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

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\section*{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.

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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 irreproachability 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 snub-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 ecological 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 km², comprising three provinces and forty-three adjacent sub-regions. The western and middle sections are covered with high mountains of 2000–3000 masl elevation, the highest peak (Taibai Mountain) at 3767 masl 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/lzyx/), 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 overpassed 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
hierarchy according to the distribution extent of species (Pressey et al., 2003; Solomon et al., 2003). Specifically, the targets were categorized as follows: 50% for species with distribution extent less than 100 km², 30% for species of 100–1000 km², 20% for species of 1000–5000 km², 10% for species of 5000–10,000 km², and 5% for species of >10,000 km². In our study, we selected 2 km resolution which resulted in 20,720 planning units covering the study area. We ran the occurrence matrix of 259 species × 20,720 planning units combined with a conservation target for each species to proceed an irreplaceability analysis for achieving the targets that we describe as follows. The outcome of this analysis are planning units with value of irreplaceability \( I \). \( I \) is scaled between 0 and 1, where a value of 1 indicates that the unit is the most important for the achievement of overall conservation targets, and a value of 0 indicates that the unit has no contribution to regional conservation because of non-occurrence of species or redundancy. Selecting and evaluating of planning units with high value of \( I \) can be used to aid in determining priority-settings. Here we deemed the planning units to be the most cost-effective setting of priority units when they were selected from high to low \( I \) and until the accumulative conservation efficiency could reach 90%. The conservation efficiency is the proportion of representative species accounting for all species by selected priority-settings.

Second, we performed the conservation priority analysis of BHSR based on the database of species occurrence in each planning unit. We summed and sorted the species richness of each unit, and then selected the units with high richness as candidates for priority-settings (Myers et al., 2000). The total area of accumulative units was constrained to be the same size of the result by SCP, in order to compare the efficiencies of both methods. Here, we defined two criteria of “represented” and “well-represented” to assess the conservation efficiency of priority-settings identified by SCP and BHSR methods. “Represented” indicates
the condition wherein a species can be considered as conserved when it is covered by at least one grid of priority-settings. “Well-represented” refers to the condition in which a species can be considered as well conserved when more than 20% of species distribution is covered by priority-settings. After analyzing and comparing the efficiency of results using both criteria, we finally determined the KBAs which can achieve the most optimal dual efficiency, by SCP, or BHSR, or the integration of both approaches.

2.5. Gap analysis with NNRs

We additionally conducted a gap analysis to assess coverage of protected areas (Michael, 2000; Sharafi et al., 2012). The objective of gap analysis is to identify biotic elements (species or alliances) that are either under-represented or not-represented in the existing network of conservation areas (Scott et al., 1993; Maxted et al., 2008). Here we applied the gap analysis to assess the consistency of protected
areas with priority areas. By combining and overlapping the distribution of priority areas with protected areas, we aimed to find ideal areas for expanding protection. Such planning makes it possible to improve the efficiency of conservation optimally while minimizing the cost of land area. In this study, the basic process was to superimpose the KBAs identified above and the NNRs in the Qinling Mountains. In this region, there are 23 existing biodiversity NNRs (Fig. 6), and the total area is ca. 12,668 km², accounting for 12.9% of the whole study area in Qinling Mountains.

3. Results

3.1. Distribution of biodiversity in the Qinling Mountains

Geographic patterns of total key protected species richness differ substantially among taxa (Fig. 2). Total richness of key protected wild plants and animals concentrate mostly in three regions: in the east, center and west of the Qinling Mountains. Mammal richness is highest in the center; birds in the north; gymnosperms in the west; and angiosperms in the east. The one amphibian (*Andrias davidianus*) is scattered across the whole range. Further, endemic species of key protected wild plants and animals for all taxa are consistently located in the same three regions as total species richness, and taxon-specific patterns also follow the patterns of total species richness, with the exception of birds. Endemic key protected birds are concentrated in the south slope of the Qinling Mountains. Threatened species show no consistent geographic patterns across different taxa, which indicate a need to pay more attention to conservation efforts across the region and taxonomic groups.

3.2. Conservation efficiency and spatial patterns of KBAs

For SCP, the units are prioritized according to $I$, while for BHSR they are prioritized according to species richness. The results showed that the cumulative efficiency of conservation using SCP is higher than BHSR with the “represented” criterion (Fig. 3), which was consistent with our expectation. The priority-settings of SCP represented ~90% of key protected wild plants and animals, while priority-settings of BHSR represented only ~78% of key protected wild plants and animals. Differences in conservation efficiency by using the two methods separately were highest when the cumulative areas reached ~8% of the total area. SCP can represent more species than BHSR with the minimum land costs. If we used the criterion of “well-represented”, BHSR showed better performance (~61% of species) than SCP (~55% of species) when the cumulative areas reached ~8% of the total area (Fig. 3). After accumulative areas reached more than ~10%, SCP showed better performance. With the increase of accumulative areas, the difference of conservation efficiency between both methods would be smaller.

We also found different spatial patterns when mapping the distribution of priority-settings by both BHSR and SCP covering 8% of the total areas (Fig. 4). This is intuitively apparent by viewing differences in spatial patterns of the two methods by superimposing them (Fig. 5). The shared placements are located in the center and east of the Qinling Mountains, which accounted for 43.3% of priority areas and 3.3% of the study areas. A unique location of BHSR is located in the west, while unique locations of SCP are mainly in the south and center. The choice of algorithms would lead to different results of conservation efficiency and distribution. No matter which one selected alone could not meet our conservation objectives. In view of the above results, we proposed that the overlapped areas of BHSR and SCP could be considered as KBAs to achieve the most optimal conservation efficiency. This makes a strong case for candidate KBAs for further protection.

3.3. Match or mismatch between KBAs and NNRs in the Qinling Mountains

By overlapping the spatial patterns of KBAs with the distribution of NNRs in the Qinling Mountains, we found that some regions of KBAs match NNRs, while other regions of KBAs mismatch NNRs (Fig. 6). Surprisingly, 63% of KBAs were still outside the NNRs. We highlight the unoccupied KBAs as deserving additional protection. The expansion of the NNRs to KBAs will make the total area of reserves network reach 15.1% of the study area, which could increase conservation efficiency to represent 236 species (91.1%) and well-represent 182 species (70.3%).

4. Discussion

4.1. What are the spatial patterns of biodiversity distribution?

Are available biodiversity data sufficient to make informed choices about conservation priorities? Widely distributed species dominate overall patterns of species richness, but are generally not the species in need of conservation. Given data limitations, we will always need to prioritize based on some subset of species or other proxy measures of overall biodiversity (Austin et al., 2014). To address this, we compiled key protected wild plant and animal range distributions for taxa which are relatively well-documented. We mapped diversity by overlapping the maps for various subsets of species from each taxon. We

![Fig. 3. Comparison of represented efficiency using BHSR and SCP.](image)

![Fig. 4. Priority areas identified using BHSR and SCP in the Qinling Mountains.](image)
recommend one improvement of wider ranging investigations and assessments of threatened species. Furthermore, assessments of other taxonomic groups would enable more comprehensive planning for biodiversity, for example invertebrates and butterflies.

Knowing precisely where individual species occur limits inferences. Thus another possible improvement relates to the range maps themselves. Especially in China, explicit geographical data for biodiversity conservation remain incomplete and difficult to obtain because there is no legal requirement to report such data to the Central Government.

Given that terrain and habitat have a direct and significant impact on the large-scale spatial distribution of species (Tews et al., 2004), in this study we selected elevation range and habitat type as the main factors to model the potential distribution of species. Certainly, more factors such as soil and topography will improve the accuracy of the prediction model, especially for actual protection work at fine resolution. However, the information on the relationship between species distribution and these factors are still lacking. In future field works, precise species distribution investigation based on global position system (GPS)
and dynamic monitoring based on infrared video camera system may greatly increase the validity of the results (Tyre et al., 2003; Pettorelli et al., 2010).

We also assumed that suitable habitats that species once occupied, but currently do not, will affect shorter-term planning, because species may recoup vacant areas currently and habitat can potentially recover. Of course, we need to consider other factors which could discount the value of longer-term planning, for example climate change, land-use and land cover change (Mantyka-Pringle et al., 2015; Sutton et al., 2015). For conservation objectives, we only considered the distribution in the Qinling Mountains, which may overestimate the necessary conservation coverage of species because of not considering distribution areas out of the study region. In this study, though there exist regions with high richness identified universally for any taxon, different taxonomic groups show no consistent geographic patterns. These patterns are worthy of further study, but are not here considered directly as KBAs to protect.

### 4.2. How well do key biodiversity areas match the distribution of protected areas?

In this study we selected BHSR and SCP to evaluate and determine the KBAs, rather than choosing only one approach. Illustrating the different nature of priority areas selection, SCP emphasizes irrepeatability and complementarity (Rouget, 2003), while BHSR emphasizes degree of species richness (Margules and Pressey, 2000; Myers et al., 2000). Our aim was to identify KBAs which can achieve optimal combined efficiency with the smallest cost of land area. We confirmed a substantial difference between the results of BHSR and SCP with regard to the two metrics of conservation, “represented” and “well-represented”. We attached the most importance to the KBAs (constructed here as the intersection, BHSR∩SCP), at the same time we recommend greater focus on the regions of union of BHSR and SCP (BHSR∪SCP), if enough lands can be allocated as protected areas. The difference between both methods becomes smaller with the increase of available area (Fig 3). Of course, directly overlapping the results of BHSR and SCP is just a primary attempt.

Our analysis focused exclusively on the relationship of KBAs and NNRs. First, we were skeptical of the efficiency of existing NNRs, which might be attributable to the experience based on expert input and decision-makers rather than systematic planning. Then we overlaid them to test whether KBAs match the reserves. As we expected, the distribution of NNRs mismatched the KBAs. Some KBAs are partly covered by NNRs; some are covered by several isolated NNRs; and others are located outside the existing NNRs. Our study implemented a spatial analysis procedure based on an integrated method for the selection of KBAs for conservation, which can serve to guide spatial analysis of reserves. Additionally, we focus on another question that some NNRs have no relationship with KBAs, which needs to be further investigated at smaller scale.

### 4.3. Where are the optimal locations for expansion of protected areas?

Most reserves remain isolated and are unrelated to one another in China’s landscape. The efficacy of NNRs is important because the amount of land realistically available for biodiversity protection is very limited (Tang et al., 2011). In our study, we provide guidance for immediate action for conservation work, upon which future expansion of strict nature reserves may be based (Fig 6). Our results show that a combined SCP-BHSR method can serve as a framework for repeatable and quantitative assessment of KBAs, and promote awareness to governments and the public at large. We recommend that existing NNRs can be expanded toward KBAs (Fig 5; 6). We also suggest filling the conservation gaps between KBAs and NNRs by establishing new protected areas and enlarging isolated NNRs, which require policies in priority setting for actual reserve designation in these gap areas. Better management strategies should also be developed to ensure the efficiency of nature reserves in general. At the same time, we recognize the shortcoming that there appear to be many gaps in our results of KBAs, which need to eliminate fragmentation analysis in future study.

### 5. Conclusions

The Qinling Mountains are an internationally treasured biodiversity hotspot in China. Within this region many reserves have already been established. Given the large amount of biodiversity and the potential resources available, one might expect a high degree of biodiversity conservation. But we found important conservation gaps in this region. The protected areas do not match the KBAs identified and failed to cover the key protected wild plants and animals in the Qinling Mountains. This study presents an optimized method for priority areas identification by using combined SCP with BHSR. Consideration of conservation efficiency is essential for priority-settings that maximize conservation achievement while minimizing cost and resources. Our results provide valuable insights for strategic conservation and land-use planning in the Qinling Mountains, and for national and local-scale systematic conservation practice. Of course, improved data, especially from more taxa, will further enhance its applicability. We draw three conclusions in this research: (1) Although there are a variety of spatial analysis methods developed for species distribution, we found that elevation range and habitat type preference data can quickly facilitate selecting suitable habitat for species. (2) Using different algorithms can produce different priority-settings. Not only are the spatial distributions different, but efficiency metrics are different. Therefore, choosing the appropriate method to identify priority conservation is considered as a very important issue. (3) Addressing a current lack of scientific system planning for protected areas, the method developed here can provide a new perspective and insight for expansion of protected areas network.

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