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A model-based method to evaluate the ability of nature reserves to protect endangered tree species in the context of climate change

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ABSTRACT

Climate change has the potential to severely threaten endangered tree species. These species are important and sometimes dominant elements of natural communities. We conducted four years of field surveys to identify the distributions of endangered tree species present in the forests of north-eastern China. We conducted a detailed investigation of 1886 study plots and selected seven endangered trees (each with a total of $\geqslant$5 records) for further analysis. We modelled and mapped the distributions of potentially suitable climatic habitat for these species using the case of north-eastern China. We then developed a method that uses a combination of a species distribution model and geographic information system (GIS) to evaluate the ability of nature reserves to protect endangered tree species from disruptions caused by climate change. We found that the locations of suitable habitats for the seven endangered trees would shift variously according to different emissions scenarios and that this would result in a change in the effectiveness of each nature reserve to conserve the trees. Hence, emissions scenarios that result in increased amounts of suitable habitat give those nature reserves a strong ability to protect endangered trees. Emissions scenarios that result in decreased amounts of suitable land will decrease the ability of some nature reserves to protect endangered trees. Some of the tree species may be able to adapt to climate change, allowing the trees to survive in many of the nature reserves, but some may not. Ultimately, our method assesses the ability of nature reserves to protect endangered trees effectively and is a methodology that can be applied to any endangered species requiring planning for future protection and management.

1. Introduction

Endangered trees are the foundation of vulnerable forest ecosystems and possess high protected value (Soulé et al., 2003; Strange et al., 2007). Unfortunately, populations of endangered trees have decreased dramatically over the last few decades because of human interferences such as deforestation, overgrazing and forest fire (Abril et al., 2005; Salati and Nobre, 1991; Nepstad et al., 1996), climate change (Garcia et al., 2013) and natural disasters (Smith, 2013). Climate change should be considered as an important disturbance factor because it can influence the habitat, geographical distribution and genetic diversity of tree populations (Collevatti et al., 2011). Nature reserves play an important role in conserving the habitats of wild endangered plants through *in situ* and *ex situ* conservation, and establishing more nature reserves is a direct and effective way to protect wild species and manage forest resources (Holzschuh et al., 2011; Sang et al., 2011). Although nature reserves adequately protect some endangered trees, these reserves are not designed to be robust to changes in species habitat distributions or changes in the locations of endangered trees caused by climate change (Groves et al., 2012; Hamann and Wang, 2006). Climate change may drive endangered trees out of nature reserves. Consequently, serious deficiencies exist in the future ability of current nature reserve areas to protect endangered tree populations (Guisan and Thuiller, 2005; Velásquez-Tibatá et al., 2013). It is necessary for foresters and conservation biologists to propose a method to evaluate the ability of nature reserves to protect endangered trees facing the prospect of climate change.

Endangered trees are generally key species in forest communities in that they are essential components of healthy vegetative succession and provide habitats for many other species (Burns et al., 2003; Kohyama, 1993; Yu et al., 2011). Populations of many

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endangered trees have been sharply reduced, which has had a severe impact on the stability of forest ecosystems. At the same time, rapid climate change has placed pressure on the habitats of endangered trees, and the proper combination of temperature and precipitation for a given species may shift dramatically across the landscape (Hansen et al., 2001; Noss, 1999; Brukas et al., 2013). The localities of habitats may migrate indefinitely (Thuiller, 2004). Nature reserves cannot shift boundaries and move in response to climate change, so conservation biologists should consider the impacts of climate change on nature reserves (Mokany et al., 2013; Levy and Ban, 2013). To emphasise this issue, we have offered a method to evaluate the ability of nature reserves to protect endangered trees in the face of climate change.

Climate change has had a huge impact on the population stability and habitats of endangered tree species, many of which continue to decline in numbers (Dawson et al., 2011). These trees face serious challenges to their survival. Previous studies have found that climate is positively correlated with species habitat distributions (Ackerly et al., 2010). Preserving the habitats of endangered trees in the face of climate change is both imperative and urgent. Therefore, developing strategies to protect the habitats of endangered trees has become an urgent ecological issue.

We studied nature reserves in north-eastern China for this research. This region contains some of the richest temperate forest resources on Earth (Xiao et al., 2002; Yu et al., 2011). We selected seven endangered trees that are negatively impacted by climate change and human disturbance and are also listed as endangered or are under national protection in China (Chen and Li, 2003; Yu et al., 2011). The growth and distribution of these endangered trees can be seriously affected by precipitation and temperature (Liang et al., 2006; Iverson and Prasad, 1998).

Recently, new computational methods have been developed based on prediction algorithms that use species distribution models (SDM), one example being Maxent. In combination with geographic information systems (GIS), these programs predict the potential geographic distributions of species (Moreno et al., 2011). We used SDM and GIS to predict the potential distribution of suitable climatic habitat of endangered tree species. Maxent uses a model that predicts the density and distribution of species. All pixels are regarded as the possible distribution space of maximum entropy for that species (Phillips et al., 2006). The advantages of using Maxent were as follows: (1) it has the ability to handle low sample sizes, which drastically impacts both the performance and the adjustment of the SDM (Pearson et al., 2007), (2) it is insensitive to multicollinearity among predictors, which could disturb the analysis of species-environment relationships in multiple regression settings (Holcombe et al., 2007) and (3) it provides the relative contribution of each variable (Yang et al., 2013). It is important to consider the suitable climatic habitat distributions of endangered trees, while at the same time taking into account the roles of important nature reserves in northeastern China. Furthermore, GISs have been useful tools that support and allow the processing of the outputs of SDM algorithms (Hernandez et al., 2006; Zhao et al., 2013). Validation tests of our model show that it is reliable and generates good predictive performance in terms of the AUC, Kappa, and TSS results, which provided a solid foundation for habitat model building for these species (Allouche et al., 2006).

The objective of the study was to evaluate the ability of nature reserves to protect endangered trees according to two aspects: the protective ability of all of the nature reserves and of each nature reserve in the context of climate change (Guisan and Thuiller, 2005; Velásquez-Tibatá et al., 2013). The broader goal of this study is to help form the knowledge base needed to create preservation plans for endangered tree species in each nature reserve.

2. Materials and methods

2.1. Study area

We comprehensively surveyed the area of north-eastern China consisting of Heilongjiang, Jilin, and Liaoning provinces along with parts of Inner Mongolia, covering an area of 1.29×106 km^2 (38°40′38N–53°30′N, 115°05′E–135°02′E), representing 9.8% of the total area of China (Fig. 1). The morphological characteristics of this area are the Changbai Mountains to the east, the Daxing'an Mountains to the north, the Xiaoxing'an Mountains, and the western mountains of Liaoning to the west. The maximum elevation of these mountain chains is below 1000 m. These mountains surround the vast fertile plains of northeastern China, including the Sanjiang Plain, the Songnen Plain, and the Liaohe Plain (from south to north), with a maximum elevation of 200 m. This region belongs to the temperate humid/semihumid continental monsoon climate zone, with cold and dry winters and humid and rainy summers. In the past 60 years, the mean annual temperature has been 5.68 °C with a standard deviation (SD) of 1.47 °C. Precipitation during the summer months accounts for 50–70% of the total annual precipitation, with an annual mean precipitation of 614.9 mm (SD: 80.9 mm; Changchao et al., 2009). This area of northeastern China includes the largest area of natural forests (50.5 million ha) in the country. The forest stock in the region (3468 million m^3) accounts for 27.8% of the national total (Liu et al., 2013).

2.2. Sampling

Field investigations of species occurrences for all tree species were conducted across northeast China. We used the meshing tool in ArcGIS 9.2 to divide the map of northeast China into 25×25 km^2 grid squares. Each grid square located in the mountains and forests of northeastern China was systematically surveyed. Investigation plots (occurrence localities) of 30×30 m^2 were selected in each study square, and 3–7 plots were established according to the vegetation conditions of the survey area. When possible, plots were located in the centre of each grid square, but a plot's distance from the edge of the square was never less than 15% of the side length of the grid. A GPS unit was used to determine the centre location of each plot, and the presence or absence of endangered trees was recorded in each plot (Yu et al., 2012; Boria et al., 2014). A total of 1886 plots were investigated across the northeast region of China from 2008 to 2012. We selected seven endangered trees (each with $\geqslant 5$ total records of occurrence localities; Pearson et al., 2007): *Tilia amurensis*, *Chosenia arbutifolia*, *Phellodendron amurense*, *Pinus koraiensis*, *Fraxinus mandshurica*, *Pinus sylvestris*, and *Juglans mandshuricaby,* which are listed as under national protection (first-, second-, and third-degree protection) in China (http://www.plant.csdb.cn/protectlist). We found some of these endangered trees growing together in the same plot, namely, in similar habitats.

2.3. Environmental variables

The current and future data used for modelling were at 0.5-arc-minute spatial resolution (0.86 km^2 at the equator), making up the environmental layer input for SDM. Six bioclimatic variables were downloaded from the WorldClim database (www.worldclim.org): mean annual temperature, mean annual precipitation, temperature seasonality, precipitation seasonality, the minimum temperature of the coldest month and the maximum temperature of the warmest month. These variables, whose Pearson correlation coefficients with other variables were between 0.8 and −0.8, are important because they are considered critical parameters for modelling the geographical distributions of plant species (Gallagher et al.,