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An integrative approach to assessing the potential impacts of climate change on the Yunnan snub-nosed monkey

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ABSTRACT

Species with distributions severely restricted and isolated by human-related factors are of a challenge to niche modelers. And for those species that have high dietary plasticity and tolerance to different climatic conditions, such as Yunnan snub-nosed monkey, *Rhinopithecus bieti*, possible impacts of climate change can be assessed by the species' ecology and the presence of migration barriers surrounding the current ranges. This study demonstrates an integrative approach for assessing the potential impacts of climate change on the distribution of a species not suitable for common niche models and its implications on species conservation. We first developed vegetation models using regional vegetation cover, and a combination of climatic, geographic and disturbance-related variables. The vegetation cover was simulated referring to the A1B climate change scenario for year 2050 and 2100. We then analyzed migration pressure faced by *R. bieti* based on simulated vegetation changes and the species' habitat preferences, and evaluated feasibility of range shift/expansion based on the presence of migration barriers around current group ranges. The results show that while the coverage of the most suitable habitat type (mixed forest) is expanding, regional forest cover is becoming increasingly fragmented. Four out of fifteen groups (G8–10, 12) of *R. bieti* are particularly vulnerable to climate change where habitat quality is reducing rapidly, while five of the groups (G8–12) have low adaptability to habitat change due to genetic isolation and limitations to range shift. This integrative approach offers a new and an important tool for evaluating potential impacts of climate change on highly adaptable but range-restricted species and is useful in guiding conservation practices.

1. Introduction

1.1. Simulating species response to climate change using ecological niche models

Climate change has been emerging and is considered to be the largest threat to biodiversity in the coming decades. Its major effects include vegetation shifts and animal migrations (Engler et al., 2011; Hannah et al., 2002; IPCC, 2007a) that would consequently lead to an array of ecological problems. To predict potential impacts of climate change on species distribution, a large number of ecological niche models have been developed in recent years. These models are built on species' ecological niche, which is defined as the conjunction of ecological conditions within which the species can sustain viable populations (Alberti et al., 2003; Bruno et al., 2003). Thus, all niche models rest on the assumption that the distribution data used for building these models represent the species' true and complete environmental preferences, and that these preferences would be retained as the climate changes. In other words, the modelling performance decreases when there is a mismatch between the realized niche (the range of conditions and resources in which a species has occupied) and the fundamental niche (the full range of conditions and resources in which a species can survive and utilize) of a species, which is without doubt common in regions of high human activities (Alberti et al., 2003; Braunisch et al., 2008; Malanson et al., 1992; Pearson and Dawson, 2003). Human activities can affect species distributions in intricate ways. Their impacts are often significant, yet evaluation requires detailed historical data or long-term studies that are rarely available (Alberti et al., 2003). This poses a great challenge to modellers because current distributions of species, especially the threatened species, could have been severely altered by human disturbances or habitat destruction, etc., deeming distributional data unsuitable for niche modelling.

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Furthermore, model simulations are often used to project distributional change of species under different climatic conditions without considering human-related factors that may prevent or alter the rate and direction of animal dispersal. If these factors are not taken into account, the results would have little implications to species conservation. The species for our case study, Yunnan snub-nosed monkey, *Rhinopithecus bieti*, is a highly mobile folivore species, with high adaptability to different forest types and climatic conditions (Ding and Zhao, 2004; Grueter et al., 2009a). In theory, such species should be able to adapt to climate change by range shift or expansion. However, its current group ranges are disjunct and isolated by human activities, land-use and infrastructures, confining the groups to small regions at high elevations. The presence of migration barriers could eventually lead to its demise. So for conservation purposes, an innovated assessment approach is required.

In response to the above issues regarding ecological niche modelling, we assess the potential impact of climate change on Yunnan snub-nosed monkey with the following framework: (1) rather than modelling species distribution, we model regional vegetation cover change to reflect future habitat change for *R. bieti*, (2) we assign habitat quality index to each vegetation type, and use it to evaluate the level of migration pressure different groups may experience in the future, and (3) we integratively assess potential migration based on projected migration pressure, future vegetation cover and the presence of migration barriers around current group ranges. The goal is to demonstrate an integrative approach to assess the possible impacts of climate change on an ecologically flexible, but range-restricted species that is not suitable for ecological niche modelling.

1.2. Distribution and ecology of Yunnan snub-nosed monkey

The Yunnan snub-nosed monkey (*R. bieti*) is one of the most endangered animal species endemic to China. It is distributed solely in parts of Hengduan Mountains, a narrow strip of area descending from north to south off Tibetan Plateau, and between the upper reaches of Yangtze (Jinshajiang) and Mekong (Lancangjiang) Rivers (Fig. 1). The latest survey conducted between 2004 and 2009 indicated that the species now comprised of approximately 2500 individuals living in 15 distinct groups (Long, unpublished data). The recognized group ranges vary from 11 to 208 km^2, adding up to an area of approximately 1038 km^2 (Long, unpublished data). Although systematic survey of the species was not conducted until the 1980s, there are evidences suggesting that the species was once more widely distributed. It had inhabited the east side of Yangtze River (Batang County, Tibet and Haba Snow Mountain) and the west side of Mekong River (Lanping County) several decades ago (Bai et al., 1988), and had probably inhabited Fumin County in central Yunnan back in the quaternary period (Bai et al., 1988). It is generally agreed that *R. bieti* is now confined to its current range due to the rise of Tibetan Plateau, climate change during glacial periods in the quaternary (Bai et al., 1988), as well as human disturbances in recent decades (Bai et al., 1988; Liu et al., 2009; Xiao et al., 2003). Between year 1958 and 1997, suitable habitat of the species in the region had reduced by 31%, and the mean size of forest patches had decreased from 15.6 to 5.4 km^2 (Xiao et al., 2003).

The Yunnan snub-nosed monkey is now primarily found in temperate montane forests above 3000 m in altitude, with an annual average temperature of 4.7 °C and an annual rainfall of 650 mm (Bai et al., 1988). *R. bieti* is amongst the few non-human primate species able to cope with harsh environmental conditions characterized by low temperature, low rainfall, low species diversity, high environmental variability, and an extended season of food scarcity (Hanya et al., 2011). Studies conducted on seasonal variation on *R. bieti* in the use of elevational zones showed that temperature is not the primary determinant of ranging, but seasonal food availability (Li et al., 2008). Species living in temperate regions are often more ecologically flexible than other related species, as they are exposed to a broader set of environmental conditions (Kamilar and Paciulli, 2008). The diet of *R. bieti* varies from mostly lichen at their northern range (Ding and Zhao, 2004; Xiang et al., 2007), to primarily bamboo leaves at their southern range (Yang and Zhao, 2001). Its habitat varies from dark coniferous forests in the north to subtropical broadleaf forests in the south. The species' breath of diet and wide range of habitat types reflect its high dietary plasticity and adaptability to different climatic conditions (Grueter et al., 2009a; Jablonski et al., 2000; Xiang et al., 2007). Despite this, studies have found that the species gives highest preferences for deciduous broadleaf plants as food (Grueter et al., 2009a) and mixed broadleaf-conifer forest as habitat (Li et al., 2008). Mixed forest not only provides the highest variety and the highest quality of food items for the species (Xiang et al., 2011), but also the most desirable roosting sites – large evergreen conifers with high boles and large crown areas (Cui et al., 2006; Li et al., 2006; Liu and Zhao, 2004). It is known that the milder mixed forests represent the species' characteristic habitat and that its high dependence of other forest types at some locations is at least partly a consequence of habitat degradation (Li et al., 2008). Because of close associations between species ranging and vegetation, we believe that models built from climate and vegetation data can provide more accurate estimate of potential range shift than do niche models based on climate variables alone, as suggested by Carroll (2010).

2. Material and methods

2.1. Site descriptions

The study area is at 25.5–30°N, 98–100°S within the Chinese national boundary (Fig. 1), covering a total area of approximately 82,804 km^2 across one county of Tibet (Mangkang), five counties of Yunnan (Lanping, Deqin, Weixi, Jianchuan, Lijiang), and two counties of Sichuan (Derong, Xiangcheng). The area forms the southern part of Hengduan Mountains, which is characterized by four major rivers (upper Yangtze – Jinshajiang, upper Mekong – Lancangjiang, upper Salween – Nujiang, and a tributary of the Irrawaddy – Dulongjiang) forming deep river valleys between mountain ranges. Elevation of the study area varies from 762 to 6041 m. Temperature in northwest Yunnan has increased by 1.6 °C between 1955 and 2005 (Wong et al., 2010), and is projected to increase further by 1–2.9 °C in the first half of this century (Hulme and Sheard, 1999). Climate change has already triggered vegetation shifts in the Hengduan Mountains (Baker and Moseley, 2007; Wong et al., 2010). According to the projected rate of warming, the regional biodiversity is likely to face severe threats in the near future (see Table 1).

2.2. Study methods

2.2.1. Climate simulation

Using meteorological records and A1B climate change scenario produced by atmospheric circulation model ECHAM5 (IPCC, 2007a), we projected the regional climate conditions by the program RegCM3 for year 2000, 2050 and 2100 on 1×1 km grid. Output variables include monthly and annual mean temperatures, relative humidity, precipitation, evaporation, cloud cover and wind speed. RegCM3 is a highly resolved regional climate model developed by the International Pacific Research Center, aimed at simulating variability of Asian–Australian monsoon system and assessing impacts of global change on the Asian-Pacific climate.