

Supplementary Materials

Dispersal behaviors stimulated by habitat alterations in golden snub-nosed monkeys (*Rhinopithecus roxellana*) in the Qinling Mountains, China

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Supplementary Materials and Methods

Study area

Our survey covered an area of the Qinling (105°30'–110°05'E, 32°40'–34°35'N) in Shaanxi Province, about 400 km-500 km from east to west, and about 150 km - 200 km from south to north, with an area of 53,000 km² (Basic geographical conditions of Shaanxi province, 2011). The vegetation displays a significant vertical differentiation: deciduous broadleaved forests are principally distributed below 2,200m; the coniferous and broadleaved mixed forests range from 2200 to 2600 m; evergreen coniferous forests are found from 2,400 to 3,000; and above 3000 m we met deciduous, coniferous forests and alpine meadow (Liu et al., 2022). It is an area that features remarkable biodiversity hot spot (Wang et al., 2014).

The golden snub-nosed monkeys studied are the only nonhuman primate species in the area (Li et al, 2001), with about 4,000 individuals belonging to 39 troops (populations) before the 21st Century (Li et al., 2001; Li et al., 2002).

In addition to collecting historical distribution locations, the survey included camera traps to identify the current distribution location.

Database collection

Through the literature review, we compiled the data records of monkeys' distribution profiles reported from 1959 to 2020. Because those data were from multiple unplanned surveys in different periods, we filtered original locations within one km² with Spatially Rarely Occurrence Data software in the SDM toolbox to avoid spatial autocorrelation. After the filtering, we got 82 location sites in the 1980s, 94 locations in the 2010s, and 176 locations in the 2020s. Our fieldwork in 2021 aimed to verify the previous reports and found four new monkey populations (Fig 1A).

Environment variables

The environmental variables used in this study to analyze the relationship between ecological factors and monkeys' distribution patterns consist of three parts: vegetation types, topographic structure, and human activities. We obtained the data from Global Geo-information Public Product (<http://www.globallandcover.com>) recorded in 2000, 2010, and 2020, representing the profiles during the 1980s and the 2010s, and the 2020s, separately. The topographic variables include the elevations, slopes, and aspects, extracted from the Digital Elevation Model (DEM) stored in the Chinese Academy of Sciences geospatial database (<http://www.gscloud.cn>). The variables related to human-induced activities include the human footprint index (HFI), the distances of the habitats to human settlement (DS), roads (DR), and water resources (DW). HFI came from the Center for International Earth Science Information Network (http://www.ciesin.columbia.edu/wild_areas) (Venter et al., 2016). DS, DR and DW were calculated according to the Digital vector map from National Geographic Information Resources Directory Service System (<http://www.webmap.cn>).

Environmental variables were resampled to a km² resolution, unified according to WGS_1984 geographic coordinate system, and transformed into ASC format.

Data analysis

Species distribution models (SDMs) has been used to find potentially suitable habitat for the animals (Kuemmerle et al. 2011, Naundrup and Svenning 2015); among

them, the Maximum Entropy Model (MaxEnt) has recently become increasingly popular for such a purpose (Nüchel et al., 2018; Liu et al., 2019). We used this model to identify monkeys' suitability habitats in the Qinling from the 1980s to 2020s. We conducted a subsampling procedure with ten replicates (Khatchikian, 2011). We used 75% of the data as the training set for model construction and 25% as the random test set for model performance.

We also utilized the area under the receiver operating characteristic curve (AUC) to evaluate model validity and accuracy, ranging from 0.0 to 1.0. The larger the value, the more accurate the model (Zhang et al., 2019). We categorized the habitats into three levels: high-suitable, moderate-suitable, and unsuitable (Liu et al., 2022).

Based on the suitable habitat levels, we compared suitable habitat changes during the period to identify the increased or reduced distribution areas, both horizontally and vertically.

We also calculated habitat centroids of the monkeys in different periods – the 1980s, the 1990s, and the 2010s, including 2020-2021, to work out their drifting directions from period to period with a SDM toolbox. The least-cost path tool (SDM toolbox, version 2.5) was used to identify their existing and potential migration corridors in the Qinling.

Supplementary Results

1. Geographical distribution changes of the golden monkey

The newly reported monkeys' locations started in 2017, including Taibai, Zhouzhi, Foping, Yangxian, and Ningshan. Another six populations in Meixian, Huyi, Liuba, Fengxian, and Weibin were found in our survey.

2. MaxEnt model

2.1 Habitat suitability for the model

AUC value of the MaxEnt model from 1979 to 2021 is 0.922, indicating that the model can ideally model the relationship between monkeys' distribution patterns, environmental variables, and human steps.

2.2 Suitable habitat change

The suitable area in the 1980s was 30,080 km², which was expanded in some regions (466.69km²) but contracted in others (8,844.75km²). Thus, by 2021, the total suitable area was 21,701.68 km²

2.3 Centroid changes

In the 1980s, the monkeys' suitable habitat center was located in an area linking Zhouzhi and Ningshan (108.10E, 33.72N). It drifted 1.34km toward the northwest in the 1990s (108.09E, 33.73N), which further moved another 14.8km, reaching the border between Zhouzhi and Foping in 2000 (107.94E, 33.75N). Thus, from the 1980s to the present, the centroid of the golden snub-nosed monkeys moved toward the west, 15.56 km. Such a centroid is now in Zhouzhi county, near the border between Zhouzhi and Foping (107.94E, 33.75N), only a shifting of 0.3km southeast compared with the previous period.

2.4 Migration corridors.

With the application of the least-cost path tool, we generated the two migration

corridors.

2.5 Vertical habitat changes

In addition to horizontal movement, monkeys' habitats also changed vertically. During the 1980s, the average elevation was $1867.55 \pm 265.84\text{m}$, which was reduced to $1834.03 \pm 249.27\text{m}$ in the 2010s, then to $1805.12 \pm 245.25\text{m}$ in the 2020s. Such a reduction reached a significant level (Kruskal-Wallis test, $\chi^2=218.93$, $df=2$, $p<0.001$).

2.6 Variables playing a significant role in shaping habitat changes

According to the permutation importance test, the variables contributing to shaping monkeys' habitats are illustrated in Fig. 6. Among the nine, the following three were identified to have played significant roles: elevation (47.9%), Habitat tree type (14.3%), Road distance (10.6%), and Human footprint (8.3%)

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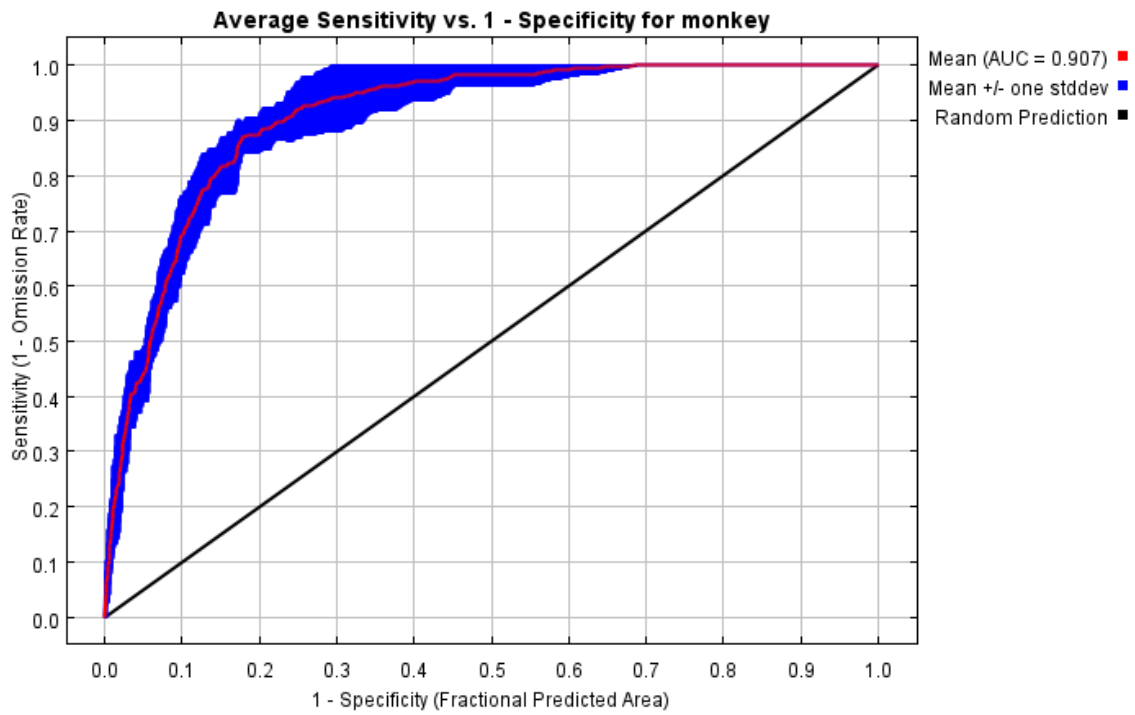
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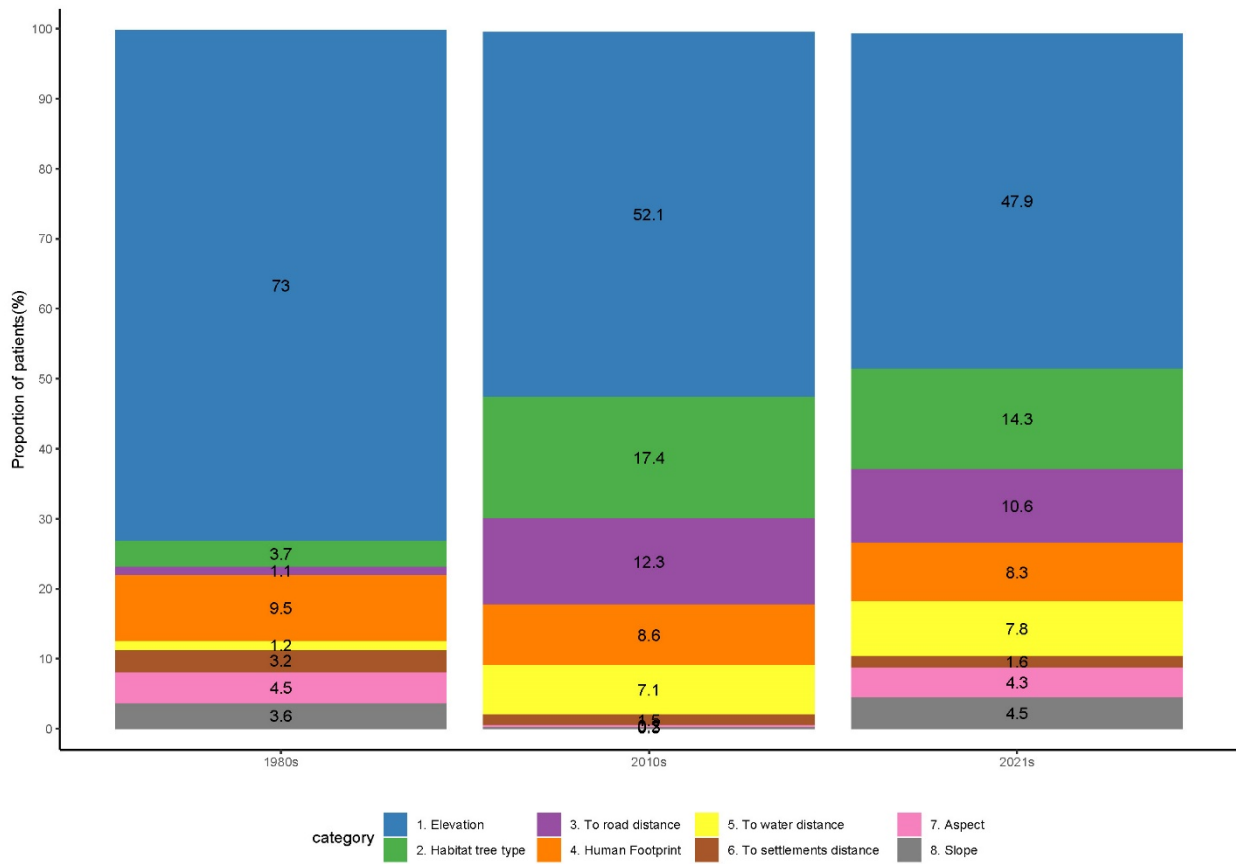
Supplementary Table S1 Road construction in the Qingling since 1958 and a significant increase over the last 20 years.

Types	Built time	From	To	Length within Qinling
Railway	1958	Baoji	Chengdu	346.7 Km
Railway	2001	Xi'an	Ankang	259 Km
Railway	2007	Xi'an	Nanjing	12.268 km
Highway	2009	Xi'an	Ankang	58.261Km
Highway	2007	Xi'an	Hanzhong	258.65 Km
Express railway	2017	Xi'an	Chengdu	135 Km
Logging road	1960- 1999	Low elevation	High elevation	1940 Km

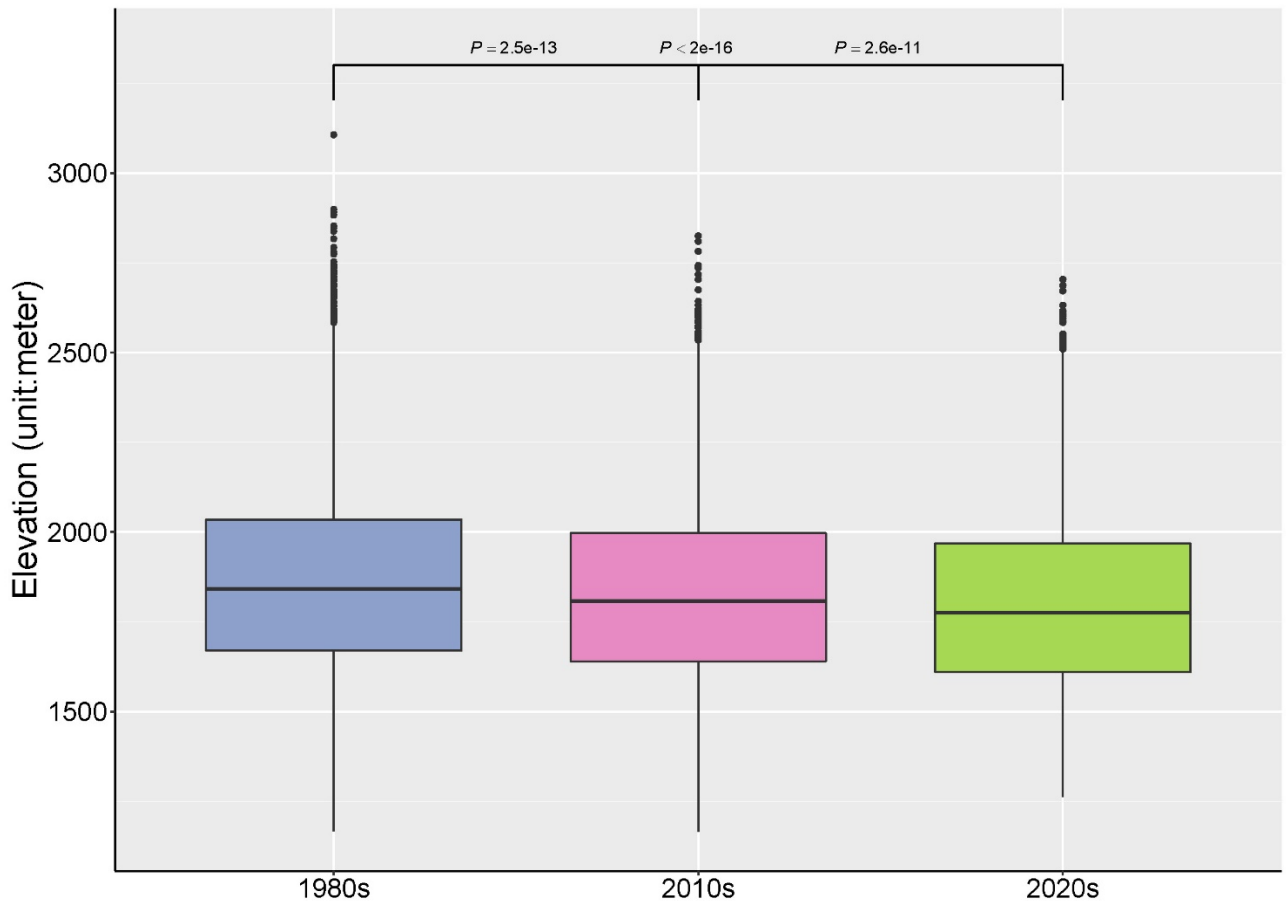
Data from Ding, 2014.



Supplementary Figure S1 The results of receiver operating characteristic (ROC) curve verification in MaxEnt model



Supplementary Figure S2 Contribution percentage of the environmental variables to the MaxEnt model.



Supplementary Figure S3 The average habitat elevations of the golden snub-nosed monkeys in different periods.