

Prediction of global potential suitable habitats of *Nicotiana alata* Link et Otto based on MaxEnt model

YanFang Zhang

Shandong Agricultural University

Shutong Chen

Shandong Agricultural University

Yun Gao

Shandong Agricultural University

Long Yang

Shandong Agricultural University

Hua Yu (✉ yuh@sdau.edu.cn)

Shandong Agricultural University

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Abstract

Nicotiana alata Link et Otto, widely used in landscaping, is not only of great ornamental value but also of high commercial and medical value. The global potential habitat of *N. alata* and the environmental factors affecting its distribution are not that clear at present. To provide a reference for the reasonable and extensive planting of *N. alata* now and in the future, MaxEnt model was used to predict its global suitable habitats under current and future climate conditions, respectively, based on global geographic distribution data of *N. alata* and the current and future world bioclimatic variables. The results showed that mean annual temperature (bio1), annual precipitation (bio12), temperature seasonality (bio4), and mean temperature of driest quarter (bio9) were the key bioclimatic variables governing the distribution of *N. alata*. The global suitable habitats of *N. alata* were mainly distributed in Europe, the United States, Mexico, southeastern South America, and southern Africa under current climate conditions. Compared with current climate conditions, the future climate decreased suitable habitats of *N. alata* under SSP1-2.6 scenario and increased suitable habitats of *N. alata* under SSP2-4.5, SSP3-7.0 and SSP5-8.5 climatic scenarios. The results provided valuable information and theoretical reference for the reasonable planting of *N. alata*.

Introduction

Nicotiana alata Link et Otto, also known as *N. alata*, jasmine tobacco, nicotiana and sweet tobacco, is a limited perennial herb of the Solanaceae genus *Nicotiana* L. *N. alata* has a variety of flower colors, continuous flowering, bright flower colors, long flowering period, and high ornamental value ¹. It also exists a variety of plant types: the tall type is 45–55 cm high, the middle type is 25–30 cm high, and the common type is shorter, only 10–15 cm, therefore *N. alata* can be planted in clusters in curbs, flower beds, parks as greenery, and can be placed on balconies, rooms, and patios to beautify home. *N. alata* has many other uses. Seeds of *N. alata* contain a large amount of fatty acids and nutrients, which have become the raw materials for human health products ². Natural flavor compounds with unique aroma and biological metabolites can be separated from *N. alata* ³, which can be used in research related to cosmetics and aroma products ⁴. *N. alata* can isolate defensins and other substances, which play important roles in defense against fungi and can induce tumor cell death ^{5–10}. *N. alata* can produce acyl sugars, which have insecticidal and antibacterial properties ^{11,12}. In recent years, *N. alata* has often been cultivated as a model plant for horticulture, medicine, and scientific research ¹³.

N. alata prefers deep, fertile, well-drained soil and sunny, warm environment. It is drought tolerant but not cold tolerant. Originated in Argentina and Brazil, *N. alata* is now widely distributed in Europe, North and South America, and Oceania. It is also grown in some parts of China. However, it is not very clear whether there are still suitable areas where *N. alata* has not been introduced, or whether the areas where *N. alata* have been planted will still be suitable in the future. The prediction of suitable areas for *N. alata* under present and future climate conditions will shed light on these questions.

Species distribution models (SDMS), also known as ecological niche models ¹⁴, are a class of models used to predict the distribution of suitable species habitats based on the study of different scenarios of current and future climate development. Factors influencing the distribution of species can also be analyzed in detail. SDMS has been widely used in ecology, biogeography and evolutionary studies ^{15,16}. With the development of GIS (Geographic Information System) and the application of new statistical techniques, a variety of ecological niche models have been established internationally for the prediction of species suitable habitats ¹⁷, such as the generalized additive model (GARP), domain model (DOMAIN), bioclimatic model (BIOCLIM), niche factor analysis model (ENFA), maximum entropy model (MaxEnt), etc ¹⁸. Among these models, MaxEnt is the most widely used ecological niche model because of its easy operation, fast running speed ¹⁹, and accurate prediction of the potential suitable habitats of species based on the longitude and latitude of known presence points and climate factors or even small sample data. MaxEnt has been widely used in invasion management of biological species ^{20–22}, protection of endangered plants and animals ^{23–26}, control of pests and diseases ¹⁹, and environmental risk assessment of species habitats ²⁷.

At present, scholars about *N. alata* at home and abroad had focused on the expression pattern analysis of essential genes ^{1,28,29}, cultivation management ^{30–33} and characteristics of fertilizer requirements, self-incompatibility mechanism and regeneration system ^{29,34–36}, etc. No research has been done on the distribution and growing areas of *N. alata*. Here, in order to provide a reference for the planting of *N. alata*, MaxEnt ecological niche model was used to predict the range of suitable planting areas for *N. alata* under current and future climate conditions. This study will reveal the suitable areas of *N. alata* at present and predict possible changes of suitable areas in the future, and hence provide a theoretical basis for the reasonable planting of *N. alata*.

Materials And Methods

Global sample sites of *N. alata*

Records of the presence of *N. alata* were obtained from the Global Biodiversity Information Facility (GBIF, <https://www.gbif.org/>), the Chinese Virtual Herbarium (CVH, <https://www.cvh.ac.cn/>), the National Specimen Information Infrastructure (NSII, <http://nsii.org.cn/2017/AboutUs.php>), and Chinese Field Herbarium (CFH, <https://cfh.ac.cn/>). Then, these sample points were screened to ensure the correct information of *N. alata* data. Firstly, sample points with correct Latin names and accurate latitude and longitude were selected, and obviously wrong geocoded data and duplicate data were excluded. Secondly, sample points with detailed geographic location but no latitude and longitude information were located using Google Earth to obtain accurate latitude and longitude information. Finally, 1023 sample points of *N. alata* were obtained.

Distributional data are usually non-random and the datasets are hardly used for systematic studies, therefore the datasets that emerge have strong geographical bias and spatial autocorrelation, which can

lead to spurious model results. Using the Thin function of the R package spThin, a refinement distance of 50 km was chosen to spatially dilute the dataset of *N. alata*³⁷, resulting in 300 sample points of *N. alata* (Fig. 1).

Environmental variable data

Climate variables are the main determinants of species ecological niches in the study of species distributions at large spatial scales³⁸. The current bioclimatic data used in this study were obtained from the WorldClim 2.1 climate database (<https://www.worldclim.org/data/worldclim21.html>) with a spatial resolution of 2.5 min. These bioclimatic variables are recorded as mean values from 1970 to 2000 and represent annual mean temperature and precipitation trends, seasonal trends, and extreme trends. During the model runs, covariance between bioclimatic variables exists, resulting in overfitting of the model. To reduce the covariance of bioclimatic variables, six bioclimatic variables (Table 1) related to temperature and precipitation were selected based on the growth habit of *N. alata*.

To better predict the potential future suitable habitats of *N. alata*, four shared socio-economic pathways (SSPs), SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, were selected from the moderate resolution National (Beijing) Climate Center climate system model (BCC-CSM2-MR) for the year 2070 (2061–2080 average) of the Coupled Model Intercomparison Project Phase 6 (CMIP6). The shared socio-economic pathway examines different future greenhouse gas emissions, providing a range of different end-of-century climate change outcomes. SSP1-2.6 is a sustainable development pathway showing an average global temperature increase of 2°C. SSP2-4.5 is a moderate development pathway showing an average global temperature increase of 3°C. SSP3-7.0 is a partial development pathway showing an average global temperature increase of 4.1°C. SSP5-8.5 is the conventional development path, showing a global average temperature increase of 5°C.

Table 1
The six bioclimatic variables used for the MaxEnt model.

Bioclimatic variables	Variable description	Unit
bio1	Annual Mean Temperature	°C
bio3	Isothermality (BIO2/BIO7) (×100)	–
bio4	Temperature Seasonality (standard deviation ×100)	–
bio5	Max Temperature of Warmest Month	°C
bio9	Mean Temperature of Driest Quarter	°C
bio12	Annual Precipitation	mm

Model Simulation

MaxEnt model software (version 3.4.4) was downloaded from https://biodiversityinformatics.amnh.org/open_source/maxent/ for maximum entropy simulations to predict suitable habitats of *N. alata*. ArcGIS 10.7, a comprehensive GIS invented by ESRI (Environmental Systems Research Institute, Inc), was used for the analysis of layers, transformation of data formats and reclassification of results.

Import the respective data of global sample points and bioclimatic variables of *N. alata* into MaxEnt software. Run linear features, quadratic features, hinge features, and product features. Then, 75% of the randomly selected occurrence records were used as the training set with the remaining 25% as the test set to construct the MaxEnt prediction model. For each training partition, 10 replications were generated and the results were averaged after 500 iterations at the end³⁹. Response curves and jackknife were used to analyze the effects of bioclimatic variables on species distribution. The accuracy of the MaxEnt prediction model was analyzed using receiver operating characteristic (ROC) curves. The final software output file format was logistic and the output file type was ASC.

Model performance evaluation and area calculation

The receiver operating characteristic (ROC) curve, widely used in the prediction of the potential suitable habitats of species³⁰, is a highly recognized parameter for the evaluation of diagnostic tests. The area under the ROC curve is AUC (Area Under Curve) which is used to analyze the model accuracy. AUC values are evaluated on the following criteria: 0.50–0.60 represents an invalid prediction, 0.60–0.70 represents a poor prediction, 0.70–0.80 represents a moderate prediction, 0.80–0.90 represents a good prediction, and 0.90–1.00 represents an excellent prediction. In general, when AUC > 0.9, it indicates that the prediction is accurate enough.

Import the model results into ArcGIS to a raster format, project the raster data (WGS1984), classify and visualize the simulated distribution into suitable habitats. The suitable habitats were classified into four categories according to the Jenks's natural breaks approach: (I) highly suitable habitats (0.411802–1), (II) moderately suitable habitats (0.213882–0.411802), (III) lowly suitable habitats (0.063845–0.213882), and (IV) unsuitable habitats (0–0.063845). The raster file was converted into a polygon file by using the raster to polygon conversion tool in ArcGIS and then the calculation function in ArcGIS properties was used to calculate the area of each suitable habitat and determine the proportion of each area.

Results

Accuracy analysis of the MaxEnt prediction model for the global suitable habitats of *N. alata*

In order to characterize the prediction accuracy of the obtained MaxEnt prediction model, the receiver operating characteristic (ROC) curve and the corresponding AUC were calculated. The results showed that the mean value of AUC was 0.949 (Fig. 2), which indicated that the prediction accuracy of the obtained

MaxEnt prediction model was high and the model would be very accurate in predicting the global suitable habitats of *N. alata*.

Contribution of each bioclimatic variable to the MaxEnt prediction model

Further calculation was performed to characterize the contribution of each bioclimatic variable to our MaxEnt prediction model. The results showed that among the six bioclimatic variables used to construct the MaxEnt prediction model (Table 2), annual precipitation (bio12) contributed the most, accounting for 39.1%, followed closely by annual mean temperature (bio1) with a contribution rate of 35.2%. Then, temperature seasonality (bio4), mean temperature of the driest quarter (bio9), max temperature of the warmest month (bio5) and isothermality (bio3) contributed 11.2%, 9.2%, 4%, and 1.4%, respectively. Overall, annual precipitation (bio12), annual mean temperature (bio1), and temperature seasonality (bio4) were the main bioclimatic variables that had the greatest impact on the MaxEnt prediction model.

Table 2
Contribution of the six bioclimatic variables to the MaxEnt prediction model

Variables	Contribution(%)
Annual Precipitation(bio12)	39.1
Annual Mean Temperature (bio1)	35.2
Temperature Seasonality (bio4)	11.2
Mean Temperature of Driest Quarter (bio9)	9.2
Max Temperature of Warmest Month (bio5)	4
Isothermality (bio3)	1.4

Contribution of each bioclimatic variable to the distribution of *N. alata*-jackknife test of the MaxEnt prediction model

Jackknife test was used to estimate the contribution of each bioclimatic variable to the distribution of *N. alata* based on the performance of our MaxEnt prediction model for the global suitable habitats of *N. alata*. From the results of the test with only variable (Fig. 3, blue bars), the top three bioclimatic variables in regularized training gain, AUC and test gain were all annual mean temperature (bio1), mean temperature of the driest quarter (bio9) and annual precipitation (bio12), implying the importance of these three bioclimatic variables to the distribution of *N. alata*, since the longer the bar, the more important the bioclimatic variable was for the species distribution. The results of the test without variable (Fig. 3, green bars) showed that annual precipitation (bio12), temperature seasonality (bio4), and annual mean temperature (bio1) had the most reduced values in test gain, AUC, and regularized training gain

respectively, indicating that these bioclimatic variables contained more specific environmental information in the prediction of the distribution of *N. alata*, as the green bar represented the specificity of the variable, and the shorter the bar, the more special information the bioclimatic variable contained that was not present in other variables. Additionally, the red bar represented the performance of the model with all six bioclimatic variables involved, which acted as a control group for other tests. In summary, the results of the jackknife analysis indicated that annual mean temperature (bio1), annual precipitation (bio12), temperature seasonality (bio4), and mean temperature of the driest quarter (Bio9) were the key bioclimatic variables governing the distribution of *N. alata*.

To better cultivate *N. alata*, the optimum value range of the above four key bioclimatic variables, obtained from the results of the jackknife test, were further explored. 0.411802-1 was used to determine the optimum value range of each variable (Fig. 4), which was also the judgement standard of highly suitable habitats. As a result, all four bioclimatic variables obtained an optimum value range, in which *N. alata* grows well, from their respective response curve (Fig. 4). The optimum value range of temperature seasonality (bio4, Fig. 4d) was 230–765. The optimum value range of annual mean temperature (bio1) was 5–20°C, with a whole suitable range of -1–25°C in which *N. alata* can grow (Fig. 4a). The optimum value range of mean temperature of driest quarter (bio9) was -3–19°C (Fig. 4b) with the probability of *N. alata* presence increased from -10°C to 7°C and decreased from 7°C to 28°C. The optimum value range of annual precipitation (bio12) was 500–2000 mm (Fig. 4c). At 200–700 mm, the probability of *N. alata* presence increased with the increase of precipitation, while at 700–2800 mm, the probability of *N. alata* presence decreased with the increase of precipitation.

Prediction of the global potential suitable habitats of *N. alata* under current climate conditions

The MaxEnt prediction model obtained above was used to predict the potential suitable habitats of *N. alata* under current climate conditions. The results showed that the highly suitable habitats of *N. alata* were mainly located in Ireland, the United Kingdom, the Netherlands, Belgium, Luxembourg, Switzerland, France, Estonia, Latvia, Lithuania, Poland, the Czech Republic, southern Sweden, Germany, the Czech Republic, Poland, Uruguay, southern Brazil, eastern Argentina, southern China, and New Zealand (Fig. 5a). The moderately suitable habitats were located in southern Finland, eastern Belarus, Greece, Albania, Macedonia, Montenegro, Bulgaria, eastern China, southern Finland, Zimbabwe, Zambia, and so on (Fig. 5a). The lowly suitable habitats were located in the United States, western Russia, Turkey and other regions (Fig. 5a). Among them, the area of highly suitable habitats was 8.18×10^6 km², accounting for 22.30% of the total suitable habitat area (Fig. 5c). The area of moderately suitable habitats was 11.10×10^6 km², accounting for 30.26% of the total suitable habitat area (Fig. 5c). The area of lowly suitable habitats was 17.40×10^6 km², accounting for 47.44% of the total suitable habitat area (Fig. 5c). It was noteworthy that Yunnan, Guizhou and Sichuan provinces in China were highly suitable habitats of *N. alata* (Fig. 5b).

Prediction of the global potential suitable habitats of *N. alata* under future climate conditions

The MaxEnt prediction model obtained above was used to predict the global potential suitable habitats of *N. alata* under future climate conditions. The predictions showed that the global potential habitats of *N. alata* under the four different scenarios of future climate conditions (Figs. 6a, 6b, 6c and 6d) were slightly different from the prediction result under the current climate conditions (Fig. 5a). In the SSP1-2.6 scenario, the total area of the global suitable habitats of *N. alata* was $30.02 \times 10^6 \text{ km}^2$, which was $6.66 \times 10^6 \text{ km}^2$ less than that under the current conditions (Fig. 6e). The area of highly, moderately and lowly suitable habitats was $5.0 \times 10^6 \text{ km}^2$, $8.57 \times 10^6 \text{ km}^2$ and $16.45 \times 10^6 \text{ km}^2$, respectively, which all decreased compared with corresponding area under the current conditions (Fig. 6e). Under the SSP2-4.5 scenario, the total area of the global suitable habitats of *N. alata* was $37.89 \times 10^6 \text{ km}^2$, which was $1.21 \times 10^6 \text{ km}^2$ more than that under the current conditions (Fig. 6e). The area of the highly, moderately and lowly suitable habitats was $8.40 \times 10^6 \text{ km}^2$, $11.53 \times 10^6 \text{ km}^2$ and $17.95 \times 10^6 \text{ km}^2$, respectively, which all expanded compared with corresponding area under the current conditions (Fig. 6e). The trend was that the area of SSP2-4.5 was expanding. Under the SSP3-7.0 scenario, the total area of the global suitable habitats of *N. alata* was $38.49 \times 10^6 \text{ km}^2$, which was $1.83 \times 10^6 \text{ km}^2$ more than that under the current environment (Fig. 6e). The area of highly, moderately, and lowly suitable habitats was $8.92 \times 10^6 \text{ km}^2$, $11.40 \times 10^6 \text{ km}^2$, and $18.19 \times 10^6 \text{ km}^2$, respectively, which all expanded compared with corresponding area under the current conditions (Fig. 6e). The trend was that the area of SSP3-7.0 was expanding. Under the SSP5-8.0 scenario, the total area of the global suitable habitats of *N. alata* was $40.66 \times 10^6 \text{ km}^2$, which was $3.98 \times 10^6 \text{ km}^2$ more than that under the current environment. The area of highly, moderately, and lowly suitable habitats was $9.68 \times 10^6 \text{ km}^2$, $11.55 \times 10^6 \text{ km}^2$, and $19.43 \times 10^6 \text{ km}^2$, all of which expanded compared with area under the current conditions (Fig. 6e). Overall, if the future climate adopts a moderate, a partial or a conventional development pathway, the suitable habitats of *N. alata* would expand compared to the current situation, and the larger the carbon emission, the larger the suitable area. But, if the future climate adopts a sustainable development pathway, the suitable habitats of *N. alata* would be less than they are now.

Discussion

N. alata is a well-known ornamental flower. Detailed knowledge of its distribution is a prerequisite for its rational distribution and utilization in an ecosystem. This study provides a detailed analysis of the potential global habitats of *N. alata* under current and future climate conditions based on the MaxEnt model. Our results provide a theoretical basis for the development of practical planting and management measures for *N. alata*.

Temperature and precipitation have important effects on species distribution, however, each specific bioclimatic variable may have different effects on different species owing to the differences in the species' own growth habits. In this study, the MaxEnt model was used to predict the global potential distribution of suitable habitats for *N. alata* and further analyze the bioclimatic factors influencing the distribution of the species. Among the six bioclimatic variables involved in the MaxEnt model construction, the total contribution of temperature-related bioclimatic variables was 60.8% and the

contribution of precipitation-related bioclimatic variables was 39.2%. These results not only verify the importance of temperature and precipitation for *N. alata* distribution, but also demonstrate much more influence of temperature than precipitation. Actually, the main bioclimatic variables of *N. alata* are mean annual temperature (bio1), annual precipitation (bio12), temperature seasonality (bio4), and mean temperature of driest quarter (bio9) according to our analysis. However, different from *N. alata*, in a prediction of the suitable habitats of *Sapindus mukorossi* using the MaxEnt model, precipitation of warmest quarter (bio18), min temperature of coldest month (bio6), temperature seasonality (bio4), and isothermality (bio3) were found to be the main bioclimatic variables affecting *Sapindus mukorossi*¹⁸. The analysis of the suitable habitats of *Osmanthus fragrans* using the MaxEnt model found that UV-B seasonality, precipitation seasonality (bio15), temperature annual range (bio7) and mean diurnal temperature range (bio2) were the most important factors interpreting the environmental demands of this species³⁹. The prediction of suitable habitats of *Pinus densiflora* using MaxEnt model revealed that warmest seasonal precipitation (bio18), seasonality of temperature (bio4), mean annual temperature (bio1) and mean temperature of wettest season (bio8) were the main environmental variables affecting the growth of *Pinus densiflora*⁴⁰. Thus, it is clear that the contribution of bioclimatic variables to specific species needs to be studied specifically, and the process of this paper provides a reference and comparison for other species.

The prediction results of this study provide reference for *N. alata* planting in China. Currently, the presence of *N. alata* is recorded in Inner Mongolia, Heilongjiang, Guangxi, Fujian, Chongqing, Jiangsu, Shanghai, Hubei, and Zhejiang provinces and cities in China. According to the model prediction results (Fig. 5b), the moderately-highly suitable habitats of *N. alata* under current climate conditions covers 3084000 km² in China, and in addition to the above known distribution areas of *N. alata*, Shanxi, Guizhou, Guangdong, Yunnan, Sichuan, and Ningxia are also suitable for *N. alata* growth, providing a wider planting area for *N. alata* cultivation. In the next four scenarios of future climate conditions, there are still large areas of moderately suitable habitats, although the area of highly suitable habitats in China will reduce. Besides, only climatic factors affecting the growth of *N. alata* were considered in this study, other factors such as human activities, variety selection, soil type, were not considered, but all factors should be considered in the actual introducing of *N. alata* in a certain area to ensure the quality of flowering.

With future climate change, the suitable habitat of *N. alata* increased globally in the three scenarios SSP2-4.5, SSP3-7.0 and SSP5-8.5, with an increase of 3.30%, 4.99% and 10.85% in the suitable area, respectively, while the decrease only occurred in the SSP1-2.6 scenario, suggesting that climate change will be detrimental to the survival of *N. alata* if the world shifts to a sustainable development path in the future. In the SSP1-2.6 scenario (Fig. 6a), the area of the suitable habitat in south-central North America decreases, while in the other three scenarios the area of the suitable habitat increases (Fig. 6b, 6c and 6d). This is probably due to the global warming which is more significantly influenced by the warm, humid and hot climate of the Gulf of Mexico, making the climate warmer and more suitable for *N. alata* growth in the other three scenarios. In the four future scenarios, the increase is mainly located in the central-eastern part of Africa, which belongs to the savanna climate, and as the temperature rises, the

region should enter a high-temperature environment, which is more conducive to the migration of *N. alata*. In the four future scenarios, the area in northern Russia is decreasing, and the region has a temperate continental climate. The increase in temperature is often accompanied by drought, low precipitation and large temperature differences, which is not conducive to the growth of *N. alata*. It is noteworthy that in China the suitable area of *N. alata* is expanding northward and the suitable area is increasing.

Global climate change has been reported to affect the distribution of various species. Climate change may lead to regional or local extinction of *N. alata* in certain areas as what has predicted in this paper. For the conservation of *N. alata*, three main recommendations are proposed. (1) Protect or introduce *N. alata* according to the predicted results under different climate conditions and the actual local conditions. (2) Track and monitor the actual growth of *N. alata*, and then make reasonable planting planes on the basis of the predicted results and the actual conditions, especially for regions where the planting areas of *N. alata* is likely to change according to predictions here. (3) It is necessary to strengthen systematic research on germplasm resources to increase the quality of *N. alata*, since researches on *N. alata* cultivation, growth environment, and variety improvement are less at present.

Declarations

Data availability

Data from the current study are available from the corresponding author upon reasonable request.

Author contributions statement

Y.Z. and S.C. collected the data and performed the experiment. Y.Z. analyzed the results and wrote the manuscript. L.Y. and H.Y. supervised the project and provided resources. All authors participated in the revision of the manuscript and approved the final version.

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Figures

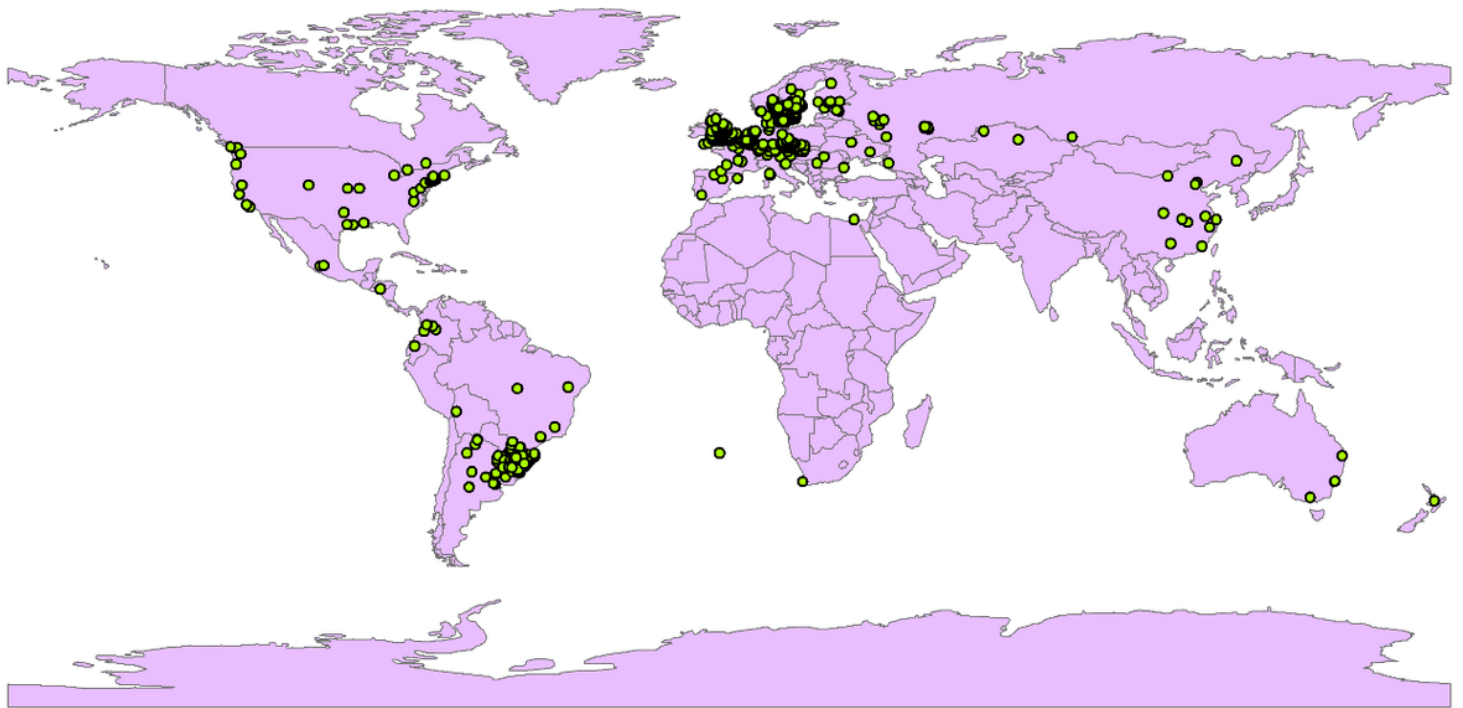


Figure 1

Global sample sites used for the model simulation to predict the global potential suitable habitats of *N.alata*.

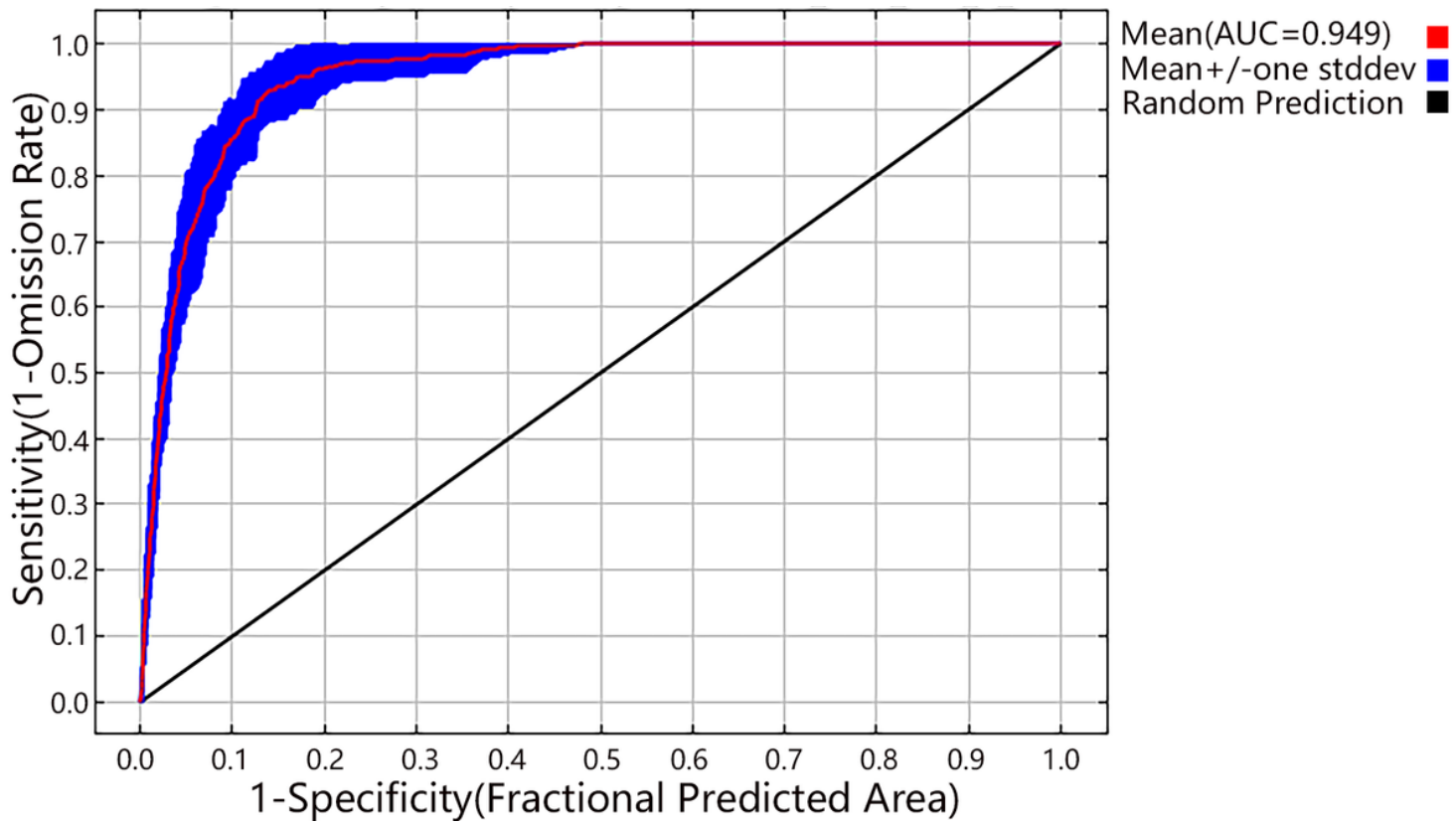


Figure 2

The receiver operating characteristic (ROC) curve of the obtained MaxEnt prediction model for the global suitable habitats of *N. alata*. AUC, area under the curve.

Without variable ■ With only variable ■ With all variable ■

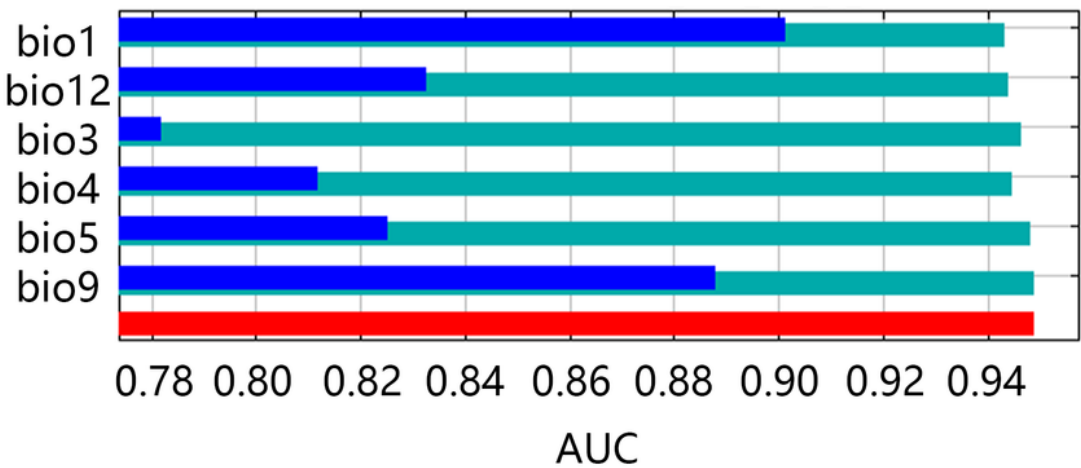
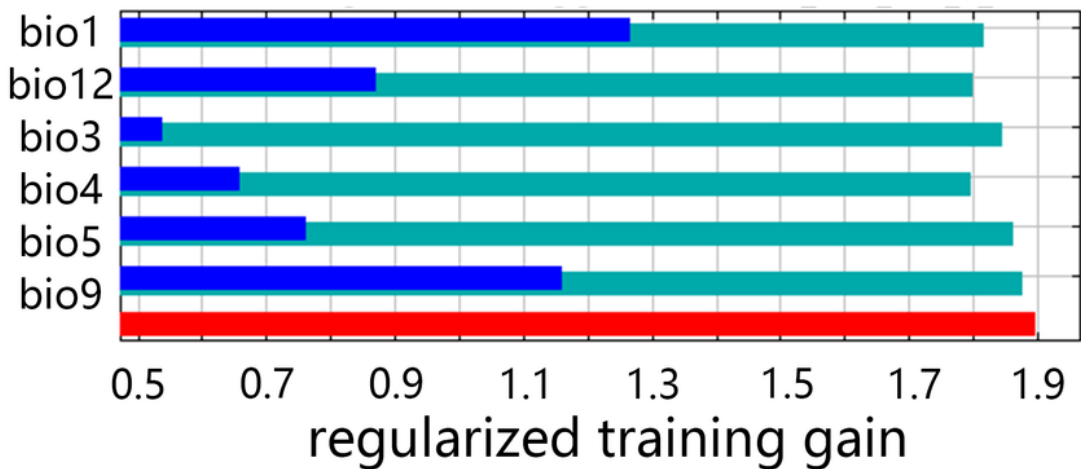
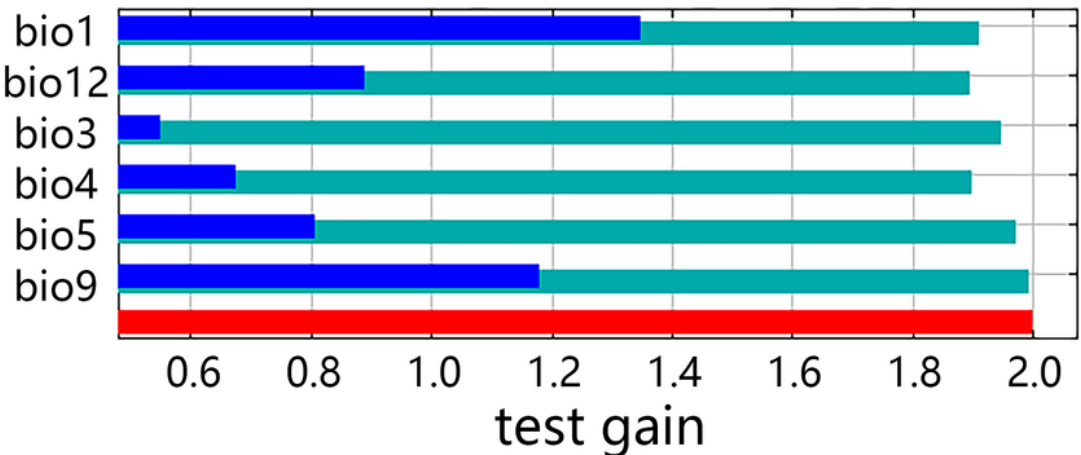


Figure 3

The jackknife test of the MaxEnt prediction model for the prediction of the global suitable habitats of *N. alata*.

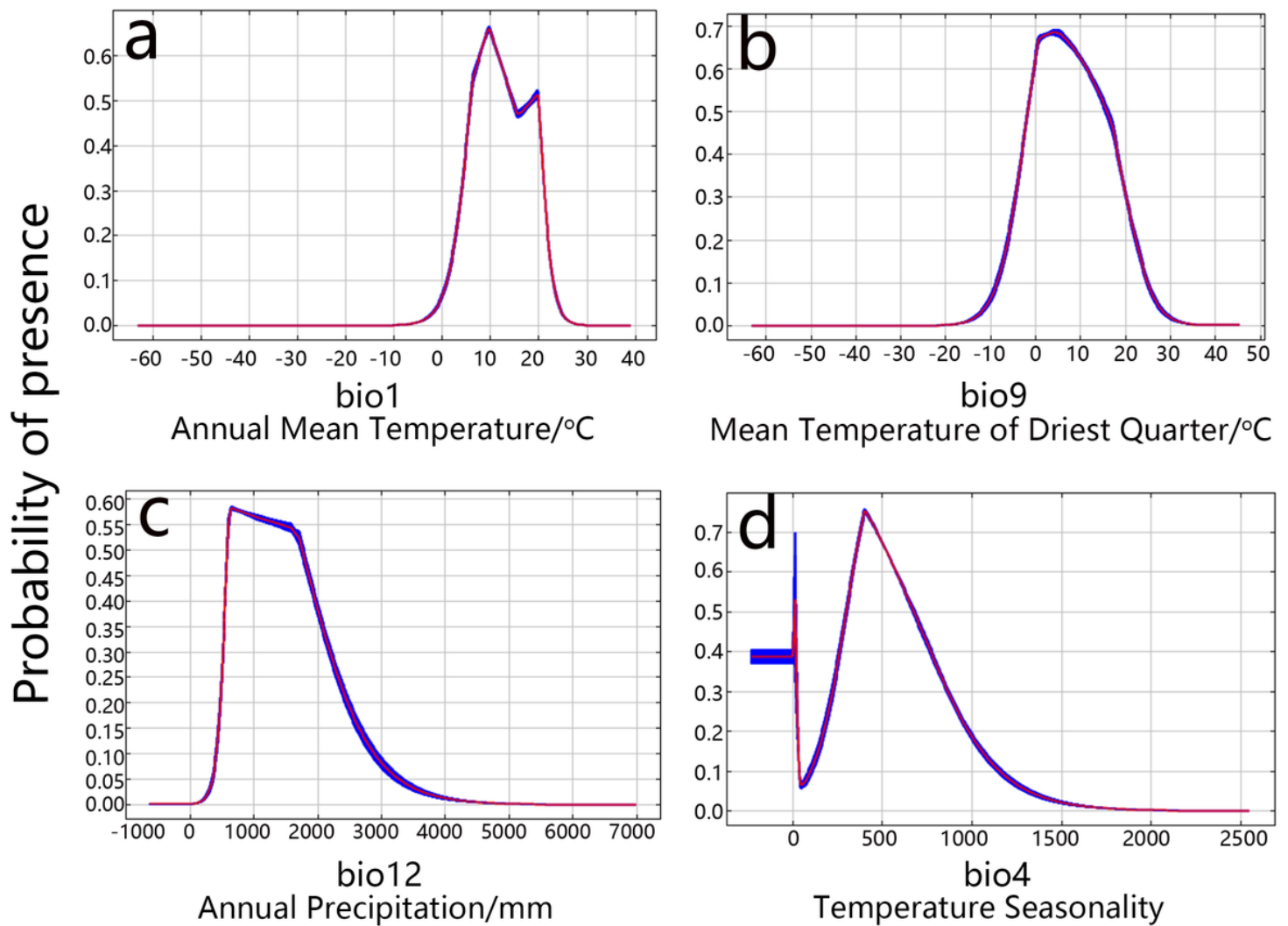


Figure 4

Response curve showing the relationships between the probability of the presence of *N. alata* and the key four bioclimatic variables. (a) response curve of *N. alata* to annual mean temperature, (b) response curve of *N. alata* to mean temperature of driest quarter, (c) response curve of *N. alata* to annual precipitation, (d) response curve of *N. alata* to temperature seasonality. Probability values shown are the average over 10 replicate runs. Blue margins show $\pm$ SD (standard deviation) calculated over 10 replicates.

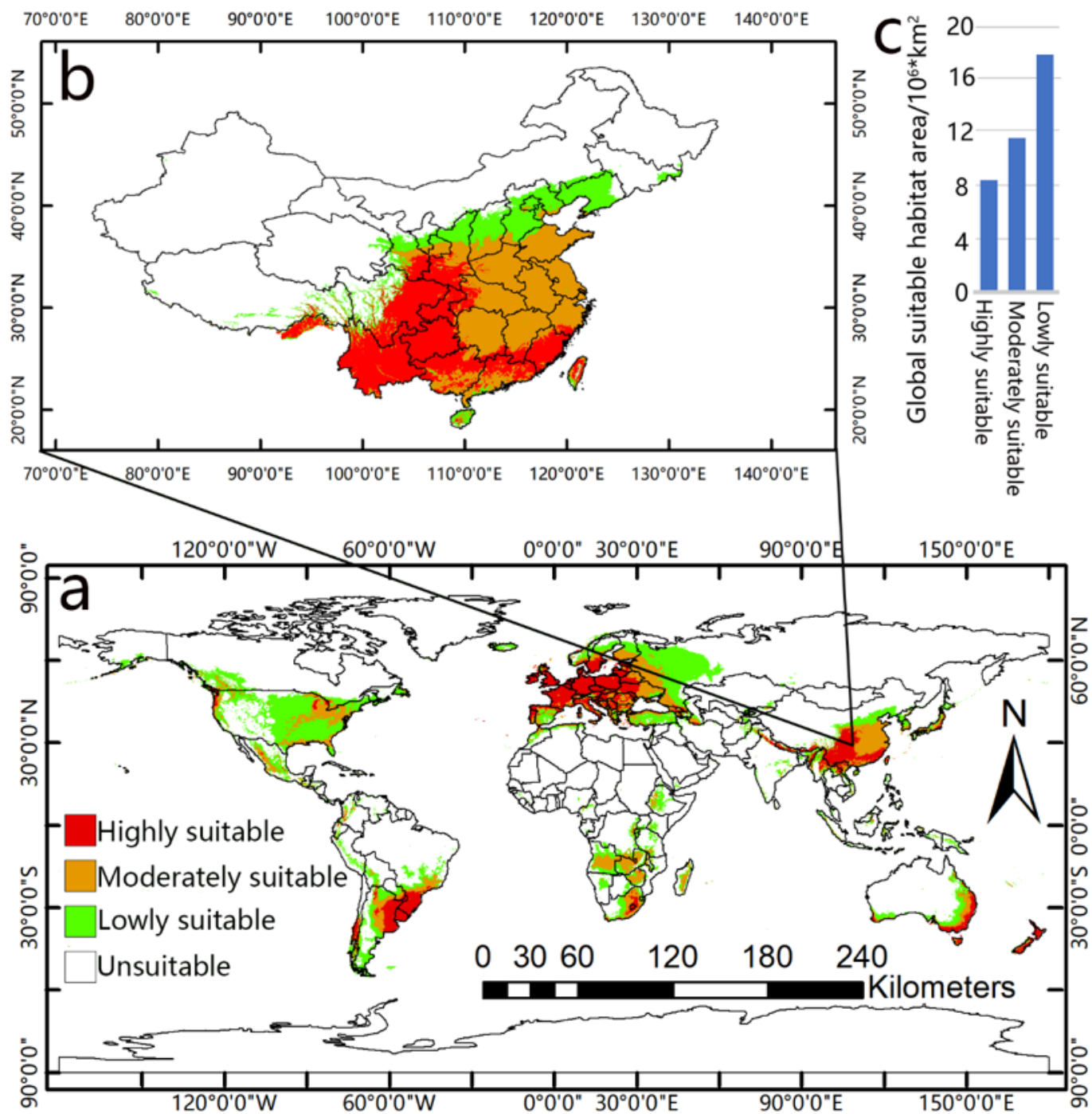


Figure 5

The predicted global suitable habitats of *N. alata* under current climate conditions. (a) global suitable habitats of *N. alata*, (b) suitable habitats of *N. alata* in china, (c) global suitable habitat areas of *N. alata*.

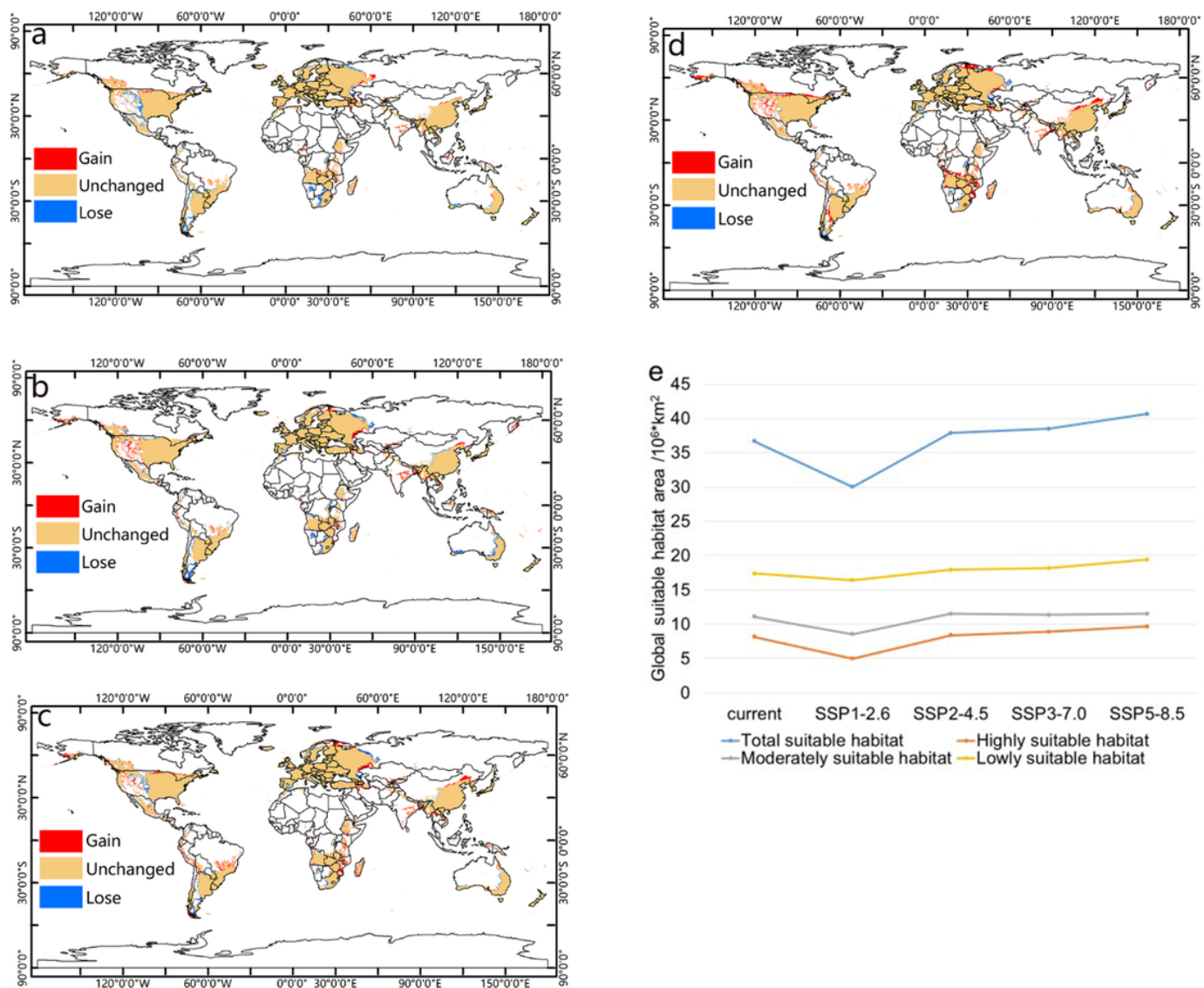


Figure 6

Changes of the global suitable habitats of *N. alata* between different future climate scenarios and the current climate conditions. (a) the global suitable habitats changes of *N. alata* between the future SSP1-2.6 climate scenario and the current climate conditions, (b) the global suitable habitats changes of *N. alata* between the future SSP2-4.5 climate scenario and the current climate conditions, (c) the global suitable habitats changes of *N. alata* between the future SSP3-7.0 climate scenario and the current climate conditions, (d) the global suitable habitats changes of *N. alata* between the future SSP5-8.5 climate scenario and the current climate conditions, (e) area line chart of suitable habitats of *N. alata* between different future climate scenarios and the current climate conditions.