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Microhabitat selection by François' langur *Trachypithecus francoisi* in Mayanghe National Nature Reserve, China

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ABSTRACT: Understanding microhabitat use and selection by terrestrial animals and their driving factors is one of the major tasks in ecology and conservation biology. Many habitat selection studies do not differentiate habitat characteristics between core (the key protection area of a national nature reserve) and non-core (the buffer zone and experimental zone of the reserve) areas, relying instead on presence/absence data. In this study, we compared microhabitat characteristics between core and non-core areas of François' langur *Trachypithecus francoisi* in the Mayanghe National Nature Reserve, southwestern China. Using a resource selection function (RSF), we systematically surveyed 20 transects, establishing 228 tree quadrats (162 in the core area and 66 in the non-core area). The collected data included topographic, anthropogenic, and vegetation-related variables. The results indicate that quadrats in core areas had higher elevations and greater distances from roads, rivers, settlements, and agricultural land compared to those in non-core areas. Moreover, we found that elevation, distance to rivers, distance to roads, tree quantity, and tree diameter at breast height are key factors driving microhabitat selection by François' langur. The findings highlight the importance of prioritizing high-elevation areas that are far from roads to improve habitat management and restoration for this species. This study enhances our understanding of habitat selection and contributes to current population conservation efforts.

KEY WORDS: Microhabitat use and selection · François' langur · RSF · Resource selection function · Mayanghe National Nature Reserve

1. INTRODUCTION

Understanding microhabitat use and selection by terrestrial animals and their driving factors is one of the major tasks in ecology and conservation biology (Loe et al. 2006). Habitat structure, such as vegetation type, is perhaps the most prominent factor in determining habitat selection by terrestrial animals because it is often closely linked to factors that affect survival and reproduction (Grinnell 1917, Lack 1933, Enstam & Isbell 2004). At the same time, other environmental factors, such as topographic and anthropogenic factors, can drive microhabitat selection and use (Hanski 2011, Luan et al. 2022). In particular, recent studies have suggested that human-induced land use change, such as urbanization and road construction, may have a negative effect on microhabitat selection by animal groups (Han et al. 2023). Owing to increasingly intense land use changes, such effects will become more intense in the coming decades (Zhao et al. 2017). Evaluating and comparing species-specific habitat selection preferences across a gra-

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dient of anthropogenic impacts is crucial. This approach is essential for understanding how animal populations respond to these drivers. Furthermore, it provides critical insights for effective habitat management and restoration (Kopp et al. 1998, Mayor et al. 2009, Stabach et al. 2016).

Resource selection functions (RSFs) are robust tools in ecological research, offering a quantitative framework to understand wildlife habitat selection (Boyce et al. 2002, Gillies et al. 2006, Johnson et al. 2006, Stabach et al. 2016). These models provide a nuanced insight into environmental variables influencing fauna habitat utilization, identifying key factors shaping distribution (Wei et al. 2015, Stabach et al. 2016, Bai et al. 2020). Unlike alternatives like MaxEnt models, RSFs directly estimate resource utilization probability, providing a more mechanistic understanding (Phillips et al. 2006, Wei et al. 2015, Bai et al. 2020). Their advantages extend to diverse conservation contexts, aiding informed decision-making in preservation and restoration. While RSFs have been pivotal for large, wide-ranging species, there is a growing recognition of the need to broaden their application to diverse taxa (Wei et al. 2015, Bai et al. 2020). This ensures a comprehensive, inclusive approach to conservation research, aligning with evolving scholarly inquiry.

François' langur *Trachypithecus francoisi*, a primate listed as Endangered on the International Union for Conservation of Nature (IUCN) Red List (Nadler et al. 2020), is considered a first-grade protected species of wildlife in China. This species mainly inhabits karst mountain areas in China and Vietnam (Ma et al. 1989). Historically, François' langurs were widely distributed in China, including Guizhou, Guangxi, Chongqing, Guangdong, and Hainan provinces (Niu et al. 2016). In the past 30 yr, due to the continuous expansion of human activities, such as hunting, deforestation, and other production and living activities, the distribution range of this species has been drastically reduced and its numbers have also declined; the population of langurs has decreased by approximately 2100 individuals, and the number of isolated distribution areas has decreased from 41 to 22 (Huang et al. 2002, Hu et al. 2004, Niu et al. 2022). Recent studies have suggested that François' langurs currently comprise about 1700~1800 individuals, of which about 150~190 individuals are distributed in Vietnam and about 1500 individuals are distributed in China (Zhou et al. 2018, Deng et al. 2019, Niu et al. 2022). Currently, this species is found in Guizhou, Guangxi, and Chongqing in China (Huang et al. 2002, Hu et al. 2004, Zhou et al. 2007, Hu 2011), and within the provinces of Ha Giang, Cao Bang, Tuyen Quang, Bac Can, Thai Nguyen, and other areas along the Red River in northern Vietnam (Nadler et al. 2007). François' langurs are mixed feeders, foraging on leaves, young shoots, flowers, and fruit in summer–autumn months (Zhou et al. 2006, 2018, Hu 2011). In addition, they rely on rock caves, crevices, platforms, and pits for shelter (Zhou et al. 2010, 2013, Wang et al. 2011). The langurs exhibit a distinct habitat preference, showing a propensity for lower elevations, steep slopes, and broadleaf forests; additionally, they demonstrate a pronounced aversion to anthropogenic disturbances (Han et al. 2023).

Mayanghe National Nature Reserve, China, is in the northeastern part of the distribution range of François' langurs and holds the largest subpopulation of this species (Hu 2011, Zeng et al. 2013). Recent studies suggest that there are about 72 subpopulations with about 554 individuals in and around the reserve (Niu et al. 2016). However, despite substantial descriptive evidence suggesting that a narrower range of habitats are used by François' langur populations, to date no quantitative studies have explicitly quantified and compared microhabitat selection between the core and non-core areas (i.e. disturbed areas), nor has any study compared the factors that determine microhabitat selection in the core and non-core areas in the Mayanghe National Nature Reserve. Core areas are expected to have better habitat quality, greater tree diameter at breast height (DBH), higher tree quantity, and lower shrub quantity than non-core areas. Therefore, understanding habitat selection by François' langurs has become a major priority for prioritizing habitat restoration.

In this study, we explored differences in microhabitat selection by François' langurs between core and non-core areas in the Mayanghe National Nature Reserve. Our specific objectives were as follows: (1) identify key environmental factors that determine François' langur microhabitat selection between core and non-core areas; (2) improve our understanding of and approaches towards studying habitat selection by François' langurs; and (3) identify significant factors that enhance the conservation and management of the progressively fragmented François' langur habitat through a more targeted investigation into specific aspects or goals. To our knowledge, this study is the first attempt to investigate the differences in habitat selection by François' langurs in different parts of their distribution areas and could have important implications for future conservation of this species.

2. MATERIALS AND METHODS

2.1. Study area

This study was conducted in the Mayanghe National Nature Reserve (28° 37′ 30″ –28° 54′ 20″ N, 108° 3′ 58″ –108° 19′ 45″ E) in northeast Guizhou Province in southwestern China. The reserve spans an area of 311.13 km^2; the core area covers 105.43 km^2, while the non-core area covers 160.70 km^2 (Fig. 1). As one of the national nature reserves established for conserving François' langur and other rare wildlife (e.g. Elliot's pheasant *Syrmaticus ellioti* and Indian civet *Viverra zibetha*, among others), the study area harbors one of the world's largest wild François' langur populations, with a population size of 500~600, which makes this region suitable for investigating microhabitat selection by this species (Han et al. 2023). The study area is characterized by a warm, humid, and rainy climate, with an average annual temperature of 17°C and average annual precipitation of 1158 mm. Its elevation ranges from 280 to 1441 m, and the main vegetation type is humid evergreen broad-leaved forest, which covers 65% of the reserve (Hu 2011). Other vegetation types, including coniferous forest, coniferous–broad-leaved mixed forest, broad-leaved forest, bamboo forest, and shrubland, can provide sufficient food for François' langurs (Hu 2011).

2.2. Field survey and data collection

The core area is the key protection area of the national nature reserve, and ecosystems within the core area are distinguished by their intrinsic primordial state and minimal human-induced disruptions, boasting abundant vegetation and serving as primary habitats for endemic species. Economic activities are greatly restricted and constrained; this requires taking strict protection measures to reduce or eliminate human interference with the natural environment, thereby maintaining the integrity and stability of the ecosystem and protecting wild species and their habitats to the greatest extent possible.

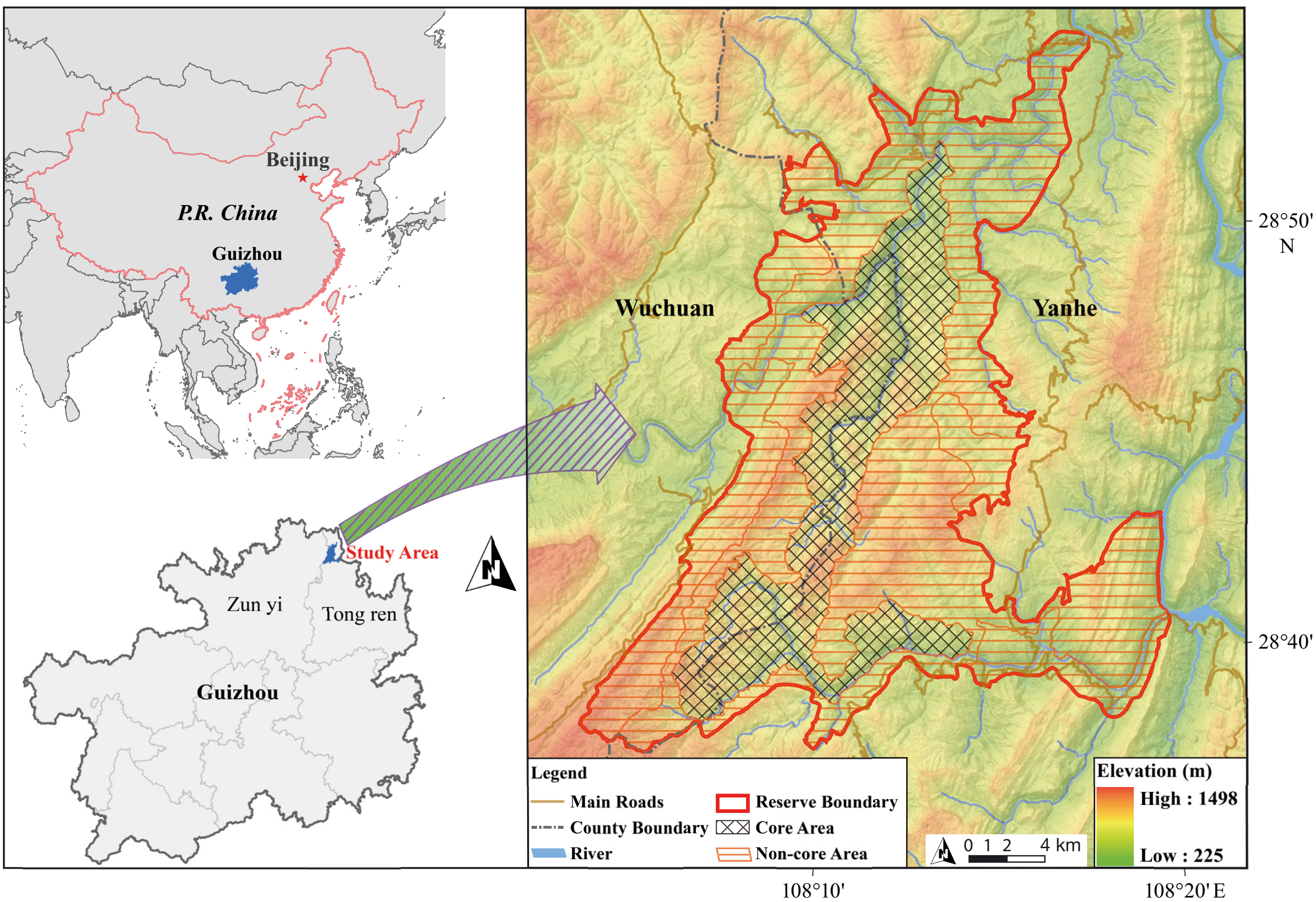

Fig. 1. Mayanghe National Nature Reserve in Guizhou, southern China

The non-core area of the reserve, a relatively wide area designated around the core area to alleviate conflicts between human activities and wild species. Within the non-core area, human activities are usually restricted and managed, such as limiting industrial development, land reclamation, mining, etc., to reduce human interference with the natural ecosystem. In non-core areas, implementing specific organizational management models and selecting appropriate technologies can help explore and optimize local conservation measures and management systems. This approach can also attract more scientific and technological expertise and social capital investment to stimulate the development of the local conservation economy and enhance ecological benefits.

Field surveys took place between October 2017 and August 2018 in the reserve. In this study, transects were surveyed to obtain (1) information on the presence of François' langurs and (2) environmental data in the habitat where the langurs were detected. The transect configuration was primarily based on the distribution areas of François' langurs (Niu et al. 2016), encompassing all of these regions within the reserve. In total, 20 transects, each with a length of about 500 m, were selected pseudo-randomly across the whole study area (including 12 transects in the core area and 8 in the non-core area), except in inaccessible areas (e.g. steep cliff faces). These transects covered all vegetation types and elevation ranges that are suitable for François' langurs. On each transect, the presence of François' langurs was determined through direct observations, presence of sleeping sites, foraging traces, fecal traces, and manager reports. If the actual points of the direct/indirect observations were off-transect, we estimated them from a position on the transect line. When François' langurs were detected, we established a tree quadrat (10 × 20 m) centered around the presence records and further established 5 shrub quadrats (5 × 5 m) within each tree quadrat. Owing to the limitations imposed by the karst topography, the establishment of square plots measuring 20 × 20 m proved to be exceedingly difficult. In total, 228 tree quadrats were established along the 20 transects, including 162 quadrats in the core area and 66 quadrats in the non-core area. For each tree quadrat, macro-aspect, micro-aspect, and substrate type were recorded (Table 1). Elevation and slope were measured using a handheld Garmin eTrex 30× GPS device (±5 m). The distances to water, roads, settlements, and cultivated land were calculated using ArcGIS 10.3. Canopy density of forest (%), vegetation type (coniferous forest: dominated by coniferous trees; mixed coniferous: mix of coniferous and broadleaf [deciduous] trees; broadleaf forest: primarily composed of broadleaf trees; shrubland: dominated by shrubs and small woody plants), number of trees, tree height (m), tree diameter (DBH, cm), shrub coverage (%), number of shrubs, height of shrubs (m), and diameter of shrubs (cm) were recorded in a quadrat survey. The determination of percentages relied on estimations, while the identification of 'vegetation types' was conducted through direct visual inspection in the field. Specifically, visual categorization of vegetation was

Table 1. Habitat characteristics measured in the vegetation quadrats set up in Mayanghe National Nature Reserve, China

Habitat characteristic	Unit	Definition (measuring method)
Elevation	m	Elevation at center of the tree plot (handheld GPS)
Slope	°	Slope at center of the tree plot (handheld GPS)
Slope orientation	°	Aspect of the slope at the locations ranging from 0 to 360°
Distance to water	m	Distance between center of the tree plot and a flowing stream
Distance to road	m	Distance between center of the tree plot and the nearest road
Distance to settlement	m	Distance between center of the tree plot and the nearest settlement
Distance to cultivated land	m	Distance between center of the tree plot and the nearest cultivated land
Canopy density of forest	%	Proportion of the ground covered by the projection of the tree canopy
Vegetation type		Coniferous forest, broadleaf forest, or mixed forest
Number of trees		Number of trees with height >5 m in the tree plot
Height of trees	m	Average height of all counted trees in the tree plot
Diameter of the tree	cm	Average diameter at breast height (~1.5 m) of all counted trees in the tree plot
Shrub coverage	%	Average estimation of the shrub coverage in the 5 shrub sub-plots
Number of shrubs		Average number of shrubs and trees <5 m tall in the 5 shrub sub-plots
Height of shrubs	m	Average height of all counted shrubs in the 5 shrub sub-plots
Diameter of shrubs	cm	Average diameter of the main stem of all counted shrubs in the 5 shrub sub-plots

carried out by direct observation, utilizing unaided eyesight to classify and recognize distinct vegetation types. In the study, surveyable François' langur habitat use points were selected based on a systematic pseudo-random approach to ensure representative sampling across the non-core area. Specifically, we divided the non-core area into equal-sized grid cells and selected random points within each cell, taking care to avoid bias in selection. We employed a rigorous approach where availability points were systematically generated across the non-core area and were matched with observed 'used' points from direct and indirect observations along transects. This ensured a robust comparison between microhabitat characteristics in core (used) and non-core (available) areas.

2.3. Statistical analysis

To compare the microhabitat characteristics between the core and non-core areas, we performed statistical tests in R v3.4.0. We assessed normality and homogeneity of variances required for parametric tests. Normality and homogeneity of variances were tested using Shapiro-Wilk and Levene's tests, respectively. If data did not meet these assumptions, we applied appropriate transformations (logarithmic) to satisfy the assumptions of the tests. Chi-squared and Student's *t*-tests were used to evaluate whether there were significant differences in categorical variables (e.g. vegetation type and slope orientation) and numerical variables (e.g. slope, average DBH and height of trees, canopy density, average height of shrubs, shrub coverage, distance to road, distance to water source, distance to residential and distance to cultivated land). In the analyses, we used a significance level (alpha) of 0.05 to determine the statistical significance of results.

To determine microhabitat selection by François' langurs, RSFs were used to explore the relationship between habitat variables and species occurrence (Gillies et al. 2006, Johnson et al. 2006, Stabach et al. 2016, Bai et al. 2020). Specifically, we modeled resource selection differences between the core areas (1) and non-core areas (0) using generalized linear mixed-effects logistic regression with the following formula:

$$w(x_i) = \exp(\beta + \beta_1 x_{1i} + \ldots + \beta_n x_{ni}) \quad (1)$$

where $w(x_i)$ is the RSF, and β_j ($j = 1, 2, \ldots, n$) is the coefficient for the predictive variable x_j (Gillies et al. 2006, Bai et al. 2020).

Before model processing, to minimize multicollinearity between variables, Pearson's correlation coefficients were used for variable selection ($|r| < 0.7$) (Bai et al. 2020). When faced with collinearity between 2 variables, we only retained variables that have importance and clear biological meaning for François' langurs: 3 topographic variables (elevation, slope orientation, distance to river), 1 anthropogenic variable (distance to road) and 3 vegetation-related variables (vegetation coverage, tree DBH, number of trees). Furthermore, all continuous selected variables were normalized. We then built a series of models based on all possible combinations of the above selected environmental variables and obtained the optimal model based on Akaike's information criterion (AIC) using the 'dredge' function in the R package 'MuMIn' (Bartón 2013). The relative probability of each environmental factor in the optimal model was also plotted to represent the preference of langurs for the microhabitat characteristics of their habitat in the Mayanghe National Nature Reserve (Bai et al. 2020). Variable importance was used to evaluate the contribution of each factor to the model, and the importance values of each variable in the model were averaged (ΔAIC < 2, where ΔAIC is the difference in the AIC value relative to the top performing model). We employed k-fold cross-validation to assess the accuracy of the models before predicting the probability of use across the landscape. This method involves dividing the data set into k subsets, training the model on $k - 1$ subsets, and evaluating its performance on the remaining subset. We repeated the process k times, with each subset used as the validation set exactly once. By averaging the performance metrics across the k iterations, we obtained a robust estimate of the model's accuracy and generalization ability. Additionally, we conducted other checks and validation procedures to ensure the reliability and validity of our models. We employed a mixed-effects model to consider random effects among locations. All statistical analyses were conducted in R v3.4.0.

3. RESULTS

3.1. Microhabitat differences between core and non-core areas

Our analyses indicated significant microhabitat differences between core and non-core areas (Tables 2 & 3). Specifically, core areas were found to have higher elevations and be farther from roads, rivers,

Table 2. Comparison of categorical variables between core and non-core areas of François' langur in Mayanghe National Nature Reserve, Guizhou, China: comprehensive data analysis beyond chi-squared tests

Habitat variable	Frequency (proportion, %) Core area quadrats		Non-core area quadrats		Results of chi-squared test (df = 3)
Slope orientation					
North	40	24.69	19	28.79	$\chi^2 = 2.6275$
East	43	26.54	14	21.21	p = 0.4527
South	39	24.07	20	30.31	
West	40	24.69	13	19.69	
Vegetation type					
Conifer forest	10	6.17	4	6.06	$\chi^2 = 11.816$
Conifer–broadleaved mixed forest	32	19.75	7	10.61	p = 0.008
Broadleaved forest	99	61.11	35	53.03	
Shrubland	21	12.96	20	30.30	

Table 3. Comparison of habitat characteristics between core area and non-core area quadrats: summary statistics and *t*-test results. *p < 0.05; **p < 0.01; ***p < 0.001

Habitat variables	Core-area quadrats Mean	SD	Non-core area quadrats Mean	SD	*t*	df	p
Elevation (m)	647.91	149.2	451.62	107.86	10.92	155.758	0.003**
Slope	32.89	14.51	30.59	12.71	1.10	226	0.277
Distance to river (m)	256.2	220.79	193.34	183.21	2.01	226	0.046*
Distance to road (m)	1026.13	463.4	320.61	265.98	11.37	191.861	<0.001***
Distance to settlement (m)	872.38	406.85	468.03	313.87	7.59	145.889	<0.001***
Distance to cultivated land (m)	624.13	332.68	340.99	192.36	6.35	190.791	<0.001***
Vegetation coverage (%)	55.59	15.3	52.14	17.75	1.45	226	0.149
Tree diameter (cm)	10.07	4.34	8.19	3.55	3.06	226	<0.01**
Height of trees (m)	9.15	2.71	8.41	2.45	1.87	226	0.063
Number of trees	31.96	10.31	24.57	9.26	4.96	226	<0.001***
Shrub coverage (%)	34.39	22.11	51.95	22.86	-5.29	226	<0.001***
Shrub diameter (cm)	1.7	0.45	2.84	0.65	-1.19	226	0.235
Shrub height (m)	2.77	0.62	2.84	0.65	-0.71	226	0.478
Number of shrubs	18.31	9.85	23.92	10.86	-3.72	226	<0.001***

settlements, and agricultural land than non-core areas. Student's *t*-test was used to examine numerical variables; core areas had higher tree height (t = 1.87, df = 226, p > 0.05), higher tree DBH (t =1.87, df = 226, p < 0.01), higher tree quantity (t = 4.96, df = 226, p < 0.001), and lower shrub quantity (t = −3.72, p < 0.001) than non-core areas (Table 2). A chi-squared test was used to examine categorical variables. We found significant difference in vegetation types utilized by François' langur between core and non-core areas (χ^2 = 11.816, df = 3, p < 0.008; Table 3). In the core areas, 61.11% of quadrats were located in the broadleaved forest and 12.96% of quadrats were located in shrubland, while the respective percentages of quadrats in the non-core areas were 53.03 and 30.30%, respectively. There was no obvious selectivity for slope orientation (χ^2 = 2.6275, df = 3, p > 0.05).

3.2. Habitat selection in the study area

Our RSF analysis showed that the best model predicting differences between core and non-core areas included 5 variables: elevation, distance to river, distance to road, tree quantity, and tree DBH (Tables 4 & 5), Random effects in the model captured latent variation not observed in the data, providing additional insights into model fit and interpretation. However, only 2 variables of the above 5 variables (i.e. elevation and distance to road) were significant (p < 0.05, Table 4). Accordingly, elevation (relative importance value = 1.00) and distance to road (relative importance value = 1.00) were the 2 most important predictors of habitat selection by François' langur between core area and non-core areas, followed by tree quantity (relative importance value = 0.89) and distance to river (relative importance value = 0.64) (Table 5).

Table 4. Top 9 generalized linear models for the effect of variable characteristics on habitat selection by François' langurs between core area and non-core areas. DBH: diameter at breast height; AIC: Akaike's information criterion; ΔAIC: difference in AIC rank relative to the top model; logLik: log-likelihood; Akaike weight: probability that a model is best given the particular set of models considered

Model	df	logLik	AIC	ΔAIC	Akaike weight
Elevation + Distance to river + Distance to road + Tree DBH + Number of trees	6	−48.02	108.05	0.00	0.12
Elevation + Slope orientation + Distance to river + Distance to road + Tree DBH + Number of trees	7	−47.26	108.51	0.46	0.10
Elevation + Slope orientation + Distance to river + Distance to road + Number of trees	6	−48.35	108.69	0.64	0.09
Elevation + Distance to river + Distance to road + Number of trees	5	−49.4	108.81	0.76	0.09
Elevation + Distance to road + Tree DBH + Number of trees	5	−49.61	109.23	1.18	0.07
Elevation+ Slope orientation + Distance to road + Tree DBH + Number of trees	6	−48.77	109.53	1.48	0.06
Elevation + Slope orientation + Distance to road + Number of trees	5	−49.83	109.65	1.60	0.06
Elevation + Distance to river + Vegetation coverage + Tree DBH + Number of trees	7	−47.91	109.82	1.77	0.05
Elevation + Distance to road + Number of trees	4	−51.01	110.01	1.97	0.05

Table 5. Parameter estimates of the optimal model ordered by importance value; asterisks denote significant contributions to the model (***$p < 0.001$). *Wi*: relative probability of selection for a given resource unit

Habitat variables	*Wi*	Estimate	SE	*Z*	p
Elevation	1.00	−0.001	0.003	3.373	<0.001***
Slope	0.47	−0.000	0.002	0.331	0.741
Distance to river (m)	0.64	0.001	0.002	0.718	0.472
Distance to road (m)	1.00	−0.005	0.002	5.117	<0.001***
Vegetation coverage	0.28	−0.002	0.000	0.168	0.866
Tree diameter at breast height (cm)	0.56	−0.041	0.070	0.584	0.559
Number of trees	0.89	−0.034	0.039	0.863	0.388

4. DISCUSSION

The study identified significant microhabitat distinctions between core and non-core areas, underscoring the imperative to assess microhabitat selection by threatened species like François' langur. Core areas, characterized by higher elevations and greater distances from road, river, settlement, and agricultural land, exhibited superior habitat quality compared to non-core areas. Our RSF analysis highlighted elevation and distance to road as the most influential predictors of habitat selection between core and non-core areas. These findings emphasize the intricate interplay between microhabitat features and habitat selection by François' langur, which is crucial for holistic conservation management. Habitat quality determines the availability of resources, which can directly or indirectly determine the intensity of intra- and interspecific competition and affect the sustainable survival and reproduction of species (Go 2010, Grueter et al. 2012, Apolloni et al. 2018). Biological characteristics are comprehensive indicators of forest quality, which can not only provide adequate food but can also provide good hiding places for animals. Habitats with high plant density and canopy density not only provide rich food resources for François' langur, but also provide good hiding conditions (Zhou et al. 2006, 2013, Wang et al. 2011).

Generally, compared to non-core areas, the core areas had higher elevation, less human disturbance, and more abundant food resources, which is more suitable for François' langur. As this species is a semi-arboreal primate, it is more likely to scan the surroundings to find food and identify potential dangers. While moving, François' langurs rely on shrubs to build bridges. In order to support their weight, the animals select trees with larger DBH and shrubs with a larger base diameter.

With economic development, human disturbance to wildlife becomes more and more frequent. Human activities (such as deforestation, reclamation of agricultural land, construction of roads and housing for people in villages, etc.) can cause habitat loss and fragmentation and accordingly lead to a decline in habitat quality (Wassie et al. 2009, Zhao et al. 2017, 2019). Therefore, human activities can affect the home range, feeding habits, activity pattern, reproductive rate, mortality, and survival of non-human primates living in the habitat (Wang et al. 2011, Zeng et al. 2013, Deng et al. 2019). Our results showed that François' langurs preferred low-disturbance areas (i.e. core areas) in the Mayanghe National Nature Reserve. In the high-disturbance areas (i.e. non-core areas), the langurs were restricted to narrow strips along the rivers, due to the extensive distribution of roads, settlements, and agricultural land. However, François' langurs have gradually become accustomed to the impact of human interferences (Han et al. 2023); langurs in the non-core areas often feed on trees along roads, cross the roads, and have negative interactions with tourists, which increases their risks, such as the potential for vehicle collisions, increased exposure to road traffic, and disturbances caused by human activities. Vehicle collisions can result in injury or mortality among langurs, while increased road traffic can disrupt their natural behaviors and habitats, leading to stress and decreased reproductive success. Negative interactions with tourists, such as disturbance and harassment, can also cause stress and disrupt social structures within langur populations. These risks collectively threaten the survival and well-being of François' langurs in the non-core area. Addressing these risks through effective management and conservation strategies is essential to ensure the long-term viability of langur populations in the region. Settlements compressing langur habitat will not change significantly in a short time, posing obstacles to the movement of François' langurs, hindering their migration, and reducing the connectivity of the habitat within the landscape (Han et al. 2023). Furthermore, activities of local communities in the area increase the frequency of direct human–monkey conflict. During the study period, langurs were frequently found surrounding settlements, leading to potential exposure to cross-infection, e.g. with parasites or diseases, from humans.

Based on the AIC values derived from different models, our results further suggest that François' langurs exhibit a preference for habitats characterized by lower elevation, steeper slopes, shorter distance to rivers, and considerable distance from human disturbances. According to the model results, elevation, distance to river, distance to road, tree quantity, and tree DBH composed the best model, indicating that geographical and anthropogenic variables were the most important variables, whereas vegetation-related variables were relatively important, in influencing habitat selection by François' langurs. Thus, our results demonstrate that topographic and anthropogenic variables are more important than vegetation-related variables in microhabitat selection by this species. The study highlights the importance of distinguishing among variables that may be acting at different spatial scales. Variables such as distance to road, forest type, slope, and tree DBH have been shown to be useful for identifying suitable habitat of François' langurs in past research (Zhou et al. 2018), but finer-scale variables, such as access to shrubs, shrub density, or distance to cultivated land may be more important for managers to consider at the local scale when they are prioritizing areas to conserve because they support more frequent use by individual langurs.

As the largest remaining wild population of François' langurs in the world, strict prohibitions on construction and deforestation in the core areas of the reserve are imperative for the purpose of habitat management and restoration. Building of new roads and houses and the development and utilization of farms should be effectively controlled in the non-core areas where François' langurs are distributed on both sides of the river. To reduce habitat fragmentation and minimize the impact of human disturbance on wildlife, we recommend the following. (1) Community outreach: the reserve's management bureau could coordinate public relations activities, inviting professionals to educate local residents about the ecology and behavior of the langurs. This approach aims to enhance public understanding of the significance of François' langurs and the importance of ecological protection. Additionally, relevant promotional materials could be distributed to reinforce this awareness. (2) Collaboration with community media: acknowledge the importance of working with local newspapers, television stations, and other media outlets. Various formats, such as special reports and promotional features, can effectively convey knowledge about protection measures to underscore the significance of François' langur conservation within the reserve. (3) Organizing youth activities: organize youth to volunteer and participate in wildlife-protection activities in schools, communities, and other places. Introducing them to protected areas would allow them to personally experience the beauty and fragility of wildlife and its environment, to cultivate a sense of protection and responsibility, increase awareness of wild animals in the reserve, and further enhance their awareness of the need for protection, so that more people can take action to protect François' langurs. (4) Enhancement of protected areas: advocating for the protection and potential expansion of existing protected areas would ensure a secure habitat for François' langurs. (5) Road infrastructure: establish of road bridges to facilitate safe wildlife crossings, thereby minimizing the risks associated with road-related hazards. (6) Creation of forest corridors: to connect fragmented populations, fostering genetic diversity, and promoting ecological connectivity. In conclusion, to ensure the long-term survival of the François' langurs in the Mayanghe National Nature Reserve, it is essential to implement these recommendations through collaborative efforts, effective monitoring, and community engagement.

Data availability. The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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