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Letter to the editor Open Access

Climate change challenge, extinction risk, and successful conservation experiences for a threatened primate species in China: Golden snub-nosed monkey (*Rhinopithecus roxellana*)

DEAR EDITOR,

Despite the vulnerability of primates to the negative impacts of human activities and climate change, there is still room for optimism. Notably, years of conservation efforts may have paid off for the golden snub-nosed monkey (*Rhinopithecus roxellana*). Our field surveys confirmed the existence of 188 to 220 wild multilevel societies (MLS) of *R. roxellana*, with an estimated 22 710 to 26 130 individuals in 2019, as well as a 3.5% increase in potential available habitat from 1992 to 2018. Thus, golden snub-nosed monkeys appear to have escaped the primary drivers (poaching and deforestation) that nearly led to their extinction, suggesting it may be possible to change their extinction risk from endangered to vulnerable. However, several new threats, especially global warming, will increase uncertainty about downgrading their conservation status. According to the species distribution model, the current total area of suitable habitat available for the three golden snub-nosed monkey subpopulations is 22906.48 km^2. Unfortunately, golden snub-nosed monkeys may experience range contractions in the future (2070s), with up to 24.81% of currently suitable habitat lost under the most severe climate scenario. These findings highlight the importance of nation-wide environmental planning and sustainable development for the conservation of *R. roxellana* and its habitat. Continuous conservation efforts and investment remain essential to protect this species from the threats of climate change.

As an endemic primate in China, golden snub-nosed monkeys are found in montane forests, where snow cover can last up to six months a year (Zhang et al., 2016) and seasonal food shortages necessitate a wide habitat range (Xiang, 2020). Due to the long-term effects of habitat fragmentation caused by climate change, human population growth, agricultural expansion, and extensive deforestation over the past 400 years (Li et al., 2007), the distribution of this species has contracted to three isolated mountainous regions in central and west-central China: i.e., Shennongjia (SNJ), Qinling (QL), and Sichuan/Gansu (SG) from east to west (Liu et al., 2015). The latest IUCN Red List reported a total wild golden snub-nosed monkey population of 16 470 to 16 500 (Long & Richardson, 2020). However, these data were based on a series of surveys conducted approximately 20 years ago, which differed dramatically in their population estimates. No recent range-wide surveys of this species have been conducted. As a result, the basic information required to assess extinction risk, such as distribution and population size, is outdated. Thus, in the current study, we examined the entire population of golden snub-nosed monkeys across China utilizing field surveys and local interviews. First, we interviewed nature reserve staff and surrounding villagers to collect information on the distribution history of the monkey population, including year, season, and location/coordinates of observed golden snub-nosed monkey MLSs or monkey traces, and the approximate number of individuals and one-male units (if known). We combined these data to map the general distribution of golden snub-nosed monkey populations and identify sites for field investigation. Second, we recruited experienced nature reserve staff and local farmers as field guides and surveyed all investigation sites identified in Step 1. At the same time each day, research teams selected adjacent

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areas for sampling and followed a "V" route (going down a ridge into a valley and ascending again or vice versa). The teams moved quietly and stopped every 300–500 m to conduct a 10 min observation session, including listening for monkey vocalizations and looking for signs of monkey activity, e.g., feces, hair, broken branches, and partially consumed fruit or lichen. If a golden snub-nosed monkey MLS was discovered, we used walkie-talkies to coordinate with other group members and approach and track the MLS from several different directions. Once an MLS was discovered, we documented the time, number of individuals, location coordinates, altitude, and habitat category of the observed monkeys. If we were unable to count all individuals in a band, we estimated size based on the number of observed adult males. We also used thermal imaging drones to survey the monkey population and distribution in the Qinling Mountains (but not at the other sites). However, thermal imaging underestimated the number of individuals compared to the ground surveys, with a detection rate of only 60%–70% (He et al., 2020).

Based on our field surveys, we identified 188 to 220 wild MLSs in 2019, with an estimated population size of 22 710 to 26 130 individuals. Specifically, there were an estimated 114–146 MLSs in the SG subpopulation, containing 15 880 to 18 190 individuals; an estimated 62 MLSs in the QL subpopulation, containing 5 240–5 760 individuals; and an estimated 12 MLSs in the SNJ subpopulation, containing only 1 590–2 180 individuals (Supplementary Tables S1, S2). Approximately 95% of the wild golden snub-nosed monkeys were found in 47 nature reserves, 28 of which were national natural reserves. Total area of the nature reserves was 20 744.93 km^2, which has doubled since the Chinese government accelerated the establishment of nature reserves in 1990 (Figure 1B; Supplementary Table S3).

Golden snub-nosed monkeys are only found in highland forests between 1 300 and 3 500 m a.s.l. (Quan & Xie, 2002). As forest is the only suitable land cover type for this species, we used a model that included elevation and forest cover to quantify changes in available golden snub-nosed monkey habitat across time. We used a digital elevation model (DEM) to obtain elevation data (resolution of 90 m/pixel). For forest cover, we used a land-cover dataset with a spatial resolution of 300 m/pixel and yearly entries from 1992 to 2018 retrieved from the European Space Agency (https://www.esa-landcover-cci.org). Our results suggested that available habitat increased by 3.5% from 1992 to 2018, with significantly more pixels for habitat gain (23 257/480 050) than habitat loss (7 949/456 793) (Z-test, Z=83.702, P<0.001). This gain occurred despite the Wenchuan earthquake (magnitude 8.0) in 2008, which caused considerable landslides and the loss of 980 km^2 of forest in Sichuan Province (Stone, 2009) (Figure 1C, D).

Using the updated population and geographic information from our study, we reassessed the extinction risk of *R. roxellana* using Criteria v3.1 based on IUCN Red List A2 (population reduction over a period of 10 years or three generations), B1 (extent of occurrence (EOO)), and B2 criteria (area of occupancy (AOO)) (IUCN, 2012). Using minimum convex polygons (MCPs) to enclose each location where monkeys were found in our field survey, we determined the current EOO of each subpopulation: i.e., *R. roxellana*, *R. r. qinlingensis*, and *R. r. hubeiensis*. The AOO was scaled using a 2×2 km grid (i.e., cells with an area of 4 km^2) and computed to ensure effective usage of the criteria and maintain consistency in Red List assessments as follows:

$$\mathrm{AOO} = \text{No. occupied cells} \times \text{area of an individual cell} \quad (1)$$

Comparing this work with previous surveys (Supplementary Table S2), the total population size of *R. roxellana* appears to have increased markedly (51.4%–75.4%, compared with a survey in 1998) over the past 20 years. Notably, the EOO was estimated at 55 355.93 km^2 (Figure 1A) and the AOO was estimated at 752.00–880.00 km^2, neither of which meet the current IUCN criteria for endangered species. According to the Guidelines for Using the IUCN Red List Categories and Criteria, if a taxon does not meet any of the criteria for the higher threat category for five years or more, it may be moved from the higher threat category to the lower threat category (IUCN Standards and Petitions Committee, 2019). As such, we recommend that the conservation status of *R. roxellana* (at the global level) should be cautiously reassessed and possibly downgraded from endangered to vulnerable based on the IUCN criteria. Because it is not possible to identify the year in which this species may have qualified as vulnerable, we suggest that the current assessment year serves as the start of the 5-year period. However, as the golden snub-nosed monkey is a flagship species in China, we suggest that it retains its status as a first-class protected species in China so that it can continue to promote ecosystem health and conservation.

At the regional level, the three isolated subpopulations are at different degrees of risk and should therefore be classified under different IUCN Red List categories. Specifically, the SG subpopulation should be classified as vulnerable based on IUCN Red List criteria B2ab (i.e., AOO estimated to be less than 2 000 km^2, and severely fragmented, and continuing decline, observed, inferred, or projected in area, extent, and/or quality of habitat). The QL subpopulation should be classified as endangered based on IUCN Red List criteria B1ab (i.e., EOO estimated to be less than 5 000 km^2, severely fragmented, and continuing decline, observed, inferred, or projected in area, extent, and/or quality of habitat) and B2ab (i.e., AOO estimated to be less than 500 km^2, severely fragmented, and continuing decline, observed, inferred, or projected in area, extent, and/or quality of habitat). The SNJ subpopulation should be classified as endangered based on IUCN Red List criteria B1ab and B2ab (IUCN, 2012) (Supplementary Table S1).

We further evaluated the area of suitable habitat currently available and that expected in the future (2070s) to explore the potential impact of climate change on *R. roxellana*. The species distribution model for the golden snub-nosed monkey was created using MaxEnt software (v3.4.1). A total of 179 occurrence points and 11 climatic and other environmental variables (details in Supplementary Text and Table S4) were used as parameters in the monkey distribution models. Both climatic and environmental factors influenced the distribution of the golden snub-nosed monkeys. In general, elevation

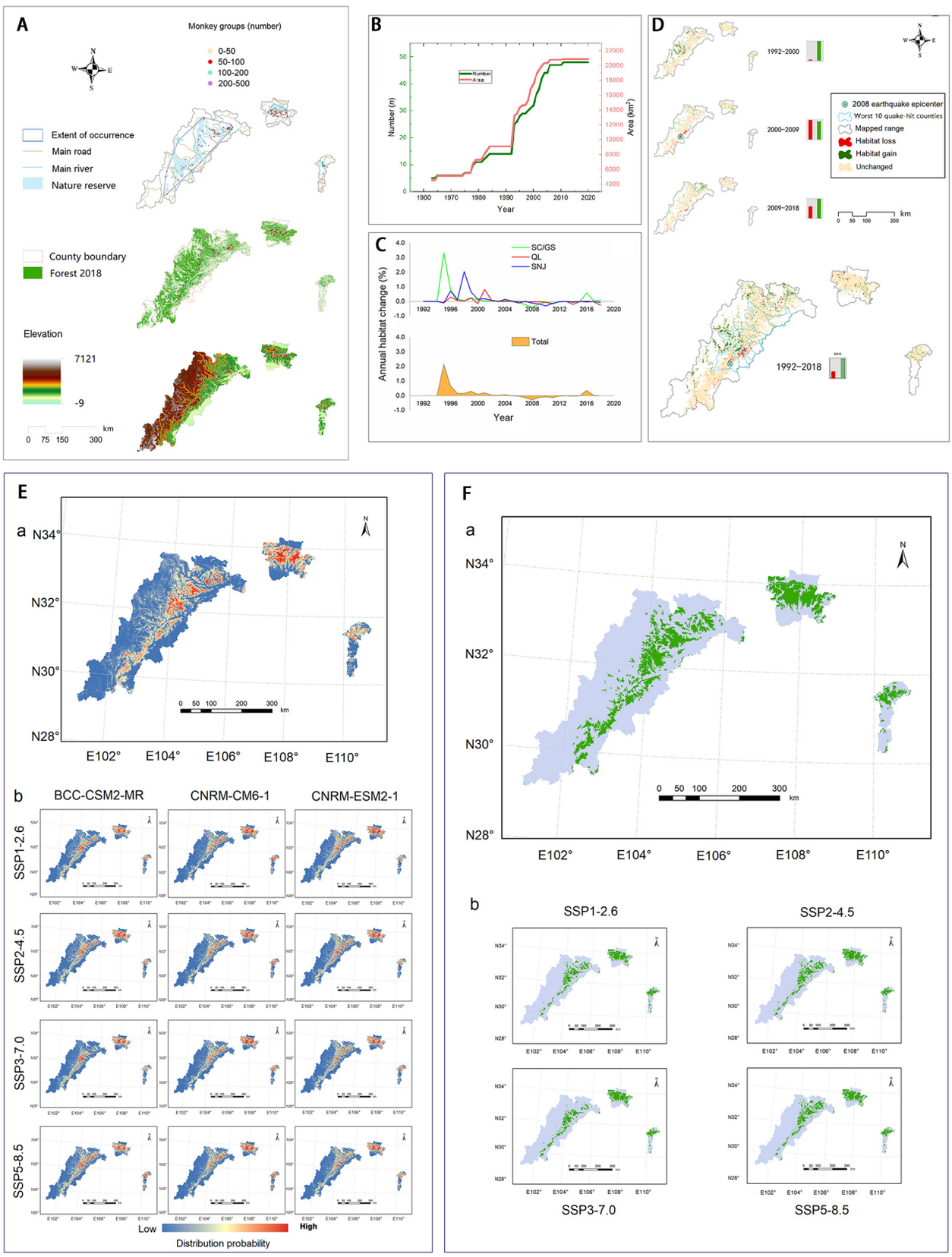
A
Monkey groups (number)
0-50
50-100
100-200
200-500
Extent of occurrence
Main road
Main river
Nature reserve
County boundary
Forest 2018
Elevation
7121
-9
km
0 75 150 300
B
Number
Area
Number (n)
Area (km²)
Year
C
SC/GS
QL
SNJ
Total
Annual habitat change (%)
Year
D
1992–2000
2000–2009
2009–2018
1992–2018
2008 earthquake epicenter
Worst 10 quake-hit counties
Mapped range
Habitat loss
Habitat gain
Unchanged
km
E
a
N34°
N32°
N30°
N28°
E102°
E104°
E106°
E108°
E110°
0 50 100 200 300 km
b
BCC-CSM2-MR
CNRM-CM6-1
CNRM-ESM2-1
SSP1-2.6
SSP2-4.5
SSP3-7.0
SSP5-8.5
Low
High
Distribution probability
F
a
N34°
N32°
N30°
N28°
E102°
E104°
E106°
E108°
E110°
0 50 100 200 300 km
b
SSP1-2.6
SSP2-4.5
SSP3-7.0
SSP5-8.5

Figure 1 Study area, population, habitat, and protected status of golden snub-nosed monkeys

A: Occurrence and size of each golden snub-nosed monkey MLS across its current geographic distribution range in China, including spatial relationships with isolating factors (main rivers, human settlements, and roads), nature reserves, forest cover, and topography. Extent of occurrence (EOO) was delineated for each golden snub-nosed monkey subpopulation (*R. r. roxellana, R. r. qinlingensis, R. r. hubeiensis*). B: Temporal trend in establishment of nature reserves with distribution of golden snub-nosed monkeys. C: Annual changes (change in % from previous year) in potential golden snub-nosed monkey habitat between 1992 and 2018. D: Changes in pixels in potential golden snub-nosed monkey habitat between 1992 and 2018. SC/GS, Sichuan/Gansu; QL, Qinling; SNJ, Shennongjia. E: Current (a) and future (b) distribution probabilities of golden snub-nosed monkeys (*Rhinopithecus roxellana*). F: Predicted suitable habitat of Sichuan golden monkeys (three subpopulations: *R. r. roxellana, qinlingensis, and hubeiensis*) under current and future climate scenarios. Future distributions are the intersection area of three GCMs (BCC-CSM1-1, CNRM-CM6-1, and CNRM-ESM2-1).

(Ele), distance to nearest main road (dis_road), density of forest (den_forest), precipitation seasonality (bio15), distance to nearest human settlement (dis_settle), and annual precipitation (bio12) accounted for 92.6% of the variance (Supplementary Table S5 and Figure S1). The predicted presence of golden snub-nosed monkey habitat under current and future climate scenarios is presented in Figure 1E. Based on model output, the habitat suitability index (HSI) ranged from 0 (least suitable) to 1 (most suitable). We classified pixels with probability values greater than 0.3021 (average threshold value for the probability of presence when sensitivity and specificity are equal) as suitable habitat for the monkeys (Li et al., 2018). According to our MaxEnt model, the total area of suitable habitat currently available for the three subpopulations was 22 906.48 km^2. To capture possible changes in future climate scenarios, we used the same bioclimatic variables from three general circulation models (GCMs), i.e., BCC-CSM1-1, CNRM-CM6-1, and CNRM-ESM2-1, to predict future species distributions (average for 2 061–2 080, hereafter referred to as the 2070s) (Eyring et al., 2016). For each GCM, we used four shared socioeconomic pathway (SSP) scenarios (i.e., SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) to represent the most optimistic and most pessimistic emission scenarios driven by different socioeconomic assumptions (Meinshausen et al., 2020). Results indicated that the golden snub-nosed monkeys are predicted to experience range contractions in the 2070s, with suitable available habitat predicted to decrease by 23.69%, 13.94%, 24.81%, and 14.73% under the SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 emission scenarios, respectively (Figure 1F).

In conclusion, our findings suggest that the conservation status of *R. roxellana* should be reclassified as vulnerable at the species level, but under a higher threat at the subpopulation level. Overall, the golden snub-nosed monkey population is showing signs of recovery, primarily due to the establishment of nature reserves and restoration of habitat following the implementation of China's many environmental protection policies and sustainable development strategies (Supplementary Figure S3). Years of conservation efforts by the Chinese government, including the enactment of strict habitat protection laws, creation of national nature reserves, and prohibition on hunting, have greatly benefited this iconic species. National environmental planning and targeted strategic conservation have helped prevent habitat loss and improve the trajectory of the monkey population. Thus, China's efforts offer hope for wildlife conservation if countries and their citizens commit to similar efforts in creating and strictly enforcing protected areas, funding scientific research, and implementing a comprehensive program of landscape restoration. However, our study also highlights the challenge of climate change, which may cause a substantial decline in suitable golden snub-nosed monkey habitat in the future. Sustained conservation efforts and investment are essential to ensure that climate change does not threaten the survival of this species. Working together, we can change the course of conservation history, although there is still a long way to go.

SCIENTIFIC FIELD SURVEY PERMISSION INFORMATION

Before conducting surveys, we obtained approval from the State Forestry and Grassland Administration and Ministry of Ecology and Environment of China, all nature reserves, and the Institutional Animal Care and Use Committee of the Institute of Zoology, Chinese Academy of Sciences. All data collected were purely observational.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

M.L., Z.F.X., and B.G.L. designed the project. Y.Y., D.Y.L., G.H., and X.C.L. conducted field work. Y.Y., D.Y.L., and G.H. compiled the data and conducted the analyses. X.M.Z., C.J., and X.C.L. provided help with analysis. Y.Y., M.L., and Z.F.X. wrote the paper. All authors read and approved the final version of the manuscript.

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REFERENCES

Eyring V, Bony S, Meehl GA, Senior CA, Stevens B, Stouffer RJ, et al. 2016. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development*, **9**(5): 1937−1958.

He G, Yang HT, Pan RL, Sun YW, Zheng PB, Wang JH, et al. 2020. Using unmanned aerial vehicles with thermal-image acquisition cameras for animal surveys: a case study on the Sichuan snub-nosed monkey in the Qinling Mountains. *Integrative Zoology*, **15**(1): 79−86.

IUCN. 2012. IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, UK: IUCN. iv + 32pp.

IUCN Standards and Petitions Committee. 2019. Guidelines for Using the IUCN Red List Categories and Criteria. Version 14. Prepared by the Standards and Petitions Committee. http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Li J, Li DQ, Xue YD, Wu B, He XJ, Liu F. 2018. Identifying potential refugia and corridors under climate change: a case study of endangered Sichuan golden monkey (*Rhinopithecus roxellana*) in Qinling Mountains, China. *American Journal of Primatology*, **80**(11): e22929.

Li M, Liu ZJ, Gou JX, Ren BP, Pan RL, Su YJ, et al. 2007. Phylogeography and population structure of the golden monkeys (*Rhinopithecus roxellana*): inferred from mitochondrial DNA sequences. *American Journal of Primatology*, **69**(11): 1195−1209.

Liu ZJ, Liu GJ, Roos C, Wang ZM, Xiang ZF, Zhu PF, et al. 2015. Implications of genetics and current protected areas for conservation of 5 endangered primates in China. *Conservation Biology*, **29**(6): 1508−1517.

Long Y, Richardson M. 2020. *Rhinopithecus roxellana*. The IUCN red list of threatened species 2020: e. T19596A17943886. https://dx. doi.org/10.2305/IUCN.UK.2020-2.RLTS.T19596A17943886.en.

Meinshausen M, Nicholls ZRJ, Lewis J, Gidden MJ, Vogel E, Freund M, et al. 2020. The shared socio-economic pathway (SSP) greenhouse gas concentrations and their extensions to 2500. *Geoscientific Model Development*, **13**(8): 3571−3605.

Quan GQ, Xie JH. 2002. Research on the Golden Monkey. Shanghai: Shanghai Scientific & Technological Education Publishing House. (in Chinese)

Stone R. 2009. A deeply scarred land. *Science*, **324**(5928): 713−714.

Xiang ZF. 2020. A review on the socioecology of snub-nosed monkeys. *Chinese Bulletin of Life Sciences*, **32**(7): 692−703. (in Chinese)

Zhang P, Hu KJ, Yang B, Yang DH. 2016. Snub–nosed monkeys (*Rhinopithecus* spp.): conservation challenges in the face of environmental uncertainty. *Science Bulletin*, **61**(5): 345−348.