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

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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;

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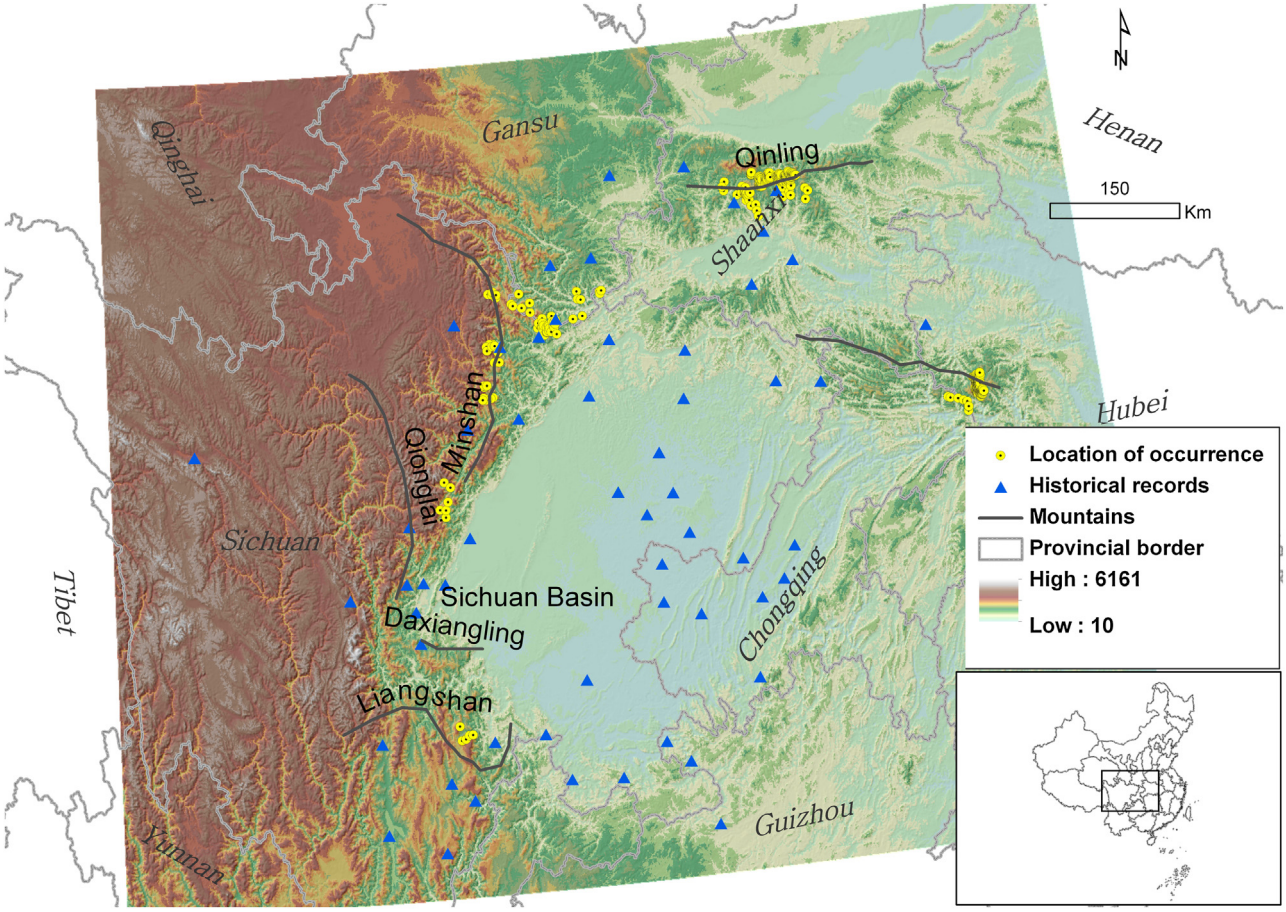

Fig. 1. Study area of the Sichuan golden monkey is indicated by yellow circles. Sichuan Basin characterized with lower elevation and large human population is located in the center of the study area, and surrounded by mountains (locations are shown by grey lines with names above them). It still contains 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