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# Correlating habitat suitability with landscape connectivity: A case study of Sichuan golden monkey in China

Fang Liu[a], William J. McShea[b], Diqiang Li[a,*]

[a] Key Laboratory of Forest Ecology and Environment of State Forestry Administration, Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing 100091, China
[b] Smithsonian Conservation Biology Institute, National Zoological Park, Front Royal, VA 22630, United States

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ABSTRACT

We examined the landscape suitability of the region currently occupied by the Sichuan golden money (Rhinopithecus roxellana) using occupancy models constructed in Maxent with presence-only data and environmental variables. The aim of the study was to estimate potential dispersal corridors between presently disjunct populations. Least-cost path analysis was used to estimate its dispersal paths across the fragmented landscape. The results indicate that core areas of suitable habitat are located in the Qinling, Dabashan, and Minshan Mountains, as well as small patches in the Qionglai, Daxiangling and Liangshan Mountains; the most suitable habitats are in nature reserves of the Minshan Mountain. Elevation and density of the human settlements were the most important factors for identifying suitable habitat; and we identified location of less populated areas where some suitable forest patches offer the potential for dispersal corridors for this species. The study implies that there is potential for expansion of the species distribution, if steps are taken to preserve current forest patches that maybe too small for residency but suitable for dispersal.



## 1. Introduction

Habitat loss and fragmentation are among the major threats to many endangered species (Kruess and Tscharntke, 1994; Krauss et al., 2010). One way to slow the decline of species' populations, is to accurately map their current geographic distributions and identify potential suitable habitat for their expansion (Wisz et al., 2008; Franklin, 2010; McShea 2014). Thus, it is necessary to construct their distribution models based on the relationship between a species' occurrence and environmental attributes, while complete survey data are lacking (Saatchi et al., 2008; Wisz et al., 2008; Elith and Leathwick, 2009). Species' distribution models (SDMs), therefore, have been increasingly used for alternative purposes (MacKenzie, 2005; Elith et al., 2006; Jiménez-Valverde et al., 2008), such as designing reserves and corridors (Cabeza et al., 2004; Carranza et al., 2012; Wang et al., 2014), predicting the impacts of climate change on species (Pearson and Dawson, 2003; Perry et al., 2005; Austin and Van Niel, 2011), and assessing the spread of invasive species (Václavík and Meentemeyer, 2009; Costa et al., 2015).

The occurrence records used for SDMs include presence-absence and presence-only data (Brotons et al., 2004), but it is more difficult to confirm the absence than the presence of a species (Hirzel et al., 2002; Brotons et al., 2004; MacKenzie, 2005), thus, the application of SDMs based on presence-only data are burgeoning in recent years (Phillips et al., 2009; Elith et al., 2011; Fernández and Nakamura, 2015). Amid the new techniques, Maxent is the most commonly used in predicting species distributions (Elith et al., 2006; Hernandez et al., 2006; Wisz et al., 2008; Warren and Seifert, 2011). With the principle of maximum entropy, Maxent seeks the relationship between presence-only data and related environmental variables to estimate species' niche and their potential geographic distribution (Phillips et al., 2006; Elith et al., 2011).

Habitat suitability maps created by SDMs estimate the probability for a species using each landscape unit (Boyce et al., 2002; Wang et al., 2008), thus, they provide a base for evaluating landscape connectivity (Binzenhöfer et al., 2005; Wang et al., 2008). Least-cost path (LCP) analysis is one of the means assessing landscape connectivity (Verbeylen et al., 2003; Pullinger and Johnson, 2010) that combines animal location data and a friction map to determine the most likely path for animal movement (Ray, 2005). A friction map (i.e., cost layer) can be generated by weighting the landscape components (Adriaensen et al., 2003) based on expert-opinion, data-based SDMs, or experiments (Stevens et al., 2006;

* Corresponding author.
*E-mail address:* lidq@caf.ac.cn (D. Li).

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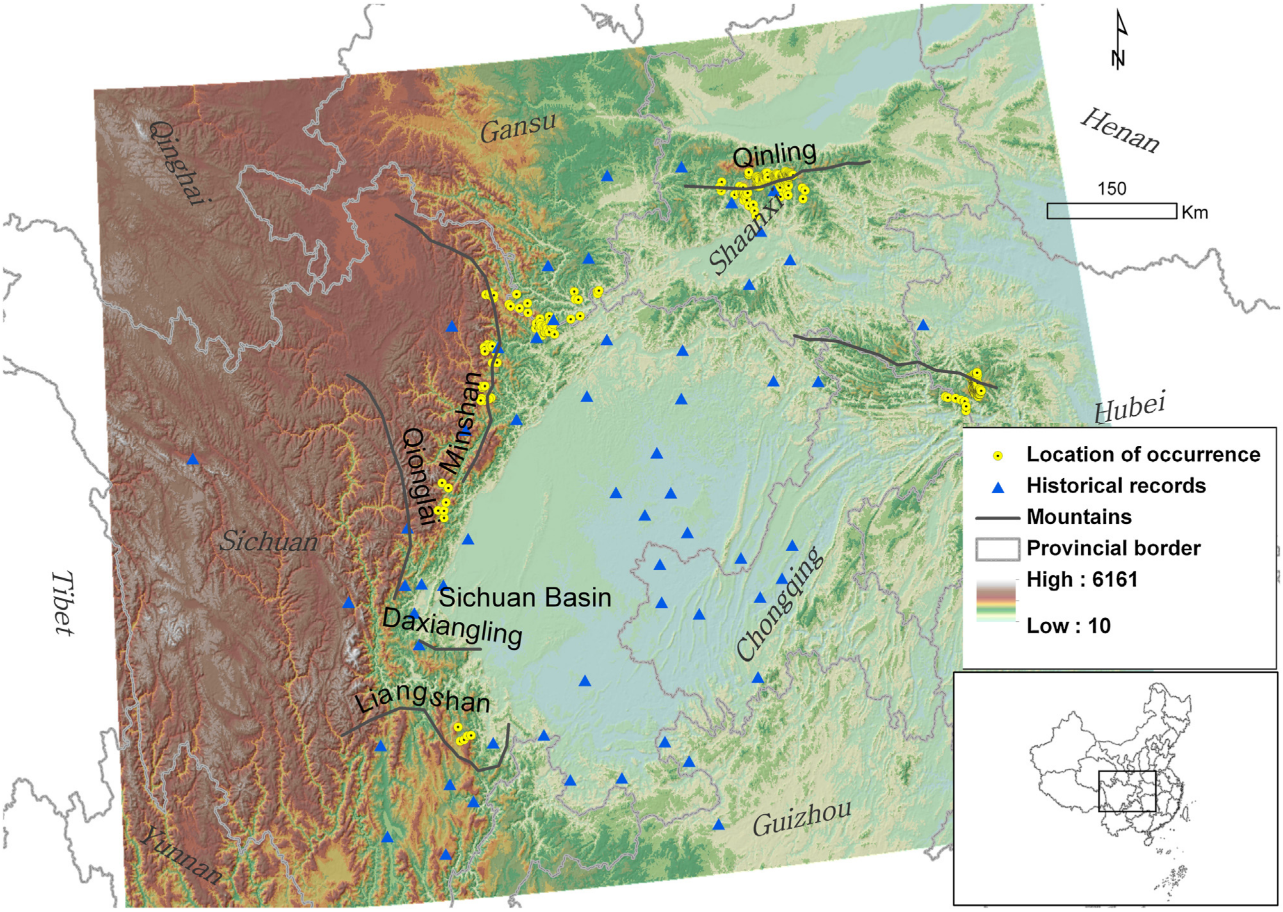


**Fig. 1.** Study area of the Sichuan golden monkey is indicated by yellow circles. Sichuan Basin characterized with lower elevation and large human population is located in the center of the study area, and surrounded by mountains (locations are shown by grey lines with names above them). It still contains the habitat adapted by the species. Historical records of its geographic distribution from 1616 to 1949 are obtained from Li et al. (2002). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Epps et al., 2007). By using a habitat suitability index obtained by SDMs (Binzenhöfer et al., 2005; Hirzel et al., 2006), a distribution map can be created by setting a cutoff value for the probability of presence, and habitat patches codified as "present" can be source data for LCP analysis (Wang et al., 2008).

The Sichuan golden monkey (*Rhinopithecus roxellana*) is one of the endemic primate species in China, which was once widely distributed in south, southwest, central, and northwest China (Li et al., 2002). However, its current distribution range has been compressed to mountainous areas in Sichuan, Hubei, Shaanxi, Gansu, and Chongqing provinces (Li et al., 2002; Quan and Xie, 2002; Fig. 1). In other words, it had been suffered a dramatic reduction in the last 400 years following a series of human-induced social and environmental alternations, such as habitat fragmentation, accelerated deforestation, and hunting (Quan and Xie, 2002; Li et al., 2003; Long and Richardson, 2008).

The species is found in evergreen broadleaf, mixed broadleaf, coniferous forest, and coniferous forests at the elevation of 1200–3500 m (Hu et al., 1980; Su et al., 1998; Gao, 2004). Although there have been several distribution maps for the species (Quan and Xie, 2002; Li et al., 2003), they are at a coarse scale (county level) without analysis of suitable habitats covering the whole distribution range. In addition, a quantitative analysis of its habitat connectivity has not been reported although its habitat is assumed to be deteriorating (Quan and Xie, 2002; Li et al., 2003; Gao, 2004).

Thus, it is criticial to further understand a species' geographic distribution, particularly its fragmentation and habitat connectivity, the two important components impacting its survival and potential development, and appropriately design the conservation strategies and policies of the species. Therefore, the main purpose of this study is to apply Maxent modeling and least-cost path analysis in order to: (1) predict the potential distribution of the golden monkey at a fine spatial scale; (2) assess the attributes of its fragmentated habitats; (3) identify the least-cost path for its movement within each mountain landscape and migration corridors between habitats; and (4) identify the nature reserves that are suitable for the species, particularly the priority areas that are not currently within the protected area network. Better understanding the distribution range, and the connectivity of habitat in a fragmented landscape, is crucial to design a management strategy for this endangered species.

## 2. Methods

### 2.1. Study area

We limited our study area from the central to the southwestern China, covering the current distribution of the species, including Sichuan, Gansu, Shaanxi, Hubei, and Chongqing provinces (Fig. 1), with elevation range from 10 to over 6000 m. The Sichuan Basin, the center of our study area with surrounding mountains including Liangshan, Daxiangling, Qionglai, Minshan, Dabashan and Qinling mountains (Fig. 1) contains more than 90% of the human population of the province (Sichuan Statistics Dept., 2007), but with lower

**Table 1**
The code and description of environmental variables used in Maxent model to predict the habitat suitability of Sichuan golden monkey.

| Variable code | Description | Unit | Type | Min | Max | Mean | SD |
|---|---|---|---|---|---|---|---|
| Landscape | | | | | | | |
| Alt | Elevation above sea level | m | Continuous | 10 | 6161 | 1909.86 | 1492.56 |
| Climate | | | | | | | |
| Bio1 | Annual mean temperature | °C | Continuous | −12.8 | 20.7 | 10.01 | 6.52 |
| Bio2 | Mean diurnal range (mean of monthly (max temp – min temp)) | °C | Continuous | 5.9 | 16.6 | 10.26 | 2.90 |
| Bio3 | Isothermality | | Continuous | 21 | 50 | 32.58 | 7.85 |
| Bio4 | Temperature seasonality (standard deviation *100) | | Continuous | 4515 | 10343 | 7171.72 | 1075.92 |
| Bio5 | Max temperature of warmest month | °C | Continuous | 1.0 | 35.1 | 24.70 | 6.88 |
| Bio6 | Min temperature of coldest month | °C | Continuous | −31.7 | 6.3 | −6.20 | 8.62 |
| Bio7 | Temperature annual range | °C | Continuous | 23.1 | 41.6 | 30.97 | 3.69 |
| Bio8 | Mean temperature of wettest quarter | °C | Continuous | −4.3 | 28.5 | 17.92 | 6.61 |
| Bio9 | Mean temperature of driest quarter | °C | Continuous | −21.2 | 13.2 | 0.66 | 6.12 |
| Bio10 | Mean temperature of warmest quarter | °C | Continuous | −3.7 | 28.7 | 18.90 | 7.19 |
| Bio11 | Mean temperature of coldest quarter | °C | Continuous | −22.8 | 13.0 | 0.31 | 6.29 |
| Bio12 | Annual precipitation | mm | Continuous | 352 | 1817 | 931.85 | 274.35 |
| Bio13 | Precipitation of wettest month | mm | Continuous | 77 | 458 | 174.92 | 45.60 |
| Bio14 | Precipitation of driest month | mm | Continuous | 0 | 54 | 11.75 | 10.38 |
| Bio15 | Precipitation of seasonality (Coefficient of variation) | | Continuous | 43 | 118 | 77.12 | 15.18 |
| Bio16 | Precipitation of wettest quarter | mm | Continuous | 210 | 1115 | 476.22 | 115.66 |
| Bio17 | Precipitation of driest quarter | mm | Continuous | 1 | 213 | 42.02 | 36.22 |
| Bio18 | Precipitation of warmest quarter | mm | Continuous | 210 | 1081 | 454.61 | 111.03 |
| Bio19 | Precipitation of coldest quarter | mm | Continuous | 1 | 217 | 42.12 | 36.28 |
| Resource | | | | | | | |
| Veg | Vegetation type (categorical) | | Categorical | – | – | – | – |
| -Rvdes | The density of river | m/km$^2$ | Continuous | 0 | 0.47 | 0.16 | 0.08 |
| Disturbance | | | | | | | |
| Setdes | The density of settlements | #/km$^2$ | Continuous | 0 | 1.96 | 0.62 | 0.37 |
| Rddes | The density of road | km/km$^2$ | Continuous | 0 | 1.05 | 0 | −1 |

human density in mountain areas. The study area is characarized with subtropical humidity monsoon, the annual mean temperature is between −5 and 20 °C, and the annual precipitation is 200–1800 mm (estimated from the WorldClim climate data at the 1 km scale; Hijmans et al., 2005). Such environment and vegetation form ideal habitats for the golden monkey (Quan and Xie, 2002; Li et al., 2003).

### 2.2. Species data and predictor variables

Occurrence data for the golden monkey were obtained from published literature, and field observations from the monitoring programs were conducted in several nature reserves. Maps of species distribution show its geographic ranges from 1998 to 2010 (please see Appendix S1). If the geolocation of these data were not available in the text, maps were georeferenced and digitized using ArcGIS 9.0 (ERSI company).

Environment layers (Table 1) were produced according to Hijmans et al. (2005) (also available at http://www.worldclim.org) using data maps of China at the scale of 1:1000 000 (National Geomatics Center of China, data are available at http://atgcc.sbsm.gov.cn). All layers were interpolated into a resolution of 30 arc seconds (approximately 1 km) and projected to an equal area projection (i.e., Asia North Albers Equal Area Conic). They were clipped to the polygon boundary of the study areas with ArcGIS. Nineteen bioclimatic variables and the layers of altitude were obtained from WorldClim database representing various aspects of temperature, precipitation, seasonality (Hijmans et al., 2005) and topography. These data are at the highest spatial resolution currently available from global climate data which have been widely used in generating species distribution models (Rodríguez et al., 2007; Lobo et al., 2010). Layers obtained from 1:1000 000 map of China included vegetation types, river density, roads, and residential sites (2001). We used vegetation and the distribution of rivers to reflect natural resource requirements for the golden monkey, while road distribution profiles and residential settlements served as the surrogates of human disturbance. Although many of these variables are spatially correlated, we retained the entire set in the model in order to increase the predictive ability of the models, as Maxent can account for colinearity between variables (Cumming, 2000; Elith et al., 2011).

### 2.3. Habitat suitability model

Maxent version 3.3 (Phillips et al., 2006; available from http://www.cs.princeton.edu/~schapire/maxent/) was used to species distribution model for the golden monkey.

We filtered the occurrence data by randomly choosing one record per cell. Finally, 439 localities were applied to the Maxent model to predict potential distribution of the species (Fig. 1), We divided the occurrence data into two sets: training (75%) for model building and testing (25%) for model evaluation. The k-fold cross validation (Burman, 1989) can be used to evaluate habitat suitability model (Hirzel et al., 2006) and 10-fold cross validation by setting 10 replicates was applied to Maxent. We kept all other settings as default in Maxent (Phillips and Dudík, 2008).

The area under the receiver operating characteristic curve (AUC) has been extensively used in the SDMs as a threshold-independent measure of the ability in a model to discriminate species presence and absence (DeLeo, 1993; Freeman and Moisen, 2008). A value of AUC close to 1 indicates a good model. Model performance was evaluated by calculating the average value of $AUC_{test}$ and $AUC_{train}$ with 10 replicate runs.

Using jackknife tests, Maxent provides the response curves of each of the variables (Phillips et al., 2006). First, we created a model using all variables and then we created a model with all variables but one, and a model using the only excluded variable; we then performed an iteration of this process for all combinations of variables. We compared the regularized gain of each unique model to identify which variables individually contributed the most. Comparing the response curves created for each model with only corresponding variable with its companion model reflected the effect of each variable on the predicted probability of presence.

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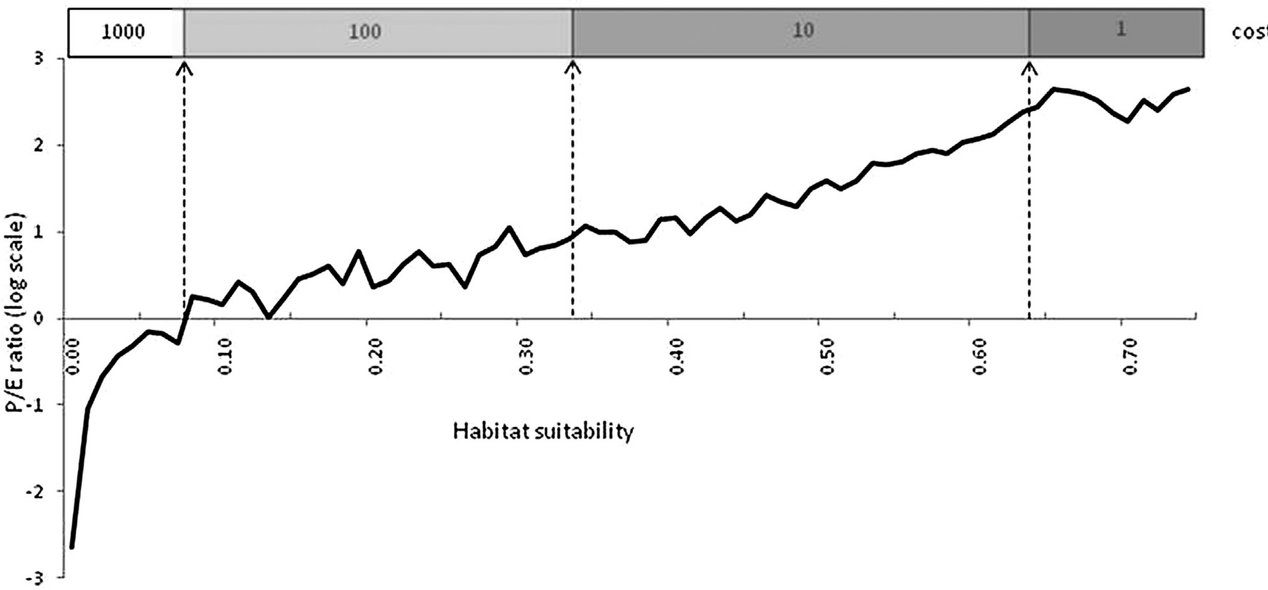


**Fig. 2.** Ratio of predicted/expected (P/E) frequency of evaluation data versus the values of mean suitability. The intersected point where P/E ratio equal 0 and steps on the P/E curve (solid line) help with reclassifying habitat suitability and weighting cost (grey scale bars).

The outputs of Maxent are the values between 0 and 1, the indication of a probability of occurrence (Phillips et al., 2006). To reclassify the probability into presence or absence, we used a cut-off value where sensitivity equals specificity [i.e., the false positive error rate equal to the false negative rate (Fielding and Bell, 1997; Phillips et al., 2006)]. We chose the polygons with probability above the cut-off value as suitable habitat patches in this study. Patches <2 km$^2$ and >3 km distant from the nearest patch (distance based on the daily dispersal ability of the species, Li et al., 2005) were considered unsuitable. We then calculated landscape features of the suitable habitat patches in each mountain using the Patch-analyst extension for ArcGIS (Rempel et al., 2012). To compare the landscape features (e.g. size and number of patches) between mountains we used a Chi-square test to examine the difference in numbers of patches and ANOVA test to compare the difference of mean patch size.

### 2.4. LCP analysis

Pathmatrix extension (Ray, 2005) for the ArcView GIS 3.3 (ESRI company) was used to generate the least-cost paths between suitable habitat patches based on our SDM process. The patches with probability of presence above our cut-off value were regarded as suitable habitat for the species. To create cost layer we reclassified habitat suitability (HS, that is predicted occurrence probability) (into classes based on the boundaries defined by P/E and steps in the P/E curve) and assigned cost of each class as 1000, 100, 10, 1, respectively (Wang et al., 2008).

If the distance between the two closest suitable habitat patches was longer than 3 km (the maximum daily movement distance recorded for species, Li et al., 2005) and/or the paths went through areas with high density of residential settlements (based on model results) or encountered large rivers, the potential paths were classified as unsuitable for migration of the species, otherwise, we regarded the paths as suitable for dispersal between core patches.

## 3. Results

According to our 10-fold cross-validation, the training AUC is 0.984 ± 0.0005 and the test AUC is 0.981 ± 0.003. The P/E ratio increasing with habitat suitability is presenting as a Logarithmic curve (Fig. 2).

Average threshold for probability of presence of ten duplicate runs in Maxent where training sensitivity equal to specificity (Cantor et al., 1999; Bean et al., 2012) is 0.171 ± 0.010. The polygons with probability value of presence >0.171 is regarded as suitable habitat patches. The projected suitable habitats for the species are mainly located within the mountain areas (Figs. 3 and 4). Path numbers identified in the six mountains are significantly different (Table 2; $X^2 = 344.65$, d.f. = 5, $P < 0.001$). More patches were found in Dabashan (234), Minshan (223), and Qionglai (190) Mountains; fewer patches were found in other areas including Qinling (125), Liangshan (28), and Daxiangling (14) Mountains. The percentage of suitable habitat in Qinling Mountains is 37.7% of the total (8468.4 km$^2$), very close to those in Minshan (26.6%, 5982.8 km$^2$) and Dabshan (25.9%, 5819.6 km$^2$) Mountains, but significantly larger than either the Qionglai (6.5%, 1459.8 km$^2$; $X^2 = 21.36$, d.f. = 1, $P < 0.001$), Liangshan (0.9%, 646.9 km$^2$; $X^2 = 21.36$, d.f. = 1, $P < 0.001$), or Daxiangling (0.3%, 63.24 km$^2$; $X^2 = 21.36$, d.f. = 1, $P < 0.001$) Mountains. The mean suitable patch size in the Qinling Mountains is significantly larger than those in both the Minshan (S.E. = 47.382, P = 0.040) and Qionglai (S.E. = 47.951, P = 0.014) Mountains, but not with other mountains (P > 0.05) (Table 2). The edge density and area-weighted-mean-shape indices of the patches in Minshan, Qinling and Dabashan are relatively larger than those found in Qionglai, Liangshan, and Daxiangling (Table 2).

Forty two nature reserves were found within the estimated suitable habitats covering 38.6% of the suitable range. Overlap with nature reserves varied between the mountains withthe Minshan (54.7%) having the largest proportion, followed by Daxiangling (37.4%), Qinling (31.6%), Dabashan (29.8%) Qionglai (28.6%), and Liangshan (21.5%) Mountains (Table 2).

The covariates examined did not equally contribute to the best fitting models. The environmental variable with the highest gain in probability of occurrence when used in isolation is elevation, and the one with the largest decrease when it is omitted is the density of settlements (Fig. 4). When the probability of the presence was >0.40, the elevation ranged from 1700 to 2700 m, and the density of settlements is ranged from 0.38 to 0.58 km$^2$ (Fig. 5).

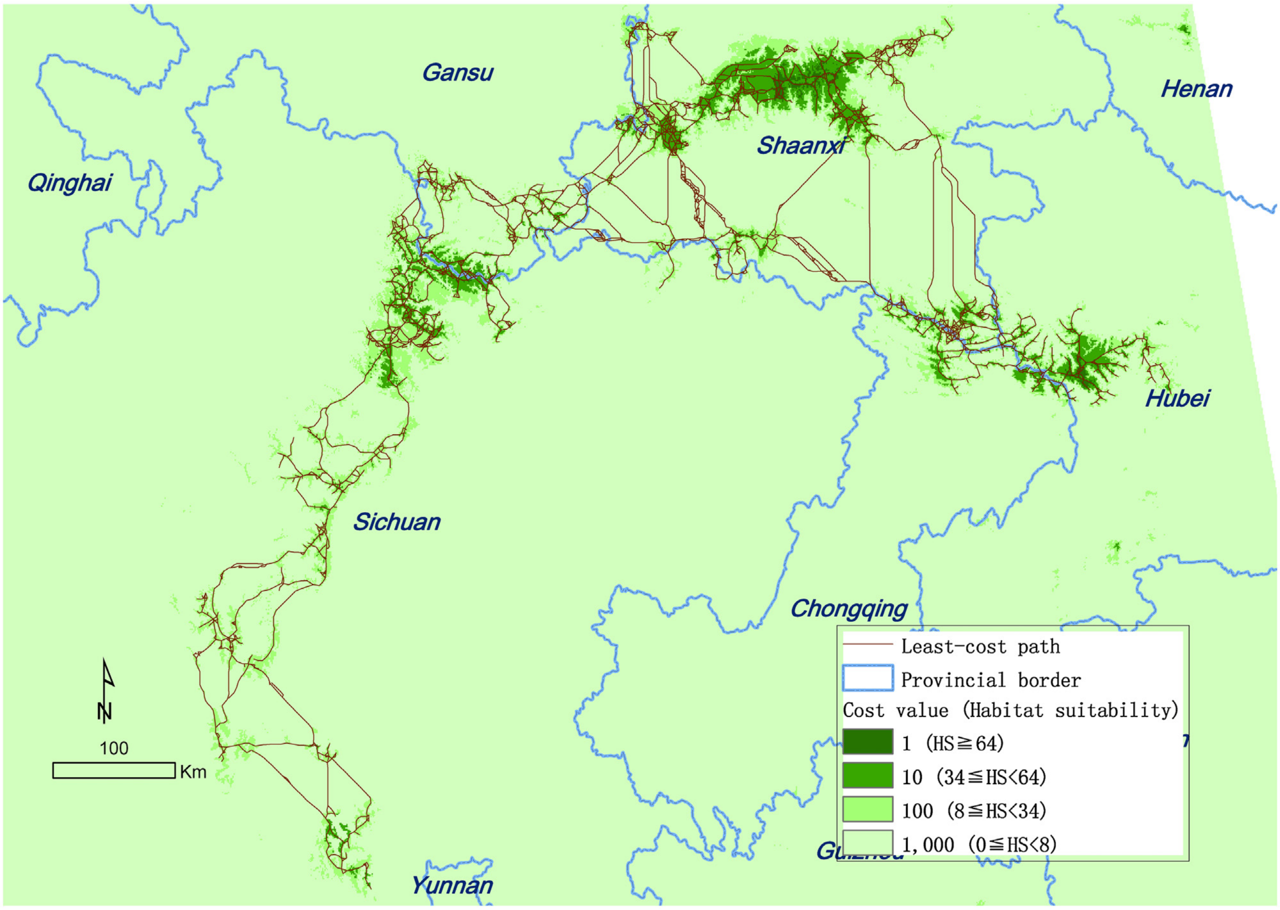


**Fig. 3.** Least-cost paths of the Sichuan golden monkey between suitable habitat patches in Southwestern China. Cost value of 1, 10, 100, and 1000 are assigned to each of the four habitat suitability classes.

**Table 2**
Patch analyst statistic summary for predicted suitable habitat of Sichuan golden monkey in six mountains.

| Landscape metric | Mountains ranges | | | | | |
|---|---|---|---|---|---|---|
| | Liangshan | Daxiangling | Qionglai | Minshan | Qinling | Dabashan |
| Area Metrics | | | | | | |
| Class Area/km$^2$ | 646.9 | 73.7 | 1459.8 | 5982.8 | 8468.4 | 5819.6 |
| Area covered by nature reserves | 139.1 | 27.6 | 417.5 | 3272.6 | 2676.0 | 1734.2 |
| Patch Density & Size Metrics | | | | | | |
| No. of Patches | 28 | 14 | 190 | 223 | 125 | 234 |
| Mean Patch Size/km$^2$ | 23.1 | 5.3 | 7.7 | 26.8 | 67.8 | 24.9 |
| Patch Size Standard Deviation/km$^2$ | 57.3 | 6.1 | 18.8 | 283.3 | 565.7 | 150.7 |
| Median Patch Size | 1.8 | 1.8 | 1.8 | 0.9 | 0.9 | 1.8 |
| Edge Metrics | | | | | | |
| Total Edge/km | 764.9 | 137.5 | 2577.4 | 5476. 9 | 4318.2 | 5218.8 |
| Edge Density (km/km$^2$) | 0.034 | 0.006 | 0.115 | 0.244 | 0.192 | 0.232 |
| Shape Metrics | | | | | | |
| Mean Perimeter-Area Ratio | 29.88 | 30.68 | 32.09 | 33.47 | 32.84 | 31.45 |

We identified 525 potential paths for the species to disperse across the landscape (Fig. 3), of which 23.3% were classified as unsuitable and 76.7% as suitable based on our selection criteria (Fig. 5). The average length of unsuitable and suitable paths are 24.6 ± 18.1 km and 6.3 ± 3.1 km, respectively.

## 4. Discussion

### 4.1. Habitat suitability and connectivity

The Maxent models created for this study were well supported and applicable to the species analysed due to high AUC values

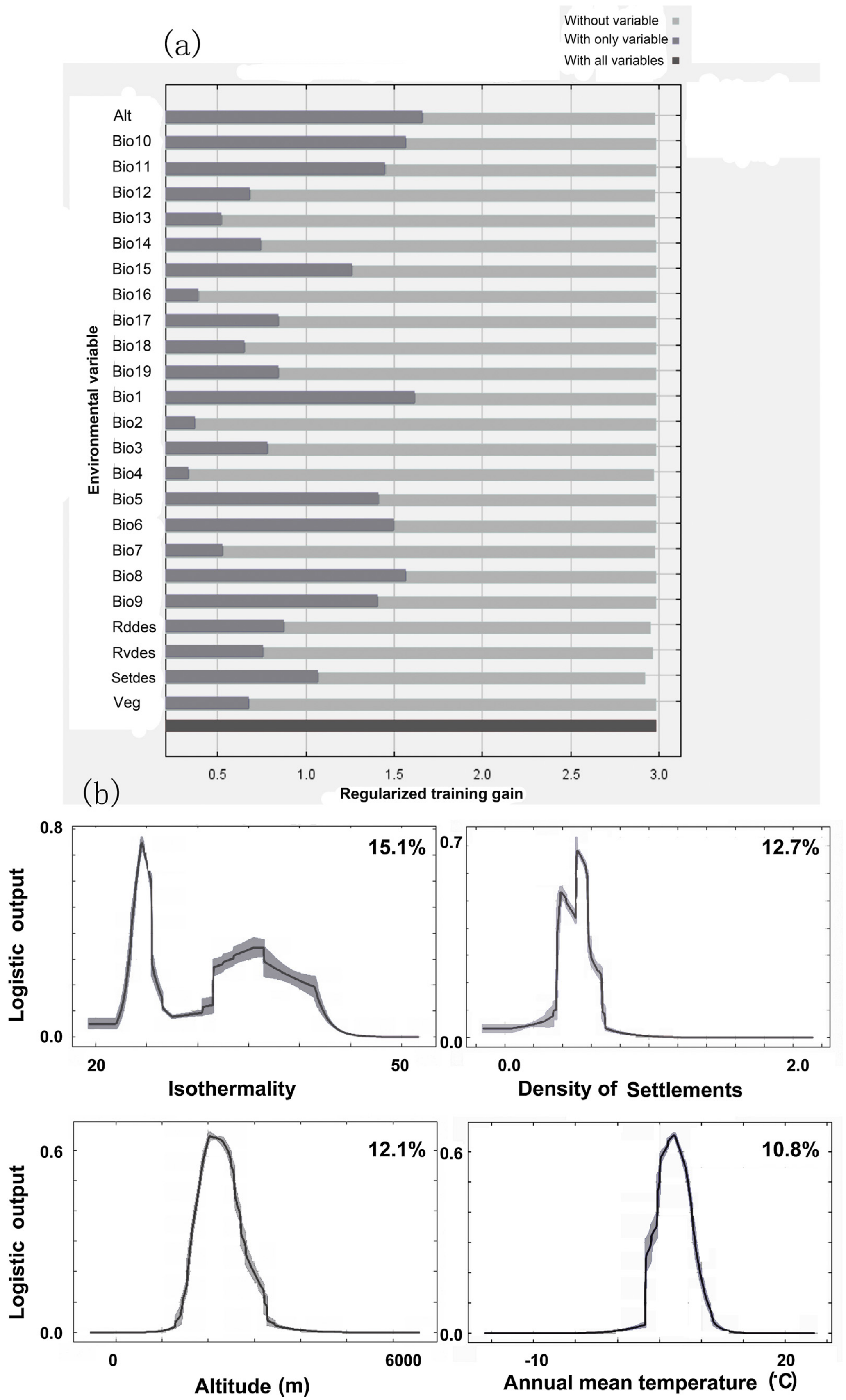


**Fig. 4.** Results of Maxent models: (a) Jackknife test of variable importance. Codes of the variables are also found in Table 1; and (b) Relationship between environmental variables and habitat suitability for Sichuan golden monkey.

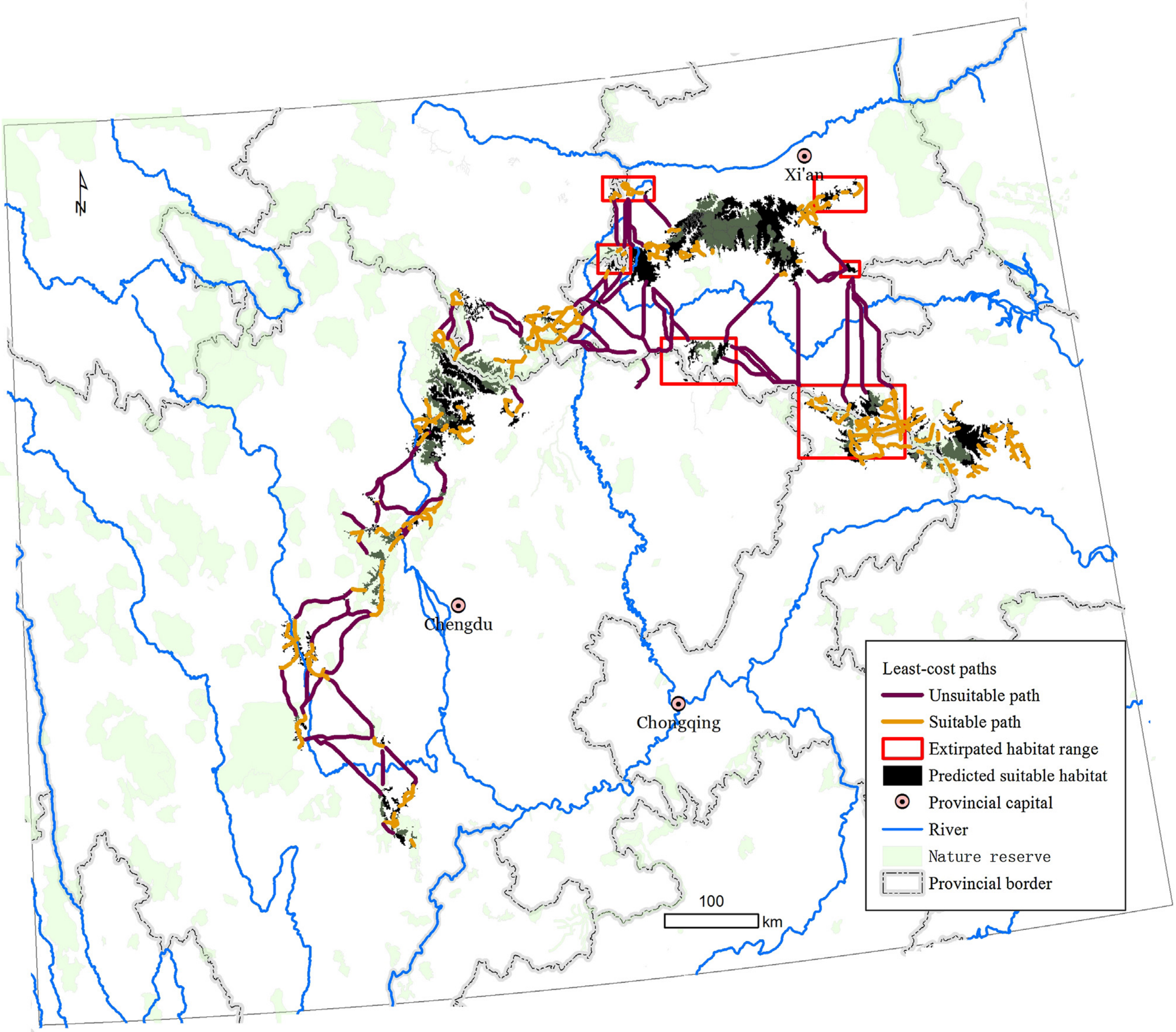


**Fig. 5.** Suitability of least-cost paths for golden monkey. Red polygon shows the predicted suitable habitats which no longer exists. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and examination of the logarithmic P/E curves reported by others (Hirzel et al., 2006; Freeman and Moisen, 2008).

The primary suitable habitats for golden monkey are located within the Minshan, Qinling and Dabashan (Fig. 3) Mountains, with smaller forest patches found within the Qionglai, Daxiangling, and Liangshan Mountains. The Qinling, Minshan, and Dabashan forest areas are also less fragmented than those in Qionglai, Daxiangling, and Liangshan. We are unsure of the quality of the forest patches in Qionglai, Daxiangling, and Liangshan Mountains due to high levels of human disturbance in the region. Not only do the Minshan contain the largest and least fragmented suitable forests, but it also possesses a high density of nature reserves due to the residency of the country's largest populations of the giant pandas (State Forestry Administration, 2006). We believe the golden monkey benefits from the country's emphasis on habitat protection and monitoring programs for the sympatric giant panda (Hu et al., 1980; Quan and Xie, 2002; Li et al., 2012).

The predicted suitable habitat for the golden monkey (pink polygons in Fig. 4) includes areas where the species used to be found prior to 1949 (Fig. 1; Quan and Xie, 2002; Li et al., 2003). The subsequent disappearance of the species in the region was thought to be induced by rapidly increasing human density, deforestation and hunting (Harcourt et al., 2001; Woodroffe et al., 2005; Li et al., 2003). Golden monkey seldom occurred in areas with a high density of settlements (Fig. 4), as reported by Harcourt et al. (2001) and Woodroffe et al. (2005).

The single environmental variable with highest predicted probability of occurrence is elevation, which can regarded as an indirect measure of suitable habitat type for the species. Although settlement density is lower and roads infrasture is less developed in the regions with high elevation in the Western Sichuan Plateau (part of Tibetan Plateau), forest cover has severely been lost (Investigation team of Sichuan Forestry Association, 1991), thus this may not considered as ideal environment for the species.

Sample size, accuracy of the environmental variables, and ecological features of the species studied can influence the validity of distribution models (Segurado and Araújo, 2004; Elith et al., 2006; Hernandez et al., 2006). There was unequal sampling between our regions, with more reports from the Minshan, Qinling, and Dabashan Mountains than the remaining mountains ($X^2 = 358.14$, d.f. = 5, $P < 0.001$). This problem is inherent in all presence-only models (Yackulic et al., 2013), as few samples are derived from

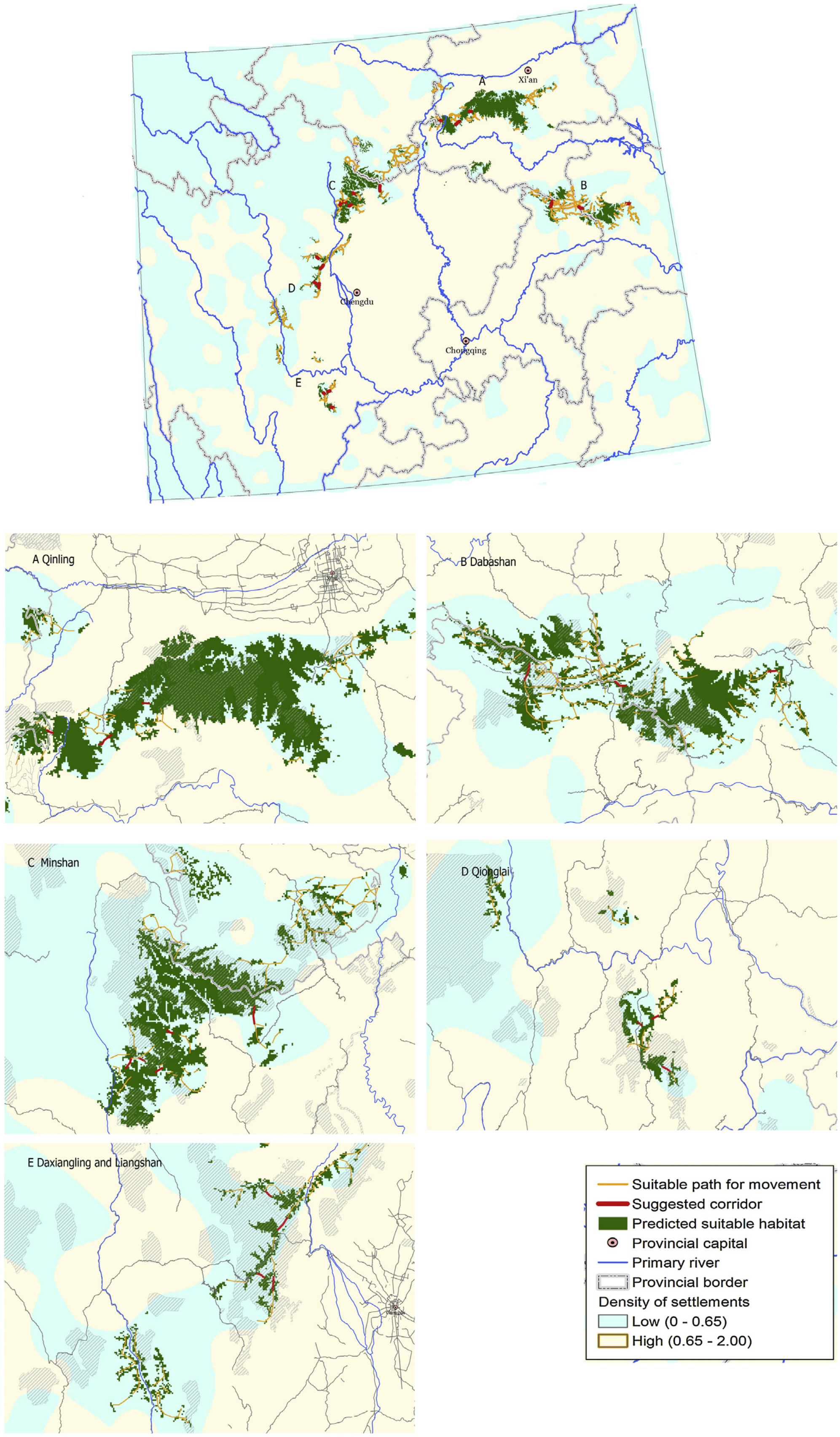


**Fig. 6.** The suggested corridors for golden monkey in six mountains. Shaded line indicates nature reserves.

areas with few animals. However, we feel the high priority placed on this species by the government makes it likely that most current populations have been located their efforts. As we indicated, future monitoring efforts should include presence and absence records in order to address potential biases (Newbold, 2010).

The estimated movement paths for golden monkeys across the fragmented landscape (Fig. 3) seems approriate when we examine regional environmental profiles and residential density. Gene flow data have been used to validate landscape connectivity modeled by LCP (Epps et al., 2007; Wang et al., 2008) but are lacking in our study. Such data for the species would complement our models by identifying historic movement paths.

Potential connectivity of habitat patches relies, in part, on the dispersal ability of the targeted species (Calabrese and Fagan, 2004). Previous studies indicate that a troop of the species could move 0.3–3 km per day (Li et al., 2005; Zhao and Li, 2009) and annual home range of a troop is between 10 to 30 $km^2$ (Li et al., 1999, 2002; Quan and Xie, 2002). So, although suitable forest patches do still exist between the six mountains, many of them are beyond distance of the daily movement capacity, thus they have low conservation value for the species.

### 4.2. Conservation implications

With regard to conservation status of the golden monkey and other animals in the regions, the Chinese government has established 38 nature reserves since 1963, covering 55% of the species' range (Quan and Xie, 2002). In 1998, the government carried out two ecological protection projects- the Natural Forest Conservation Program and the Sloping Land Conversion Program (Ren et al., 2007), which aimed at conserving habitats. However, the conservation status of the golden monkey is still precarious (Li et al., 2002), mainly due to the disturbance from communities in and/or around nature reserves and habitat isolation induced by previous logging activities (Quan and Xie, 2002).

The habitat fragmentation facing the species seems to be accelerated in recent years, which will certainly reduce its genetic diversity, and increase the threat of extinction (Wang et al., 2008). Thus, researching effective ways to protect the species is crucial. And our finding of the potential suitable habitats could help build a long-term monitoring plan for each of its six current mountain regions and maintain viable corridors for the species (Fig. 6). An accurate fine-scaled distribution map can serve as a baseline for monitoring the species by comparing rates of expansion or contraction (Araújo and Guisan, 2006; Liu et al., 2009). Based on our findings we suggest that wildlife conservation agencies maintain all small patches within the potential dispersal corridors even if these patches are unlikely to contain species troops or groups. In addition the southern core regions do not contain sufficient conservation reserves. Small and isolated wildlife populations, like the golden monkey, are vulnerable and the extending of their distribution is critically required (Harrison, 1991; Travis et al., 2010), particularly for small forest patches in the Daxiangling and Liangshan Mountains.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolmodel.2016.09.004.

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