and MaxEnt model prediction results. The DEM data were obtained from the Geospatial Data Cloud (www.gscloud.cn). Information regarding the water system and land use types (2020) was acquired from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (<http://www.resdc.cn>). Road and residential area data were retrieved from the Open Street Map website (www.openstreetmap.org). The existing population distribution data of the BWSM were provided by the Yunling black-and-white snub-nosed monkey observation and research station. The MaxEnt model prediction results were based on previous research

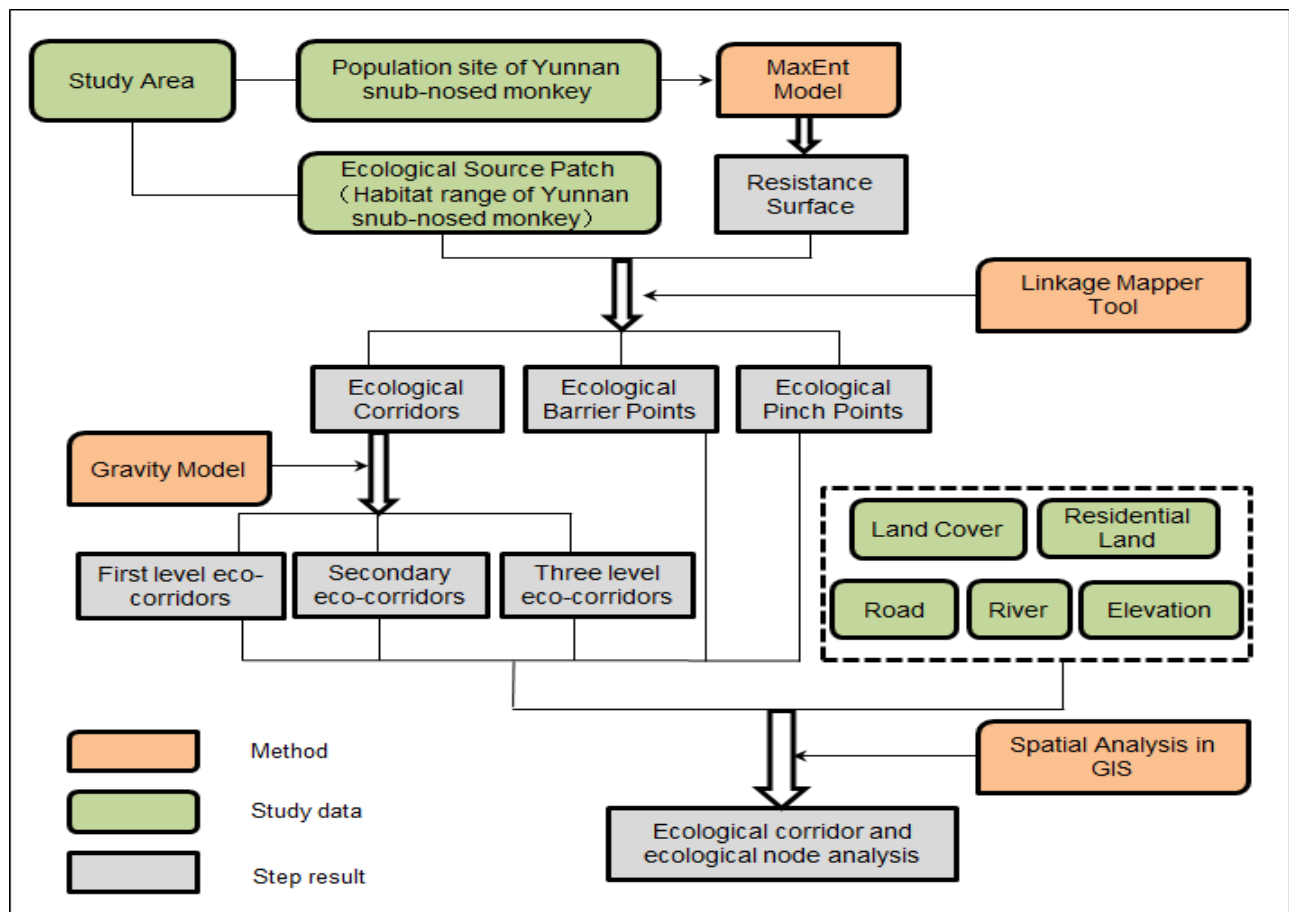


Figure 2 Technical flowchart

Identification of ecological source areas: Ecological source areas provide significant ecological services and represent the primary activity range and crucial habitat for biological species. In this study, the existing distribution range of the BWSM population was designated as the ecological source area. Specifically, the populations in Gehuaqing, Shikuadi, Xiangguqing, and Gemaorong were merged into a single ecological source

area because of their adjacent distributions, partial habitat overlap, high connectivity, and absence of barriers to intergroup movement (He *et al.*,2021). Following data processing, 28 ecological source area patches were identified, covering a total area of 1,347.35 km² (Figure1).

Construction of the resistance surface: The MaxEnt model in the study area achieved an AUC test index

exceeding 0.9, indicating that the habitat suitability index (HSI) predicted by the model effectively reflects the potential distribution of suitable habitats for BWSM (Shi *et al.*, 2025). The HSI can be approximated as a resistance coefficient, where higher habitat quality corresponds to lower resistance to animal movement (Peakall *et al.*, 2010). Therefore, this study uses the MaxEnt model prediction results (HSI) as the resistance surface ([0,1000]) for monkey populations. Higher HSI values represent greater habitat suitability and lower resistance to troop migration, while lower suitability corresponds to higher migration resistance. The study employed a negative exponential transformation function (Dufлот *et al.*, 2018) to generate the resistance layer, with the transformation function defined as follows:

$$\begin{aligned} & \text{if } HSI > \text{threshold, } \text{resistance}=1; \\ & \text{if } HSI \leq \text{threshold, } \text{resistance} = e^{\frac{\ln(0.001) \times HSI}{\text{threshold}}} \times 10^3 \\ & \text{if } HSI = 0, \quad \text{resistance}=1000; \end{aligned}$$

where *resistance* is the resistance value, and *threshold* is the HSI value distinguishing between suitable habitats and sub suitable habitats (the value is 0.38) .

Extraction of ecological corridors and ecological nodes: The Linkage Mapper was a common tool for analyzing the connectivity of biological habitats internationally (Clauzel *et al.*, 2015b). It could identify ecological corridors and ecological nodes.

Identification of ecological corridors: Corridors serve as conduits for regional energy and matter and are essential ecological elements for sustaining the connectivity of ecological flows, processes, and functions (Yang *et al.*, 2021). In this research, patches of ecological source areas and MCRs are utilized within the Linkage Mapper tool to determine the optimal migration corridor for the BWSM.

Identification of ecological nodes: The ecological nodes include ecological barrier points and ecological pinch points. They can be recognized by the Linkage Mapper Tool. Ecological barrier points refer to areas where species are greatly hindered during migration between source areas (McRae *et al.*, 2012) . By repairing and removing barrier points, the connectivity of natural landscapes can be enhanced, and the smoothness and integrity of biological migration processes can be ensured (Liu *et al.*, 2022). In this study, through the barrier mapper module, the search radius of the moving window is set to 200 m, and the “Maximum” mode is selected for the iterative operation to identify barrier points. Ecological pinch points are areas with high current density in ecological corridors and are “bottleneck” areas that affect landscape connectivity. Their degradation or loss is very likely to cut off the connectivity of habitats (Gong *et al.*, 2014). In this study, through the Pinchpoint Mapper module, a weighted cost distance of 10000 m is

set as the corridor width, the “all-to-one” mode is selected for the iterative operation, and the natural breakpoint method is used to extract the area with the highest current density as the ecological pinch point.

Corridor hierarchy division: The gravity model can be used to construct an interaction matrix between ecological source areas and quantitatively distinguish the interaction intensity between ecological source areas to evaluate the effectiveness and importance of ecological corridors (Xu *et al.*, 2015). The formula is as follows:

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

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

In this study, the corridors are divided into levels according to the magnitude of G_{ab} in the gravity model, which are divided into first-level corridors (importance values greater than 1000), second-level corridors (importance values between 1 and 1000), and third-level corridors (importance values less than 1). The first-level corridor represents a very strong interaction between source areas and belongs to a key ecological corridor; the second-level corridor represents a certain interaction between source areas and belongs to an important ecological corridor; the third-level corridor represents only an extremely weak interaction between source areas and belongs to a general corridor.

RESULTS AND DISCUSSION

Spatial Distribution of Ecological Source Areas: The ecological source areas are generally distributed in a long and narrow north-south direction in an island shape (Figure1) and were concentrated in only a small area in the middle of the study area. According to statistics, a total of 16.73% (225.43 km²) of the ecological source areas are not included in the existing protected areas, and there is a protection gap.

Migration Resistance of Monkey Groups: According to the ArcGIS regional statistical analysis, the results indicated that: The migration resistance observed in the BWSM groups typically reveals that the southern region has the highest resistance, followed by the northern

region, with the central region showing the least resistance. Furthermore, the low-resistance areas demonstrate a strong aggregation trend in the central section of the study area and exhibit an island-like pattern in both the northern and southern regions. These low-resistance zones are primarily found in forested areas such as spruce forests, *Pinus densata* forests, coniferous

and broad-leaved mixed forests, and shrublands at elevations between 2800 and 4200 m. In contrast, the high-resistance zones were mostly situated in elevated areas above 4200 m in the north and in low-altitude zones below 2900 m, which are characterized by limited vegetation connectivity and considerable human interference (Figure 3).

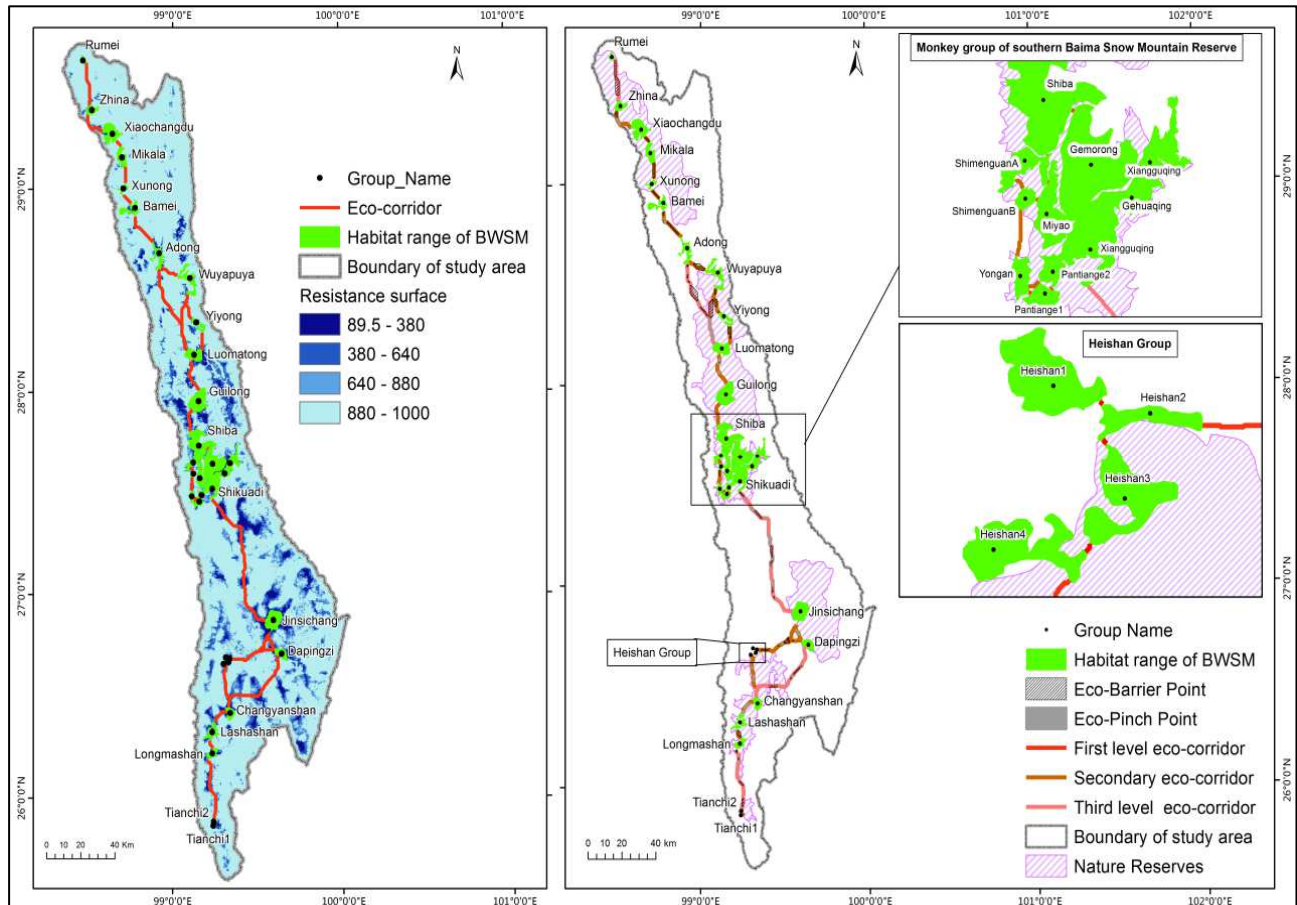


Figure 3: Resistance surface and ecological components

Ecological Corridors and Ecological Nodes:

Ecological corridors: The study extracted 37 ecological corridors, which are generally distributed in the north-south direction, with a total length of 726.90 km. Among them, there are 9 corridors with lengths of less than 1 km, which are mainly distributed among monkey groups in Heishan, Tianchi and southern Baima Snow Mountain Reserve; there are 4 corridors with lengths greater than 50 km, which are mainly distributed in the protection gap areas between each protected area; and the lengths of the remaining corridors are all between 1–50 km. In accordance with the gravity model, this study divides 10 first-level corridors, 19 secondary corridors and 8 third-level corridors. To ensure connectivity between monkey groups, two third-level corridors of excessive length and low importance values, the Heishan–Pantiange Group 2

linkage (107.21 km) and the Jinshichang–Pantiange Group 2 linkage (89.60 km), are excluded. Finally, 35 ecological corridors were selected (Table 1, Figure3).

Ecological nodes:

Ecological barrier points: The study identified a total of 45 ecological barrier points, which are distributed irregularly over an area of 179.53 km². No barrier points were detected in the first-level corridors, while the proportions of barrier point areas in the second- and third-level corridors are 41.1% and 58.9%, respectively. Among these, five corridors feature barrier point areas greater than 10 km²: Adong–Luomatong linkage, Rumei–Zhina linkage, Wuyapuya–Luomatong linkage, Adong–Wuyapuya and Jinshichang–Shikuadi linkage. These account for 57.95% of the total area of barrier points and are mainly found in third-level corridors. Furthermore,

three corridors have barrier point areas of less than 1 km², located in second-level corridors: Dapingzi-Heishan Group 2 linkage, Yongan-Pantiange Group 1 and Luomatong-Guilong linkage, which represent 0.31% of

the total area of barrier points. Other corridors also contain barrier points of varying sizes. For further details, refer to Table 2 and Figure3.

Table 1: Ecological corridors.

Type	Quantity	Length / km	Remarks
First level eco-corridors	10	3.33	The first level eco-corridors were generally short in length. Except for the Tianchi group 1 and 2 linkage (1.43 km), all other corridors are less than 1 km in length. These corridors are primarily concentrated in the Heishan and southern regions of Baima Snow Mountain within the study area.
Secondary eco-corridors	19	243.18	The secondary eco-corridors exhibit significant variation in length, with 4 corridors shorter than 5 km, 5 corridors ranging from 5 to 10 km, and 10 corridors exceeding 10 km in length (Among these, the three longest corridors were Jinsichang group-Heishan group 2 linkage (31.35km), Dapingzi group-Heishan group 2 (28.56km) and Changyanshan group-Heishan group 4 linkage (25.13km)).
Third level eco-corridors	6	283.58	The third level eco-corridors exhibited the lowest ecological significance values but the longest lengths, all exceeding 20 km. These corridors were predominantly distributed in conservation gap zones across protected areas. Notably, corridors exceeding 50 km in length include Jinsichang - Shikuadiyasa linkage (85.77 km), Changyanshan -Dapingzi (51.02km) and Adong - Luomatong linkage (52.45 km).
Total	35	530.09	/

Table 2: Ecological Barrier Points

Type	Quantity	Area/ km ²	Remarks
Secondary eco-corridors	19	73.79	A total of 12 secondary corridors are distributed with barrier points, and the areas of these barrier points vary significantly. Specifically, 2 corridors (Xiaochangdu-Mikara and Shimenguan group B-Yong'an Group linkage) have barrier areas <1 km ² ; 4 corridors contain barrier areas 1–5 km ² ; 6 corridors fall within 5–10 km ² and 1 corridor (Adong-Wuyapuya linkage) exceeds 10 km ² (14.92 km ²).
Third level eco-corridors	26	105.75	The study included 7 third-level corridors that involve barrier points, and the areas of these were relatively large. Among them, 4 corridors exhibit substantial barrier sizes exceeding 10 km ² (Adong-Luomatong linkage, Rumei-Zhina linkage, Wuyapuyal-Luomatong and Jinsichang-Shikuadiyasa linkage).
Total	45	179.54	/

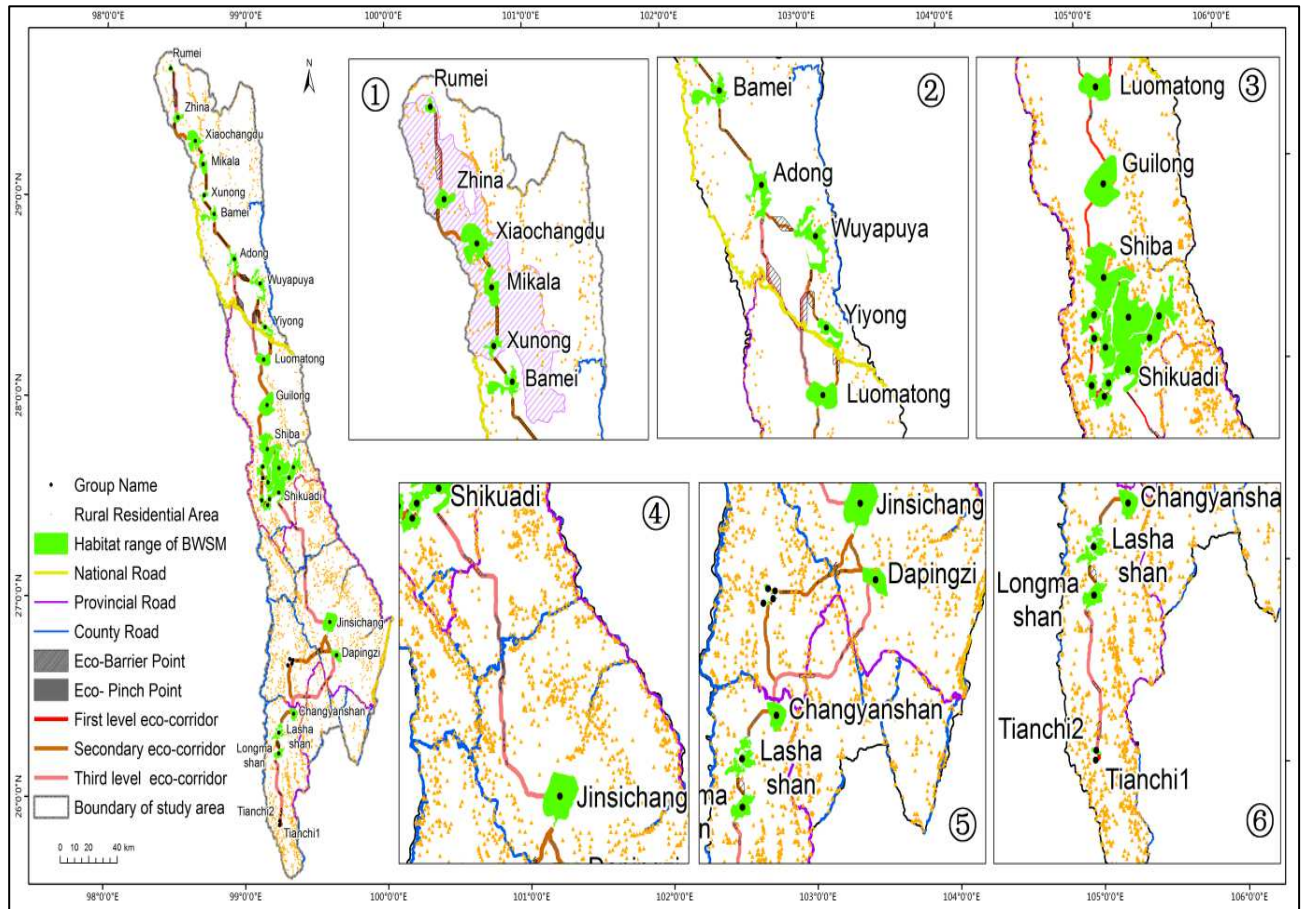
Ecological pinch points: The study identified 41 ecological pinch points, which are also discretely distributed, with a total area of 16.22 km². The ecological pinch points are located on second- and third-level corridors, and the area proportions are 30.24% and 69.76%, respectively. Among them, the Jinshichang-Shikuadi linkage possesses the largest number and area of pinch points, which are 11 and 8.091 km², respectively, accounting for 49.9% of the total area of pinch points; there is 1 pinch point in the Wuyapuya-Luomatong and Adong-Luomatong linkages, accounting for 17.22% of the total area of pinch points; there are also 7 pinch point patches in the Changyanshan-Lashashan and the Luomatong-Guilong linkage, accounting for 9.05% and

8.01% of the total area of pinch points, respectively; the areas of each pinch point on the remaining corridors are all less than 1 km², and the cumulative proportion is 15.82%. (Table 3, Figure3).

Resistance Factors of Ecological Corridors and Ecological Nodes: In this study, depths of 350 m, 1500 m, 3000 m, and 6000 m are selected to buffer the corridors to analyze the land cover, residential areas, roads, water systems, and altitude conditions under different corridor widths. The spatial distribution of Eco-Corridors, Eco-Nodes, Roads and Residential areas see Figure4.

Table 3: Ecological Pinch Points

Type	Quantity	Area/km ²	Remarks
Secondary eco-corridors	22	4.90	There were 8 secondary corridors involving ecological pinch points, of which 2 corridors have pinch point areas larger than 1 km ² . (Changyanshan-Lashan, 1.47 km ² ; Luomatong-Guilong linkage 1.30 km ²)
Third level eco-corridors	19	11.31	There were 5 third corridors involving ecological pinch points. Among these, the Jinsichang-Shikuadiyasa linkage exhibits the largest pinch point area.
Total	41	16.21	_____



Note: The corresponding sequence of the attached figures from top to bottom in the study area is ①, ②, ③, ④, ⑤, ⑥.

Figure 4: Spatial Distribution of Eco-Corridors, Eco-Nodes, Roads and Residential areas

72.27% and 16.19%, respectively. The increasing trend of grasslands is greater than that of forests; shrublands generally show a downward trend, from 8.96% to 7.23%; cultivated land shows a trend of first decreasing and then increasing and has the largest area proportion under the 350 m buffer zone, which is 4.19%. In short, although forests are the absolute dominant type in the region, grasslands, and cultivated land, with average proportions of 15.61% and 3.65%, respectively, largely block the circulation between BWSM groups (Figure 5).

Land cover composition:

Land cover composition under different corridor widths: As the corridor widened (350–6000 m), the proportion of land cover types in each buffer zone changed little. Forests, grasslands, shrublands, and cultivated land are the main land cover types under the four corridor buffers, and the sum of their proportions is greater than 99%. Among them, the area proportions of forests and grasslands increase slowly with increasing corridor width, increasing from 71.69% and 14.68% to

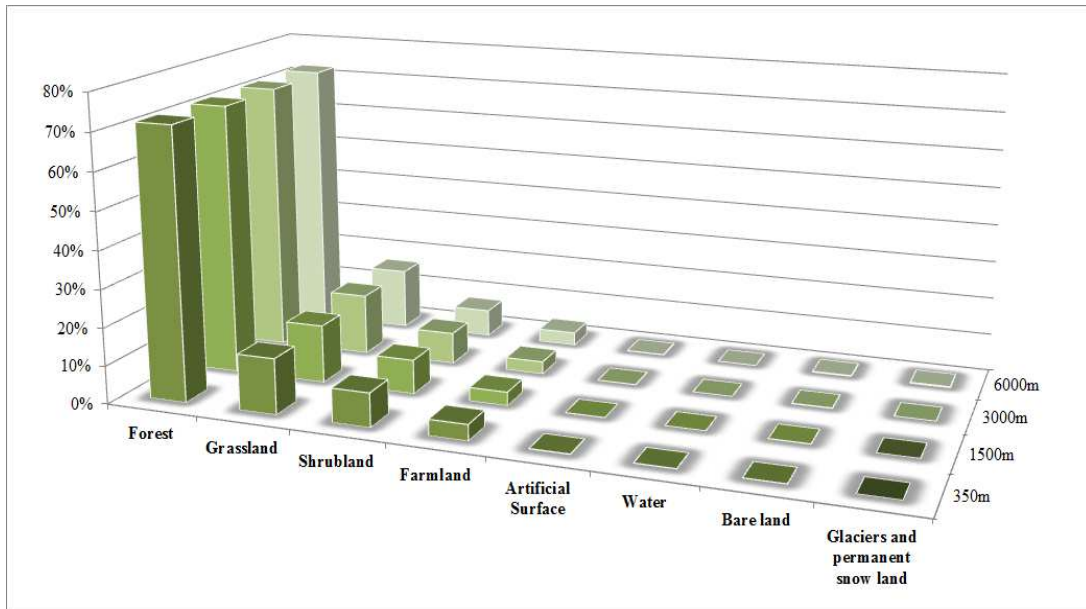


Figure 5: Land cover type composition under different widths of ecological corridors

that grasslands (pasture) predominantly obstruct this area. In contrast, the southern section features cultivated land as the main obstacle type, with proportions at the Dapingzi-Changyanshan linkage, Heishan-Dapingzi and Jinshichang linkages of 52.76% and 32.89%, respectively. The area proportions of forest, grassland, shrubland, and cultivated land cover types at the pinch points are 65.10%, 13.73%, 17.13%, and 3.21%, respectively (Figure 6). The land cover composition at pinch points across different ecological corridors is relatively consistent. This varied composition of land cover types contributes significantly to the slow ecological circulation noted in the pinch point area.

Land cover composition of each ecological node: The overlay of ecological nodes with land cover types revealed that the primary land cover types associated with each ecological node consisted of forests, grasslands, shrublands, and cultivated land. The area proportions of these cover types at the barrier points are 53.87%, 33.59%, 8.05%, and 4.19%, respectively. In the northern section of the study area, the proportions of grassland at the barrier points of the Rumei-Zhina linkage, Zhina-Xiaochangdu linkage, Xiaochangdu-Mikala linkage, Mikala-Xunong linkage, Bamei-Adong and Wuyapuya-Luomatong linkages were 69.96%, 56.48%, 53.76%, 50.66%, 49.57%, and 48.53%, respectively, indicating

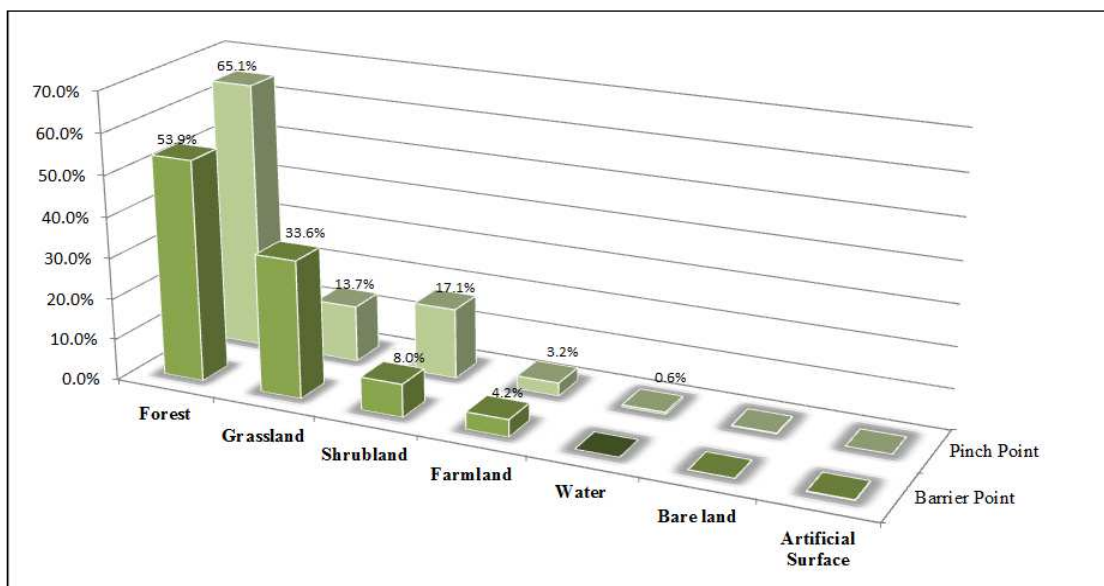


Figure 6: Land cover type composition under ecological nodes

Residential area distribution:

Number of residential areas involved in different corridor widths (Table 4): Within the four buffer zones of 350 - 6000 m, first-level corridors are free from residential areas and experience limited human interference. In contrast, the number of residential areas associated with second- and third-level corridors increases significantly with corridor width, with counts of 6, 13, 42, and 78 for second-level corridors, and 3, 13, 22, and 94 for third-level corridors. In particular, dense residential areas are found south of the Diqing Baima Snow Mountain Reserve. Across all corridor widths, the

proportion of residential areas exceeds 73%. Among these, the third-level corridors of the Jinshichang-Heishan Group 2 linkage, Dapingzi-Heishan Group 2 and Changyanshan-Dapingzi linkages were most affected by human activities. Furthermore, second-level corridors of Shimenguan Group B-Yongan Group linkage, Xiaochangdu-Mikala and the Tianchi Group 2-Longmashan linkages along with the Jinshichang-Shikuadi linkage (the third-level eco-corridor), demonstrate a significant increase in the proportion of residential areas as corridor width increases, indicating heightened vulnerability to human disturbances.

Table 4: Number of residential areas involved in different corridor widths and ecological nodes

Type	Quantity					
	Different corridor widths				Ecological Nodes	
	350 m	1500 m	3000 m	6000 m	Ecological Pinch Points	Ecological Barrier Points
First level eco-corridors	0	0	0	0	0	0
Secondary eco-corridors	6	13	42	78	0	7
Three level eco-corridors	3	13	22	94	0	8
Total	9	26	64	172	0	15

Number of residential areas involved in each ecological node (Table 4): Superimposing the ecological barrier points, pinch point areas, and residential areas reveals that a total of 15 residential areas are included within the barrier point region. Notably, the southern section of the study area accounts for 66.67% of these residential areas, comprising 10 locations. The barrier point area associated with the Heishan Group 2-Jinshichang and Dapingzi linkages includes 5 residential areas, the Changyanshan-Dapingzi linkage encompasses 3 residential areas, and the Tianchi Group 2-Longmenshan linkage has 2 residential areas. The remaining barrier points in the northern and central sections of the study area involve one and three residential areas, respectively, indicating that the southern section is primarily impacted and obstructed by residential development.

Road, water system and altitude conditions: Superimposing the 350–6000 m buffer zone of the BWSM, which encompasses an ecological corridor, ecological nodes, roads, water systems, and altitudes, the results indicate that roads have a significant impact on the ecological corridors and nodes, while altitude and water systems exert a lesser influence. With respect to roads, the majority of third-level corridors experience blockage due to road infrastructure. Specifically, the Adong-Luomatong and Wuyapuya-Luomatong linkages are obstructed by National Highway 214; the northern

segment of the Jinshichang-Shikuadi linkage faces blockage from Provincial Highway 303, with the middle section impeded by county roads; and the Changyanshan-Dapingzi linkage was hindered by the Jianlan Highway (provincial highway). Additionally, in the case of second-level corridors, the Jinshichang-Heishan Group 2 and Dapingzi-Heishan Group 2 linkages were obstructed by county road XQ23; the southern section of Changyanshan-Heishan Group 4 linkage was affected by Provincial Highway 311; and the northern part of the Yiyong-Luomatong linkage was hindered by National Highway 214. Concerning water systems, only the Xunong-Bamei linkage was obstructed by the Xilu River flowing from east to west. In terms of altitude, most ecological corridors and nodes are situated at altitudes ranging from 2800 to 4500 m, with very few areas found at altitudes near 2500 and 5000 m.

DISCUSSION

Construction of Resistance Surface: Current resistance surfaces often relied on expert scores or empirical coefficients (Su *et al.*, 2019; Wei *et al.*, 2022; Xiang *et al.*, 2023), introducing subjectivity. This study used MaxEnt-derived HSI values from 3,387 primate occurrence points as resistance surfaces, reducing expert-scoring bias and better representing BWSM migration ecology. Poor *et al.* and Stevenson-Holt *et al.* also

demonstrated that corridors derived from species distribution models exhibited higher ecological accuracy than those based exclusively on expert assessments (Poor *et al.*, 2012, Stevenson-Holt *et al.*, 2014). HSI-based resistance surfaces mitigated expert judgment errors but increased dependence on MaxEnt's predictive accuracy. This limitation stemmed from incomplete ecological equivalence between species occurrence probability and migration resistance. In addition, Dufлот *et al.*'s (2018) negative exponential transformation lacked sufficient ecological validation. Subsequent studies could integrate HSI with expert scoring (Teng *et al.*, 2022) to compare spatial differences and enhance corridor planning feasibility.

Identification of Ecological Corridors and Ecological Nodes: Identifying ecological sources, corridors, and nodes is fundamental to ecological networks (Wei *et al.*, 2022). Research on BWSM's regional ecological corridors was limited. Li *et al.* (Li *et al.*, 2015) determined potential BWSM corridors using least-cost path analysis based on 2004-2009 survey data but conducted no further analysis, requiring updated results. Su *et al.* (Su *et al.*, 2019) constructed a relatively comprehensive BWSM conservation network using pre-2016 literature data under five conservation source scenarios, but the numerous identified potential sources and corridors across extensive areas posed implementation challenges. Wang *et al.* (Wang *et al.*, 2023) proposed stepping-stone strategies to address BWSM habitat fragmentation but identified no ecological corridors. This study identified the most suitable inter-habitat migration corridors and ecological pinch points/barriers affecting connectivity using existing data from 24 BWSM groups, offering practical significance for current troop conservation. While identifying potential habitat patches remained crucial for BWSM conservation, further research on corridor identification was reserved for subsequent work given space constraints.

Analysis of resistance factors for ecological corridors and nodes: Linkage Mapper with gravity models identified corridors but could not determine widths or ecological mechanisms. Corridor width critically affected ecosystem integrity (Wei *et al.*, 2022; Zhu *et al.*, 2005). Based on BWSM daily movements (350m-3km) (Clauzel *et al.*, 2015a) and habitat quality inflection points (Qian *et al.*, 2022), four widths (350m/1500m/3000m/6000m) were tested. Width selection significantly impacted residential land and altitude but minimally affected land cover or waterways, necessitating expert consultation and field validation. The key human-resistance factors were road, settlement proximity and human density (Qian *et al.*, 2022). Land covers most negatively impacted habitat suitability (Shi *et al.*, 2025), and village development degraded habitat quality (Zhu *et al.*, 2022). In this study, connectivity analysis used land cover, residential area,

roads, water system, and altitude. However, the land cover data used in the study were from 2020, and employing static data to analyze migration resistance might have resulted in slight discrepancies in the findings. Additionally, the study revealed that forests, as the dominant cover type in corridor buffer zones and ecological nodes, were not suitable for monkey survival. Therefore, future research could further investigate the mechanisms by which natural and anthropogenic factors affect the BWSM corridors in greater detail.

In summary, the findings provide more targeted and practical references for the restoration and construction of ecological corridors for BWSM and serve as valuable supplements to existing research on their corridors. Further validation through detailed field surveys is recommended.

Conclusion: In this study, the current distribution range of BWSM groups was defined as ecological source area, and the MaxEnt model was used to generate resistance surface. A total of 28 ecological source patches and 35 ecological corridors were identified. The land cover, residential areas, and road distributions were the primary resistance factors, while water systems and altitude had less influence. First-level corridors had minimal resistance and highest connectivity; second- and third level corridors faced moderate to high resistance due to vegetation fragmentation, land cover fragmentation, land use variability (grasslands, farmland), dense settlements, and complex road systems. To enhance habitat connectivity for BWSMs, first-level corridors should be prioritized for construction due to their short distances, high connectivity, and absence of resistance nodes.

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