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Simulating the potential distribution of *Elaeagnus angustifolia* L. based on climatic constraints in China

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A R T I C L E I N F O

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A B S T R A C T

Elaeagnus angustifolia L. has considerable ecological value and plays an important role in windbreak and sand fixation, soil and water conservation, vegetation restoration and afforestation in Asia. Understanding the potential distribution and the limiting climatic factors is the first step for sustainable use of this species at regional scale. Here, we simulated the potential distribution of *E. angustifolia* and evaluated its limiting climatic factors using a maximum entropy model (MaxEnt) and geographical information system (GIS) in China, based on 190 occurrence grid cells and 13 climatic variables in China. The results show that: (1) annual range of temperature (ART), annual mean temperature (AMT), humidity index (HI), and coldness index (CI) are the dominant climatic factors limiting its potential distribution range; (2) low temperature is an important climatic factor that limits both southern and northern distribution boundaries, and high rainfall is another climatically limiting factor for the southern boundary, and (3) the potential distribution areas are mainly located in the warm temperate and middle temperate zone with cold and dry winters, and in the arid and semi-arid regions of China between 30°N and 50°N. The simulating results can improve our understanding of the geographical and ecological characteristics of *E. angustifolia*, and provide references for the introduction of this species for control and restoration of degraded land in China.

1. Introduction

Elaeagnus angustifolia L, also known as Russian olive or oleaster, is a deciduous small arbor or large multi-stemmed shrub, which is a member of the family Elaeagnaceae (Heywood, 1993), and is native to southern Europe, central and eastern Asia (Katz and Shafroth, 2003). It is a species with multiple traits of economic, ornamental, and high ecological value. Its branches, leaves, flowers, fruits, and juice extracts are widely used in food, medicine, papermaking, forage, wood, and furniture (Huang et al., 2005). Its oval crowns, silver leaves, fragrant flowers, and delicate fruits, as well as its distinct ability of resisting cold and drought stress, make it an excellent landscape tree species, especially in cold and arid areas (Asgarzadeh et al., 2014). Moreover, given its nitrogen-fixing ability (Khamzina et al., 2009; Shah et al., 2010) and saline-alkali tolerance (Liu et al., 2014), it is used as an excellent tree species for windbreak and sand fixation, soil and water conservation, vegetation restoration and afforestation not only in many native countries, but has also been introduced to non-native countries in poor soil for drought-resistant ornamental plant, such as United States and Canada (Collette and Pither, 2015a,b). Now, it has been the frequently occurring and the most dominant riparian tree species in all western United States and southern Canadian provinces (Friedman et al., 2005), where it has already been regarded it as an invasive plant because of concerns about its potential negative impacts, such as replacing native vegetation and altering stream nutrient dynamics (Katz and Shafroth, 2003; Collette and Pither, 2015b). This, however, does not prevent it from being widely used as an excellent plant for afforestation and land rehabilitation in native countries, such as China (Fu, 2016), Turkey (Yildiz et al., 2017) and Uzbekistan (Dubovyk et al., 2016).

In China, one of its native regions, *E. angustifolia* has been widely cultivated in the arid and semi-arid land since the 1980s, as an important pioneer tree species for afforestation. Currently, there are a large number of shelterbelts and windbreaks made by *E. angustifolia* in the arid and semi-arid regions in the Northwest of China. Furthermore, some economic forests are established by farmers in Ningxia, Qinghai, and Gansu provinces. Besides, it has also been cultivated massively in

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sandy wastelands and saline-alkali lands in the Northeast of China (Yu and Yan, 2009). Currently, there have been many explorations from the perspective of its germplasm resources and economic value (Guo and Wang, 2008), morphological and ecological characteristics (Sun and Lin, 2010), resistance physiology (Liu et al., 2014), and so forth. Recently, the environmental constraints of this species have been well studied in United States and Canada (Nagler et al., 2011; Friedman et al., 2005; Guilbault et al., 2012; Collette and Pither, 2015a), but these predictions were not informed by occurrence records from native countries. Whether their results is necessarily in line with China is still unknown. Therefore, the efforts to estimate the potentially distribution areas based on a wide range of occurrences data is still needed for widespread planting and afforestation management of this species at the national and provincial scale in China.

At present, the common method to study potentially species distribution and environmental suitable habitats is to use species distribution models (SDMs) (Hirzel and Le Lay, 2008; Elith and Leathwick, 2009; Booth et al., 2014; Booth, 2016). SDMs explore the niche requirements and potential distribution range of a species using specimen records from museums and a series of environmental variables (Khamzina et al., 2009; Li et al., 2014; Booth, 2016). The popular species distribution models include ecological niche factor analysis (ENFA), genetic algorithm for rule-set production (GARP) and maximum entropy (MaxEnt), among others. Each model has its own advantages and disadvantages. Nevertheless, several comparative studies show that MaxEnt has better prediction ability than most other models and it is considered as a robust modelling approach that incorporates statistical models and machine learning for characterizing probability distributions from incomplete information and determining the current and/or projected potential distribution of different species (Elith et al., 2006; Phillips et al., 2006; Pearson et al., 2007; Wisz et al., 2008). For example, Phillips et al. (2004, 2006) found that MaxEnt outperformed GARP on observational data for North American breeding birds and two Neotropical mammals (*Bradypus variegatus* and *Microryzomys minutus*). Furthermore, the ability of mapping the limiting factor and similar surface for range-shifting species, which expanded in the MaxEnt model by Elith et al. (2010), make it especially suitable for predicting potential species distributions and interrogate the causes behind predictions.

Many environmental variables are used to simulate the species niches with MaxEnt. Among them, climatic factors are widely used as the predictive variables, because they are thought to play a much more important role in determining the potential distribution of a species than soil and topographical factors with coarse resolution, and at a large scale (global or national) (Toledo et al., 2011; Guisan et al., 2013; Li et al., 2016a,b). Previous studies have also shown that climatic factors have a significant effect on the distribution of on *E. angustifolia* (Nagler et al., 2011) and its occurrence frequency is closely related to low temperature (Friedman et al., 2005; Guilbault et al., 2012) in western USA and Canada. Therefore, our goal was to identify the potential distribution of *E. angustifolia*, and climatic constraints in China using MaxEnt and geographic information system (GIS). This study mainly focused on the following two questions: (1) Whether the climatic limiting factors determining the range of *E. angustifolia* in China are similar as that of in exotic ranges? (2) Where are the climatically suitable habitats of this species in China? These two questions may help to better understand the geographical and ecological characteristics of *E. angustifolia* in China, which could serve as a reference for policy makers and planners for afforestation using this species in China.

2. Materials and methods

2.1. Study area

The study area is located in China, which covers a land area of approximately 9.6 million km^2 (3°52′–53°33′N, 73°40′–135°2′E) and its topography descends in a three-step staircase-like manner from west to east (Hou, 1983). The hydrothermal condition of China is strongly affected by the monsoon climate and the continental climate (Fang et al., 2002). There are a large areas of desertification in northwest of China (Zhu, 1998). Therefore, a number of desertification control initiatives have launched since late 1970s, such as the Three-North Shelterbelt Development Program (1979–2050, widely known as the Great Green Wall), National Program on Combating Desertification (1991–2000), and Croplands to Forests or Grasslands Program (2000–2010). During the implementation of these initiatives, many plants with the characteristics of drought resistance and saline-alkaline tolerance, among which *E. angustifolia* is considered an important candidate plant, were used for revegetation and afforestation in arid and semi-arid deserts, saline-alkali wastelands, and bare mineral substrates. The current distribution of *E. angustifolia* with deserts in China is shown in Supplementary Material Fig. S1.

2.2. Species data and climate variables

The occurrence records of *E. angustifolia* in continental China were retrieved from the Chinese Virtual Herbarium (CVH, http://www.cvh.ac.cn/, last accessed on 20 February 2017), Chinese Academy of Sciences Node of Global Biodiversity Information Facility (GBIF-CAS, http://www.gbifchina.org, last accessed on 20 February 2017), and published literatures. CVH integrated the herbarium data from 35 institutes in China, including the leading and important museums of China, and more than 45,000 data records. GBIF-CAS was established in 2013, through which, one can visit the National Specimen Information Infrastructure (NSII) to access more than 8 million specimen records in China. The published literatures mainly included the relevant papers searched with the keyword of '*Elaeagnus angustifolia*' from the China National Knowledge Internet (CNKI http://www.cnki.net/) and Wanfang Data Knowledge Service Platform (http://www.wanfangdata.com.cn). We compiled the species location data from the above sources for a period spanning 1960 to 2016. During data collection, the distribution data for *E. angustifolia* var. *orientalis*, as a synonym of *E. angustifolia* (Sun and Lin, 2010), were also collected. The location data were accurate at the county level. Records without the location information, as well as the repetitive data, were deleted. Records in parks, botanical gardens and orchards were also removed, because there would be regular or irregular human maintenance management in these places, which can not reflect the adaptability of the species themselves to the environment. Then the remaining location data were converted to points by digitising the centroid of each county. The occurrence data of those points were located on a map of China with a grid cell spacing of 10 arc min. We assumed that a grid cell was suitable for *E. angustifolia* survival, if one or more specimens were present in the grid cell. Then, a binary grid map (presence/absence map) with a 10 arc min spatial resolution was converted into points by using the "raster-to-point" function in ArcGIS 9.3 (ESRI, Redlands, CA, USA). Finally, a total of 190 occurrences were identified (shown in Supplementary Material Fig. S2). The latitude and longitude coordinates for each record were stored in an Excel database for MaxEnt model building.

A set of climatic variables compiled from Bioclim system (http://www.worldclim.org/), Kira system (Kira, 1945) and Holdridge life zone system (Holdridge, 1947) was adopted to characterize the climatic niche of the species, which consisted of 13 climatic variables: annual mean temperature (AMT), max temperature of warmest month (MTWM), min temperature of coldest month (MTCM), annual range of temperature (ART = MTWM − MTCM), annual precipitation (AP), precipitation of driest month (PDM), precipitation of wettest month (PWM), precipitation of seasonality (PSD = Monthly coefficient of variation of precipitation), annual biotemperature ($ABT = \Sigma T/12$, $0\,^{\circ}C < T < 30\,^{\circ}C$, T is the mean monthly temperature), potential evapotranspiration rate ($PER = 58.93 \times ABT/AP$), coldness index ($CI = -\Sigma(5 - T)$, $T > 5\,^{\circ}C$), warmth index ($WI = \Sigma(T - 5)$, $T > 5\,^{\circ}C$), humidity index ($HI = AP/WI$). The first eight variables were