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THE CURRENT AND FUTURE POTENTIAL GEOGRAPHICAL DISTRIBUTION OF COMMON RAGWEED, *AMBROSIA ARTEMISIIFOLIA* IN CHINA

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Abstract

Common ragweed (*Ambrosia artemisiifolia*), originally from North America, has had an effect on the ecological environment, social economy and human health in the invaded area. The potential distributing area of common ragweed and the main factors that affect its distributions, were analyzed in China by Maxent model under the current and future conditions. Results showed that the accuracy of Maxent model is high in forecasting its potential distribution area, with an AUC value of 0.943 and 0.920 for model training and testing under the current conditions. The dominate factors were altitude, precipitation of coldest quarter, precipitation of driest month, precipitation of wettest month, isothermality, and precipitation of wettest quarter with thresholds of -50 to 300 m, 120 to 689 mm, 25 to 140 mm, 200 to 420 mm, 16 to 26 and 400 to 1200 mm. Under the current condition, 4.63% of the areas were identified as the optimum suitable areas of the ragweed, mainly located in south, north, east, central and northeast China, while moderately suitable area was 14.53%. To 50s and 70s of this century under 4 scenarios of RCP_s, proportion of the suitable areas are predicted to changes to 7.97%~10.72%and 7.87%~9.30%while moderately suitable area to 11.04~13.00% and 12.38%~13.09%, respectively. The results show that to 50s and 70s of this century, the suitable distribution area increases gradually and moderately suitable areas declines, while between 50s and 70s, the suitable area fluctuates in the small-scale. However, total area of suitable and medium suitable areas almost not change, indicating that in the future ragweed stably spread in present optimum and moderately suitable regions.

Key words: Common ragweed, Maxent model, Climate change, Potential distribution, $RCP_{s.}$

Introduction

Common ragweed (*Ambrosia artemisiifolia*), a member of Compositae, is an annual herb originally from North America, and was listed firstly as the list of invasive species from State Environmental Protection Administration in China (Liu *et al*., 2016). It is a malignant weed with strong reproductive and environmental adaptability, which seriously endangers agriculture, ecology and human health (Fumanal *et al*., 2007; Smith *et al*., 2013). For example, it can releases very allergenic pollen leading to health problems for sensitive persons (Galzina *et al*., 2010). And the species is introduced into other countries with seeds along with growing trade and transportation and is a noxious invasive plant worldwide (Hulme, 2009). In China, ragweed was first discovered in 1935 in Hangzhou city, Zhejiang Province of China (Chen *et al*., 2007; Liu *et al*., 2016). Since then and up to nowadays, it has been found in 1038 counties of 21 cities/provinces, which are mainly distributed in northeast, north, central, east China (Hao *et al*., 2015). Although some measures have been adopted since the arrival of this species, it is relatively time-consuming, laborious, expensive and has little effect. As a result, now the species has caused a series of local ecological, crop production in agricultural areas, and public health in our country (Hao *et al*., 2015; Liu *et al*., 2016). However, the detailed actual distribution of this species under current environmental condition in China is unclear as to pose great challenges for managers of biological invasion. So it is of great importance to know well the invasive area and future potential area of invasive species and species-environment relationships. Consequently, its potential hazards can be estimated scientifically, so as to take some effective measures for prevention and early warning efforts.

Many studies have shown that prediction and prevention of invasive alien species is more economical and effective than a single control after its outbreak (Chen *et al*., 2007; Xu *et al*., 2014). Recently, ecologists have developed some techniques to model species distribution based on ecological niche principles (Phillips *et al*., 2006; Wang *et al*., 2010). Currently, species distribution modeling (SDM), known as the ecological-niche modelling, is one of the most important tools to be able to assess species-environment relationship and ascertain the potentially suitable areas for a species (Guisan & Thuiller, 2005; Wang *et al*., 2019). However, of many species distribution model (i.e., Bioclim, Domain, Maxent and Garp), Maxent (Maximum Entropy) widely used in many academic disciplines, is a maximum entropy-based machine learning plan, which has a number of advantages for species distribution modelling relative to other models (Phillips *et al*., 2006; Qin *et al*., 2017). For example, Maxent model can utilize continuous and categorical data, incorporates interactions between different variables (Phillips *et al*., 2006), and has been proved to perform better than other ecological niche models, with only small sample sizes or presence-only occurrence data (Elith *et al*., 2006; Hu *et al*., 2015). Additionally, these models can also recognize some mainly environmental factors that limit a species' distribution. Therefore, Maxent model is very popular for accurately predicting species distribution (Elith *et al*., 2006; Wang *et al*., 2010).

Moreover, global climate change is expected to accelerate species invasion through ecosystem disturbance and enhance its competition (Bethanya *et al*., 2010). Previous studies lack dynamic analysis of the ragweed (Fumanal *et al*., 2007; Liu *et al*., 2016). Therefore, we used Maxent model to simulate the potential distribution of this species by combining known presence records with layers of environmental variables in China under current and future environmental condition. The purposes of our study were: (1) to ascertain the potential distribution of the ragweed under current and future environmental condition, (2) to identify which variables have the most important influence on its potential distributions; (3) to analyze whether the future environmental variation will promote invasion of the ragweed in China, ultimately providing targeted management strategies for preventing the species from invading and spreading.

Materials and Methods

Species distribution samples: The occurrence records of *A. artemisiifolia* were mainly obtained from two databases, namely, the Plant Specimen Database (http://mnh.scu.edu.cn), Chinese Digital Plant Specimen Database (http://www.cvh.org.cn) and some published scientific references (Wang *et al*., 2012; Li *et al*., 2015; Hao *et al*., 2015), which only provide small place names where it has been recorded. The coordinates of occurrence points were acquired by the Geographic Names Database (http://www.geonames.org/). Additionally, in order to avoid spatial autocorrelation, repeating records were removed and only one per grid cell was retained, so the 163 unique records was retained after checking these records. On the basis of the requirement of Maxent model, the occurrence points were kept in csv format by species name, longitude, and latitude in order.

Environmental data: In general, the geographical distribution of species relies mainly on its adaptability to environmental factors, such as climate, terrain, and so on (Xu *et al*., 2014; Qin *et al*., 2017), so environmental factors including 19 bioclimatic parameters and 3 topographic variables were selected. These bioclimatic parameters expressing a combination of annual trends, seasonality, and extreme conditions of temperature and precipitation (Hijmans *et al*., 2005) with 30 seconds spatial resolution were downloaded from the worldclim data portal (http://www.worldclim.org), which includes annual mean temperature (bio-01), mean diurnal range (bio-02), isothermality (bio-03), temperature seasonality (bio-04), max temperature of warmest Month (bio-05), min temperature of coldest month (bio-06), temperature annual range (bio-07), mean temperature of wettest quarter(bio-08), mean temperature of driest quarter (bio-09), mean temperature of warmest quarter (bio-10), mean temperature of coldest quarter (bio-11), annual precipitation (bio-12), precipitation of wettest month (bio-13), precipitation of driest month (bio-14), precipitation seasonality (bio-15), precipitation of wettest quarter(bio-16), precipitation of driest quarter (bio-17), precipitation of warmest quarter (bio-18) and precipitation of coldest quarter (bio-19). Elevation (DEM), with the same spatial resolution as the above one, also obtained from the WorldClim website, was utilized to generate the slope degree, slope aspect and elevation data layers using the surface analysis function of the software ArcGIS 10.2. The Representative Concentration Pathways (RCPs) is released by the fifth Assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). RCPs (i.e., RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were encoded in the light of a possible range of radiative forcing values in the year 2100 relative to preindustrial values (Hu *et al*., 2015). PCRs-2050 (average value for the years 2041–2060) and PCRs-2070 (average value for the years 2041–2060) were chosen and also downloaded from the World Climate Database (Hijmans, 2005). And the 3 topographic parameters (the slope degree, slope aspect and elevation data) were retained unchanged for the following analyses of Maxent under the future conditions. Meanwhile, all environmental data with GCS-WGS-1984, were obtained from the above global raster data overlaid by the administrative boundary maps of China in ESRI shape format in ArcGIS 10.2 and then be converted into 'ASCII' format in order to be compatible with Maxent. Additionally, the 1:400 million maps of national boundaries selected in this paper were downloaded from the national fundamental geographic information system (http:‖nfgis. nsdi. gov. cn/).

Predicting potential distribution and evaluation: Potential distribution of *A. artemisiifolia* was simulated by using the Maxent model because it has been proved to perform better with small sample sizes or presence-only occurrence data relative to other modeling methods (Phillips *et al*., 2006; Qin *et al*., 2017). Maxent software (version 3.4.1), downloaded from the portal (http://www.cs.princeton.edu/∼schapire/maxent/), was utilized in the present study, and the known distribution data and all environment variables can be directly imported into the Maxent model. In our models, 25% of the data points was utilized for testing, and the remaining 75% for training (Phillips, 2006; Qin *et al*., 2017). Meanwhile, "do jackknife to measure variable importance" and "create response curves" command were also checked in the model with other settings as default. The result generated by Maxent forecasts suitability of a habitat in logistic and ASCII types. Further, this result was transformed into raster format and then completed the grade classification based on the suitable values by using Jenks' natural breaks in ArcGIS 10.2. At the same time, all kinds of habitat area are calculated after projection conversion.

The area under the Receiving Operator Curve (AUC), widely utilized in ecological studies. was chosen to evaluate model's goodness-of-fit (Phillips, 2006; Qin *et al*., 2017). The value of AUC changes from 0.5 to 1.0 (Kumar *et al*., 2014). An AUC value of 0.50 suggests that the performance of the model is near to random and the prediction is poor, whereas a value of 1.0 suggests perfect discrimination (Jaryan *et al*., 2013; Xu *et al*., 2014). The model with the highest AUC value was regarded as the best performer.

Determining important variables and its threshold values: According to predictor contributions in the Maxent model, the main influencing factors for habitat suitability were able to be identified for *A. artemisiifolia.* Specifically, when the cumulative contribution rate of environmental factors is greater than 85% and the contribution rate of subsequent factors is less than 5%, these above factors are identified as the leading factors (Kumar *et al*., 2014). In addition, response curves also are used to analyse the relationships between habitat suitability for *A. artemisiifolia* and environmental factors (Hu *et al*., 2015).

Result

Current geographic distribution and evaluation: Based upon known coordinates of *A. artemisiifolia* and current environmental data, its suitable habitats was predicted by Maxent. In the model, the value of AUC (0.946 for training and 0.920 for testing) is near to 1, which suggests that the model displayed better than random performance. Therefore, Maxent model displayed well in forecasting the suitable habitat area for *A. artemisiifolia*. According to the classification standard adjusted slightly (Yang *et al*., 2013; Qin *et al*., 2017), the final potential distribution map were reclassed into three classes of potential habitats (0–1 range), namely 'suitable habitat' (>0.42), 'moderatly suitable habitat' (0.15–0.42), 'unsuitable habitat' (<0.15). The suitable distribution of *A. artemisiifolia* in China mainly is distribuated in northeast China (Liaoning and Jilin provinces), south China (Guangdong, Guangxi and Hainan, Fujian provinces and Taiwan), central China (Hunan, Hubei, Jiangxi and Henan provinces), east China (Jiangsu, Anhui and Zhejiang provinces and Shanghai city), and north China (Shandong and Hebei provinces, and Beijing city). The moderate suitable habitat lies in southwest China (Guizhou, Sichuan provinces and Chongqing city) and surrounding area of the suitable habitats of the above provinces and cities (Fig. 1).

Importance of environmental variables and their threshold: Among the 22 environmental parameters, altitude variable made the largest contribution (25.1%); and then followed by precipitation of coldest quarter (bio-19), with 21.0%. The percent contributions of precipitation of driest month (bio-14), precipitation of wettest month (bio-13), isothermality (bio-03) and precipitation of wettest quarter (bio-16) were 16.2%, 11.2%, 5.9% and 5.0%, respectively. The cumulative contributions of these six parameters reached to 84.4% (Table 1). Based on predictor contributions (Kumar *et al*., 2014), the above first six factors were regarded as the major environmental parameters. Using individual response curve for six different variables alone, we obtained the thresholds for these main environmental parameters (probability of presence >0.5): altitude variable ranged from -50 to 300 m, precipitation of coldest quarter (bio-19) from 120 to 689 mm, precipitation of driest month (bio-14) from 25 to 140 mm, precipitation of wettest month (bio-13) from 200 to 420mm, isothermality (bio-03) from 16 to 26 and precipitation of wettest quarter (bio-16) from 400 to 1200 mm (figures are not shown).

Predicted future potential distribution for 2050s and 2070s: The future potential habitats was also predicted by Maxent model with future environmental parameters. In these models, all the values of AUC is near to 1, indicating that these models' predictions are excellent too. According to the same classification regulation and projection coordinates discussed previously, habitat suitability for *A. artemisiifolia* is divided into 3 categories, and the area of each category is calculated. As shows in Fig. 1, under future environmental parameters, *A. artemisiifolia* could be potentially distributed in northeast, south, central, east, north and southwest China too. However, the proportion of each category has changed with the changes of the times. Under the current condition, 4.63% of the areas were identified as the suitable areas for *A. artemisiifolia*, while 14.53% was identified as moderatly suitable areas (Table 1). To the 2050s and 2070s of the century, the suitable distribution area increases gradually and moderately suitable areas declines, while between 50s and 70s of this century, the suitable distribution area fluctuates in the small-scale. However, total area of suitable and medium suitable areas almost not change (Table 2).

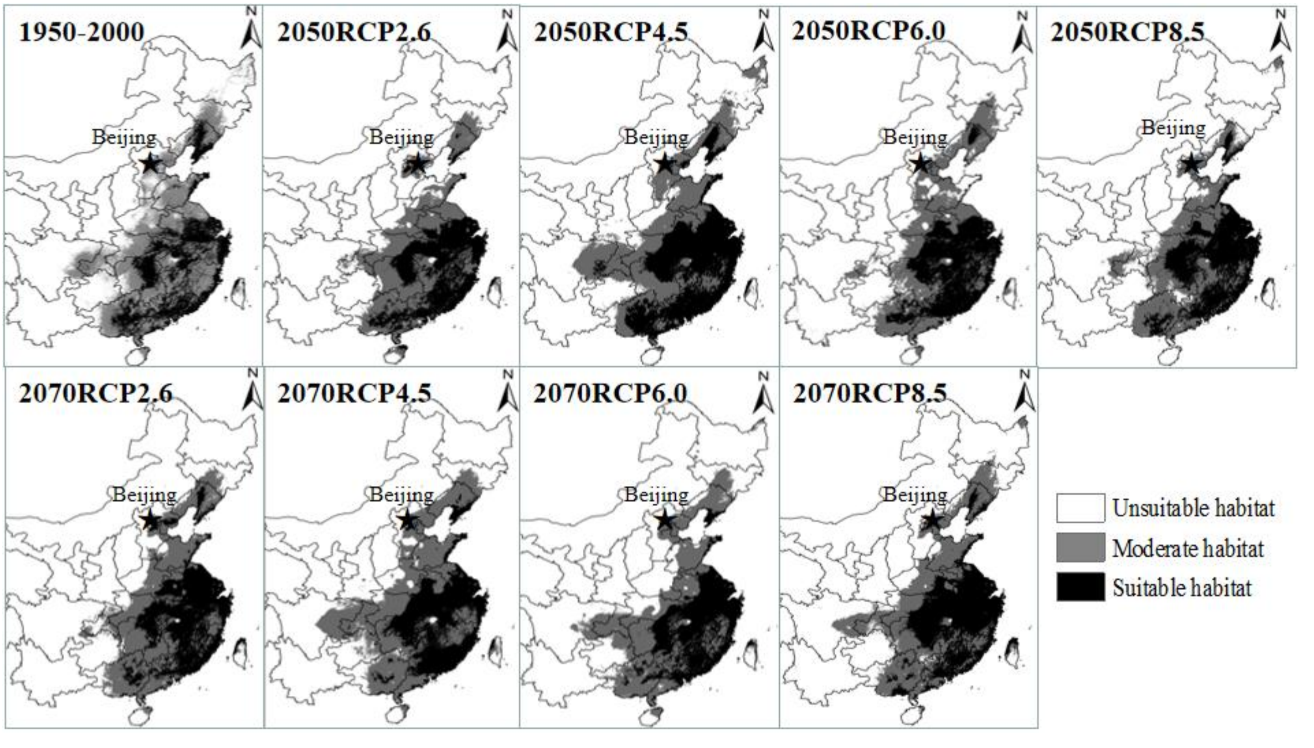

Fig. 1. Map of potential distribution for *A. artemisiifolia* under different environmental conditions in China.

Table 1. Environmental data used in the study and and their contribution.

Type	Code	Percent contribution (%)	Code	Percent contribution (%)
	Bio-01	2.3	Bio-12	0.4
	Bio-02	1.8	**Bio-13**	**11.2**
	Bio-03	**5.9**	**Bio-14**	**16.2**
	Bio-04	1.3	Bio-15	0
	Bio-05	1.8	**Bio-16**	**5.0**
Climate and terrain factors	Bio-06	0.3	Bio-17	0.4
	Bio-07	1.0	Bio-18	0.7
	Bio-08	1.2	**Bio-19**	**21.0**
	Bio-09	0.5	**Alt**	**25.1**
	Bio-10	0.1	Slope	1.8
	Bio-11	0.5	Aspect	1.4

Table. 2. Percentage of potential distribution for *A. artemisiifolia* under different environmental parameters.

Environmental parameters	Year	Percentage of area (%)		
		Suitable habitat	Moderatly suitable habitat	Unsuitable habitat
Current	1950–2000	4.63	14.53	78.75
RCP2.6	2041–2060	7.97	11.98	80.05
	2061–2080	8.54	12.38	79.07
RCP4.5	2041–2060	10.72	13.00	76.27
	2061–2080	8.53	12.45	79.02
RCP6.0	2041–2060	8.52	12.13	79.35
	2061–2080	8.87	13.09	78.03
RCP8.5	2041–2060	8.29	11.04	80.67
	2061–2080	9.30	12.89	77.80

Discussion

Ragweed is recognized as a kind of malignant invasion weed with strong reproductive and environmental adaptability, which has seriously endangered agriculture, ecology and human health in the invaded area (Fumanal *et al*., 2007; Smith *et al*., 2013). At present, one of the most important ways to prevention of invasive alien species is to prevent invasive species from entering areas suitable for their survival (Gallien *et al*., 2010). The species distribution models were regarded as an important tool for evaluating and forecasting the changes of the distributing area in species distribution (Phillips *et al*., 2006; Qin *et al*., 2017). Compared with other species distribution models, Maxent model is a commonly popular model for accurately forecasting species distribution in a certain region (Phillips *et al*., 2006; Jaryan *et al*., 2013; Qin *et al*., 2017). In present study, the potential distributing area of ragweed was simulated in China by using Maxent model under the current and future conditions and all the values of AUC is near to 1, implying that the Maxent model displayed well and the predicted results of the potential distribution of the ragweed were highly accurate. As shown in Fig. 1, under the current conditions, the suitable distribution of *A. artemisiifolia* in China mainly is distributed in northeast, south, central, eastand north China, and the moderate suitable habitat lies in southwest China and surrounding area of the suitable habitats of the above provinces and cities. The map is roughly consistent with the geographical distribution of previous studies and surveys (Chen *et al*., 2007; Liu *et al*., 2016). To 50s and 70s of this century, the suitable distribution area increased gradually from 4.63% to 7.97%~10.72% and 7.87% ~9.30% while the moderate suitable habitat decreased from 14.53% to 11.04~13.00% and 12.38%~13.09%, respectively. Besides, total area of suitable and medium suitable areas fluctuated around 20% or so, which indicated that *A. artemisiifolia* in China mainly is distributed in northeast, south, central, east, north, southwest China in the future, and global climate change accelerates this species to enter into the moderately suitable region (Fig. 1). So monitoring should be strengthened in these areas to prevent the species from the optimum area to the moderately suitable region.

Many studies indicated that the main factors restricting the geographical distribution of plants are cold tolerance, energy supply needed to complete life cycle and available water (Woodward, 1987; Jia *at al*., 2017). In present study, altitude, precipitation of coldest quarter, precipitation of driest month and precipitation of wettest month, isothermality and precipitation of wettest quarter with thresholds of -50 to 300 m, 120 to 689 mm, 25 to 140 mm, 200 to 420 mm, 16 to 26 and 400 to 1200 mm respectively were regarded as the major environmental parameters. It is reported that Ragweed spreads to other places with seeds, which experienced the dormant period in winter (Bassett & Crompton, 1975; Hao *et al*., 2015) and dormant seeds of ragweed cannot germinate at temperatures below 20 degrees (Kang *et al*., 2010). The lowest temperature in the coldest month can damage ragweed cells (Deng *et al*., 2010). Precipitation of coldest quarter with thresholds of 120 to 689 mm were conducive to enhance the temperature of the environment by maintaining soil moisture. The isothermally with thresholds of 16 to 26 increases germination rate of ragweed seeds (Bassett & Crompton, 1975). Altitude with thresholds of -50 to 300 m may influence climatic conditions, which result in changes to the timing and length of fruit bearing and flowering seasons for the ragweed. This is same as the viewpoint of the past research (Chen *et al*., 2007). Ragweed is a plant that likes dampness and is afraid of drought (Wang *et al*., 2006). Therefore, probability of presence is higher at precipitation of wettest month, and wettest quarter with thresholds of 200 to 420 mm, 400 to 1200 mm. Even if it is in driest month, life limit of the ragweed is in precipitation with thresholds of 25 to 140 mm. At present, few common ragweed has been recorded in northwest China (Shaanxi, Gansu, Ningxia, Xinjiang and Qinghai provinces) and southwest China (Xizang and Yunnan provinces), by guess, the reason may be drought in these provinces. In a word, rainfall is the limiting factor for the distribution of Common ragweed (Deng *et al*., 2010).

Conclusions

The suitable geographic distribution of *A. artemisiifolia* in China is mainly concentrated on southern, east, central, north and northeast China under current environmental condition; (2) To 50s and 70s of this century, the suitable distribution area increased gradually and moderately suitable areas declined, while between 50s and 70s of this century, the suitable distribution area fluctuates in the small-scale. However, total area of suitable and medium suitable areas almost not change; (3) altitude, precipitation of coldest quarter, precipitation of driest month, precipitation of wettest month, isothermally and precipitation of wettest quarter were regarded as the major environmental parameters. Monitoring should be strengthened in these areas to prevent the species from the optimum area to the moderately suitable region.

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