Prediction of potential intrusion areas of *Ambrosia* L. plant in Jilin Province

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**Abstract:** *Ambrosia* L. plant refers to one of the critical alien invasive species in Jilin Province, which can significantly jeopardize the environment. In this study, the MaxEnt model and the ArcGIS were combined to predict the potential intrusion areas of *Ambrosia* plant in Jilin Province. Subsequently, the dominant environmental factors affecting the geographical distribution of *Ambrosia* plant were determined. Next, the geographical distributions and ecological niche overlap degrees of two species of *Ambrosia* plant were analyzed. As revealed from the results, the total areas of *Ambrosia artemisiifolia* L. and *Ambrosia trifida* L. in potential high and middle suitable distribution areas of Jilin Province reached 11988.71 km² and 48039.68 km², respectively. According to results, the environmental factors primarily affecting the distributions of *Ambrosia artemisiifolia* L. and *Ambrosia trifida* L. consisted of solar radiation (sard9) and annual mean temperature range (bio7) in September, as well as solar radiation (sard9) and isothermality in September (bio). *Ambrosia* plant was suggested to exhibit a high degree of ecological niche overlap and a large geographical distribution overlap. For the mentioned reason, this study laid a scientific basis for monitoring and controlling the spread of alien invasive species of *Ambrosia* plant in Jilin Province.

1. Introduction

*Ambrosia* L. plant pertains to Asteraceae. In Jilin Province has primarily two species of Ambrosia plants, i.e., *Ambrosia artemisiifolia* L. and *Ambrosia trifida* L., both recognized as annual anemophily herbaceous plants. Moreover, it originated from the southwestern United States and the Sonoran region of northwestern Mexico, and it is considered an extensively distributed malignant invasive weed worldwide [1]. In 2003, *Ambrosia artemisiifolia* was listed in “China’s First List of Invasive Alien Species”, and it has also been one of the top 10 alien invasive herbaceous plants released by the National Forestry and Grassland Administration. Jilin Province refers to a main invasive area of *Ambrosia* plant in China. Over the past few years, researches on *Ambrosia* plant largely concentrated on the transmission characteristics [2], biomass characteristics [3], community characteristics [4], harm and control [5, 6], etc. However, the prediction of potential invasive areas of *Ambrosia* plant in accordance with the MaxEnt model has not yet been reported.

Since the development in 2006 [7], the MaxEnt model has achieved wide applications in several...
research fields (e.g., the response of the species distribution to climate changes, the prediction of species distribution under future climate changes, prediction of invasive species surveillance areas, as well as the prediction of the potential distribution of endangered species)[8]. Such a model raises a low requirement for sample size and exhibits a high accuracy and a great stability even for small samples. On that basis, the MaxEnt model was combined here with the Geographic Information System (ArcGIS) to predict the major potential invasive areas of *Ambrosia* plant in Jilin Province, as well as to determine the dominant environmental factors of the distribution of *Ambrosia* plant. Based on the prediction results, this study attempted to analyze the geographical distributions and niche overlap degrees of two species of *Ambrosia* plant. Accordingly, this study laid a scientific basis for monitoring and controlling the spread of *Ambrosia* plant.

2. Materials and methods

2.1. Geographical distribution data of species and environmental variables

(1) Geographic distribution data. The following methods were employed to determine the geographical distribution coordinates of *Ambrosia* plant. (1) The field survey and the measurement were conducted on the distribution places of *Ambrosia* plant in Jilin Province, and the precise longitude and latitude were recorded by using the GPS. (2) Digital Herbarium of Plants of China (CVH, http://www.cvh.ac.cn/) was adopted. (3) Literatures related to *Ambrosia* plants were searched [9]. 56 geographical distribution points of *Ambrosia artemisiifolia* and 18 geographical distribution points of *Ambrosia trifida* were determined by applying the mentioned methods. To avoid spatial autocorrelation attributed to geographical aggregation, the nearest neighbor distance method was adopted to screen the sample data, i.e., only one distribution point was retained in 1km. Lastly, 52 and 18 geographical distribution data of *Ambrosia artemisiifolia* and *Ambrosia trifida* were applied for the simulation.

(2) Environment variables. The selected environmental variables consisted of 1) Climate variables: 19 climate factors related to temperature and precipitation (e.g., monthly maximum temperature (tmax), minimum temperature (tmin), average temperature (tavg), precipitation (prec), solar radiation (sard), wind speed (wind) and water vapor pressure (vappr)), overall originating from the World Meteorological Database [10]. The time range was 1970-2000a. 2) The terrain variable was the altitude (alt). On the whole, there were 104 environment variables.

Based on the method proposed by Li and Yang et al. [8, 11], the jackknife method was employed for the two species to detect the relative importance of environmental variables (7 species, 104 variables in total), and the variables with the contribution rate over 1.0% were retained. Subsequently, the ENM Tools were adopted to conduct a correlation analysis on the rest environmental variables. When the correlation coefficient reached over 0.85, the variables contributing less to the prediction were deleted, and 26 and 22 environmental variables were determined to finally simulate the distributions of *Ambrosia artemisiifolia* and *Ambrosia trifida*, respectively (Table 2).

2.2. Ecological niche model

Based on the MaxEnt model, the potential geographical distribution of *Ambrosia* plant in Jilin Province was predicted. With the collected distribution points of Artemia imported into the MaxEnt model software, 75% of these distribution points were randomly selected for the modeling, and 25% of these were adopted to verify the model. The maximum number of iterations was set to 1000, and the Bootstrap repetitive calculation was set to 10 times. The response curves were plotted. The environmental factors of the distribution of *Ambrosia* plants were analyzed by applying the jackknife method, and the feature and β multiplier applied in the training model were set. Subsequently, the optimal model was selected by setting β multiplier and the environmental characteristic parameters. β multiplier was set ranging from 0.1 to 4, which was elevated by 0.1 each time, and there were 40 levels in total. Besides, two different environmental characteristic parameters were set: (1) automatic selection of characteristic parameters. The model automatically adapted to five types of characteristics (e.g., linear-L, quadratic-Q, hinge-H, product-P, and threshold-T). (2) 5 characteristic parameters were set manually to obtain 6
feature combinations (i.e., L, LQ, H, LQH, LPQ and LQHP). Next, Lambdas files generated after the MaxEnt model was run and calculated with the ENM Tools program to determine AIC values (i.e., AICc) of different parameter combinations. The minimum value of AICc was taken as the optimal setting, and then the model was built [8, 12-14].

2.3. Evaluation of model results and grading of suitable areas

Through the Conversion Tools-ASCII to Raster in ArcGIS 10.4, the file of the asc format in the simulation results that were achieved after running the optimized parameters with the MaxEnt was converted into Raster data, and the suitable area was split. By referencing the method proposed by Shao et al. [9], the levels of suitable areas were divided, and the range of existence probability was marked. To be specific, if the existence probability was less than 0.1, a non-suitable area would be formed; if the existence probability equaled to or reached over 0.1 but less than 0.35, a low suitable area would be formed; if the existence probability was equal to or larger than 0.35 but less than 0.6, a medium suitable area would be formed; if the existence probability equaled to or exceeded 0.6, a highly suitable area would be formed. Next, the area of each suitable area was calculated and compared.

In the present study, the MaxEnt model used the AUC scoring method (area value under the ROC curve) to assess the accuracy of the model proposed. The evaluation criteria fell to 5 grades (e.g., poor (AUC ≤ 0.80), average (0.80 < AUC ≤ 0.90), good (0.90 < AUC ≤ 0.95) and very good (0.95 < AUC ≤ 1.00) [15]).

2.4. Geographical distribution and ecological niche overlap

ENMTools 1.4.4 was adopted to calculate the ecological niche overlaps of Ambrosia artemisiifolia and Ambrosia trifida. Such a software is capable of exploiting the output result of the MaxEnt to directly measure the parameters (e.g., the ecological niche overlaps and geographical distribution overlaps of species). Schoener’s D (D) and Hellinger’s-based I (I) values were employed to represent the ecological niche overlap. D and I values ranged from 0 to 1. With the increase in the value, the ecological niche overlap would be improved [16, 17].

3. Results and analysis

3.1. Model accuracy test

This study predicted the potential geographical distribution area in accordance with the number of the geographical distribution points and the corresponding environmental factors of Ambrosia artemisiifolia and Ambrosia trifida in Jilin Province. After the combinations were screened by using the AICc index, the combinations of the minimum AICc values of the two species were selected; to be specific, the feature was LQ and LP, and β multipliers reached 1.5 and 1.4, respectively. As indicated from the results, the degree of fitting predicted through the AICc minimum model prediction was higher than that predicted based on the default parameter model. Next, the optimized combination was exploited to rebuild the model, and then the model was repeated 10 times. Given the ROC curve, the average value of the training AUC of such a model reached 0.950 and 0.965, respectively, which demonstrated that the model prediction exerted a ‘prominent’ effect. Thus, the prediction results were suggested to exhibit a relatively high accuracy and a great reliability (Fig.1).
3.2. Prediction of potential invasive area

As indicated from the prediction results based on the potential suitable distribution diagram of *Ambrosia artemisiifolia* and *Ambrosia trifida* (Fig. 2):

1. The areas highly suitable for the growth of *Ambrosia artemisiifolia* were largely located in N125°5'6" ~ 125°52'15", E43°31'6" ~ 44°4'44", which comprised the central and western regions of Changchun City, the south region of Jiutai City, the west region of Yongji City, the southwest region of Jilin City, and the south region of Nong'an County in Jilin Province. The medium and low suitable areas were distributed around or close to those highly suitable areas, which primarily covered Dehui City, Huidian City, Panshi City, Gongzhuling City and Siping City in Jilin Province (Fig. 2A).

2. The highly suitable areas of *Ambrosia trifida* achieve the major locations in N124°30'43" ~ 126°53'45", E41°39'39" ~ 44°28'26", which covered Changchun City, the south region of Jiutai City, the west of Yongji City, west of Huidian City, the west of Linjiang City, Liaoyuan City, the east of Siping City, the east of Gongzhuling City, as well as the south of Dehui City in Jilin Province. The medium and low suitable areas were distributed around or close to the highly suitable areas, which primarily covered Yushu City, Linjiang City, Shuangliao City, Da’an City, Huidian City, Panshi City, Gongzhuling City, and Siping City in Jilin Province (Fig. 2B).

The potential high and medium suitable areas of *Ambrosia artemisiifolia* and *Ambrosia trifida* in Jilin Province covered 11,1988.71 km² and 4,8039.68 km², respectively, taking up 6.4% and 25.63% of the overall land area of Jilin Province. To be specific, the high suitable areas of *Ambrosia artemisiifolia* and *Ambrosia trifida* covered 1846.72 km² and 19,789.48 km², respectively, and the medium suitable areas covered 10,141.99 km² and 28,250.20 km², respectively (Table 1).
Figure 2. Potential suitable distribution of *Ambrosia* L. plant in Jilin Province based on the MaxEnt model

Table 1. Predicted areas for *Ambrosia* L. plant under each environmental variable condition

|                    | *Ambrosia artemisiifolia* L. | *Ambrosia trifida* L. |
|--------------------|------------------------------|-----------------------|
|                    | Area (km²)                   | Percentage of area (%)|
| Unsuitable habitat | 129245.19                    | 68.97%                |
| Poorly suitable    | 46166.10                     | 24.64%                |
| Habitat            | 10141.99                     | 5.41%                 |
| Highly suitable    | 1846.72                      | 0.99%                 |
| Habitat            | 100073.16                    | 53.40%                |
|                    | 39287.16                     | 20.96%                |
|                    | 28250.20                     | 15.07%                |
|                    | 19789.48                     | 10.56%                |

3.3. Determination of dominant environmental factors

According to the calculation results achieved by using the MaxEnt model, the contribution rates of different environmental variables to the potential distribution of *Ambrosia* plant are listed in Table 2.

(1) *Ambrosia artemisiifolia*: According to Table 2, the contribution rates of the solar radiation in September (srad9), the annual mean temperature variation range (bio7), the solar radiation in March (sard3) and the wind speed (wind1) in January accounted for 29%, 28%, 21.5% and 5.6%, respectively, and the cumulative contribution rate reached 84.1%. However, the contribution rates of other environmental variables (e.g., annual mean temperature (bio1), solar radiation in January (srad1) and precipitation in July (prec7)) to the potential distribution of *Ambrosia artemisiifolia* were relatively small. Given this, the solar radiation in September (srad9) and the annual average temperature range (bio7) primarily help predict the possible geographical distribution of *Ambrosia artemisiifolia* in Jilin Province.

(2) *Ambrosia trifida*: According to Table 2, the contribution rates of the solar radiation in September (srad9), the isothermality (bio3), the wind speed (wind1) and the monthly total precipitation in the wettest month (bio13) accounted for 29%, 28%, 21.5% and 5.6%, respectively, and the cumulative contribution rate took up 67%. Other environmental variables (e.g., the isothermality (bio3), the monthly total precipitation in the wettest month (bio13) and the water vapor pressure in January (VAPR1)) insignificantly contributed to the potential distribution of *Ambrosia trifida* Accordingly, the solar radiation in September (srad9) and the isothermality (bio3) could be critical to predict the possible geographical distribution of *Ambrosia trifida* in Jilin Province.

In brief, the environmental variables of solar radiation in September acted as the common dominant environmental factors affecting *Ambrosia* plant.
Table 2. Percent contribution of each environmental variable in MaxEnt modeling

| Environmental variables | Percent contribution/% |
|-------------------------|------------------------|
|                         | Ambrosia artemisiifolia L. | Ambrosia trifida L. |
| alt                     | 0                       | 0                     |
| bio1                    | 3.7                     | 0.1                   |
| bio2                    | 0.1                     | -                     |
| bio3                    | 28                      | 9.8                   |
| bio4                    | 0                       | -                     |
| bio5                    | 0.1                     | -                     |
| bio6                    | 0.2                     | -                     |
| bio7                    | Temperature Annual Range | - 15.7                |
| bio10                   | Mean Temperature of Warmest Quarter | - 0.1 |
| bio11                   | Mean Temperature of Coldest Quarter | - 0.3 |
| bio13                   | Precipitation of Wettest Month | 5.6 7.4 |
| bio14                   | Precipitation of Driest Month | 0.1 - |
| bio15                   | Precipitation Seasonality | 0.4 0.5 |
| prec6                   | Precipitation in June    | 0.3 2.3               |
| prec7                   | Precipitation in July    | 3.1 -                 |
| prec8                   | Precipitation in August  | 1.4 2.9               |
| prec11                  | Precipitation in November | 0.1 - |
| srad1                   | Solar radiation in January | 3.2 1.1 |
| srad3                   | Solar radiation in March | - 13.5               |
| srad6                   | Solar radiation in June  | 1.2 -                 |
| srad9                   | Solar radiation in September | 29 27 |
| srad10                  | Solar radiation in October | 0 - |
| tavg11                  | Average temperature in November | 0.2 - |
| tmax3                   | Maximum temperature in March | - 0 |
| tmax6                   | Maximum temperature in June | 0 - |
| tmax8                   | Maximum temperature in August | - 1.3 |
| tmin1                   | Minimum temperature in January | - 1.5 |
| tmin4                   | Minimum temperature in April | 0 - |
| tmin10                  | Minimum temperature in October | - 0 |
| vapr1                   | Water vapor pressure in January | - 3.7 |
| vapr4                   | Water vapor pressure in April | - 1.1 |
| vapr7                   | Water vapor pressure in July | 0.2 - |
| vapr8                   | Water vapor pressure in August | - 0.8 |
| vapr10                  | Water vapor pressure in October | 0 - |
| wind1                   | Wind speed in January    | 21.5 10.8             |
| wind5                   | Wind speed in May        | 1.6 0.1               |

3.4. Comparison of ecological niche and geographical distribution of Ambrosia plant

Given the prediction results achieved by using the ecological niche model, the ecological niche overlap degrees and geographical distribution overlap degrees of *Ambrosia artemisiifolia* and *Ambrosia trifida* were determined with ENM Tools, and the geographical distribution threshold was set to 0.5. Table 3 lists the niche overlap between *Ambrosia artemisiifolia* and *Ambrosia trifida*. The values of D and I indicated the consistency of niche overlap per pair, the niche overlap was high between *Ambrosia*
artemisiifolia and Ambrosia trifida (D = 0.678089367, I = 0.911675744), and the overlap degree of the geographical distribution reached 0.954313357 (Table 4). It was therefore demonstrated that besides the high degree of niche overlap, the two species achieved a relatively large geographical distribution overlap as well.

Table 3. Ecological overlap of potential distribution areas of Ambrosia L. plant

| Species               | Ambrosia artemisiifolia L. | Ambrosia trifida L. |
|-----------------------|-----------------------------|---------------------|
|                       | D                      | I                   | D                | I                   |
| Ambrosia artemisiifolia L. | 1                     | 1                   | 0.678089367      | 0.911675744         |
| Ambrosia trifida L.   | 0.678089367            | 0.911675744         | 1                | 1                   |

Table 4. Range overlap of potential distribution areas of Ambrosia L. plant

| Species               | Ambrosia artemisiifolia L. | Ambrosia trifida L. |
|-----------------------|-----------------------------|---------------------|
|                       |                            |                     |
| Ambrosia artemisiifolia L. | 1                     | 0.954313357         |
| Ambrosia trifida L.   | 0.954313357               | 1                   |

4. Discussion

4.1. Limitations of default parameters of the MaxEnt model

The MaxEnt model refers to a highly complex machine learning model. When adopted to simulate the potential distribution of species, such a model will cause the model’s over-fitting, thereby directly affecting the transfer ability of species [18]. However, the model complexity can be constrained by selecting the characteristic parameters of AICc and regulating the built-in normalization parameter $\beta$ in the MaxEnt model [19]. In the present study, Kuenm software package [20] of R language was adopted to screen 1240 model results set by 40 $\beta$-multiplier levels and 31 selection feature combinations, etc. Moreover, the minimum optimization setting of AICs value was taken. After the re-modeling, the predicted results of potential invasive areas of Ambrosia plant in Jilin Province were concluded to outperform those of the default parameters.

4.2. Prediction of potential invasive area

In areas from Jilin City in the central region of Jilin Province to Baicheng City in the western region of Jilin Province, the main crops consist of corn, rice, peanut and soybean. Moreover, the aforementioned important areas of the agricultural development are located in the potential diffusion range of Ambrosia plant. Accordingly, the corresponding prevention and control measures should be formulated by complying with the potential diffusion characteristics and vital diffusion areas of Ambrosia plant, as an attempt to avoid serious harm from being caused to the agricultural economy. In the intersections of Jilin Province and neighboring provinces, there are both middle and low suitable areas of Ambrosia trifida, and Yushu City, Linjiang City, and Siping City of Jilin Province act as the vital diffusion areas of Ambrosia trifida. Thus, the monitoring direction of Ambrosia plant should be regulated with regional changes, and the vital control areas should be subdivided.

4.3. Determination of dominant environmental factors

As suggested from the analysis results of the knife-cutting method (Table 2), the solar radiation in September acted as the main common environmental factor affecting the geographical distribution of Ambrosia plant. Accordingly, it was speculated here that Ambrosia plant is a type of positive plant. As reported from the field investigation conducted by the authors, September was the mature period for the fruits of Ambrosia plant. The coverage of Ambrosia plant accounted for 25-60% of the sample land investigated, and the plant height reached 1.3~1.5m. Moreover, September was proven as a critical period for agricultural crops (e.g., corn, rice and peanuts) to reach maturity, which requires considerable soil nutrients. If Ambrosia plant growing in agricultural areas is not removed in time, they will compete...
with crops for light and nutrients, thereby adversely affecting the emergence rate and yield of crops in the next year.

4.4. Comparison of ecological niche and geographical distribution of Ambrosia plants
Niche overlap acts as a critical indicator to describe the actual ecological niche of species, which indicates the characteristics exhibited by the plants and their adaptability to the environment to a certain extent [21]. Niche overlap refers to the similarity and competition between species for resource utilization [22]. With the increase in the niche width, the adaptability of the plants to the environment will be improved, the distribution will be more extensive, and the niche overlap will be greater [23]. As revealed from the results, *Ambrosia artemisiifolia* and *Ambrosia trifida* exhibited higher degrees of similarity in resource utilization and more significant competitive relationships. Furthermore, the geographical distribution of *Ambrosia trifida* was wider than that of *Ambrosia artemisiifolia*, which demonstrated that *Ambrosia trifida* exhibited a better environmental adaptability than *Ambrosia artemisiifolia*.

5. Conclusion
(1) The total areas of the potential high and middle suitable areas of *Ambrosia artemisiifolia* and *Ambrosia trifida* in Jilin Province cover 11,1988.71 km² and 4,8039.68 km², respectively, accounting for 6.4% and 25.63% of the total area of Jilin Province. To be specific, the areas of high suitable areas reach 1846.72km² and 19,789.48 km², respectively. On the whole, the potential invasive areas are distributed in Changchun, Yongji, Huadian, Linjiang, Siping, Gongzhuling and Dehui in Jilin Province.

(2) The dominant factors of the distributions of *Ambrosia artemisiifolia* and *Ambrosia trifida* comprise the solar radiation in September (sard9) and the change range of annual mean temperature (bio7), and solar radiation in September (sard9) and isothermality (bio3).

In brief, since the *Ambrosia* plant are key alien invasive plants in China, and alien invasive plants will seriously affect the local ecological security, agricultural productions and economy, so this study lays a theoretical basis for monitoring the invasion dynamic of *Ambrosia artemisiifolia* and *Ambrosia trifida* in wide regions and habitats of Jilin Province, as well as for formulating comprehensive control countermeasures.

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