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Bridging the "gap" in systematic conservation planning

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ABSTRACT

Biodiversity hotspots at the global and national scale have contributed important information for biodiversity conservation; however, in hotspot designation two kinds of "gap" greatly limit conservation planning, which this study identifies as the "scale gap" and the "conservation gap". To address the gap, we integrated systematic conservation planning (SCP) with gap analysis to optimize solutions of protected areas planning at local scales. In this study, we presented a quantitative spatial methodology for prioritization and downscaled to a planning case study in the province of Shanxi, China. First, the spatial distribution of 54 threatened plant species were mapped at fine resolution, and scenarios of conservation targets for taxa were generated according to species attributes, which are both the necessary inputs in selection algorithm of priority conservation. Then we determined 17 priority conservation areas using SCP, which only cover ~5% of the total area but could represent 100% of the threatened plant species in Shanxi Province. We confirmed that priority conservation areas determined based on SCP can achieve maximum efficiency of conservation, especially considering representation of small-ranged species. Further, through overlapping priority conservation areas with nature reserves, six conservation gaps were identified for future conservation efforts. Our findings provide suggestions for protected areas network planning of botanical conservation in real-world contexts. The proposed method of integrating SCP with gap analysis can be generally used in bridging the gap between biodiversity priority areas and protected areas in proactive planning and management protocol for biodiversity conservation.

1. Introduction

Biodiversity is being lost at an unprecedented rate due to human activities (Gaston, 2000), and how to effectively decrease the rate of species extinction has become a substantial challenge for conservation biologists and decision makers (Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000; Joppa, Visconti, Jenkins, & Pimm, 2013). Although 34 global biodiversity hotspots have been identified for conservation priorities (Conservation International, 2007), little guidance is available on the relationship between global and local conservation efforts (Knight et al., 2008; Whittaker et al., 2007; van Gils, Conti, Ciaschetti, & Westinga, 2012).

Systematic conservation planning (SCP) is a theoretical framework for biodiversity conservation, which can be applied to identify priority conservation areas representing the largest amount of species with the minimum costs (Margules & Pressey, 2000). It has become an effective approach to biodiversity conservation at the global and national scale (Withey et al., 2012; Wu et al., 2014). Priority conservation areas identified by SCP at large scale can serve to dynamically inform further priority investigations and consideration of biodiversity conservation at local scale (Huang et al., 2012; Bosso, Rebelo, Garonna, & Russo, 2013). However, there exist two kinds of "gap" which make them far from adequate and suitable for conservation planning and management across smaller area extents (Ocampo-Peñuela & Pimm, 2014; van Gils et al., 2012). The first "gap" is a "scale gap", which refers to inconsistencies of conservation planning between global/regional scales with coarse spatial resolution and local scales with fine spatial resolution, which correspond to inconsistencies in strategic researches and tactical actions (van Gils et al., 2012; van Gils, Westinga, Carafa, & Antonucci, 2014);

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the second "gap" is a "conservation gap", which refers to the gap areas wherein biodiversity distributions mismatch existing protected areas in the spatial distributions (Jenkins, van Houtan, Pimm, & Sexton, 2015). The existence of these two kinds of "gap" makes conservation assessments rarely transformable into conservation actions (Knight et al., 2008). To bridge and fill the "gap" in systematic conservation planning is very important in biodiversity conservation.

Gap analysis is widely used to evaluate effectiveness of existing protected areas by overlapping biodiversity distribution with existing protected areas network (Scott, Davis, & Csuti, 1993; Rodrigues et al., 2004; Rodríguez, Brotons, Bustamante, & Seoane, 2007). However, gap analyses are often hampered by the lack of fine resolution and up-to-date information (Oldfield, Smith, Harrop, & Leader-Williams, 2004). At the same time, single gap analysis can identify what is missing from existing protected areas, but provides no direct guidance on how to efficiently fill these gaps (Seyedeh, Atte, Matt, & Mark, 2012). Generally, protected areas are selected not primarily on the basis of protection needs, but because they offer no suitable value for resource exploitation and urban development. This generates an inconsistency in the location of high conservation value without protection. Due to lack of systematic and scientific planning, little is known about the effectiveness of protected areas (Crain, White, & Steinberg, 2011). The selection of effective protected areas will become a vital issue for saving remaining biodiversity. For improving conservation efficiency, gap filling to optimize reserve layout plays an important role in building and enhancing ecological functioning of reserve networks (Downes, Handasyde, & Elgar, 1997; Wang et al., 2014).

To improve understanding of current biodiversity patterns and conservation effectiveness, enough accurate and precise data of biodiversity distribution at fine resolution is primary and necessary (van Gils et al., 2012). Species distribution modeling (SDM) has been suggested as an effective method to determine species suitable ranges and geographic distribution patterns at large spatial scales (Phillips, Anderson, & Schapire, 2006; Zhang et al., 2012). However, it is rarely used at fine spatial resolution, and is not suitable for threatened and rare species with fewer distribution records (Wisz, Hijmans, Peterson, Graham, & Guisan, 2008). For threatened plant species, fine-scale location data are dispersed among herbaria and literature at uncertain degrees of spatial accuracy. Knowledge of local distribution patterns of threatened plant species is incomplete and, therefore, conservation efforts cannot be evidence-based.

Here we integrated survey records of species in a variety of formats to produce a consistent data set at fine enough resolution for conservation planning. Moreover, we aspired to develop an optimal quantitative method to identify conservation gaps that can provide guidance for the expansion of protected areas network. Priority conservation areas identified by SCP combined with gap analysis may guide effective planning of protected areas and downscale strategic research to tactical conservation actions (Peterman, Crawford, & Kuhns, 2013; Pimm & Ocampo-Peñuela, 2014). We applied this approach to a case study in Shanxi Province, China.

In this study, we aimed to (1) map the distribution of threatened plant species at fine spatial resolution by comparing distribution patterns of species diversity at different levels; (2) develop a selection algorithm combined with different scenarios of conservation targets for taxa to determine optimal settings of priority conservation areas based on SCP; and (3) overlap the priority conservation areas with existing protected areas using gap analysis to identify conservation gaps. The results provide useful information for future botanical conservation in maintaining species habitats and fulfilling the need for *in situ* conservation in Shanxi. Our intent was to demonstrate that the methodology is transferable and applicable for bridging conservation gaps elsewhere.

2. Data and methods

2.1. Study area

The study was carried out in Shanxi Province, China (Fig. 1), which has an area of ~156,000 km^2. Shanxi Province is an inland province, located in the northern region of China (34°34′–40°44′N, 110°14′–114°33′E). It is a typical mountain plateau characterized by loess coverage, with an average elevation of 1500 m above sea level with the highest peak at 3061 m. There are mountains/plateaus in the east and west and respective down-faulted basins in the central portion. The geomorphic types are complicated and various; mountains and hills account for 80.1% of the total area of the province, while plains and valleys account for 19.9%. The province has a temperate continental monsoon climate. The flora and vegetation types are characteristic of a distinct transition zone and intersection of temperate and cold temperate plant species. Being the most famous coal base in China, Shanxi is bearing serious environmental damage from intensifying coal mining, which has been severely threatening biodiversity. It is an urgent task to preserve the remaining biodiversity and develop protected areas in Shanxi. Since the first nature reserve was established in 1980, until 2014, a total of 46 nature reserves have already been established in Shanxi Province. Nature reserves are the main entities in China's protected areas system, and may potentially fulfill criteria to qualify as strict nature reserves defined in IUCN protected areas categories. Therefore, we focused on nature reserves research in this study.

2.2. Threatened plant species

In this study, threatened plant species were determined according to the "List of National Key Protected Wild Plants in China" (The national forestry administration and the department of agriculture, 1999) and the "List of Provincial Key Protected Wild Plants in Shanxi" (The government of Shanxi Province, 2004). There were 57 threatened plant species in Shanxi, belonging to 38 families and 45 genera (Appendix A in Supplementary data). Among them, two species were under state protection I level; six species were under state protection II level; and another 49 species were under provincial protection level. As indicator of species status, these plant species have at least one of characteristics, including endangered, endemic to China/Shanxi, narrow distribution range, or small population (referenced to the IUCN Red List Categories and Criteria (IUCN 2001).

2.3. Species database

All available occurrence data of threatened plant species were selected and extracted from academic literature and specimen records (http://www.cvh.org.cn/). The species database consisted of scientific names, endemic description, administrative locations as well as specific geographic location designations (such as village and town, hill, nature reserve, etc.), altitude range, and habitats of 54 species, except for three species under data deficiency (DD). Based on the database, geographic distributions of species richness were mapped at the administrative city and county level. Considering that records on threatened plant species location cannot be geo-referenced to *XY* coordinates, the occurrence data were converted and scored into grid cells of 10 km resolution. In this analysis, we took into account species habitat preference to identify suitable locations with reference to the land use and land cover (LULC) map and vegetation map across Shanxi. The recommended 10 km resolution is roughly equivalent in spatial extent to the village and town level, which is less than the size of the smallest nature reserve established in Shanxi. In total, the study area amounted to 1075