Predicting the potential distribution of *Campsis grandiflora* in China under climate change

Xianheng Ouyang\(^1\) · Jiangling Pan\(^2\) · Zhitao Wu\(^3\) · Anliang Chen\(^1\)

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**Abstract**

Because the research on the geographical distribution of species significantly influences people’s understanding of species protection and utilization, it is important to study the influence of climate change on plants’ geographical distribution patterns. Based on 166 distribution records and 11 climate and terrain variables, we used MaxEnt (Maximum Entropy) model and ArcGIS software to predict the potential distribution of *Campsis grandiflora* under climate change and then determined the dominant climate variables that significantly affected its geographical distribution. In our study, the area under the curve (AUC) value of the training data was 0.939, proving the accuracy of our prediction. Under current climate conditions, the area of potentially suitable habitat is \(238.29 \times 10^4\) km\(^2\), mainly distributed in northern, central, southern, and eastern China. The dominant variables that affect the geographical distribution of *C. grandiflora* are temperature, precipitation, and altitude. In the future climate change scenario, the total area of suitable habitat and highly suitable habitat will increase, whereas the area of moderately suitable habitat and poorly suitable habitat will decrease. In addition, the centroid of the potentially suitable area of *C. grandiflora* will migrate to higher latitude and higher altitudes areas. The results could give strategic guidance for development, protection, and utilization of *C. grandiflora* in China.

**Keywords** MaxEnt model · ArcGIS · *Campsis grandiflora* · Climate variables · Area of potentially suitable habitat

**Introduction**

Climate is one of the most dominant factors in determining the distribution of a species (Qin et al. 2017). According to the Intergovernmental Panel on Climate Change (IPCC), the earth’s surface temperature has risen by 0.85 °C over the past 100 years, and it will continue to trend upward in the near future (Jose et al. 2016; Li et al. 2019). Climate change influences the geographical distribution and abundance of species, as well as population change and stability to a certain degree (Brown et al. 2020; Sofi et al. 2022). Hence, understanding the change of geographical distribution of species in the future climate environment will significantly contribute to the protection, research, and utilization of species (Yang et al. 2013).

The principle is to predict the actual distribution and potential distribution of species through the Niche model, according to the actual distribution locations of species and the related environmental data (Yi et al. 2018). Recently, this model has been widely used in the protection of endangered animals and plants and in studying the effects of species invasion and climate change on species distribution (Franklin 2013; Zhang et al. 2019). The application of Niche models in predicting the potential distribution of plants under future climate conditions can provide important references for the future distribution, migration, and diffusion trends of corresponding species (Warren et al. 2013). If the future distribution area of a species does not overlap with the current distribution area, this indicates that the species may be affected by global warming (Dai et al. 2021). The most commonly used Niche models include MaxEnt, CLIMEX, ENFA and GARP, Bioclim, and Domain-based on bioclimatic data (Venette 2017). Compared to other models, MaxEnt is very
popular due to its stable results, short running time, and exact prediction ability (Ortega-Huerta et al. 2008; Phillips et al. 2006).

Campsis grandiflora, a climbing deciduous vine, belongs to Bignoniaceae, Campsis (Kim et al. 2005). In traditional Chinese medicine, it belongs to the liver and pericardium meridians; it is used to cooling the blood, resolving addiction, dispelling wind, alleviating irregular menstruation, postpartum breast swelling, rubella redness, and skin phlegm itching (Hua et al. 2012). In addition, it has become a popular flower in garden landscaping (Oku et al. 2019). C. grandiflora is mainly found in Hebei, Shandong, Henan, Jiangsu, Zhejiang, Jiangxi, Fujian, Guangdong, Guangxi, Hubei, Hunan, Sichuan, and Shaanxi provinces, and the main areas for the cultivation of medicinal materials are the Jiangsu, Zhejiang, and Jiangxi provinces; in addition, it mostly grows in valleys, streams, roadsides, sparse forests, and other easily observable places and it is often widely cultivated in courtyards (Ueyama et al. 1989). Nowadays, researchers mainly focus on the pharmacological uses and chemical composition of C. grandiflora, but research on the potentially suitable areas of C. grandiflora under climate change is relatively lacking (Jin et al. 2005). Therefore, it is particularly important to use MaxEnt to predict the potential distribution and migration routes of C. grandiflora in China under climate change.

Unlike previous studies that used the MaxEnt model to predict the suitable areas of species, our study not only considered the relationship with carbon dioxide concentration and climate but also explored the scenario of greenhouse gas emissions under social and economic changes and policy intervention, which was different from the past methods of using representative concentration pathways (RCP) (Van Vuuren et al. 2012). The Scenario Model Intercomparison Project (ScenarioMIP) updates climate Projection SSPs from the representative concentration pathways (RCPs) based on new future pathways of societal development released for the preparation of the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), and SSP has a higher starting point, and its forecast scenario is smoother and closer to the real value compared with RCP (O’Neill et al. 2016; Riahi et al. 2017; Zhang et al. 2018a). SSP1 is the route of sustainable development, which is a low-material, low-resource, and low-energy green development route; SSP2, the moderate development route, which represents the future social and economic development model, will continue to develop along with the current mode; SSP5 represents the high radiative forcing with climate change (Shim et al. 2020). In our study, the highest-level greenhouse gas emission scenario and the lowest-level greenhouse gas emission scenario routes were chosen to predict the potential distribution areas of C. grandiflora in 2050s and 2070s under the climate models of green development (SSP1) and conventional development (SSP5).

The major purposes of our study are as follows: (1) a model was put forward to show the relationship between species distribution patterns and environmental variables; (2) the area of suitable habitat for C. grandiflora was predicted according to future global climate change scenarios (in 2050s and 2070s); (3) changes about habitat suitability distributions in three different scenarios (2000s, 2050s, and 2070s) in China were analyzed, and shifts of the highly suitable area core distributions of C. grandiflora were shown. The results could give strategic guidance for development, protection, and utilization of C. grandiflora in China through their prediction of potential distribution based on the main variables under climate change.

Materials and methods

Species occurrence data collection

The distribution records of Campsis grandiflora were obtained from Chinese virtual herbarium (CVH, http://www cvh ac cn), the Global Biodiversity Information Facility (GBIF, http://www gbif org), and China National Specimen Information Infrastructure (NSII, http://www nsii or gn). We used Google Earth 7.1 (Google Inc., Mountain View, CA, USA) to search the longitude and latitude based on the described geographic location when the available records lacked detailed geo-coordinates. Records that were geocoding errors and duplicates were deleted. In the end, a total of 166 records of C. grandiflora in China were collected and a detailed distribution

![Fig. 1 Distribution records of Campsis grandiflora in China with annual mean temperature](image-url)
map was obtained (Fig. 1). As required by MaxEnt software, the distribution records of *C. grandiflora* were imported into Microsoft Excel and sorted into a CSV file.

**Environmental variables**

Nineteen bioclimatic variables are the most typical and main variables that simulate the distribution of the species. In addition, topographic variables of altitude, slope, and aspect are important contributors to species distribution; hence, we added these three factors into our chosen set for a total of 22 variables. Topographic data is derived from the unified world soil database of FAO soil maps and databases V1.2 (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/). The current climate data (1971–2000) and future climate data (2050s, 2070s) are from the World Climate Database (http://www.worldclim.org) (Yang et al. 2013) with 2.5’ spatial resolution. Twenty-two initial environmental variables were used, including 19 biological climate variables and three topographic variables (Table 1). For future climate scenarios, we used the BCC-CSM2-MR climate system model, which was developed by the national Climate Center (Liu et al. 2021). In our study, SSP5-8.5 and SSP1-2.6 were used to simulate the highest-level and the lowest-level greenhouse gas emission scenarios (Riahi et al. 2011). Because not all of the environmental variables were conducive to our prediction model, the Pearson correlation coefficient (*R*) was used to test the multicollinearity and thus removed the relevant environmental variables with lower contribution rate when the correlation coefficient of the two environmental variables was greater than 0.8 (Worthington et al. 2016). Finally, 11 environmental variables were used for calculation and analysis of the MaxEnt model (Table 2).

**Current and future habitat evaluations**

In our study, MaxEnt 3.4.1 k software was used to simulate the potential distribution areas of *C. grandiflora* in China under different climatic conditions. To improve the accuracy of our model analysis, 75% of the distribution points were randomly selected as the training data, and the remaining 25% of the distribution points were selected as the test data, with 500 iterations and 10 repeated runs; other parameters were set as the default (Narouei-Khandan et al. 2016). The ArcMap tool in ArcGIS software was used to convert the output to grid format for further analysis.

In our study, the receiver operating characteristic (ROC) curve of the threshold independent judgment method was used to evaluate the expected results. The area under the curve (AUC) is between 0 and 1; the closer the value is to 1, the more accurate the prediction is (Dai et al. 2019). The prediction accuracy of the model was divided into five grades: fail (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good (0.8–0.9), and

| Table 1 | Environment variables related to the distribution of *Campsis grandiflora* |
| --- | --- |
| Variables | Description | Unit | Variables | Description | Unit |
| bio1 | Annual mean temperature | °C | bio12 | Annual precipitation | mm |
| bio2 | Mean diurnal temperature range | °C | bio13 | Precipitation of wettest month | mm |
| bio3 | Isothermality (Bio2/Bio7) × 100 | – | bio14 | precipitation of driest month | mm |
| bio4 | Temperature seasonality (standard deviation × 100) | – | bio15 | Precipitation seasonality (coefficient of variation × 100) | – |
| bio5 | Max temperature of warmest month | °C | bio16 | Precipitation of wettest quarter | mm |
| bio6 | Min temperature of coldest month | °C | bio17 | Precipitation of driest quarter | mm |
| bio7 | Temperature annual range | °C | bio18 | Precipitation of warmest quarter | mm |
| bio8 | Mean temperature of wettest quarter | °C | bio19 | Precipitation of coldest quarter | mm |
| bio9 | Mean temperature of driest quarter | °C | Altitude | Altitude | m |
| bio10 | Mean temperature of warmest quarter | °C | Slope | Slope | |
| bio11 | Mean temperature of coldest quarter | °C | Aspect | Aspect | % |

| Table 2 | The contribution rate of environmental variables |
| --- | --- |
| Environmental variables | Percent contribution (%) | Permutation importance (%) |
| precipitation of driest month (bio14) | 46.1 | 0.6 |
| Precipitation of warmest quarter (bio18) | 14.6 | 9.7 |
| Mean temperature of warmest quarter (bio10) | 9.2 | 14.6 |
| Mean temperature of coldest quarter (bio11) | 8.1 | 14.7 |
| Temperature annual range (bio7) | 7.5 | 22.1 |
| Aspect | 3.4 | 4.8 |
| Altitude | 3.4 | 22.5 |
| Mean diurnal temperature range (bio2) | 2.9 | 2.7 |
| Slope | 2.1 | 2.7 |
| Precipitation seasonality (bio15) | 1.7 | 2.5 |
| Isothermality (bio3) | 1 | 3 |
excellent (0.9-1) (Zhao et al. 2021). Subsequently, we used the current climate data to simulate the spatial range of suitable habitat of *C. grandiflora* in four future scenarios (SSP1-2.6 and SSP5-8.5 in both 2050s and 2070s). The suitable habitats were divided into four grades following the method used by Yang et al (2013): unsuitable habitat (0-0.20), poorly suitable habitat (0.2-0.4), moderately suitable habitat (0.4-0.6), and highly suitable habitat (0.6-1.00). The spatial extents of the regions in these four classes were calculated and illustrated.

**Results**

**The species distribution model and its accuracy**

Our MaxEnt model for the *C. grandiflora* performed better than random prediction with the given set of training and test data. The AUC value of training data was 0.939 and the result indicated that our model showed a rather good performance in modeling *C. grandiflora* distribution in China (Fig. S1).

**The main environmental variables affecting the distribution of Campsis grandiflora**

As can be seen in Table 2, among the 11 environmental variables, the three environmental variables with the highest contribution rates were precipitation of driest month (bio14, 46.1% contribution), precipitation of warmest quarter (bio18, 14.6% contribution), and mean temperature of warmest quarter (bio10, 9.2% contribution). These variables accounted for almost 69.9% of the model prediction. Considering the importance of permutation, the variables of altitude (22.5% contribution), temperature annual range (bio7, 22.1% contribution), and mean temperature of coldest quarter (bio11, 14.7% contribution) were much higher than others. Meanwhile, the jackknife test showed that the mean temperature of coldest quarter (bio11), mean diurnal temperature range (bio2), and precipitation of driest month (bio14) were the main variables (Fig. S2).

In summary, temperature (bio2, bio7, bio10, and bio11), precipitation (bio14, bio18), and altitude played a vital role in predicting the distribution of *C. grandiflora*. By the response curve (Fig. S3), we obtained thresholds (probability of presence > 0.5) for the main bioclimatic parameters. Mean diurnal temperature range (bio2) ranged from 7.3 to 9.5 °C, temperature annual range (bio7) ranged from 28 to 33 °C, mean temperature of warmest quarter (bio10) ranged from 25.5 to 28 °C, mean temperature of coldest quarter...
(bio11) ranged from 5 to 15 °C, precipitation of driest month (bio14) ranged from 30 to 100 mm, precipitation of warmest quarter (bio18) ranged from 500 to 720 mm, and altitude ranged from 400 to 1200 m.

**Current potential distribution**

General layout of the climatical zone in China is in table S1. It can be seen from Fig. 2. *C. grandiflora* is mainly distributed in middle subtropical humid regions, north subtropical humid regions, and south subtropical humid regions. Among them, the highly suitable habitat is mainly distributed in the northeast and southeast Jiangxi, northeast and southeast Hunan, the northeast Sichuan, and the southeast and northeast Hubei. The area of moderately suitable habitat is mainly distributed in coastal and southern Shandong, western Hunan, eastern Sichuan, and parts of Hubei. The poorly suitable habitat is mainly distributed in central Yunnan, eastern Guizhou, southern Sichuan, western Guangxi, and northern, western, and eastern Henan. We calculated the areas of suitable habitat in each province according to the classification of suitable habitats (Table 3). The suitable distribution area of *C. grandiflora* in China is $238.29 \times 10^4$ km$^2$. The area of highly suitable habitat is $50.05 \times 10^4$ km$^2$, accounting for 21% of the suitable area. The area of moderately suitable habitat

### Table 3 The potential distribution areas for *Campsis grandiflora* under current climatic conditions

| Province municipality autonomous regions | Poorly suitable habitat ($10^4$ km$^2$) 20–40% | Moderately suitable habitat ($10^4$ km$^2$) 40–60% | Highly suitable habitat ($10^4$ km$^2$) ≥ 60% | Total suitable habitat ($10^4$ km$^2$) |
|-----------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------------------|
| Beijing                                 | 0.92                                          | 0.17                                          | 0.00                                          | 1.09                                  |
| Tianjin                                 | 0.57                                          | 0.19                                          | 0.03                                          | 0.79                                  |
| Hebei                                   | 7.04                                          | 0.80                                          | 0.02                                          | 7.86                                  |
| Shandong                                | 1.81                                          | 0.00                                          | 0.00                                          | 1.81                                  |
| Inner Mongolia                          | 0.00                                          | 0.00                                          | 0.00                                          | 0.00                                  |
| Liaoning                                 | 2.06                                          | 0.17                                          | 0.01                                          | 2.24                                  |
| Jilin                                    | 0.00                                          | 0.00                                          | 0.00                                          | 0.00                                  |
| Heilongjiang                            | 0.00                                          | 0.00                                          | 0.00                                          | 0.00                                  |
| Shanghai                                | 0.18                                          | 0.10                                          | 0.03                                          | 0.31                                  |
| Jiangsu                                 | 2.79                                          | 4.20                                          | 1.06                                          | 8.05                                  |
| Zhejiang                                | 2.93                                          | 3.48                                          | 2.21                                          | 8.62                                  |
| Anhui                                   | 3.63                                          | 6.32                                          | 2.39                                          | 12.34                                 |
| Fujian                                  | 3.77                                          | 2.75                                          | 3.38                                          | 9.9                                   |
| Jiangxi                                 | 1.39                                          | 2.83                                          | 10.90                                         | 15.12                                 |
| Shandong                                | 6.43                                          | 6.57                                          | 0.46                                          | 13.46                                 |
| Henan                                   | 11.02                                         | 3.35                                          | 0.21                                          | 14.58                                 |
| Hubei                                   | 5.39                                          | 6.95                                          | 4.37                                          | 16.71                                 |
| Hunan                                   | 3.67                                          | 6.66                                          | 8.68                                          | 19.01                                 |
| Guangdong                               | 6.03                                          | 3.49                                          | 4.05                                          | 13.57                                 |
| Guangxi                                 | 8.36                                          | 5.70                                          | 4.48                                          | 18.54                                 |
| Hainan                                  | 1.09                                          | 0.20                                          | 0.00                                          | 1.29                                  |
| Chongqing                               | 2.41                                          | 2.89                                          | 1.97                                          | 7.27                                  |
| Sichuan                                 | 9.70                                          | 7.56                                          | 4.99                                          | 22.25                                 |
| Guizhou                                 | 10.11                                         | 3.92                                          | 0.26                                          | 14.29                                 |
| Yunnan                                  | 13.70                                         | 2.59                                          | 0.47                                          | 16.76                                 |
| Tibet                                   | 2.78                                          | 0.24                                          | 0.03                                          | 3.05                                  |
| Shaanxi                                 | 5.71                                          | 1.47                                          | 0.07                                          | 7.25                                  |
| Gansu                                   | 1.49                                          | 0.15                                          | 0.01                                          | 1.65                                  |
| Ningxia                                 | 0.00                                          | 0.00                                          | 0.00                                          | 0.00                                  |
| Xinjiang                                | 0.00                                          | 0.00                                          | 0.00                                          | 0.00                                  |
| Taiwan                                  | 0.51                                          | 0.00                                          | 0.00                                          | 0.00                                  |
| Xianggang                               | 0.01                                          | 0.00                                          | 0.00                                          | 0.01                                  |
| Total (China)                           | 115.49                                        | 72.75                                         | 50.05                                         | 238.29                                |
is $72.75 \times 10^4$ km$^2$, accounting for 30.53% of the suitable area. The area of poorly suitable habitat is $115.49 \times 10^4$ km$^2$, accounting for 48.47% of the suitable area. Jiangxi, Hunan, Sichuan, Guangxi, and Guangdong have relatively large areas of highly suitable habitat. Among them, the highly suitable distribution area of *C. grandiflora* in Jiangxi is $10.90 \times 10^4$ km$^2$, and it has the largest suitable distribution area of all provinces in China. Sichuan, Hubei, Hunan, and Shandong have larger moderately suitable habitat areas than other provinces. There are no suitable distribution areas of *C. grandiflora* in Inner Mongolia, Jilin, Ningxia, Heilongjiang, Taiwan, or Xinjiang.

**Fig. 3** The potentially suitable climatic distribution of *Campsis grandiflora* under different future climate change scenarios in China

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Future potentially suitable climatic distributions

In the SSP1-2.6 and SSP5-8.5 climate change scenarios for the 2050s and the 2070s, predictions of future potentially suitable distributions of *C. grandiflora* are illustrated (Fig. 3). In these scenarios, *C. grandiflora* is mainly distributed in the middle subtropical humid region, south subtropical humid region, and north subtropical humid region. Our study shows that under SSP1-2.6 for the 2050s, the moderately suitable habitat area of *C. grandiflora* will be $50.05 \times 10^4$ km$^2$, the highly suitable habitat area will be $148.41 \times 10^4$ km$^2$, and the total suitable habitat area will be $275.72 \times 10^4$ km$^2$ (Table 4). The total suitable habitat of *C. grandiflora* will mainly be located in northern and eastern Guangdong, northeastern Guangxi, northern and southern Yunnan, eastern Sichuan, northern Chongqing, northern Sichuan, southern and eastern Hubei, southern Shanxi, eastern and southern Henan, central and southern Anhui, western Jiangsu, eastern Shanghai, western and southern Zhejiang, western and northern Zhejiang, western and southern Fujian, central Shandong, southern and eastern Hubei, southern Jiangxi, and eastern Hunan. Under SSP5-8.5 for the 2050s, the moderately suitable habitat area will be $45.06 \times 10^4$ km$^2$, the highly suitable habitat area will be $142.88 \times 10^4$ km$^2$, and the total suitable habitat area will be $273.64 \times 10^4$ km$^2$ (Table 4). The total suitable habitat will mainly be distributed in northern Guangdong, northern and eastern Guangxi, central and eastern Hunan, eastern Sichuan, eastern Chongqing, eastern Hebei, southern Liaoning, northern and eastern Hunan, southern and eastern Hubei, southern and eastern Henan, southern and eastern Anhui, northern and southern Jiangsu, southern Shandong, northern Zhejiang, and southern Fujian. Under SSP1-2.6 for the 2070s, the moderately suitable habitat area will be $54.54 \times 10^4$ km$^2$, the highly suitable habitat area will be $142.88 \times 10^4$ km$^2$, and the total suitable habitat area will be $273.64 \times 10^4$ km$^2$ (Table 4). The total suitable habitat is not much different from that projected for the 2050s under SSP1-2.6. Under SSP5-8.5 for the 2070s, the moderately suitable habitat area will be $35.57 \times 10^4$ km$^2$, the highly suitable habitat area will be $211.51 \times 10^4$ km$^2$, and the total suitable habitat area will be $302.91 \times 10^4$ km$^2$ (Table 4). The total suitable habitat will mainly be distributed in southern Shandong, northern Zhejiang, northern Anhui, eastern Jiangsu, southern Fujian, western Sichuan, southern Guangxi, southern Guangdong, and southern Henan. Under SSP5-8.5 for the 2050s, the area loss of *C. grandiflora* will be $0.07 \times 10^4$ km$^2$, the area gained will be $99.18 \times 10^4$ km$^2$, and the stable area will be $124.33 \times 10^4$ km$^2$ (Table 5). The distribution range of area gained will be similar to that under SSP1-2.6 for the 2050s. The area gained will mainly be distributed in warm temperate humid regions and south subtropical humid regions. Under SSP1-2.6 for the 2070s, the area loss of *C. grandiflora* will be $0.12 \times 10^4$ km$^2$, the area gained will be $72.48 \times 10^4$ km$^2$, and the stable area will be $124.71 \times 10^4$ km$^2$. The distribution range of area gained will be similar to that under SSP1-2.6 for the 2050s. The area gained will mainly be distributed in warm temperate humid areas. Under SSP5-8.5 for the 2070s, the area loss of *C. grandiflora* will be $0.14 \times 10^4$ km$^2$, the area gained will be $123.41 \times 10^4$ km$^2$, and the stable area will be $123.71 \times 10^4$ km$^2$. The area gained will mainly be distributed in the warm temperate humid regions, middle subtropical humid regions, and south subtropical humid regions of southern and eastern Hebei, southern Shaanxi, northern and southern Shandong, southern Sichuan, northern Guizhou, central Yunnan, southern Guangxi, southern Zhejiang, eastern Fujian, southern Guangdong, northern Hainan Island, and parts of Hebei.

The core distributional shifts

Figure 5 shows the centroid of the current habitat of *C. grandiflora* located at 112°88′E and 29°04′N in central Hunan. The centroid of the suitable area will shift to 112°67′E.
29°65′N during the 2050s under SSP1-2.6, and to 112°47′E, 29°81′N during the 2050s under SSP5-8.5. During the 2070s under SSP1-2.6, the centroid of the future suitable area will be located at a northeast position (112°73′E, 29°81′N), but during the 2070s under SSP5-8.5, the centroid of the suitable area will shift to the northwest (112°40′E, 30°09′N). Overall, we predict the centroid of the potentially suitable area of C. grandiflora to migrate to higher latitude and higher altitudes areas.

Fig. 4 Potentially suitable climatic distribution change of Campsis grandiflora under different climate change scenarios in China
Discussion

The evaluation indicators of the used model are accurate, sensitive, and specific (Tang et al. 2019). Currently regarded as the best evaluation indicator, the ROC curve could be immediately drawn by MaxEnt software, and the AUC of the model could be also directly calculated, which makes judging the predictive accuracy much easier. This is why ROC curves have been extensively used in evaluating MaxEnt models. For instance, Zhang et al. (2018a) used ROC curves to evaluate the prediction of the potential geographical distribution of two peony species under climate change, and Zhao et al. (2020) used ROC curves to study *Taiwania cryptomerioides* under climate change. Consequently, ROC curves are used to estimate the predictive accuracy of the MaxEnt model. The results of our study indicated that the simulation effect was excellent and proved that the model could be used to predict the current and future distributions of *C. grandiflora* under climate change in China.

The results of the MaxEnt model showed that temperature, rainfall, and altitude were the main variables affecting the distribution of *C. grandiflora*. The humid and warm climate all year round is crucial for the distribution of *C. grandiflora*. *C. grandiflora* likes a warm, humid, and sunny environment, which makes it more resistant to shade; it also requires good drainages, leeward and sunny locations, fertile and loose soil, drought resistance, and avoiding water, and water availability is an important factor affecting the germination of seeds (Poorter and Nagel 2000). The roots of *C. grandiflora* are fresh when it has enough water; previous research has proved that the optimum relative soil moisture content is 75%; water validity can directly affect emergence, and too much water can cause root rot and increase the risk of plant diseases and insect pests (Zhang et al. 2018b). These hydrothermal factors would affect the ecological adaptation of *C. grandiflora* and species distribution. Altitude includes the drastic changes of many environmental variables, such as temperature, water, and soil fertility, and environmental heterogeneity caused by altitude gradient often affects the vertical distribution pattern of plants (Fagre et al. 2003).

Some studies have shown that under the influence of global climate change, the continuous increase of global temperature and the change of precipitation patterns will lead many plants to migrate to higher latitudes and higher altitudes (Sun et al. 2020). Zhang et al. (2018a) used MaxEnt to predict the potential geographical distribution of two peony species under climate change and found that a shift in the distribution of suitable habitat to higher elevations would gradually become more significant. Mckenney et al. (2007) used two different assumptions to predict how 130 tree species in North America would react to climate change and found that the distribution areas would migrate northward by 700 and 330 km respectively. The results of our study are consistent with these findings. Based on the environmental changes, the following table summarizes the future changes in suitable habitat area.

Table 5 Future changes in suitable habitat area

| Decades scenarios | Predicted area/10^4 km^2 | Loss | Gain | Stable |
|-------------------|--------------------------|------|------|--------|
| 2050s, SSP1-2.6   | 0.18                     | 83.66| 124.33|
| 2050s, SSP5-8.5   | 0.07                     | 99.18| 124.33|
| 2070s, SSP1-2.6   | 0.12                     | 72.48| 124.71|
| 2070s, SSP5-8.5   | 0.14                     | 123.41| 123.71|

Fig. 5 The core distributional shifts.
variables of four different emissions scenarios under the future climate change scenario, combined with current climate conditions, MaxEnt modeled the potential geographical distribution of *C. grandiflora* in China under the future climate change scenario, predicting that the potentially suitable area of *C. grandiflora* will increase, and the core area of potential distribution will migrate to higher latitudes. This means that there may be new areas suitable for the growth of *C. grandiflora* under the future climate change scenario. The global temperature will rise 1.5°C/2°C by 2030/2050 relative to preindustrial levels (1861-1900) under three future scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5) based on the projection of CMIP6, and warming under SSP5-8.5 will occur the fastest compared to the other scenarios (Zhang et al. 2021). With the global temperature rising, some species may migrate to higher altitudes or latitudes (Lenoir et al. 2008; Parmesan et al. 2011). However, some species may adapt to this change in physiology or phenology (Hu and Liu 2014).

**Conclusions**

A model of potential distribution of *C. grandiflora* with changing environmental variables was successfully established in this study. With the model representing the distribution of observed occurrence records, the impacts of climate change on the suitable habitats of *C. grandiflora* in China were estimated. The results indicate that the area of total suitable habitat and highly suitable habitat will increase in the future climate change scenario. However, the area of moderately and the poorly suitable habitat will decrease. The dominant variables that affect the geographical distribution of *C. grandiflora* are temperature, precipitation and altitude. Besides climate and topographic variables, other variables such as soil, biotic factors, and human activity also affect the distribution of *C. grandiflora*. The results will provide a theoretical basis for the scientific management and resource protection of *C. grandiflora*.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s11356-022-20256-4.

**Author contribution** Xianheng Ouyang: conceived and designed the study; contributed to data collection; analyzed the data and wrote the manuscript; Jingling Pan: revised the manuscript; Zhitao Wu: contributed to data collection; Anliang Chen: supervised the project; revised the manuscript and acquired the fund.

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**Declarations**

**Ethics approval** Not applicable.

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