Biodivers Conserv (2015) 24:2383–2397
DOI 10.1007/s10531-015-0928-2

ORIGINAL PAPER

Management planning for endangered plant species in priority protected areas

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Received: 6 January 2015 / Revised: 17 March 2015 / Accepted: 1 April 2015 / Published online: 14 May 2015

Abstract We propose an improved planning method for priority protected areas (PPAs) to conserve endangered plant species that are threatened by climate change and human disturbance. Recent researches have shown that the actual approaches used in planning PPAs are useful for the conservation of endangered plants. The next required step is to determine how to protect endangered plants effectively in PPAs. Here, we used the case of 84 endangered plants in China to integrate conservation management into the planning of PPAs. First, we identified locations for proposed PPAs based on current and future suitable habitats of species, based on shifts due to climate change, as modelled by Maxent; secondly, we classified the species into different clusters based on the value of protecting them and the factors that threaten them; finally, we determined the best regions for conservation management. We found that species with high material, medicinal, and scientific research values of protection were threatened by over-exploitation and excess reclamation in PPAs. The best candidate PPAs were distributed mainly in southern China—the provinces of Fujiang, Guangxi, Guangdong, Fujian, Hunan, Zhejiang and Guizhou held large potential for the protection of endangered plant species. Given the attention that we paid to conservation management for the planning of PPAs, and the practical value of study, our method will provide an important point of reference for the implementation of policy to protect endangered plants from the effects of climate change, along with information about the values of protecting species and the factors that threaten them.

Keywords Conservation management · Endangered plants · Value of protection · Threatening factors · Climate change · Maxent · Zonation · China

Communicated by Peter Ashton.

Electronic supplementary material The online version of this article (doi:10.1007/s10531-015-0928-2) contains supplementary material, which is available to authorized users.

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Introduction

Endangered plant species are the subject of heightened concern around the world, because of their narrow extent of occurrence, small viable population sizes, and high scientific values. Such plants have become threatened or even become extinct due to the intensive use of nature resources, and anthropogenic climate change (Albrecht and McCue 2010; Bean 2009; Zeigler et al. 2013; Huang 2011; Sjöström and Gross 2006; Harris et al. 2012; Gibson et al. 2010). Extinction can be a natural process—conservationists aim to prevent unnatural extinctions that are associated with anthropogenic activities (Menéndez-Guerrero and Graham 2013; Neel and Che-castaldo 2013). Previous studies have proposed the creation of priority protected areas (PPAs) for endangered plants that have a narrow extent of occurrence, in order to monitor human disturbance and support the development of effective conservation policies (Adams-Hosking et al. 2014; Sravut et al. 2011; Carroll et al. 2010; Whitehead et al. 2014; Summers et al. 2012). Endangered plants can have significant socio-economic value, such as their uses as natural resources (e.g. wood processing), medicines, and in scientific research. Hence, over-exploitation of endangered plants is an ongoing concern, and the effective management of endangered plants in PPAs is an important conservation goal. Multiple facets must therefore be considered, such as the selection of suitable habitats based on the potential outcomes of climate change, the conservation values of regions, and other factors that threaten species (Sven et al. 2014; Summers et al. 2012; Lindenmayer 2009).

Climate change is having a significant impact on biological diversity (Bellard et al. 2012). One effect is likely the re-distribution of plants, and possibly even extinction, particularly for populations that are especially sensitive to the environmental change (Heino et al. 2009; Ruiz-Labourdette et al. 2012). Climate change has had a profound effect on biodiversity hotspots, whereby species either migrate, adapt, or become extirpated or extinct as the climate changes, all of which make endangered species harder to protect (Bellard et al. 2012; Zhang et al. 2014a). Recent studies have indicated that the adaptation of conservation management to change climate is a site-specific and potentially complex task (Sven et al. 2014; Abigail et al. 2014). Scientists currently use species distribution models (SDMs) and systematic conservation planning to make decisions about the conservation of endangered plants that are threatened by climate change (Zhang et al. 2014b; Moilanen et al. 2012). SDMs are useful tools for determining the suitable habitats of endangered plant species, based on their locations of occurrence and associated environmental variables (Merow et al. 2013; Conlisk et al. 2013). Although previous studies have defined the PPAs for endangered species based on SDMs and the theory of systematic conservation planning (Wan et al. 2014; Zhang and Zhang 2014), the challenges involved in the management of PPAs are increasing rapidly, so innovative approaches and tools are needed urgently (Richardson 2012).

How should conservation management be undertaken in PPAs? Recent studies have shown that the management of endangered plant species is far behind the practical needs outlined by the global Convention on Biological Diversity (1990); this body of research revealed some important factors that would cause poor implementation of the Convention in some regions: (1) the location of protected areas may be too unreasonable to sufficiently cover the suitable habitats of endangered plant species; (2) protected areas may be unable to adapt to climate change; (3) local laws and policies on the conservation of endangered plant species are not based on a reasonable assessment of species extinction (Muzaffar et al. 2011; Tsitsi 2014; Faleiro et al. 2013; Bellard et al. 2012; Rondinini et al. 2006;

Jørgensen 2013; Convention on Biological Diversity 2010). Jurisdictions often face challenges caused by the excessive exploitation of species and by harvesting the plant resources because endangered plant species have such high economic and medicinal values (Hamilton 2004; Joel et al. 1991; Richardson 1998). Solving these practical issues demands planning of the most appropriate locations for PPAs to conserve endangered plant species based on based on the conservation values of regions, shifts in species ranges predicted by climate change scenarios, and other factors that threaten species.

Located in the East Asian mainland, China is a large developing country with a marked continental monsoonal climate characterized by diverse weather patterns; it therefore possesses very rich plant resources, representing more than 10 % of the world's vascular plant species. The conservation of endangered species and their habitats is one of the most urgent tasks in the face of climate change, increasing human activity, and economic development, so it is expected that such plants in China will be impacted substantially. Moreover, with rapid economic development and ongoing resource exploitation, the sizes of endangered plant populations are declining significantly (Zhang et al. 2014a; Huang 2011; Wan et al. 2014; Yu et al. 2011). Previous studies have conducted PPA planning for endangered plants, such as the woody plants in Xinjiang, and orchid species in northeastern China (Zhang and Zhang 2014; Wan et al. 2014; Zhang et al. 2014a). However, PPAs obviously cannot cover all of China, although many species need to be studied. Hence, there is a need for continued development of effective approaches for planning PPAs.

Here, we address the problem of how to undertake management planning to support PPAs for endangered plant species under the scenario of climate change. We used Maxent (SDM), followed by Zonation, to delineate PPAs for endangered plant species. Maxent summarizes the potential relationship between the occurrence of a particular species and its habitat requirements; it is used widely to predict the probability of species existing in a target area (Phillips and Dudík 2008). Zonation is usually used as a spatial conservation prioritization framework to establish PPAs for multiple biodiversity features (e.g. endangered species) across large space–time scales (Lehtomäki and Moilanen 2013). First, we predicted the current and future suitable habitats of endangered plants based on a climate change scenario. Second, we integrated the current and future suitable habitats of endangered plants into PPAs. Third, we used principal component analysis (PCA) to evaluate the potential of PPAs to protect endangered plant species. Finally, we generated maps of conservation management and proposed effective suggestions for the management of PPAs in China.

Materials and methods

Species data

As study species, we selected endangered plants based on the List of National Key Protected Wild Plants approved by the State Council of China (http://www.plant.csdb.cn/protectlist)—the occurrence localities of those species were used as the input for SDMs. We obtained the geographical coordinates of occurrence localities from 175 scientific research reports of national nature reserves (detailed information provided in Acknowledgments) with a fair sampling to cover all provinces of China except Xianggang, Macao, Shanghai, Tianjing, and Taiwan. Although some reports did not report the geographical coordinates of some species, we were able to translate the recorded locations of species into latitude and longitude using Google Earth and ArcGIS 10.2 based on: (1) the detailed location and habitat description of species from research reports (Zhang and Zhang 2014; Zhang et al. 2014b); (2) vegetation information about species from the *1 : 1 Million Vegetation Atlas of China* (Compilation group of Vegetation Atlas of China (1:1000000) 2001); (3) county distribution information about the plant species from the *Atlas of Woody Plants in China: Distribution and Climate* (Fang et al. 2009); and, (4) the locations of species within 10 arc-min grid cells to avoid any georeferencing errors. These four factors limited the extent of species occurrences to 10 arc-min grids, roughly (Zhang and Zhang 2014; Zhang et al. 2014b). Finally, we used 5027 records that represented 84 endangered plant species, the number of recorded occurrence (the input of SDM) over 10 (Elith et al. 2011). It was important to consider whether the endangered plants considered in our study could represent the overall endangered plant species in each study region (i.e., we used the province as the given study region in our analysis). Our data on the recorded occurrences of Chinese endangered plant species were limited, so we could not conduct a full and accurate analysis for some study regions. To maximize precision, we calculated the proportion of our study species that appeared on the List of National Key Protected Wild Plants, which was equal to the representativeness of the study plant species for a target study region, as follows:

$$R = \frac{S}{N}$$

where R is the representativeness of endangered plants for a given study region, S is the number of endangered species studied in the singular study region, and N is the actual number of endangered species from the List of National Key Protected Wild Plants in this region.

Environmental data

Environmental data used for SDM modelling were eight current bioclimatic variables at a 10-arc-min spatial resolution, downloaded from the WorldClim database (Table S1; Hijmans et al. 2005). The resulting eight bioclimatic variables can influence the distribution and physiological performance of plants (Gallagher et al. 2012; Zhang and Zhang 2014; Zhang et al. 2014b). Eight future bioclimatic variables, to match the present day variables, were assessed using the average values of mohc_hadgem2, csiro_mk3_6_0 and cccma_canesm2 analogue data (for 2070–2089; 2080s), downloaded from the International Centre for Tropical Agriculture (http://www.ccafs-climate.org).

Representative Concentration Pathways (RCPs) 4.5 (mean 780 ppm; range 595–1005 by 2100) and 8.5 (mean 1685 ppm; range 1415–1910 by 2100) were chosen to represent the low and high greenhouse gas concentration scenarios (IPCC 2013; http://www.ipcc.ch/report/ar5/). The Special Report on Emission Scenarios (SRES) within that IPCC Assessment Report was used to determine projected changes in temperature and precipitation, and these projections were simulated using the global climate model (GCM). We used two RCPs to model a distribution of possible climate scenarios to estimate future distributions of endangered plants. RCP 8.5 differs from RCP 4.5 by having larger cumulative concentrations of carbon dioxide. The predicted direction of change favored environmental conservation and the sustainable development of society. RCP 8.5 differs from RCP 4.5 by having larger cumulative concentrations or emissions of carbon dioxide, resulting in a different pattern of climate change due to varying anthropogenic emissions of greenhouse gases and other pollutants (IPCC 2013).

Modelling suitable habitats of species

Occurrence locality data, were inputted to the Maxent software, along with climate variables, the eight selected environmental variables, to determine the current and future potential species distributions, namely, suitable habitats with maximum entropy (Elith et al. 2011). Maxent is advantageous for this type of modeling for a variety of reasons. (1) It has the ability to handle small sample sizes, which drastically and negatively impacts both the performance and the adjustment of SDM. (2) It is insensitive to multicollinearity among predictors, which can alter the analysis of species-environment relationships in multiple regression settings. (3) It provides the relative contribution of each variable using a jackknife test (Pearson et al. 2007; Merow et al. 2013; Yang et al. 2013).

When using Maxent to predict map cells, cell values of 1 are the highest occurrence probability, whereas values close to 0 are the lowest. We used information in Elith et al. (2011) and Calabrese et al. (2014) to set the reference for model parameters. We set the regularization multiplier (beta) at 1.5 to produce a smooth, general response that could be modelled in a biologically realistic manner (Saupe et al. 2014). The maximum number of background points was set at 10,000. We used a fivefold cross-validation approach to remove bias with respect to recorded occurrence points. We assessed the overall current and future suitable habitats for each endangered plant species, using the decade of the 2080s as the future, and we superimposed the suitable habitat maps of all endangered plant species to produce the overall current and future maps for all species combined (Calabrese et al. 2014).

We evaluated the predictive precision of Maxent using the area under the curve (AUC) of the receiver operation characteristic (ROC) that regards each value of the prediction result as a possible threshold, and then obtained the corresponding sensitivity and specificity through calculations (Wan et al. 2014). The models were graded as either poor ($AUC < 0.8$), fair ($0.8 < AUC < 0.9$), good ($0.9 < AUC < 0.95$), or very good ($0.95 < AUC < 1.0$). Models of each species distribution with values above 0.9 (good predictive precision, at least for ensuring the reliability of our analysis) were considered useful in our study (Faleiro et al. 2013).

Planning PPAs

Our definition of "conservation management" was based on three aspects: projected climate change, values of protection, and threatening factors. First, the delineation of PPAs in our study was based on climate change. We used Zonation conservation planning software (http://www.cbig.it.helsinki.fi/software/) to develop plans to protect the richness of endangered plant species threatened by the effects of climate change. Zonation is usually used as a spatial conservation framework to prioritize large-scale conservation projects that involve many species, to model the map with the most meaningful proportions of the most valuable areas of species richness. Hence, we could use Zonation to plan PPAs for endangered plants based on the current and future suitable habitat maps of species due to climate change. In this study, we adapted the reverse heuristic algorithm used in Zonation to establish protection areas for endangered plant species across large space–time scales. The highest priorities for conservation, namely, the suitable habitats of endangered plants, were confirmed by identifying the top-ranking cells after computation (Moilanen et al. 2012). We minimized the geographic distance between the current and future habitat distributions of endangered species, and considered the influence of climate change on the future suitable habitats of plants when selecting potential sites for reserves. The resulting maps generated using the current and future overall maps (combined for all species), assessed by the Maxent value for each pixel, were considered as biodiversity feature maps in the current, RCP 4.5 and RCP 8.5 scenarios. We used the original core-area cell removal rule as the definition of marginal loss in modelling, which aims to balance the solution across all features at each removal step (Leach et al. 2013). We set spatial priorities and calculated the marginal loss of each cell, which we could then use to determine if a conservation goal had been reached according to a given protection proportion of protected distributions for all of the species with the high priority ranking (Wan et al. 2014). The suitable habitat maps for the present days and future were assigned equal weight for the inputs of Zonation. We used information in Moilanen et al. (2012) to set the reference for model parameters. For practical purposes, we set only the top 17 % of sites in the landscape of Zonation result as the PPAs in China mainland, according to the target defined for terrestrial environments from Aichi Biodiversity Targets to 2020 (Faleiro et al. 2013). We used the value of pixels from Zonation as an index to evaluate the potential of each province to protect its endangered plant species, based on the future impacts of climate change.

Conservation management

We integrated conservation management considerations into the delineation of PPAs that accounted for 17 % of China's mainland areas, based on the values of protection and factors that threaten species. First, we classified the species into seven clusters based on their values of protection: ornamental, material, edible, fodder, medicinal, scientific research and greening, according to the assessment of *Rare and Endangered Plants in China* (China's State Forestry Administration and the Institute of Botany, Chinese Academy of Sciences 2013; Table S2). We also classified the species into six clusters based on threatening factors: over-exploitation, habitat fragmentation, excess reclamation of endangered plants, relic species, a small viable population size, and the lack of natural regeneration, using the same reference source (Table S3). Secondly, we superimposed the suitable habitats of species in each cluster to produce the suitable habitat maps for every cluster based on the values of protection and threatening factors, respectively. Thirdly, we extracted the suitable habitat map for each cluster using the PPAs (the regional template of suitable habitat maps for a given cluster) as the explanatory variables in PCA (ESRI 2014). PCA is a common method of multivariate analyses considering the correlation between multiple variables and can determine the index representing the most primitive variables (Franklin et al. 1995). A smaller data set can be generated from a large data set through the use of PCA, which objectively synthesizes and reduces redundancies in the data. In this study, it was assumed that the principal components (PCs) with the highest eigenvalues, and explanatory variables with the highest absolute eigenvectors, best represented the minimum data set. PCA has previously been used to identify discriminant management properties, based on values of protection and factors that threaten species. We used PCA in ArcGIS 10.2 (Esri, RedLands, CA) to demonstrate the impact of threatening factors on endangered plants, and the contribution of endangered plants to economy and society (ESRI 2014). We used the value of the leading PC of pixels as an index to evaluate the potential of each province to protect its endangered plant species, based on the values of protection and factors that threaten species, respectively.

We selected provinces with the high representativeness of endangered plants, and evaluated the potential of each province to protect its endangered plant species based on climate change, the values of protection, and factors that threaten species as follows (Araújo et al. 2004, 2011):

$$E_j = \sum_{k=1}^{k} p_{i,k}$$

where E_j represents the potential of each province to protect the endangered plant species in province j; k is the number of pixels in province j; and $P_{j,k}$ is the index value of potential to protect endangered plant species of pixel i in province j (based on climate change, the values of protection, and factors that threaten species, respectively).

Finally, we used linear regression analysis to compute the relationships between potentials of provinces to protect their endangered plant species based on climate change, the values of protection, and factors that threaten species; we then developed relevant suggestions for conservation of endangered plants in PPAs, and put them forward in this paper.

Results

Our modelling of all environmental variables produced high AUC scores for 84 endangered species (>0.9; mean 0.976; Table S4). The current and future suitable habitats of species were localized in central and southern China in the present day, and in the future (RCP 4.5 and 8.5 scenarios). Also, the areas of future suitable habitats of species would decrease under a low emission scenario, and move towards China's coastal provinces under a high emission scenario (Fig. S1). We found that temperature seasonality, minimum temperature of the coldest month, annual precipitation, and precipitation of the driest month were the important variables that influenced distributions of suitable habitats for plant species (Table S4).

We planned the PPAs for 84 endangered species that account for 27.27 % of National Key Protected Wild Plants, and found that these species could not represent the overall set

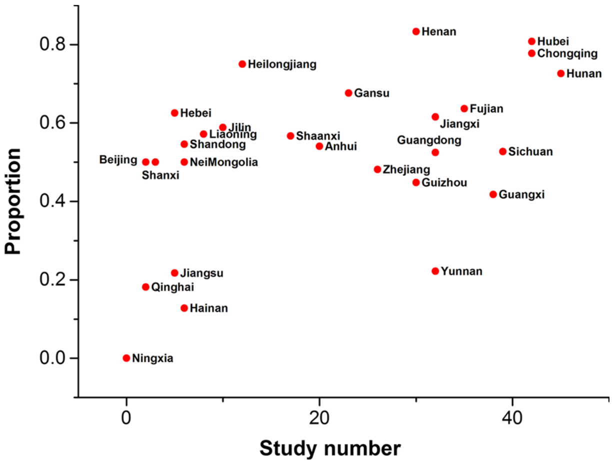

Fig. 1 Distribution of the proportion of endangered plants studied versus the actual number of species in the List of National Key Protected Wild Plants. Proportion: the proportion of endangered plants studied per province compared to the number of species in the List of National Key Protected Wild Plants. "Study number" represents the actual number of species in this study

of endangered plants based on the full list of National Key Protected Wild Plants in some provinces, such as Xinjiang, Xizang, Qinghai, Ningxia, Xianggang, Macao and Yunnan, because of the lack of information about endangered plants in those areas (Fig. 1). Some provinces such as Hubei, Chongqing, and Hunan had a high proportion and a large number of the study species (Fig. 1).

Using Zonation based on climate change, PPAs were distributed mainly in central and southern China including Guangxi, Guangdong, Fujian, Taiwan, Zhejiang, Jiangxi, Hunan, Guizhou, Chongqing and Sichuan (Fig. 2). We found that Fujian, Taiwan, Zhejiang, Jiangxi, Guizhou, Chongqing and Sichuan had the highest degrees of priority for protection (Fig. 2a). PC 1 explained 95.05 % of protection values and 81.38 % of threatening factors for species. That axis mainly described the protection values labelled as material, medicinal, and scientific research (i.e., the the major protection values), and the threatening factors of over-exploitation and excess reclamation (i.e., the most harmful factors for endangered plants). We found that endangered plants had high medicinal, material and scientific research values in Sichuan, Chongqing, Guizhou, Guangxi and Jiangxi (Fig. 2b), and that those species would be threatened by strong over-exploitation and wide excess reclamation in China's coastal provinces such as Guangdong, Zhejiang, Fujian and Taiwan (Fig. 2c).

Finally, we evaluated the ability of 14 provinces to totally protect their endangered plant species. There were significant associations between the potentials of provinces to protect their species based on climate change and the values of protection and factors that threaten species (Fig. 3; $P < 0.05$). We found that Guangxi, Guangdong, Fujian, Hunan, Zhejiang and Guizhou had the greatest potential to protect their species, indicating that these provinces should have large predicted PPAs for endangered plants, and those species had high values of protection and were threatened severely by human disturbance (Fig. 3). Taiwan and Xianggang had large potential to protect their endangered plants, but we did not consider those provinces due to the lack of recorded information about endangered plants there. Although Zhejiang, Guizhou and Guangxi had medium levels of regional representativeness of endangered plants, we do need to take these province into consideration due to their large potentials to protect their endangered plants, as evaluated by our study.

Discussion

In this study we constructed maps of conservation management, and proposed an improved method to integrate conservation management into PPAs for endangered plant species, based on suitable habitats and modeling with Maxent and Zonation. We found that species with high material, medicinal, and scientific research values of protection would be threatened by over-exploitation and excess reclamation in PPAs. The provinces localized in southern China, such as Guangxi, Guangdong, Fujian, Hunan, Zhejiang and Guizhou, had large potentials to protect endangered plant species. We need to concentrate efforts in those southern provinces, to protect endangered plants based on a combination of impacts of predicted climate change, the values of protection, and other factors that threaten species.

When using Maxent to model suitable habitats of species, three specific problems must be solved: (1) the limited records for occurrence of endangered plant species due to small wild populations; (2) low predictive precision; (3) the sampling bias of occurrence records (Pearson et al. 2007; Merow et al. 2013). Here, we used first-hand data for occurrence

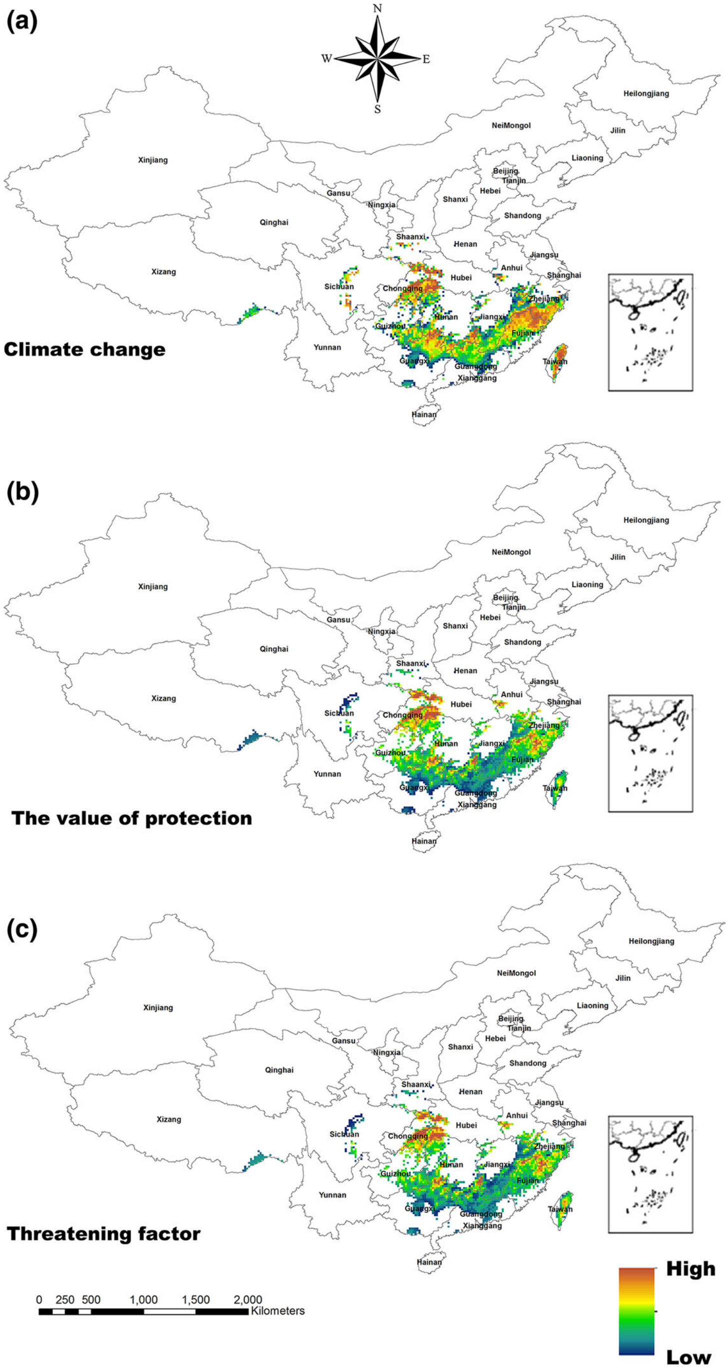

Fig. 2 The map of potential to protect endangered plant species based on projected climate change, values of protection, and threatening factors for plant species in PPAs. The color distribution from *light* to *dark* represents increasing potential to protect the endangered plant species based on climate change, the values of protection and factors that threaten species. (Color figure online)

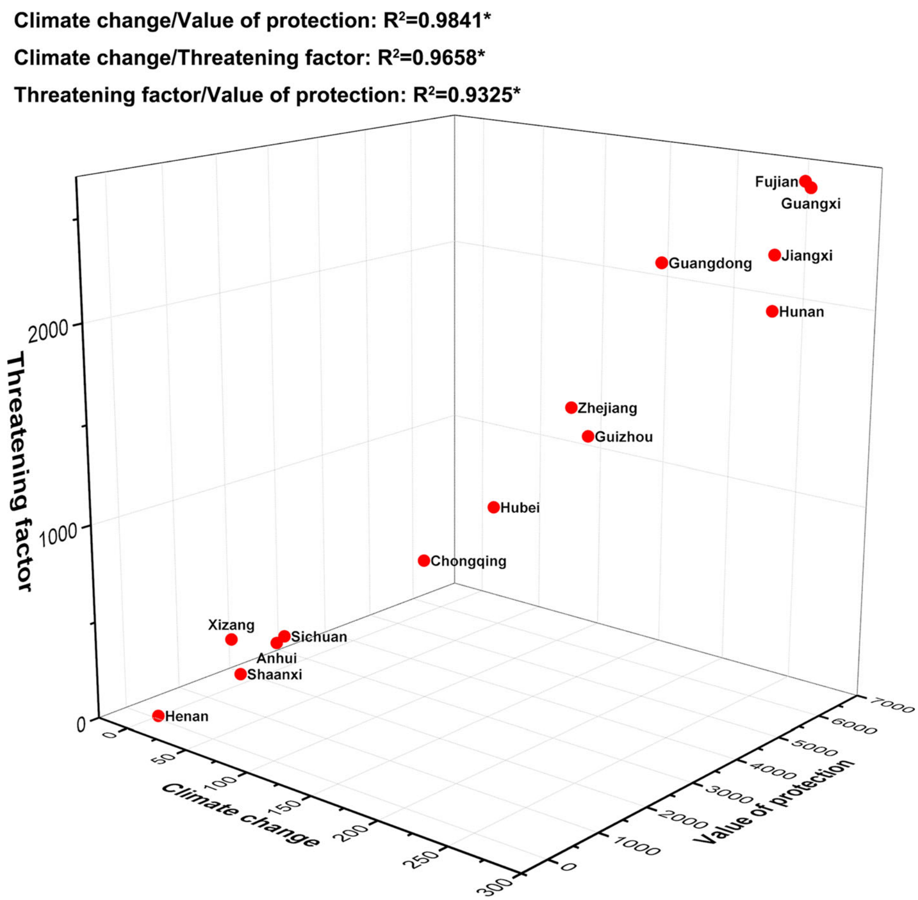

Fig. 3 Evaluation of potential of each province to protect its endangered plant species based on projected climate change, the values of protection, and factors that threaten species

localities based on various sources of reference to ensure the reliability of the information, and corrected errors in georeferencing of species. Moreover, we enhanced the level of AUC values (up to 0.9; Faleiro et al. 2013) for improving the predictive precision of Maxent. Our study was extensive, and included 84 species that account for 27.27 % of endangered plants in China, but our study was unable to represent endangered plants in some regions such as Yunnan, Hainan, Xianggang, Macao and Xizang—we are therefore unable to recommend a reliable conservation strategy for the endangered plant species in those regions. However as observed by Marcer et al. (2013), conservation action cannot wait until sufficient information is available for endangered plants, because in the interim we may lose the opportunity to conserve such species. We produced the visual management maps for endangered plants using a combination of Maxent and Zonation, to improve the effectiveness and practicality of PPAs. We did not attempt to plan PPAs based solely on climate change in China, but rather we also studied the values of protection and threatening factors for species, to better capture the management needs such as the conservation of endangered plant species.

We found that PPAs provided suitable habitats for endangered plants in the current and future scenarios, and that endangered plants with high values of protection were also threatened by human disturbance in PPAs.Thus, we addressed the protection of endangered plant species based on the impacts of climate change, values of protection, and other threatening factors.

First, we found that effective PPAs would be distributed in southern China and south-central China, which corresponds with the biodiversity hotspots for conservation priorities and covers the provinces with high plant diversity (except for Yunnan and Hainan)—this indicated that PPAs could play an important role in the conservation of endangered plants in the future (Myers et al. 2000). Moreover, some proposed PPAs would lose their protection function for endangered plants, due to re-distribution of species under climate change (Wan et al. 2014). These results compelled us to also consider the timeliness and effectiveness of PPAs in their planning (Sven et al. 2014; http://www.conservation.org). In these PPAs, we need to take action related to climate change, such as the monitoring of climate-induced impacts, assessing sensitivity to climate change, and policy recommendations for climate-adapted management (Sven et al. 2014). That could include monitoring of the climate variables that we determined were the most important, such as temperature seasonality, and improving the integration of climate-adapted management into conservation projects. The physical environments of China, and particularly central and southern China where the endangered species are concentrated, is highly diverse in its topography and litholology. Monitoring of the climate variables at a large scale did not include the impact of local climate change on the status of endangered plant species. Thus, we also need to consider the variation in rainfall patterns and mean temperatures on a local scale. For example, some species are confined to limestone ecological islands, a situation that critically reduces the opportunities for natural dispersal under climate change. Hence, after planning priority protected areas for endangered plant species, we should implement conservation management based on thorough field study, particularly regional climatic conditions.

Second, we not only considered the need for conservation of plants in PPAs based on climate change scenarios, but also recognized that it is necessary to address the reason for the disappearance of natural resource, based on values of protection. We found that endangered plants had high material, medicinal, and scientific research values in PPAs, indicating that these species made tremendous contributions to the development of economy and society (Joel et al. 1991; Richardson 1998). When using endangered plants such as in wood processing, Chinese traditional medicine, and exploration of plant origins from relic species in PPAs, people have neglected to preserve the minimum viable populations of species required for preventing extinction (Yu et al. 2011). These types of analyses must also incorporate the driving factors for species extinction, namely the threatening factors. The endangered plants were strongly threatened by over-exploitation and excess reclamation in PPAs, especially in Sichuan, Fujian Zhejiang, Guangxi and Guizhou. Hence, we should prevent the over-exploitation and excess reclamation of endangered plants in PPAs. We also should immediately cease the use of endangered plants, and take management action to maintain or restore populations at their viable population size. Here, we need to emphasize that excessive utilization of endangered plants should be particularly prevented in Sichuan, Chongqing, Guizhou and Zhejiang, because excessive use could result in extinction of plant species in those areas.

Our findings that some regions (provinces) such as Guangxi, Guangdong, Fujian, Hunan, Zhejiang and Guizhou had large potentials to protect endangered plants indicate that these regions must pay special attention to the development and management of PPAs in terms of three aspects: climate change, values of protection, and threatening factors. (1) Even taking all of this into consideration, it is important to remember that conservation measures should not be implemented hastily, and instead need to be data-driven and methodical in order to realize both their short- and longer-term conservation goals (Wan et al. 2014). (2) The regions with high representativeness of endangered plants and large potential to protect those species should be given attention, and then the resources of endangered plants should be conserved in PPAs within those regions (Faleiro et al. 2013). Anthropogenic activity has caused excessive deforestation and reclamation, so that the species in proposed PPAs are threatened with extinction in those regions. (3) We need to provide economic incentive to bring threatened species that are useful into commercial cultivation, thereby reducing the pressure on natural populations. (4) To conserve important genetic resources, we need to take in situ or ex situ conservation measures to protect endangered plant species. For example, we could strengthen the planning of nature reserves for endangered plant species (i.e. in situ conservation), and establish botanical gardens with a mission of protecting germplasm resources of plant species with high ornamental and scientific values, (i.e. ex situ conservation). Hence, considering that PPAs preserve abundant natural resources, we hope that government managers in China will enact corresponding laws and regulations to conserve the resources of endangered plants (Zhang et al. 2014a; Tsitsi 2014; Faleiro et al. 2013; Bellard et al. 2012; Rondinini et al. 2006).

In general, this analysis allowed us to establish a good evaluation system for protecting endangered plant species based on the factors of predicted climate change, values of protection, and threatening factors. PPAs are used not only for planning, such as in gap analysis, but we would suggest the rational use of endangered plant resources can help to stop species extinction, by ensuring effective conservation. Our study is a good example of SDMs, such as Maxent coupled with Zonation, applied to biological conservation and the management of endangered plant species. Although our study involved a limited amount of on-the-ground ecological validation, such as field investigation and ecological monitoring that would cost much time and hence slow down decisions about biological conservation, we urgently propose this conservation system for endangered plant species. We also need to pay attention to the consistency between predictions generated and reality on the ground. Hence, the field investigation of endangered plant species should be enhanced with the results of predictions as a reference. Further research will be needed to complement our study, such as how to integrate more species and regions into conservation management. The challenges for biodiversity conservation are increasing rapidly, and innovative approaches and tools such as ours are urgently needed (Richardson 2012).

Acknowledgments This research was supported by the Project entrusted to the Protection Division under the State Forestry Bureau, "Investigation and in situ conservation of *Pyrus hopeiensis*, the plant species with extremely small populations" (2). We thank the following National Nature Reserves for the use of their species data: Banqiao, Gujingyuan, Qingliangfeng, Songshan, Daiyunshan, E'meifeng, Longqishan, Minjianghekoushidi, Minjiangyuan, Tingjiangyuan, Xiongjianghuangchulin, Zhangjiangkouhongshulinshidi, Gansulianhuashan, Qinzhouzhenxishuishengyeshengdongwu, Taizishan, Yuhe, Haifengniaolei, Lianzhoutianxin, Luokeng'exi, Shimentai, Xiangtoushan, Yunkaishan, Bangliangchangbiyuan, Chongzuobaitouyehou, Daguishan'exi, Dayaoshan, Encheng, Fangchengjinhuacha, Huaping, Jiuwanshan, Qichong, Shiwandashan, Yinzhulaoshanziyuanlengshan, Yuanbaoshan, Dashahe, Fodingshan, Leigongshan, Yinggeling, Changlihuangjinhaian, Hengshuihu, Qingyazhai, Tuoliang, Xiaowutaishan, Baotianman, Henandabieshan, Gaoleshan, Huangheshidi, Jigongshan, Beijicun, Zhuonahe, Daxiagu, Mudanjiangdongbeihu, Dongfanghong, Duobuku'er, Fenglin, Heilongjiangfenghuangshan, Gongbielahe, Lingfeng, Maolangou, Mingshui, Mudanfeng, Pingdingshan, Qixingdongbeihu, Sanhuanpao, Shankou, Taipinggou, Wuyiling, Wuyu'erhe, Wudalianchi, Xiaobeihu, Xinqingbaitouhe, Youhao, Zhongyangzhanheizuisongji, Badongjinsihou, Duheyuan, Hubeidabieshan, Mulinzi, Nanhe, Qizimeishan, Saiwudang, Sanxiadalaoling, Shennongjia, Shibalichangxia, Wudaoxia, Xianfengzhongjianhedani, Xingdoushan, Yerengou, Baiyunshan, Dong'anshunhuangshan,

Dongdongtinghu, Gaowangjie, Hupingshan, Jintongshan, Jiuyishan, Wuyunjie, Xidongtinghu, Baishanyuanshe, Boluohu, Hunchundongbeihu, Ji'an, Jingyu, Shihu, Wangqing, Yanminghu, Dafengmilu, Yanchengshidizhenqin, Ganjiangyuan, Jiulingshan, Lushan, Qiyunshan, Tongboshan, Wuyuansenlinniaolei, Yangjifeng, Bailiangshan, Daheishan, Hongluoshan, Louzishan, Nulu'erhushan, Qinglonghe, Shedaolaotieshan, Yalujiangkoushidi, Zhanggutai, A'lu, Bilahe, Gaogesitaihanwula, Hanshan, Hanma, Qingshan, Wulanba, Datongbeichuanheyuanqu, Huanghesanjiaozhou, Nansihu, Heichashan, Lingkongshan, Guanyinshan, Hanchenghuanglongshanhemaji, Huangbaiyuan, Huanglongshanhemaji, Luoyangzhenxishuishengdongwu, Micangshan, Motianling, Pingheliang, Taibaishan, Taibaixushuihe, Wuliangshan, Zhouzhilaoxiancheng, Anzihe, Baihe, Caopo, Gexigou, Heizhugou, Jiudingshan, Laojunshan, Liziping, Nuoshuihezhenxishuishengdongwu, Qianfoshan, Xiaozhaizigou, Xuebaoding, Ailaoshan, Daweishan, Jiaozishan, Lvchunhuanglianshan, Nan'gunhe, Tongbiguan, Wenshan, Wumengshan, Yuanjiang, Yunlongtianchi, Jiushanliedao, Wuyanling, Changxingyangzi'e, Dabashan, Jinfoshan, Wulipo, and Xuebaoshan.

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