Pol. J. Environ. Stud. Vol. 24, No. 2 (2015), 725-733

Original Research

Model-Based Assessment of Priority Protected Areas: A case Study on *Fraxinus mandshurica* in China

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Received: 4 January 2014
Accepted: 8 August 2014

Abstract

Climate change has greatly affected the natural habitats of wild plants, especially vulnerable species. However, methods to properly assess priority protected areas (PPAs) that consider climate change have not been established. The distribution of *Fraxinus mandshurica* in northeast China was assessed, and our goal was to develop model-based strategies for the assessment of PPAs in consideration of climate change. To achieve this goal, we mapped the current and future suitable habitat distributions of *F. mandshurica* and planned PPAs based on 4 field surveys in northeast China. The models used in this study included a species distribution model (Maxent), systematic conservation planning model (Zonation), and geographic information system (ArcGIS 10.0). To promote sustainable development, the current and future suitable habitats of *F. mandshurica* must be integrated into the assessment of PPAs; however, the conservation areas of *F. mandshurica* in existing nature reserves cannot realize the conservation criterion of the Global Strategy for Plant Conservation (GSPC). In the eastern and northeastern regions of northeast China, the suitable habitats are predicted to migrate slightly northwards in the future. The methods used in this study are adequate for the assessment of PPAs and may provide a reference for the conservation and management of vulnerable plants.

Keywords: *Fraxinus mandshurica*, Maxent, Zonation, geographic information system, modelling, priority protected area

Introduction

Climate change has a far-reaching effect on the natural habitats of wild plants, especially vulnerable ones. Because of rapid climate change, the population numbers of species may gradually decline and even become extinct [1-3]. Therefore, it is both imperative and urgent that suitable habitats for wild plant species be conserved in consideration of climate change. However, determining effective methods of conserving the abitats of wild plants has become a significant ecological issue that must be solved [4, 5].

Current protection measures for wildlife primarily involve in situ and ex situ conservation. In situ conservation conserves target species in a suitable habitat through habitat protection, whereas ex situ conservation conserves target species by building conservation areas

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outside of their suitable habitats, which includes removing a portion of the population from unsuitable habitats and placing them in a suitable habitat, which may be a wild or managed environment [6-8]. Because rapid climate change has placed a huge pressure on natural habitats, it is reasonable to perform systematic conservation assessments of suitable habitats of wild plants impacted by climate change [3]. To date, numerous scholars have attempted to evaluate the effectiveness of existing priority protected areas (PPAs) using different methods; however, ecological simulations that consider climate change have seldom been used in such assessments. Faleiro et al. analyzed the PPAs in the Cerrado based on changes in climate and land utilization and then performed a vacancy analysis to assess the PPAs [9]. However, their assessment was based on species diversity over the entire region, and it cannot be applied for individual species. Zhang et al. conducted PPA planning in Yunnan, China, and they assessed the plant conversation capacity of the region using a vacancy analysis [10]; however, they did not consider climate change. Yu et al. explored the potential suitable habitat distribution of individual species and assessed the index of suitability of the investigated areas [11], but they did not demarcate the PPAs. Therefore, the methods of assessing the existing PPAs of certain species with a consideration of climate change remains to be explored.

In recent years, new methods that use ecological niche modelling to predict the potential suitable habitat distribution of species have been developed based on computed prediction algorithms [12]. Maxent and Zonation are two models that have been increasingly used by protected area planners and managers for species rehabilitation and habitat conservation [13]. The former is used to predict the potential distribution of species with all of the pixels regarded as a possible distribution space of maximum entropy, whereas the latter is used to design minimum reserves for wildlife and minimize the effective space required for conservation areas to respond to conservation goals [14]. The spatial distribution of wild plant species that are modelled using a maximum entropy model (Maxent) in relation to climate change allows for adaptive measures to be applied to conserve the habitats of wild plants based on current and future suitable habitat distributions [15]. The software Zonation may be used to identify operable solutions within particular zones by assessing the inclusion and exclusion of planned conservation units. Geographic information systems (GIS) are useful tools for planning and establishing nature reserves because of their ability to handle complex data [16]. These models may serve as good tools for PPA establishment.

Northeast China contains some of the most valuable wild plant resources on Earth [17]. *Fraxinus mandshurica* is a deciduous tree that belongs to the genus *Fraxinus* and family *Oleaceae,* and it grows among various plant species. It is the primary tree found in thin forests, flat valleys, or mountain slopes, and has scientific significance for research on tertiary flora and quaternary glacial climate in cold temperate zones. *F. mandshurica* is also distributed in other parts of Asia, and because of rapid climate change in recent decades, a significant decline has occurred in the number of *F. mandshurica* and size of its habitat. Thus, it has gained status on China's Red List of Biodiversity-Higher Plant Volume (www.mep.gov.cn) as a vulnerable plant.

To determine an effective PPA assessment method, we studied *F. mandshurica* to define its PPAs based on the Maxent, Zonation, and GIS (ArcGIS 10.0 ESRI, Redlands, USA) models. First, we modelled the current and future suitable habitat distributions of *F. mandshurica* based on the principle of maximum entropy. Second, we combined

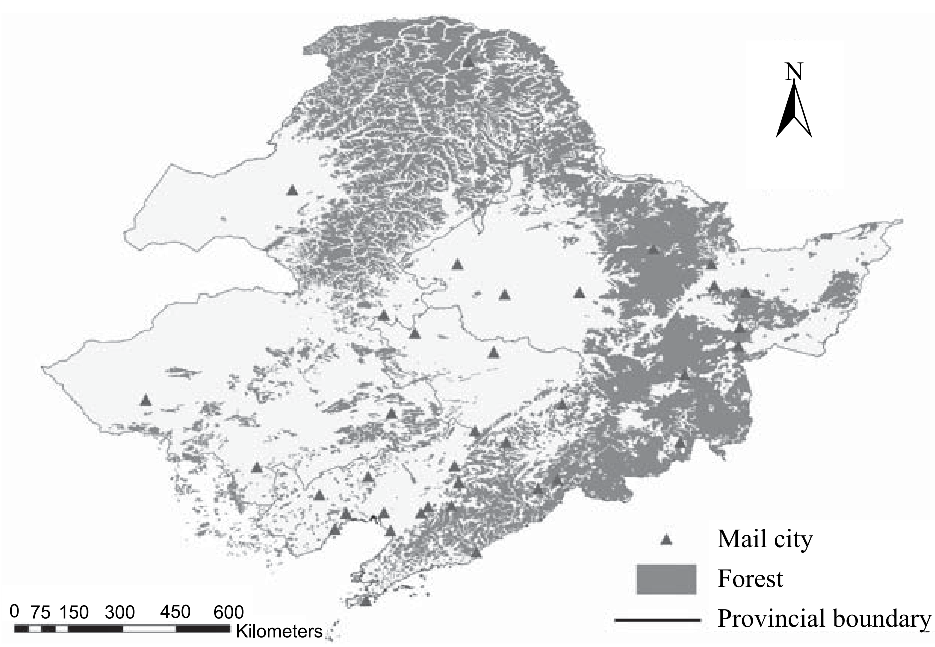

Fig. 1. The overview map of northeast China.

the suitable habitat distributions of *F. mandshurica* to generate a plan of PPAs and priorities for in situ and ex situ conservation based on PPAs. Third, we intend to assess the conservation power of the nature reserves of northeast China for *F. mandshurica* from PPAs.

Materials and Methods

Study Area

Our study involves the entire region of northeast China, including the provinces of Heilongjiang, Jilin, and Liaoning along with parts of Inner Mongolia, and it covers an area of 1.29 × 10^6 km^2 (38º 40' N–53º 30' N, 115º 05' E–135º 02' E), which represents 9.8% of the total area of China. The maximum elevation of these mountain chains is below 1,000 m. In the middle of these mountains lies the vast fertile plains of northeast China, which has a maximum elevation of 200 m. Over nearly 60 years, the mean annual temperature has been approximately 5.68ºC (standard deviation (SD): 1.47ºC). The rainfall during the summer accounts for 50-70% total annual rainfall, and there is a mean annual rainfall of 614.9 mm (SD: 80.9 mm). Northeast China includes 50.5 million ha of natural forests, which is the most in China (Fig. 1, [18-20]).

Sampling

The occurrence data of *F. mandshurica* were collected across northeast China using ArcGIS 9.2 (ESRI, Redlands, USA), which was also used as the meshing tool to divide the map of northeast China into a large number of 30×30 km^2 grids. Each grid that was located in the mountains and forests of northeast China was systematically investigated. Investigation plots (occurrence locations) of 30×30 m^2 were chosen in each study grid, and 3-7 plots were established according to the forest cover of the investigation area. Whenever possible, the plots were located at the center of the grids; however, the distance of the plot from the edge of the grid was never less than 15% of the side length of the grid. A GPS (Garmin Corporation, New Taipei City, Taiwan) was used to determine the locations of species. A total of 1,886 plots were investigated across northeast China from 2008 to 2012.

Table 1. Environmental variables used.

Code	Environmental variables	Unit
Bio 1	Annual mean temperature	ºC
Bio 4	Temperature seasonality	C of V
Bio 12	Annual precipitation	mm
Bio 15	Precipitation seasonality	C of V
LULC	Land use and land cover	23 types
ELE	Elevation	m
SLO	Slope	°
ASP	Aspect	°

Environmental variables were used as the environmental layers for the species potential habitat distribution in the Maxent model; C of V represents the coefficient of variation.

Environmental Variables

We downloaded four bioclimatic variables of 0.5-arc-minute spatial resolution, including the mean annual temperature, mean annual precipitation, temperature seasonality, and precipitation seasonality from the WorldClim database (www.worldclim.org). The selection criteria were as follows: 1) critical parameter for modelling the habitat distributions of wild plant species and 2) bioclimatic variables whose Pearson correlation coefficients with other variables were between 0.8 and -0.8 (21). A digital elevation data (DEM; 90 m resolution) was downloaded from CGIAR-CSI (srtm.csi.cgiar.org), and the aspect and slope data were obtained from the DEM using ArcGIS 10.0 (ESRI, Redlands, USA). Lastly, we used land use and land cover (LULC) data from GlobCover V2.3 (ESA Globcover Project; due.esrin.esa.int/globcover, [10]). The coding method for environmental variables is described in Table 1. We assumed that the elevation, slope, aspect, and LULC data would remain unchanged in the future. We used the A2 and B2 emission scenarios of the 2080s (HCCPR_HADCM3 analogue data) for the future environmental layer input of Maxent. The A2 scenario has a larger cumulative concentration or emission of carbon dioxide than does the B2 scenario. Therefore, different changes in climate will occur as a result of the influence of various anthropogenic emissions of greenhouse gases and other pollutants. Finally, the A2 and B2 scenarios were used as the high and low emission scenarios, respectively [22]. The conservation maps of northeast China were obtained from the World Database on Protected Areas (www.wdpa.org).

Modelling Current and Future Suitable Habitats of *F. Mandshurica*

Maxent (ver. 3.3.3; cs.princeton.edu/~schapire/maxent/) was used to map the current and future habitat distributions of *F. mandshurica* based on environmental variables with maximum entropy. The occurrence records of wild *F. mandshurica* collected from field surveys were treated as the sample occurrences, and the environmental variables, including elevation, slope, aspect, LULC, and 4 selected climate variables, were used as the environmental variables in the Maxent model. For the predicted map cells of Maxent, cell values of 1 were the most suitable, whereas values close to 0 were the least suitable [14].

Of the assessed plots (510 recorded locations or presence plots), 75% were used for model training and 25% were used for model testing. The maximum number of background points was 10,000, and auto features were used. Other values were retained as defaults. We used the jackknife test to analyze the importance of environmental

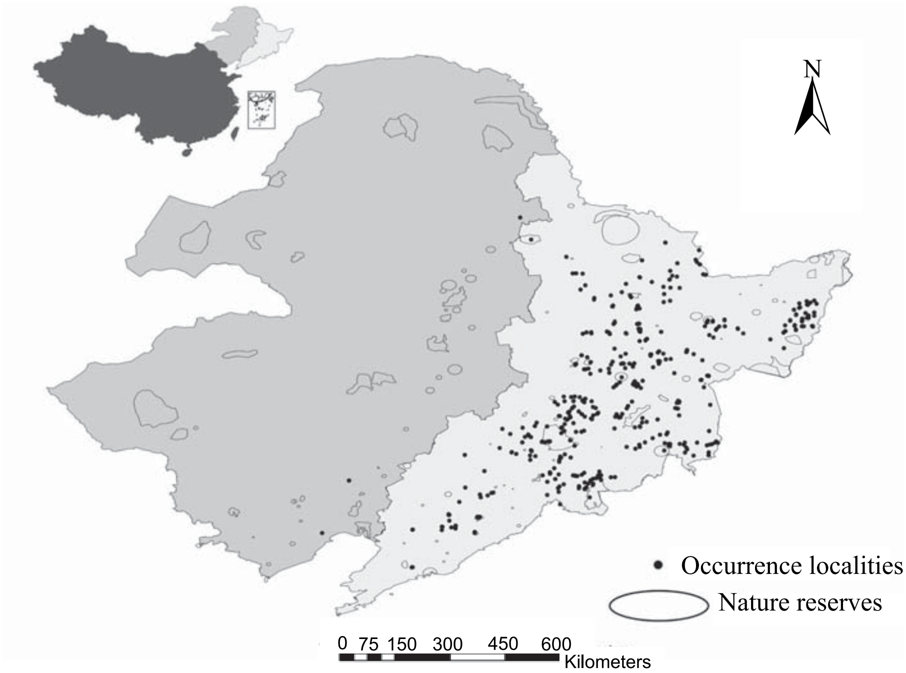

Fig. 2. Map of the 510 recorded locations of *F. mandschurica*.

factors with Maxent. The receiver operating characteristic (ROC) curve regards each value of the prediction results as a possible judging threshold, and the corresponding sensitivity and specificity are obtained through calculation. The precision of the model was evaluated by calculating the area under the ROC curve (AUC). The model was graded as poor (AUC<0.8), fair (0.8≤AUC<0.9), good (0.9≤AUC<0.95), or very good (0.95≤AUC<1.0). The value range from 0 to 1 of the final potential distribution of *F. mandshurica* was divided into four categories of potential habitats, i.e., 'high potential' (>0.6), 'good potential' (0.4-0.6), 'moderate potential' (0.2-0.4), and 'least potential' (<0.2). Finally, we regarded probability values that were equal to or greater than a threshold value of 0.5 to indicate the potential suitable habitat of the species and then created the potential presence distribution as the ecological region of this study for PPAs.

We used three measures to evaluate the model and its predictive ability, including the area under the AUC of the ROC, true skills statistics (TSS), and Cohen's kappa statistics (Kappa), to correct the overall accuracy of the model predictions. The ROC curves regarding each

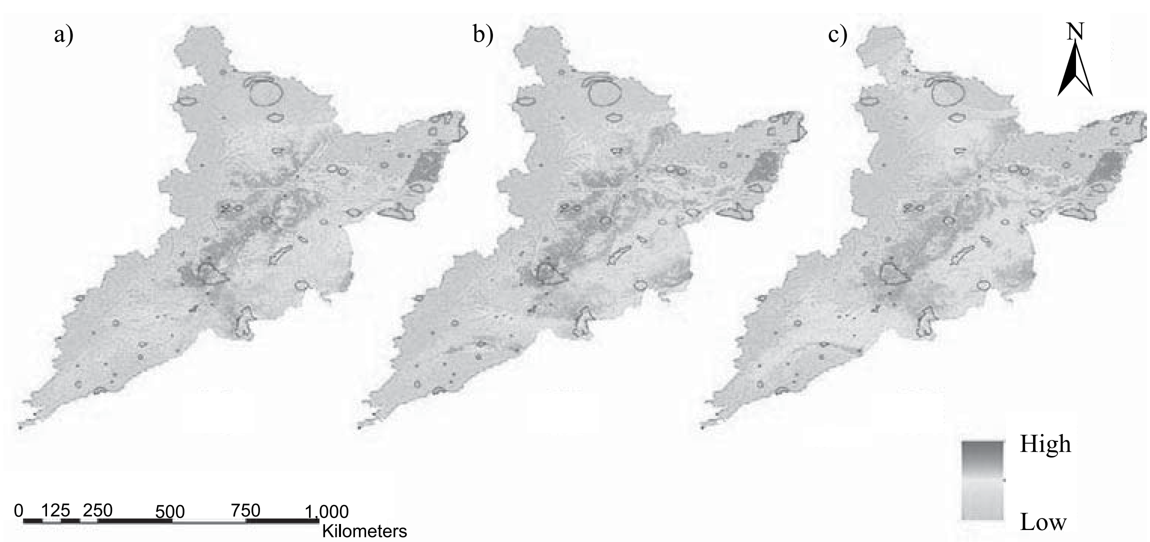

Fig. 3. Potential suitable habitat distribution of *F. mandschurica*. (a) Current potential suitable habitat distribution of *F. mandschurica* in northeast China, (b) future potential suitable habitat distribution of *F. mandschurica* in the A2 emission scenarios, and (c) future potential suitable habitat distribution of *F. mandschurica* in the B2 emission scenarios. The colour from shallow to deep represents changes in habitat suitability from low to high.

value of the prediction result were used as a possible judging threshold. An ROC was used in our analysis, and the corresponding sensitivity and specificity were then obtained through calculations. The precision of the model was evaluated by calculating the area under the ROC curve; based on its AUC value, the model was graded as poor (AUC<0.8), fair (0.8≤AUC<0.9), good (0.9≤AUC<0.95), or very good (0.95≤AUC<1.0). The TSS and Kappa ranged from –1 to +1, where values of +1 indicated a perfect agreement, and values of ≤0 indicated a random performance that is not affected by the prevalence or size of the validation data set [23].

PPA Assessment

First, we used Zonation conservation planning software (cbig.it.helsinki.fi/software) to develop plans to protect *F. mandshurica* related to climate change. The highest priorities for *F. mandshurica* conservation were confirmed by identifying the top-ranking cells after computation. We minimized the geographic distance between the current and future suitable habitat distributions of *F. mandshurica* and considered the influence of climate change on the future suitable habitats when selecting potential sites for reserves. The resulting maps were generated based on the current and future potential habitat distributions, which were assessed by the Maxent values for each pixel. Using the original core-area cell removal rule, we set spatial priorities and calculated the marginal loss of each cell, which was used to determine if a conservation goal had been reached according to a given protection proportion of distributions for *F. mandshurica* with high priority ranking. We set the current and future suitable habitat distributions at the same weight [24, 25].

We intended to protect 75% of the region selected in northeast China in accordance with Targets 7 and 8 of the Global Strategy for Plant Conservation (GSPC; www.cbd.int/gspc; [26]). For practical purposes, the potential distribution of *F. mandshurica* was used as the ecological region for in situ or ex situ conservation, and 75% of this ecological region, which includes the proportion of suitable distributions of *F. mandshurica* with a high priority, was included as a PPA [9]. Finally, we used ArcGIS 10.0 (ESRI, Redlands, USA) to compute the actual and PPA areas.

Results

The field investigations spanned 4 years and recorded 510 presence plots of *F. mandshurica* from the 1866 unique study plots. The *F. mandshurica* populations were mainly distributed in study areas that included the Changbai Mountains, Longgang Mountains, Xiaoxing'an Mountains, Daxing'an Mountains, and Wanda Mountains (Fig. 2).

Potential Suitable Habitat Distribution of *F. Mandshurica*

The model was shown to be reliable through model validation and predictive performance, with the value of

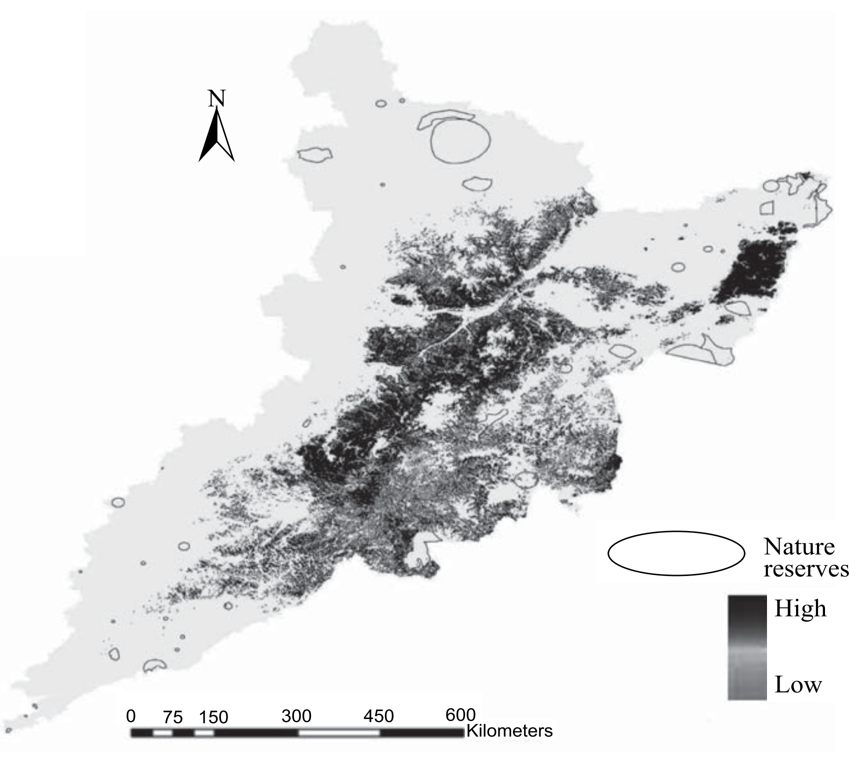

Fig. 4. Maps of the priority protection areas (PPAs) for *F. mandschurica*. The colours from shallow to deep represent an increase of the modelled values of spatial conservation used to evaluate the PPAs or higher priority protected levels.

AUC$_{training}$ at 0.925, AUC$_{test}$ at 0.923, Kappa at 0.603, and TSS at 0.762. The results of the jackknife method, which is used to validate the Maxent model, showed that Bios 12 and 15 provided the maximum contribution to suitable habitat distribution of *F. mandshurica*. The current suitable habitat distribution covered almost the entire core area of the actual distribution of *F. mandshurica*, which is shown in Figs. 2 and 3(a). The current and predicted future suitable habitat distributions of each species are presented separately in Fig. 3 (present days, a; A2, b; B2, c). The future suitable habitat distribution of *F. mandshurica* exhibited a shift toward northeastern areas with an increase in the distribution density. In certain nature reserves, the suitable habitat areas of this species varied with changing climate. Compared with the current suitable habitat distribution of *F. mandshurica*, the moving trend of B2 was more obvious and migration area was larger than that of A2.

The Definition of PPAs

Using Zonation software simulations, we generated a layer showing the PPAs in the study area that could support the conservation of *F. mandshurica*. We found that the PPAs were all distributed in the eastern, northern, and northern areas of the study region (Fig. 4), with 38.17% of the nature reserve areas in northeast China overlapping with the PPAs.

Certain priority areas are supported by existing reserves that could effectively protect *F. mandshurica*. Several nature reserves with large PPAs are located in the eastern and northeastern parts of northeastern China and include Songhuajiangsanhu, Changbaishan, Maoershan, Qixinglazi, Heilonggong, Jiejingkou, Songfengshan, Susu, Liangshui, Longwan, Laotudingzi, and Shanhe. Although the actual areas of Tiangangchaoyang, Mudanfeng, Wenziling, Anxingshidi, Xinkaihe, and Jiangnanlaoyinggou are small, their proportions of PPA-covered areas are large (Fig. 5). Some nature reserves have a small proportion of PPAs; however, they consist of areas with a relatively high density of *F. mandshurica* and contain more suitable habitats than those found in other nature reserves. However, the PPAs with a rank of very high priority that are located in the northeastern areas are covered by nature reserves.

Discussion

Four years of intensive field surveys have resulted in the collection of detailed distribution information for *F. mandshurica* in northeastern China. This information provided an important basis for predicting the suitable habitat distribution of *F. mandshurica.* Based on the model validation and predictive performance, the predicted habitat distribution of *F. mandshurica* was considered to be highly reliable [27]. We established a good general assessment system related to climate change and created and provided PPAs for in situ and ex situ conservation strategies for *F. mandshurica* in each studied nature reserve.

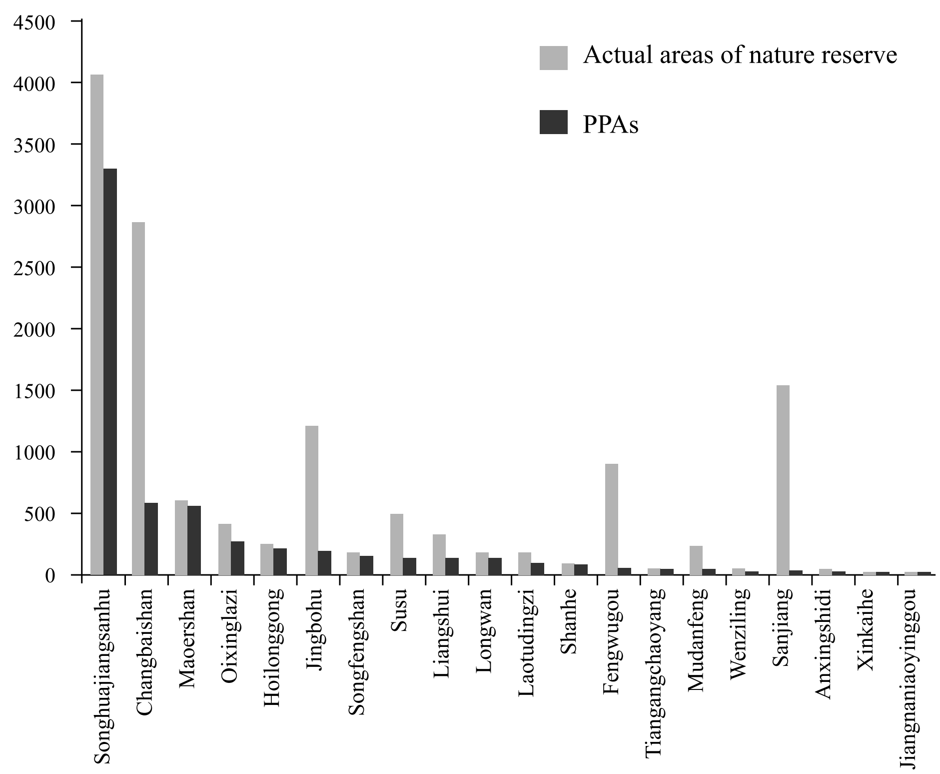

Fig. 5. Assessment of the important existing nature reserves with respect to PPAs. Actual represents the actual areas of nature reserves; PPA represents the areas within each nature reserve that can cover PPAs. Units are in km^2.

Numerous previous studies have shown that climate change has a negative effect on biodiversity and changes the distribution of species. These adverse effects have significantly impacted biological conservation measures [28-30]. The importance of emission scenarios that might improve the effectiveness of conservation measures impacted by the uncertainty of current and future habitat distributions for vulnerable species through plausible projections of climate change in the A2 and B2 scenarios for the 2080s (IPCC, Fig. 3) has been emphasised in this study. Because of the high accuracy of the model predictions of the suitable distribution of species in this study, a protection strategy could be developed for each nature reserve based on the changes in the temporal and spatial habitat distribution of *F. mandshurica*. Fig. 3 clearly shows the current and future suitable habitat distributions of *F. mandshurica* for the entire area of northeast China as well as the nature reserves over a 100-year period.

We would like to make several suggestions here. Two solutions for in situ and ex situ conservation could be used to address these various trends. In situ conservation measures that include the planning of conservation areas could be used to maintain the evolutionary and biological reproductive potential of viable populations, and ex situ conservation measures could be used to identify future suitable living environments for *F. mandshurica* that retain the persistence of the population [31-33]. The costs of climate change should be considered as a significant aspect related to protection plans in the modelling process [29]. In this study, a relative method of determining PPAs was used that might provide policy makers with a useful theoretical foundation for the establishment of conservation areas [34]. Because of the different effects of climate change across different nature reserves, developing a realistic model of universal costs has been difficult. As shown in Fig. 4, most of the actual and potential areas with suitable habitat distributions for *F. mandshurica* require urgent conservation action because most of these areas are not included in existing reserves. In addition, these existing reserves also play a crucial role in protecting plants. Therefore, in the assessment of priority areas for conservation, the priority protection measures would differ depending on the PPAs of *F. mandshurica*.

From Figs. 4 and 5 we found that the areas Songhuajiangsanhu, Changbaishan, Maoershan, Qixinglazi, Heilonggong, Jiejingkou, Songfengshan, Susu, Liangshui, Longwan, Laotudingzi, and Shanhe play vital roles in protecting *F. mandshurica*, especially Songhuajiangsanhu, Changbaishan, and Maoershan, because they have the largest areas of PPAs. For the nature reserves with large actual areas and small PPAs, such as Fengwugou and Sanjiang, protection districts for *F. mandshurica* could be established, whereas in the nature reserves that have a high coverage percentage of PPAs, such as Maoershan, Tiangangchaoyang, Mudanfeng, Wenziling, Anxingshidi, Xinkaihe, and Jiangnanlaoyinggou, sites for the in-situ and ex-situ conservation of *F. mandshurica* could be established. The eastern region of northeast China is the most important region for the protection of *F. mandshurica* throughout the entire study area. Therefore, the PPAs in these areas must be constantly monitored and provided with additional reserve lands, and they must adopt in situ and ex situ conservation methods. Additional conservation areas must be established to retain *F. mandshurica* in accordance with the importance of the PPAs and cost and manpower of nature reserve development (Fig. 4, [35-38]).

Although the existing reserves cover a certain area of northeast China, the area of protection is far smaller than the actual suitable habitat distribution area of *F. mandshurica*, and the overlap is too small. In addition, there are no nature reserves that cover the large PPAs in the northeastern areas of northeast China, so reasonable reserves based on actual local situations must be established and should then be developed into a coherent system or network, especially for the PPAs (Figs. 4 and 5). Therefore, the scope of protection should be expanded according to the results of the PPA distribution to achieve the target of the GSPC [39, 40].

Finally, this study did not consider the influence of changes in several features of the actual habitat used by *F. mandshurica*, such as the elevation, slope, and aspect. Therefore, in addition to considering climate change, these factors must also be considered to further improve conservation strategies that are focused on protecting *F. mandshurica* in northeast China.

Conclusions

Northeast China has rich wild plant resources; however, this region is strongly influenced by climate change caused by human interference. In this study, we assessed potential changes in the suitable habitat distribution of *F. mandshurica* populations in relation to climate change and considering the distribution of PPAs, which focused on the conservation power of nature reserves. This research is useful for ecological studies on the impacts of climate change to the distribution of vulnerable plant species. First, the suitable habitat distributions of *F. mandshurica* will shift in the future, so the planning of nature reserves must consider such shifts in distribution related to climate change. Second, it is not possible to effectively conserve *F. mandshurica* populations according to the uncertainty effect of climate change on the suitable habitats of species. Third, the PPAs of *F. mandshurica* cannot meet the targets of the GSPC. Therefore, because of the difficulty of establishing viable reserves over a long time period, additional research is required to improve the current conservation of *F. mandshurica*. Finally, in situ and ex situ conservation measures must be planned so that effective conservation actions for *F. mandshurica* may be realized in the future. Thus managers may adopt measures to conserve valuable species using more advanced assessment systems to promote sustainable habitats and populations.

Acknowledgements

The authors would like to thank the staff of the State Engineering Laboratory of Bio-Resource Eco-Utilization (Heilongjiang), Northeast Forestry University, China. This study was supported by the National Basic Research Priorities Program of the Ministry of Science and Technology of China (2014FY110600), the National Basic Research Priorities Program of the Ministry of Science and Technology of China (2007FY001), the National Basic Research Program of China (2011CB403200), and the National Natural Science Foundation of China (41330530) and Forestry industry research special funds for public welfare projects (201204601).

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