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Letter to the editor Open Access

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

DEAR EDITOR,

Combining location data, species distribution modeling (MaxEnt), and major conservation events, we analyzed historical distribution changes in golden snub-nosed monkeys (*Rhinopithecus roxellana*) in the Qinling Mountains of China. Our results indicated that the monkeys have changed their distribution in response to implemented conservation programs, including afforestation, reforestation, farmland to field conversion, and, most importantly, removal of residents from nature reserves. Based on these findings, we propose a conservation strategy to enhance these results to effectively protect this species and other animals in the Qinling Mountains, a global biodiversity hot spot.

Despite its considerable diversity of fauna and flora, China faces unprecedented conservation pressures due to significant environmental devastation during the second half of the last century (Pan et al., 2016). Of particular concern, among the 27 existing species of nonhuman primates in China, 80% are currently listed as threatened and more than half have populations containing fewer than 3 000 individuals (Li et al., 2018).

In acknowledgment of the serious and urgent need for better environmental protection, the Chinese Government has undertaken important measures and key projects to mitigate these issues. Firstly, six Key Forestry Projects have been initiated since 1998, including the conservation and protection of forests, especially primary forests, accounting for 60% of China's total forested area (Zhao et al., 2021), and the banning of natural forest logging for commercial purposes in certain biodiversity hot spots (Zhao et al., 2021). Secondly, the 'returning farmland to the field' project was implemented in 2000, resulting in the formation of 167 new nature reserves, bringing the total number of reserves in China to 1 156, covering some 16 million hectares and accounting for 12.09% of China's land area. Thirdly, the Chinese Government has also carried out a unique ecological emigration project since 2012. For example, in Shaanxi Province, more than 10 million people have been relocated from ecologically fragile but biologically diverse areas to lessen the impact of human activities on the environment These encouraging conservation advancements in China have aroused considerable attention from scientists, conservationists, politicians, and the public. Nevertheless, limited research has been conducted on the impact of these programs, policies, and management practices on animal behavior, habitat utilization, geographic distribution, and animal-human relationships. Such studies are critical to assess whether such endeavors have achieved their desired objectives and to provide scientific feedback to inform and enhance future conservation programs.

As a renowned biodiversity hotspot in central China, the Qinling Mountains have been significantly disturbed by human activities but have also benefited from multiple conservation projects implemented by the Chinese government. As a result, the initiatives carried out in the Qinling Mountains have become a model for biodiversity conservation in China. The endangered golden snub-nosed monkey (*Rhinopithecus roxellana*) was first recorded in the region in 1959, with their habitat severely impacted until the beginning of this century. Based on fieldwork conducted from June 2021 to June 2022 and historical data collection, we analyzed the dynamic geographic distribution of this species over the past 60 years as well as the relationships between their historical distribution and human activities and conservation strategies. Our findings should offer valuable scientific feedback and insights to inform and improve future conservation programs.

To determine the changes in geographic distribution and key variables affecting survival of the monkey population in different periods in the Qinling Mountains, we use the MaxEnt model to reconstruct suitable habitats within the study area. To obtain the necessary data for the model, we conducted a comprehensive literature review and field survey. The literature data included distribution records of the golden snub-nosed monkey from 1959 to 2021. The field survey was conducted from June 2021 to June 2022 to verify previous reports and locate new monkey populations. Because the location data were obtained from multiple impromptu surveys in different periods, we filtered original locations within one km^2 and classified them into three different time periods, i.e.,

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1980s (82 locations), 2010s (94 locations), and 2020s (176 locations). Environmental variables were divided into three categories, i.e., vegetation types, topographic structures, and human activities. We obtained these variables from official websites and converted the data into the form required by the model (Supplementary Materials).

Prior to the 21st century, golden snub-nosed monkeys in the Qinling Mountains were primarily distributed in five counties, including Zhouzhi, Taibai, Ningshan, Foping, and Yangxian (Li et al., 2001) (Figure 1A). Over time, however, their geographic distribution underwent a significant reduction, decreasing from 30 080 km^2 in the 1980s to 21 414 km^2 in the 1990s, resulting in a loss of 8 666 km^2 of habitat (Figure 1B). This decline was likely due to specific socioeconomic and agricultural activities, including extensive commercial logging, farming, and human migration into conservation areas (Li et al., 2002). Of note, commencing in the 1960s, the Shaanxi Government established six state forest bureaus that engaged in commercial logging of approximately 4 000 km^2 over nine counties, including natural primary forest habitats of the monkeys and other animals (Li et al., 2001). Furthermore, by the end of 1997, about 1 940 km of roads had been built for the logging industry, producing nearly 2 5471 000 m^3 of timber. As a result, large-scale forest destruction and severe habitat loss occurred, forcing many monkey populations to move to higher elevations.

This concerning decline began to reverse by the end of 1999, with gradual increases in habitat in the 2010s, reaching 21 701.68 km^2 by 2021 (Figure 1C), as well as the identification of six new populations in Zhashui, Huyi, Meixian, Liuba, Fengxian, and Weibin. These positive changes have been attributed to conservation projects implemented to mitigate the deteriorating status of animal populations in the Qinling Mountains.

From the 1980s to 2010s, the centroid distribution of the monkeys shifted 14.8 km northwest, followed by a period of relative stability, with a slight 0.3 km shift southeast from the 2010s to 2022, likely due to improved habitat and human relocation out of conservation areas (Figure 1D). This migration pattern is likely influenced by the fewer human activities and more extensive primary forests in Taibai Mountain (highest peak in the Qinling Mountains, 3 767 m a.s.l.).

Increasing intraspecific connectivity is critical for maintaining genetic diversity as well as ecological and habitat biodiversity to promote ecosystem potential (McGuire et al., 2016). As

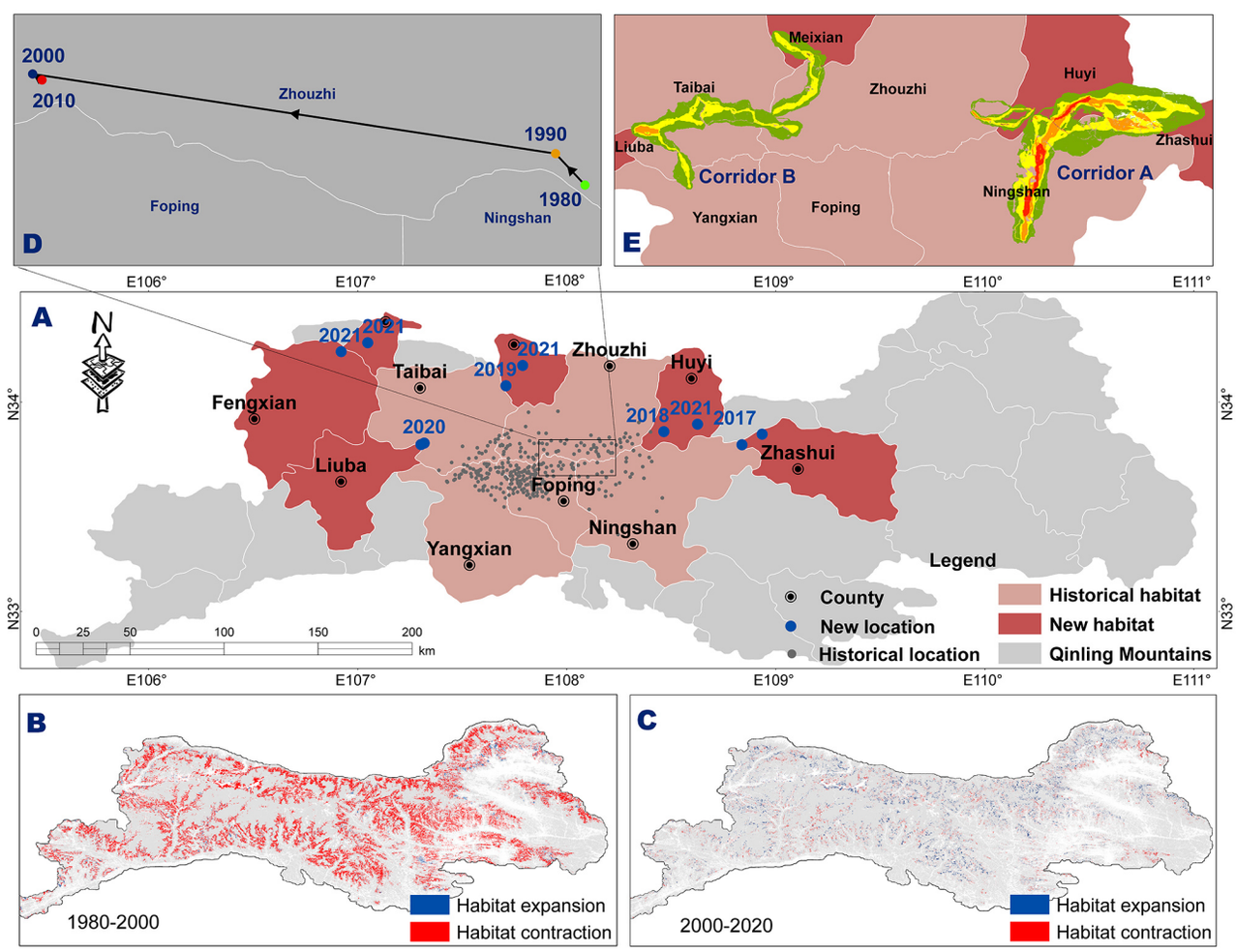

Figure 1 Geographic locations and habitat changes of golden snub-nosed monkeys in the Qinling Mountains, China

A: Current geographic locations and new reported populations in different years. B: Habitat changes from 1980 to 2000. C: Habitat changes from 2000 to 2020. Red is contracted area, blue is expanded area, and gray is area without change. D: Drifting centroid trajectory of monkeys from 1980 to 2021. E: Two migration corridors used by golden snub-nosed monkeys in the Qinling Mountains since the 1980s. Colors represent frequency scales.

illustrated in Figure 1E, two major monkey migration corridors were identified, which have shaped the distribution of the new populations and allow two-way movement. The first corridor links the Huyi and Zhashui groups to the Ningshan group (A), while the second corridor links the Meixian and Chencang groups to the Taibai group (B). During migration, the monkeys and other animals need to traverse several major traffic areas (Supplementary Table S1), including the express railway from Xi'an to Chengdu and highway from Xi'an to Hanzhong, which cross corridor A to the south. Based on our observations, monkeys move through the mountains above the tunnels, around the border between Ningshan and Huyi. Corridor B, which runs along Taibai Mountain, is crucial for monkey dispersal and is associated with less human activity, more primary vegetation, and more extensive forests.

Our findings further indicated that elevation (47.9%), tree type in habitats (14.3%), road infrastructure (10.6%), and human footprint (8.3%) were significant variables influencing monkey behavior and selection of habitat type, dispersal direction, migration, and future development (Supplementary Figures S1, S2).

Results also showed that mean elevation of the monkey habitat in the Qinling Mountains has declined from 2 000 m (1 400–2 700 m) a.s.l. prior to the 1980s (Li et al., 2002), to 1 867 m a.s.l. in the 1980s, 1 834 m a.s.l. in the 2010s, and 1 805 m a.s.l. at present (Supplementary Figure S3). Based on our field survey, we propose that this change may be attributed to human emigration out of conservation areas and the conversion of farmland into fields following government-initiated policies, allowing monkeys to extend their habitat to areas previously occupied by humans.

Deciduous broad-leaved forest, evergreen coniferous forest, and mixed coniferous and broad-leaved forest play essential roles in monkey habitat selection (Guo et al, 2008). Interestingly, our results showed that the contribution of tree type varied over time, from 3.7% in the 1980s, 17.4% in the 2010s, and 14.3% in 2021 (Supplementary Figure S2), with a progressively increasing trend before the 2010s. These findings imply that, following the loss of primary forests due to commercial logging, the monkeys primarily sought habitat that retained broad-leaved forests to ensure basic survival. However, after logging was banned and conservation projects were launched, the monkeys had a greater choice of different tree types and habitats, allowing them to extend their distribution and move to lower elevations. As vegetation recovered, the impact of tree type on monkey distribution was no longer a key constraint in the 2020s.

Road infrastructure is another major factor affecting monkey distribution. Historically, from the middle to the end of the last century, only one railway and logging road existed in the Qinling Mountains. However, the construction of several major railways and highways in the last 20 years has resulted in substantial habitat fragmentation and isolation, markedly influencing monkey migration.

Our results also showed that the human footprint, representing the impact of human activities, has played a critical role in monkey distribution. First, a range of socioeconomic factors led to significant natural resource depletion, land conversion, and deforestation in the Qinling Mountains. Notably, commercial logging activities (from 1960 to 1999) and depletion of primary forests forced the monkeys to migrate to higher elevations. Second, increased deforestation and agricultural development following an increase in human population density occurred in the Qinling Mountains, with the expansion of cultivated lands up to 2 000 m a.s.l. again forcing monkeys to move to higher elevations. Third, the implementation of environmental protection and conservation endeavors, such as the banning of logging and return of farmland to wild fields, allowed monkeys to utilize areas once occupied by local people, thereby significantly changing their distribution.

Our results also indicated that in the case of recovering habitats, the conservation strategies for monkeys should shift from habitat protection to the strengthening of dispersal pathways and migration corridors. In addition to golden snub-nosed monkeys, other mammals, such as takins (*Budorcas taxicolor*), giant pandas (*Ailuropoda melanoleuca*), carnivorans, and artiodactyls, also use corridors (Wang et al., 2021). Therefore, it is essential to implement appropriate management strategies to maintain the corridors identified in this study. Furthermore, tunnels for human traffic could be constructed at elevations between 1 700 m and 2 000 m a.s.l., allowing traffic to pass through the mountain without impacting surface habitats. Vegetation restoration along the corridors should also be promoted to link fragmented areas, thus providing more extensive coverage to monkeys and other animals during their movements.

Finally, while species distribution models can effectively simulate the status of habitats, they cannot accurately simulate the size and distribution range for each population based solely on location data. Therefore, our next step will involve distinguishing between populations and specific external factors according to variations in population dynamics.

SCIENTIFIC FIELD SURVEY PERMISSION INFORMATION

Permission for field survey in the Qinling Mountains was granted by the Shaanxi Forestry Bureau.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

The idea for this study originally came from B.G.L., R.L.P., and C.L.W. Field data were collected by G.H., L.C., X.D.Y, T.W., W.L, H.T.Z., and H.Z. Historical distribution data were collected by Y.R., W.W.F., Y.W., and X.W.W. Statistical analyses were performed by C.L.W. The manuscript was prepared by C.L.W. and W.F.W. with edits and additional suggestions for data analysis and interpretation provided by B.G.L. and R.L.P. The project and all guidance were coordinated by W.F.W. All authors read and approved the final version of the manuscript.

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