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Integrated maps of biodiversity in the Qinling Mountains of China for expanding protected areas

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A B S T R A C T

Habitat fragmentation and loss is the main cause of species extinction; thus, the appropriate placement of protected areas is critical for saving vulnerable and threatened species. However, how to expand the existing protected areas network for improving conservation efficiency is a vital concern. We examined the Qinling Mountains — a widely recognized biogeographic treasure in China and East Asia, to identify key biodiversity areas (KBAs) and compare them with existing protected areas. We focused on 259 key protected wild plant and animal species and modeled species distributions with elevation and habitat preference. We then adapted two established algorithms (biodiversity hotspots of species richness [BHSR] and systematic conservation planning [SCP]) to identify priority areas, respectively. Results from these two algorithms addressed two conservation criteria: "represented" single species and "well-represented" species assemblages. SCP showed better performance (~90%) than BHSR (~78%) using the "represented" criterion covering a small portion (~8%) of the total region; conversely, BHSR showed better performance (~61%) than SCP (~55%) using the "well-represented" criterion. The overlapping priority areas of both methods could achieve an optimal conservation that met dual criteria, which is considered as the candidate KBAs in this study. Surprisingly, we found that 63% of KBAs are not co-occurring with existing national nature reserves (NNRs). We highlight the unoccupied KBAs as deserving additional protection, with a result that the expansion of NNRs to KBAs will increase overall conservation coverage and efficiency. The integrated method developed here can be used generally as a repeatable and quantitative assessment framework to be implemented in protected areas network expansion and planning, in China and beyond.

1. Introduction

Protected areas establishment is considered a widespread and effective strategy to conserve natural resources and ecosystems (Guo and Cui, 2015). In the International Union for Conservation of Nature (IUCN) protected areas system, strict nature reserves are designated as having first priority status (CNPPA/IUCN and WCMC, 1994; IUCN, 1999). Strict nature reserves primarily serve to conserve regionally, nationally or globally outstanding biodiversity and ecosystems through a combination of habitat conservation and regulations on human activity (Dudley et al., 2010). Numerous studies have examined the effectiveness of protected areas to capture different levels of biodiversity at multiple scales (Gaston et al., 2006; Hermoso et al., 2015; Zhang et al., 2015a). However, the results confirm that existing protected areas coverage does not adequately represent ecological diversity, nor achieve conservation objectives (Brooks et al., 2004; Hoekstra et al., 2005; Scott et al., 2001). Jenkins et al. (2015) found that the United States protected areas do not perform well in protecting biodiversity and they mismatch biodiversity priorities. Wu et al. (2011) concluded that nature reserve system provides low coverage for biodiversity, even though there are numerous reserves in eastern and southern China. Although protected areas continued to increase, current strategies failed to achieve the stated 2010 Biodiversity Target of Convention on Biological Diversity (CBD) to reduce significantly the current rate of biodiversity loss (Butchart et al., 2010). Due to habitat fragmentation and loss as main causes of species extinction, the appropriate placement of protected areas is critical for saving remaining biodiversity. At the same time, how to expand the existing protected areas network is a vital concern for improving conservation efficiency.

In China, national nature reserves (NNRs) comprise the main collection of China's protected areas system, which seem to fulfill criteria to qualify as strict nature reserves as defined by IUCN. Up to 2014, China had 428 NNRs, covering approximately 10.1% of its total land area

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(MEP, 2015). But little is known about their contribution in capturing the ecological diversity of the whole country, due to the lack of a comprehensive database and the absence of spatial data. In practice, most NNRs in China were opportunistically established instead of created through systematic planning and investigation at an early stage of development (Wu et al., 2011). The original intent of some reserves established from a local government perspective was to identify regions less suitable for agriculture and extractive development, while protecting individual rare species and important ecosystems (Margules and Pressey, 2000). Nevertheless, NNRs remain the cornerstone of conservation strategies in the country, which is why it is so critical that they were expanded and designed for specific conservation objectives.

Recently two developed methods for locating protected areas are linked specifically to conservation objectives. Modeling "biodiversity hotspots of species richness (BHSR)" identifies priority areas where species richness/endemism is highest (Myers et al., 2000; Myers, 2003). BHSR can often be applied to large-scale strategic conservation action using available data of biodiversity distribution (Hobohm, 2003). On the other hand, systematic conservation planning (SCP) has emerged as a more effective approach to identify a network of priority areas than BHSR (Margules and Pressey, 2000; Brooks et al., 2006). SCP attempts to meet goals of maximizing biodiversity conservation while minimizing cost by irreplaceability analysis (Maiorano et al., 2008). Although SCP and BHSR are both effective tools to identify priority areas, they have different characteristics. The choice of two methods will result in different spatial patterns of conservation priorities and conservation efficiency.

The Qinling Mountains is an internationally treasured biodiversity hotspot in China. It is generally considered the physical geographical boundary between south China and north China, running east–west and located in the transitional region from the northern subtropical zone to the warm-temperate zone of central China (Zhao et al., 2014) (Fig. 1). Moreover, this range acts as an important watershed divider between the Yellow River and the Yangtze River (Huang et al., 2012). The Qinling Mountains also have a unique glacial history in not being subjected to direct invasion of the quaternary continental glacier (Li et al., 2005). Due to their unique geographical location and ancient geological evolution (Lu et al., 2012), the Qinling Mountains are known as the oldest precious species refuge on earth. There are some extant tertiary ancient plants and a great variety of wild plants and animals surviving in the Qinling Mountains (Wang et al., 2014), including giant pandas (*Ailuropoda melanoleuca*), golden snob-nosed monkeys (*Rhinopithecus roxellanae*), crested ibis (*Nipponia nippon*), ginkgo trees (*Ginkgo biloba*), dove trees (*Davidia involucrata*) and Chinese tulip trees (*Liriodendron chinense*). The Qinling Mountains are widely recognized as one of the important biodiversity hotspots in China (Fan et al., 2014). However, the wild animals and plants of this unique area are facing major threats from habitat loss and fragmentation because of rapid economic development and population growth, so it is critical to formulate effective conservation measures such as expanding nature reserves (Qi et al., 2011).

In this study, we modeled the geographic patterns of Key Protected Wild Plants and Animals in the Qinling Mountains, China to address three questions: (1) What are the spatial patterns of biodiversity distribution? (2) How well do patterns of key biodiversity areas (KBAs) match the distribution of protected areas? (3) Where are the optimal locations for expanding protected areas? In our analysis, we compared and combined both BHSR and SCP methods to identify KBAs of maximum conservation efficiency. We then overlaid KBAs with NNRs to map gaps that deserve additional conservation. The aim of this analysis was to develop an optimal method for determining priority areas, which may more efficiently guide expansion of protected areas. This methodology can be upscaled to the national-scale or downscaled to the local-scale to show ideal areas for expanding protected areas, in China and beyond.

2. Materials and methods

2.1. Study area

This study was performed in the Qinling Mountains (32°22′–34°48′ N, 105°13′–113°13′E) (Fig. 1). The total area is ca. 98,040 km^2, comprising three provinces and forty-three adjacent sub-regions. The western and middle sections are covered with high mountains of 2000–3000 ma.s.l. elevation, the highest peak (Taibai Mountain) at 3767 ma.s.l. elevation. In the eastern portion of the range, mountains alternate with basins. As the boundary between the warm temperate semi-humid and subtropical humid climates, deciduous broad-leaved forest dominates in the north while mixed deciduous broadleaved and evergreen broad-leaved forest dominates in the south.

2.2. Data collection

We focused on 259 threatened species in the Qinling Mountains and defined as key protected wild plants and animals according to China's National List of Key Protected Wild Plants and Animals (State Forestry Administration and the Ministry of Agriculture of the People's Republic of China, 1999; State Forestry Administration of the People's Republic of China, 2003) and IUCN Red List Categories (IUCN, 2001), including 18 mammals, 32 birds, 1 amphibian, 8 gymnosperms and 200 angiosperms (Table S1). Among the 259 species, 191 are endemic to China. We collected the species occurrence records within the Qinling Mountains from currently available published literatures of floras, monographs, specimens, and scientific field surveys (Table S2).

To obtain information on topography and land cover, we downloaded the 90 m DEM data (SRTM) from the International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn). We also downloaded 11 Landsat TM/ETM + images around 2010 from this site, covering all of the Qinling Mountains (path/row numbers 124–129/ 36–37). Details of the land cover classification methods are described in Appendix A. Results of the classification accuracy assessment showed the overall accuracies of these images were all ≥85%.

2.3. Modeling species distribution with habitat preference

According to the detailed spatial distribution data available, we modeled the range of each species distribution using ArcGIS 10.0 as follows: (1) we collected the available county occurrence data, habitat-association matrices and elevation range of each species; (2) we mapped each species' distribution of county occurrence, elevation range and preferred habitat types across the whole study area, based on administrative maps (available at http://ngcc.sbsm.gov.cn/article/khly/lyzx/), digital elevation model (DEM) at a resolution of 90 m and land cover maps at a resolution of 100 m (Appendix A), respectively; (3) we overlapped three maps above and predicted the distribution map of each species by assuming that the preferred habitat types in the suitable elevation range where one species generally occurred acted as that species' possible distribution area (Zhang et al., 2015b). We compiled richness of 259 key protected wild plants and animals and 191 endemic species for each taxon (Fig. 2). The distribution map of each species was re-sampled at a resolution of 2 km and the database of species occurrence/non-occurrence in each grid was established.

2.4. KBAs selection using SCP and BHSR

First, priority conservation analysis of SCP was performed using C-Plan, a decision support system for systematic conservation planning (http://www.ozemail.com.au/~cplan), to select optimal priority-settings of biodiversity conservation. Considering maximum conservation efficiency of such threatened and key protected species with minimum areas size, we defined conservation targets with quantitative