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Conservation priorities of forest ecosystems with evaluations of connectivity and future threats: Implications in the Eastern Himalaya of China

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ABSTRACT

International biodiversity conservation prioritization efforts often focus on biodiversity hotspots or valuable species. However, for most parts of the world, comprehensive species data with acceptable quality are still scarce to support regional priority evaluations. To model the factors that favor a high/important degree of biodiversity and threats; in this study, we provide an alternative conservation priority approach to use when species data are insufficient. Based on a Landsat-derived forest cover map of 2010 of the Eastern Himalaya of China, we defined forest nodes, measured and delineated their importance with the connectivity metric dPC at regional and sub-regional scales. Based on a deforestation map of 2000 to 2010, we simulated deforestation from 2010 to 2030 using the Dinamica EGO software at multiple scales, and calculated the threatened degree of each forest node at an optimal scale. We then ranked the conservation priorities by coupling the measurements of the connectivity importance values and simulated threatened degree of each important forest node. Six forest patches (2.5% of remaining forest in 2010) were ranked as conservation priority patch-I and II. The unprotected parts are recommended to be expanded into or established as new nature reserves. Although species information was not used, the identified forest patches accommodated existing nature reserves (48% overlapped) in this region. As a fast and efficient assessment approach, with outcomes that are valuable for regional conservation planning, this method could be widely used for any forest dominant regions when field data is insufficient to identify conservation priorities at a fine scale.

1. Introduction

Deforestation and forest fragmentation are two of the main reasons behind the loss of biodiversity and loss of ecosystem services, such as the regulation of carbon sequestration, maintenance of nutrient cycles, provision of wood and non-wood goods, habitat services for species, as well as cultural services (Boulinier et al., 2001; Costanza et al., 1997; Franklin and Forman, 1987; Garmendia et al., 2013; Reddy et al., 2014). As resources for biodiversity conservation remain constrained and the location of and threats to biodiversity are distributed unevenly, prioritization is one of the most common and essential strategies for cost-effective conservation management (Brooks et al., 2006; Wu et al., 2014). Priority areas are usually identified using information on relative biodiversity values (species richness or endemic species), past or present threats to these values, ecosystem services at different scales and current levels of protection (Margules and Pressey, 2000; Reddy et al., 2015; Rubio et al., 2015; Wilson et al., 2006; Wu et al., 2014). However, the scarcity of comprehensive species distribution data with acceptable quality for most parts of the world constrains regional conservation planning at the fine, or local scale (Brooks et al., 1999; Fajardo et al., 2014; Huang et al., 2012). Meanwhile, a large number of ecosystem-based spatial metrics are being developed and applied to define changes in composition, structure and function; to model the factors that favor a high/important degree of biodiversity; as well as modeling the threat to biodiversity for conservation planning of remaining forest ecosystems without or with a little species information (Reddy et al., 2014, 2015; Rodriguez et al., 2007, 2011; Tambosi et al., 2014).

Network-based landscape connectivity metrics derived from graph theory have been applied to rank individual habitat patches in a region, or sets of patches in each local area within a region by their contribution to connectivity (Bodin and Saura, 2010; Rayfield et al., 2011; Rubio et al., 2015; Saura and Rubio, 2010; Visconti and Elkin, 2009). Habitat patches with the highest quantified values are considered the most important to

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maintain (Opdam et al., 2003; Pascual-Hortal and Saura, 2008; Reza et al., 2013; Rubio et al., 2015; Saura and Pascual-Hortal, 2007; Zetterberg et al., 2010). Unlike species-based conservation priority assessment, which focus on species-specific habitat patches; landscape connectivity stresses the maintenance and stability of natural ecosystems, habitat availability measurement, 'stepping stones' for species dispersal, and genetic flow of species population for biodiversity conservation (Fahrig and Merriam, 1985; Kramer-Schadt et al., 2004; Tambosi et al., 2014; Taylor et al., 1993; With et al., 1997), thus, conservation options resulting from landscape connectivity approaches are efficient and cost-effective as compared to single-species conservation (Reddy et al., 2015; Rodriguez et al., 2007).

There are multiple threats, such as deforestation, to the long-term existence of forest patches. Threat assessment and prioritization can help to identify and locate where biodiversity is at risk at the ecosystem level (Reddy et al., 2014; Tulloch et al., 2015). Spatially explicit simulation models attempt to replicate and predict the possible paths of various landscape shifts and their ecological attributes with distinct localization and configuration by integrating diverse temporal and spatial scales to represent various ecological system dynamics at the landscape level (Soares et al., 2002; Soares et al., 2006). Resulting maps can capture spatially threatening processes and can reflect landscape-wide retention and the persistence of biodiversity (Reddy et al., 2015). The simulation outcome can be translated by different social, economic, political and environmental frameworks (Turner et al., 2007), and used to select a better conservation strategy or management plan (Mas et al., 2012).

In this study, we evaluated forest patches for connectivity and modeled their future deforestation to determine conservation priorities of an important forest ecosystem in the Eastern Himalaya of China as an example. This area is an important global conservation hotspot (Brooks et al., 2006). As deforestation is continuing in this region (Brandt et al., 2012; Ren et al., 2015), a practical conservation plan based on prioritization analyses at the fine scale is urgently needed (Xu and Wilkes, 2004; YEPD., 2013). As is the case in many of the remote and rugged areas found in developing countries, a dynamic robust data set of important metrics, such as species diversity and ranges or habitat quality, are insufficient to support species-based evaluations at the fine scale (Huang et al., 2012; Xu and Wilkes, 2004). The goal of the study is to try to build a fast and effective way of setting regional conservation priorities for the forest ecosystem when species data are deficient, with the objectives of: 1) refining and providing a synoptic assessment of the remaining forests through the analyses of the optimal structural or functional connectivity of forest patches; 2) simulating future deforestation with distinct localization and configuration based on historical deforestation trends; and 3) identifying and ranking conservation priority forest patches based on the above two results.

2. Methods

2.1. Study area

Our study area is located in northwestern Yunnan and southeastern Tibet, between 25°30′-30°30'N and 98°0′-100°30'E, with an area of 6,123,911 ha (Fig. 1). This region is recognized as one of the most biologically rich temperate epicenters with more than 7000 plant and 800 vertebrate species; over one third of them are identified as endangered or endemic species (Chen et al., 2013; Ji et al., 1999; Sherman et al., 2008; Xu and Wilkes, 2004). This region has been enrolled in seven global biodiversity conservation priority templates and World Heritage Sites (Brooks et al., 2006; UNESCO, 2012), as well as several key national conservation programs of China (Lu et al., 2013; Wu et al., 2014). Due to the great geographic and ecological heterogeneity and rugged mountain terrain (with river valleys at 1000 m and some glaciated peaks over 6000 m), current field data are insufficient to properly support conservation planning (Huang et al., 2012; Ma et al., 2007; Zhang et al., 2013). Therefore, abiotic surrogates, such as landscape

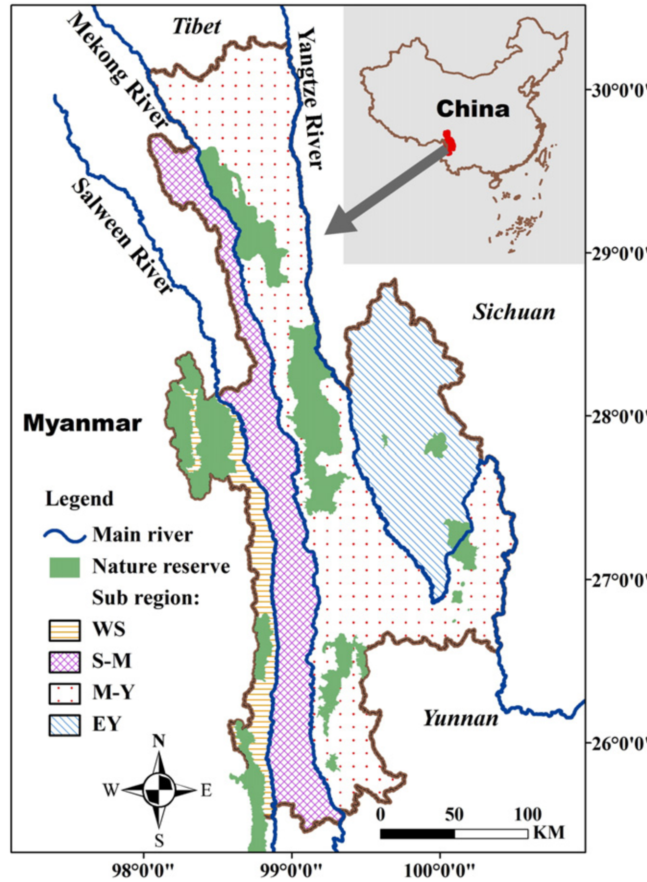

Fig. 1. The study region of the Eastern Himalaya of China was divided into four geographic sub-regions by major rivers (WS: west of Salween, S-M: between Salween and Mekong, M-Y: between Mekong and Yangtze, EY: east of Yangtze).

parameters, are in most cases the best alternative to move forward with conservation planning at the regional scale (Metzger et al., 2008). Considering the impact of natural barriers to species dispersal, we divided the study area into four geographical sub-regions bordered by major rivers (Fig. 1). Our analyses were conducted at two geographical scales: the entire region and sub-regions.

2.2. Historic forest cover and deforestation maps

Landsat TM/ETM^{+} images were used to create forest cover maps for 1992, 2000 and 2010 (Table A1). As our objective is to define conservation priorities, only high quality forests of ≥70% canopy closure (Reese et al., 2002) at ≥5 m high with an area of ≥0.5 ha (FAO, 2010) were classified as Forest; all other land cover types were defined as Non-forest. Classifications were undertaken within the *R* software using the Random Forests classifier (Breiman, 2001). Field data were collected for classification accuracy assessment by a sampling-protocol which was based on geographic strata and designed to enhance the geographic spread of the samples (Fig. A1). Results of the classification accuracy assessment showed, for the years 1992, 2000 and 2010, the Producer's, User's and Overall accuracies were all ≥0.95, and the Kappa statistics were 0.91, 0.90 and 0.91, respectively (Table A2). Deforestation for the periods of 1992–2000 and 2000–2010 were detected by overlaying the corresponding thematic forest-cover maps. Details of the classification and deforestation detection methods are described in Appendix A.

2.3. Importance of forest nodes for landscape connectivity

The probability of connectivity (PC) is a habitat availability index which integrates habitat amount, inter-patch dispersal probability and