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The rapid climate change-caused dichotomy on subtropical evergreen broad-leaved forest in Yunnan: Reduction in habitat diversity and increase in species diversity

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ABSTRACT

Yunnan's biodiversity is under considerable pressure and subtropical evergreen broad-leaved forests in this area have become increasingly fragmented through agriculture, logging, planting of economic plants, mining activities and changing environment. The aims of the study are to investigate climate change-induced changes of subtropical evergreen broad-leaved forests in Yunnan and identify areas of current species richness centers for conservation preparation. Stacked species distribution models were created to generate ensemble forecasting of species distributions, alpha diversity and beta diversity for Yunnan's subtropical evergreen broad-leaved forests in both current and future climate scenarios. Under stacked species distribution models in rapid climate changes scenarios, changes of water-energy dynamics may possibly reduce beta diversity and increase alpha diversity. This point provides insight for future conservation of evergreen broad-leaved forest in Yunnan, highlighting the need to fully consider the problem of vegetation homogenization caused by transformation of water-energy dynamics.

Human influence on the earth's climate has become more and more evident (Lindner et al., 2010). Climate observations have clearly shown that average global temperatures have increased by 0.8 °C since 1900 (http://www.sciencedirect.com/science/article/pii/S0378112709006604, Hansen et al., 2005; Hansen et al., 2010). Climate change can shape forest structure and function by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, and landslides (Dale et al., 2001). Shifts in vegetation distribution in response to past and current climate changes have previously been described (Peñuelas and Boada, 2003; Vacchiano et al., 2014; Guillera-Arroita et al., 2015). If current climate trends continue or accelerate, major changes to forest management will become necessary (Hamann and Wang, 2006).

The vast subtropical regions of Yunnan extend to mid-elevation areas where the complex topography, which includes hills, basins, river valleys, stone forests and valleys of lime rock areas, is distributed at different elevations. Compared to the subtropical regions in eastern China, subtropical Yunnan has unique features such as lower heat, mild winters and two distinct seasons, dry and wet. Influenced by landform, climate and anthropogenic effects, the present vegetation maintains its own diversity and complexity (KIBCAS, 1994; Zhao et al., 2001). Yunnan's biodiversity is under considerable pressure and subtropical evergreen broad-leaved forests in this area have become increasingly fragmented due to agriculture, logging, planting of economic plants, mining activities and changing environment (Yang et al., 2004; Xu et al., 2005; Li et al., 2007, 2011; Zhou and Grumbine, 2011). With the combined impact of anthropogenic effects and rapid climate change, understanding the compositional patterns of Yunnan's subtropical evergreen broad-leaved forest species and identifying areas of high alpha diversity as well as priority areas for conservation has become more significant for the development of sound conservation policies and their integration into a sustainable land development strategy for Yunnan (Zhang et al., 2012).

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Species distribution models (SDMs) have become a fundamental method in biogeography, ecology, biodiversity conservation and natural resources management (Guisan and Thuiller, 2005; Newbold, 2010; Franklin, 2013; Guisan et al., 2013; Guillera-Arroita et al., 2015). SDMs can be combined to model biodiversity at the community level following a 'predict first, assemble later' strategy, which has been used to identify threatened plant species hotspots, assess the invisibility of vulnerable native ecosystems and define areas of alpha diversity for conservation planning (Ferrier and Guisan, 2006; Parviainen et al., 2009; De la Estrella et al., 2012 Vorsino et al., 2014). In practice, however, SDMs provide only one point of view to correlate key environmental parameters with species distribution. Even though the models might under-represent complicated natural ecosystems by neglecting species plasticity, adaptation, time-lag and biological interactions, they can be used as the primary technique for projecting vegetation range shifts, evaluating conservation priorities and assessing reserve designs (Hijmans and Graham, 2006; Gallagher et al., 2013; Duckett et al., 2013).

In this study, we examine how rapid climate change will influence distribution patterns of Yunnan's subtropical evergreen broad-leaved forests in order to develop conservation policies. Our aims are to (1) investigate climate change-induced changes of subtropical evergreen broad-leaved forests in Yunnan; (2) identify areas of current alpha diversity centers for conservation preparation.

1. Materials and methods

1.1. Study area and data

Yunnan province, SW China, is one of the most botanically diverse terrestrial regions on Earth. Located at a transitional zone, Yunnan possesses both tropical Indochina mixed and subtropical East Asian flora, while located between major floristic regions, with the Sino-Japanese region in the east and the Sino-Himalayan in the west (Li and Li, 1997; Myers et al., 2000; Zhu et al., 2006). The region also shows a rich diversity of forest types and has a disproportionate amount of China's overall floristic diversity (51.6%), with over 18,000 plant species (Wu, 1987; Yang et al., 2004). In Yunnan, Evergreen broad-leaved forests almost extend all over whole tropical and subtropical Yunnan (Wu et al., 1987). According to ecological characteristics of vegetation, Yunnan's evergreen broad-leaved forests can be divided into 5 categories: Monsoon evergreen broad-leaved forest (ME), Semi-humid evergreen broad-leaved forest (SH), Mountainous humid evergreen broad-leaved forest (MH), Mountainous mossy evergreen broad-leaved forest (MM) and Summit mossy dwarf forest (SM).

Each category is composed of a characteristic set of species chosen from the *Vegetation of Yunnan* (Wu et al., 1987). Using the table of classification for Yunnan's vegetation, we identified four important families in evergreen broad-leaved forests: Fagaceae, Magnoliaceae, Theaceae and Lauraceae. Because SDMs with too few occurrences are considered less accurate, only valid species with at least 15 unique presences were adopted to prevent the generation of low-performance models (Stockwell and Peterson, 2002; Hernandez et al., 2006; Wisz et al., 2008). In this study, more than fifty species were dominant in Yunnan's evergreen broad-leaved forest. However, only fifty-five forest woody species, including eighteen constructive species and thirty-seven companion species, were qualified because of their reliable status in vegetation classification and their dominant position in comparison with other non-preferred tree species which only had extremely small records (<15). Every chosen species was assigned to one of five categories above in order to analyze environment conditions more individually and model species distributions more precisely as these five categories are greatly distinct in community constitution and structure as well as having very dissimilar terrains and climate specificity. The presence data of 55 forest woody species (Table 1) were provided by some herbariums in China, including 11 institutions in Chinese Academy of Sciences system and 21 national universities, totally 13,038 records (Fig. 1). All these records were also stored in Chinese Virtual Herbarium (http://www.cvh.org.cn/) or National Specimen Information Infrastructure (http://www.nsii.org.cn/) and are generally accurate, although a few identification errors occurred. We were finally able to produce 2405 geo-referenced collections which were effective and workable to continue operating. Presence data were scored at 5 arc min grid cells (ca. 10 $\times$ 10 km), because this spatial resolution is able to match the resolution for environmental data well since spatial errors in the geo-referenced records cannot be ignored with an overly high resolution.

To successfully model the distributions of 55 woody species for current environmental conditions, we used 19 bioclimatic variables (average for 1950–2000), as well as mean elevation, population density, 8 land cover or land use variables and 7 soil quality variables which are all at 5 arc min grid cells level. Current bioclimatic variables were used from WorldClim v 1.4 dataset (http://www.worldclim.org/) and land cover or land use variables, and soil quality variables were extracted from the Harmonized World Soil Database v 1.2 (http://www.fao.org/soils-portal/en/) (Hijmans et al., 2005; Fischer et al., 2008). To model distributions for future conditions only bioclimatic variables were used, as we considered soil conditions and land use beyond prediction. Therefore, 19 bioclimatic variables at 5 arc min resolution were collected from the WorldClim v 1.4 dataset for future climate conditions in 2070 (average for 2061–2080). We adopted ACCESS1-0 general circulation model under IPCC-CMPI5 RCP4.6. The ACCESS1-0 model provides the best performance simulating the climatology of atmospheric general circulations in East Asia and reproducing the historical inter-annual variability and the consistency during twenty-first century projections (Tian, 2013; Perez et al., 2014).

To avoid multi-collinearity of variables which can result in model over-fitting, highly correlated environmental predictors were removed by Pearson's pairwise correlation analyses in R v 3.2.2 (https://cran.r-project.org/) when the correlation coefficient > |0.70| (Graham, 2003; Pearson et al., 2007). Because 55 species could not share totally equal environmental conditions, we generally did the Pearson's pairwise correlation analyses based on the distributions of five classified vegetation categories. Five sets of variables were produced for both current climate conditions and future climate conditions (Supplement1).

1.2. Species distribution modeling and testing

BIOMOD2 v 3.1–64 was used to create SDMs (Thuiller et al., 2009). BIOMOD2 is a freeware, open source, package, which can efficiently generate ensemble forecasting of species distributions, and was implemented in R (Thuiller et al., 2013). This technique has been shown to greatly improve the accuracy of predictions over single-algorithm approaches and has also been widely applied in biogeography, invasion biology and conservation biology (Marmion et al., 2009). Six modeling techniques implemented in BIOMOD2 were employed in fitting and averaging the predictions: generalized linear model (GLM), generalized additive model (GBM), artificial neural networks (ANN), multivariate adaptive regression splines (MARS), Random Forest (RF) and Maximum entropy model (MaxEnt). These six models were chosen based on computation requirements and ability to evaluate response curves. The same set of responses, predictors and scenarios were used within modeling