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DISTRIBUTION PATTERNS OF *GNETUM* L. SPECIES IN CHINA UNDER CLIMATE CHANGE

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Key words: *Gnetum*, Geographic distribution, Ecological niche model, Climate change

Abstract

Gnetum L. is a unique group of nacked seeded plants which have potential medicinal values. In this work, the Maximum Entropy Model (Maxent) was built to predict the potential distribution of *Gnetum* L. species in China under five climate scenarios. The results showed that the potential distribution area of *Gnetum* L. was mainly located in south China. The moderate and highly suitable areas accounted for 2.83 and 0.77% of the total area, respectively. In two historic scenarios, the range of suitable area was larger than that of current scenario, and the moderate and highly suitable area was larger than other scenario. In the future scenario, the suitable area is likely to be expanded. The Jackknife method revealed that the main climate factors were: annual mean temperature and minimum temperature of coldest month. The results of Maxent method revealed a high reliability, which can accurately reflect the potential distribution of *Gnetum* L. species and of key climate factors.

Introduction

Species Distribute Models (SDMs) is a kind of mathematical model based on Ecological Niche Modeling (ENM) (Peterson 2006). It predicts the suitable distribution area by fitting relevant ecological factors data (Araújo and Peterson 2012). The species distribution models are significant in the field of ecology and biological conservation (Phillips and Dudík 2010). There are many types of models for estimating plant distribution, including the Genetic Algorithm for Ruleset Production (GARP), Maxi-mum Entropy Model (Maxent), Climex and so on. Maxent model is based on the maximum entropy principle, which is: when predicting the probability distribution of a random event without any subjective assumptions, the probability distribution is the most homogeneous and the entropy of distribution is the largest, and the probability distribution is closest to the real state (Phillips and Dudík 2010). In practical, Maxent is mainly applied to predict changes in species distribution using environmental factors data, especially on the large scale, and owned a good effect on prediction (Warren and Seifert 2011, Cui *et al*. 2016).

Climate is the decisive factor affecting the distribution of organisms, and the distribution pattern of species also reflects climate change (Gao *et al*. 2016). The climate change in the past few decades has had a great impact on the distribution and diversity of many species (Parmesan and Yohe 2003). Global warming has become an indisputable fact at present, the publication of the UN's Intergovernmental Panel on Climate Change (IPCC) have showed that: the degree of climate change since 1950 has never been seen in millennia, the average temperature in 2003-2012 increased by 0.85ºC over 1850-1900 (Hartmann *et al*. 2013), and natural disasters caused by extreme climate may be more frequent in the future. This is a huge challenge for the protection and utilization of species. Therefore, the understanding of climate change is very important for species distribution and protection of biodiversity (Coulston and Riitters 2005).

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The genus *Gnetum* L. (about 40 species) comprises a small unique group of gymnosperms, which mainly distributed in tropical and subtropical areas in Asia and Africa, especially in the tropical regions of South and Southeast Asia. The phylogenetic position of Gnetales is one of the most contentious issues in seed plant systematics, and is known to share a series of angiosperms characters (Hou *et al*. 2015, Chang *et al*. 2018). Despite the effects of evolutionary divergence, *Gnetum* species reportedly produce many important natural bioactive compounds such as flavonoids and stilbenoids (Deng *et al*. 2016). In Africa and Southeast Asia, many species of *Gnetum* are treated as healthy woody vegetables, such as *G. buchholzianum* and *G. africanum*. which are one of the main export products of these areas (Langenberger *et al*. 2009, Ali *et al*. 2011). There is abundant *Gnetum* resource in China, according to the previous phylogenetic studies, there are *G. montanum* Markgraf, *G. catasphaericum* H.Shao, *G. formosum* Margr., *G. parvifolium* (Warb.) C. Y. Cheng and *G. luofuense* C. Y. Cheng which are distributed in China comprising the Chinese clade (Hou *et al*. 2015, Hou *et al*. 2016), and three species are endemic to China. *Gnetum* L. is widely distributed in south China, but the research on the ecology, population diversity and distribution is very few. In addition, due to economic development and other reasons, the natural environment of *Gnetum* L. in China has been destroyed, the resources of the species are degraded. Therefore, the present research is aimed to determine the suitable distribution area of *Gnetum* L. under different climate scenarios which would be a great significance to the management, development, utilization and protection of the *Gnetum* resources.

Materials and Methods

The distribution sites of *Gnetum* L. in China were collected from online database (Chinese Virtua Herbarium, http://www.cvh.ac.cn/), related literature and field investigation. The *Gnetum* L. species of all the samples were listed as follows: *G. montanum*, *G. montanum*, *G. pendulum*, *G. catasphaericum*, *G. parvifolium* and *G. luofuense*. After screening, a total of 127 samples were collected (Fig. 1). The environmental data were download from the world climate database (WorldClim: http://www.worldclim.org/), the raster data were generated by interpolation method in the database. There are 19 bioclim variables in the database (Table 1). In addition, the climate data of four historical periods used in this research, were included the Last Glacial Maximum (extreme cold in history, about 21000 years ago), the Mid Holocene (extreme warm in history, about 6000 years ago), current stage (1950 - 2000) and future (2050, average for 2041 - 2060). The layer resolution is 30″. Among the future climate scenario, rcp26 and rcp85 greenhouse gas scenarios was selected (Mccarthy *et al*. 2007), which represent the minimum temperature increase (0.4 - 1.6, average for 1.0) and maximum temperature increase (1.4 - 2.6ºC, average for 2.0ºC), respectively. China's administrative map (1:400 million) was derived from National Geomatics Center of China.

ArcGIS (10.5) software was used to cut out all environmental variables data in the study area, and then Maxent (version 3.4.1) software was used to make model construction analysis. The 75% of all samples were selected to establish training subset, the remaining 25% of the sample points were used as test subset to verify the reliability of the model. The receiver operating characteristic curve (ROC) was used to make accuracy test. In ROC figures, the area formed by the curve and abscissa is called the Area under curve (AUC). The value of AUC ranges from 0 to 1, the greater the value is, the more accurate the predicted result is. The AUC evaluation criteria were as follows (Vanagas 2004, Gao *et al*. 2016): failed (0.5 - 0.6), poor (0.6 - 0.7), common (0.7 - 0.8), good (0.8 - 0.9) and great (0.9 - 1.0). Jackknife method was used to evaluate the weight of environmental factors, and then main influencing factors were screened out (Peterson and Cohoon 1999). At last, the distribution area of *Gnetum* was divided into four grades using natural discontinuity method, they were named as followed: Not suitable, low suitable, moderate suitable and highly suitable.

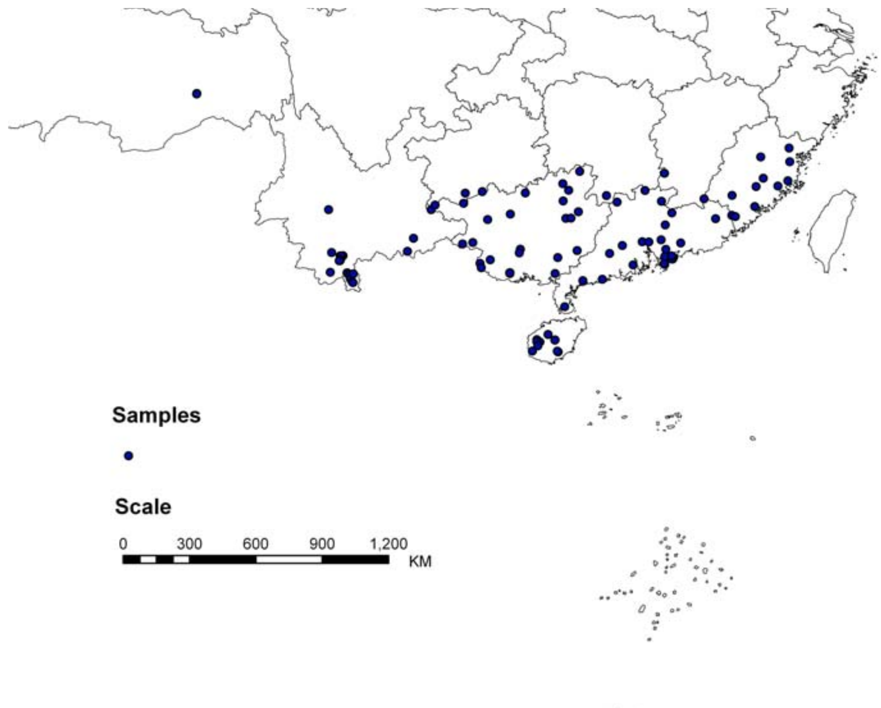

Fig.1. The location of samples used in the study.

Table 1. 19 bioclim variables used to build the model.

Code	Description
Bio1	Annual mean temperature
Bio2	Mean diurnal range (Mean of monthly (max.temp., min.temp.))
Bio3	Isothermality (BIO2/BIO7) (* 100)
Bio4	Temperature seasonality (standard deviation *100)
Bio5	Max temperature of warmest month
Bio6	Min Temperature of coldest month
Bio7	Temperature annual range (BIO5-BIO6)
Bio8	Mean temperature of wettest quarter
Bio9	Mean temperature of driest quarter
Bio10	Mean temperature of warmest quarter
Bio11	Mean temperature of coldest quarter
Bio12	Annual precipitation
Bio13	Precipitation of Wettest Month
Bio14	Precipitation of Driest Month
Bio15	Precipitation Seasonality (Coefficient of Variation)
Bio16	Precipitation of wettest quarter
Bio17	Precipitation of driest quarter
Bio18	Precipitation of warmest quarter
Bio19	Precipitation of coldest quarter

Results and Discussion

The ROC of each climate scenario were calculated, respectively (Fig. 2). As the result (Table 2), the AUC of training subset ranged from 0.974 - 0.981, and the AUC of test subset ranged from 0.961 - 0.973. According to the criteria, the accuracy of all models was great (> 0.9), which indicated the models can distinguish the distribution of species very accurately, the result showed that models were very suitable for this research.

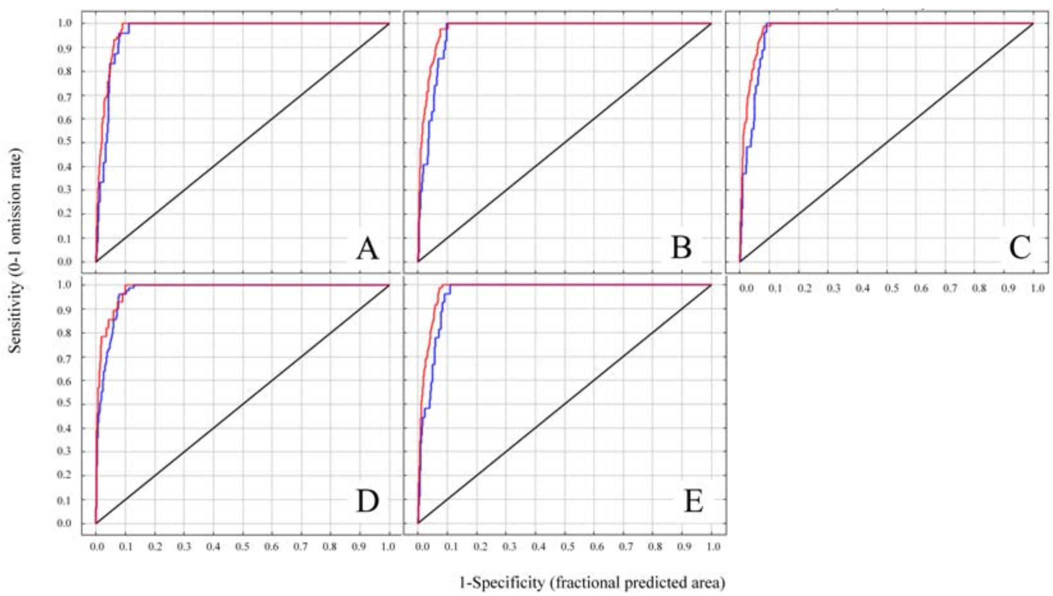

Fig. 2. The ROC curve of for the *Gnetum* distribution model. The red curve represents the training data, the blue curve represents the test data, the black line represents the random prediction. A. Last glacial maximum, B. Mid Holocene, C. Current, D. 2050-rcp26, E. 2050-rcp85.

Table 2. AUC value of different scenario.

Scenario	AUC of tranning data	AUC of test data
Last Glacial Maximum	0.9743	0.9642
Mid Holocene	0.9771	0.9635
Current	0.9776	0.9609
2050 (BCC-CSM1-1-26)	0.9776	0.9618
2050 (BCC-CSM1-1-85)	0.981	0.9729

Climate is the dominant factor affecting the distribution of plants, it is mainly shown in two aspects of temperature and water. Water is the source of life of plants, and temperature is the essential component of plants and very important for their physiological activities (Fang 1991). Therefore, 19 bioclimatic factors that affected the distribution of organisms were selected. The jackknife test results of each model are presented in Fig. 3. The result indicated the five climate scenario have essentially the same factors, they were : bio1, bio6, bio7, bio9, bio11, bio12, bio13, bio16 and bio18, the cumulative contribution of each climate scenario reached 86.2, 88.5, 94.4, 80.2 and 92%, respectively. Combined with the jackknife result, *Gnetum* species prefer moist and warm environment, and is not resistant to low temperature, especially have a need for precipitation during the peak period (usually May to September).

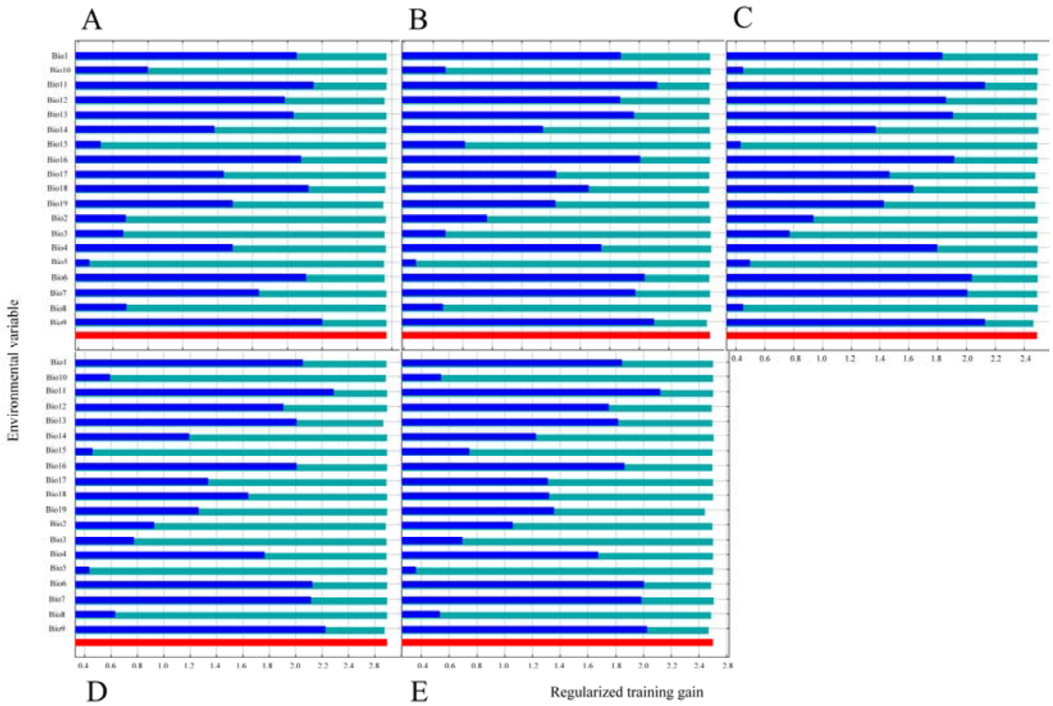

Fig. 3. The results of the jackknife test of variable importance. Light blue bars indicate without the variable; dark blue bars indicate with only the variable; red bars indicate with all variables. A. Last Glacial Maximum, B. Mid Holocene, C. Current, D. 2050-rcp26, E. 2050-rcp85.

The suitable area of the *Gnetum* L. was different under different climatic conditions (Table 3). The proportion of unsuitable regions in current was the smallest (91.6%), and then was the Last Glacial maximum (92.78%). The proportion of low and moderate suitable regions in current were the largest (4.44 and 2.83%), and then was the future scenario (rcp85, 3.80 and 2.40%). The proportion of highly suitable regions in the last Glacial maximum was the largest (1.66%), and the proportion in the Mid Holocene was the smallest (0.63). As the extreme cold/warm period in the historical climate, the suitable regions of the last Glacial maximum were larger than that of the Mid Holocene, the highly suitable area in the Mid Holocene decreased by 62% compared to the last Glacial maximum. In the future (rcp26 and rcp85), the unsuitable area will increase and the highly suitable area will decrease.

The simulated distribution of *Gnetum* L. in China is presented in Fig. 4. The suitable area of *Gnetum* was mainly located in south of China, including Nyingchi City and Sannan City in Tibet, south of the Hengduan Mountains in Yunnan province, south of Guizhou province, all territory of Guangxi, the area located along the east of the Wuyi Mountains and south of the Nanling Mountains, west of the Taiwan Mountains. The highly suitable area mainly is located in Yunnan and Hainan province. In the Mid Holocene scenario, the moderate suitable area decreased, especially the suitable area in Sichuan province disappeared, but the highly suitable area of some province increased, such as Taiwan province (compared to current). In the last Glacial maximum scenario, the suitable area ranges were mainly in south China, the moderate and highly suitable area were much larger than the current scenario. In the future scenario, the distribution pattern of *Gnetum* changed a lot. In the minimum temperature increase scenario (rcp26), the distribution area of *Gnetum* was compressed compared with current, but the moderate and highly suitable area increased. In the maximum temperature increase scenario (rcp85), the distribution area of *Gnetum* decreased obviously. The present results showed the suitable area in Taiwan province, but *Gnetum* was not found in local place except some artificial cultivation. The result also showed that the highly suitable area was mainly located in Yunnan and Hainan province, and our field investigation found these areas with a large population and diversifies biological species, which had a good agreement with prediction results.

Table 3. Area of *Gnetum* distribution under different climate scenarios.

	Last glacial maximum (%)	Mid holocene (%)	Current (%)	Future (BCC-CSM1-1-26 (%)	Future (BCC-CSM1-1-85) (%)
Not suitable	92.78	93.51	91.96	93.19	92.98
Low suitable	3.33	3.73	4.44	3.33	3.80
Moderate suitable	2.24	2.14	2.83	2.04	2.40
High suitable	1.66	0.63	0.77	1.44	0.82

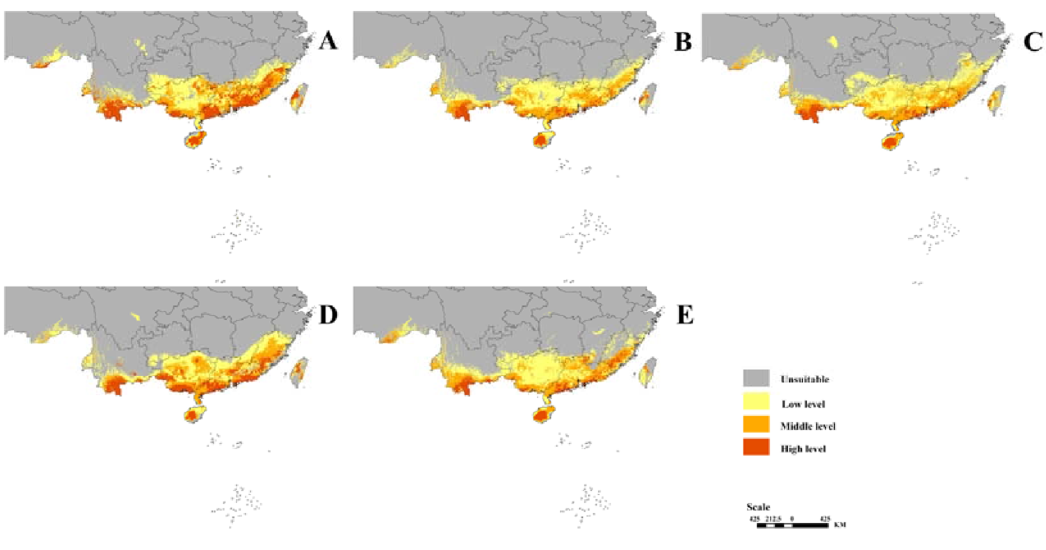

Fig. 4. The change of suitable region of *Gnetum* under different climate scenarios. A. Last Glacial maximum, B. Mid Holocene, C. Current, D. 2050-rcp26, E. 2050-rcp85.

From the last Glacial maximum to current, the distribution of *Gnetum* expanded to the north, but the moderate and highly suitable area of the last Glacial maximum were larger than the Mid Holocene and current. The reason might be that the large-scale development of land and sea ice in the last Glacial maximum period, and the low atmospheric greenhouse gas concentration caused the summer temperature decrease in East Asia to limit the North expansion of *Gnetum*. In the last Glacial maximum, the mean summer temperature difference in the range of 10°~50°N and

90°~135°E is 1.6 degrees which are lower than that in modern times, and in the Mid Holocene, due to the increase of meridional heat difference between the low latitude and highly latitude continents, the regional average summer temperature difference increased (Tian and Jiang 2015). In the future, the present results showed that the distribution area will increase, and higher temperature increase had a greater impact on the expansion of *Gnetum*, this observation is consistent with many other studies (Ma *et al*. 2014, Gao *et al*. 2016, Wu *et al*. 2016). Additionally, there has been a highly suitable area in Taiwan since last Glacial maximum, but no distribution of wild *Gnetum* was found in the area, the reason need to be further studied.

In addition, only the climate factors were used in this research, and many other factors such as soil, topography, and biological factors would also play an important role in plant distribution, and this needs to be studied further in the future. The result of this research can be used in the distribution survey, introduction and cultivation, resources protection and utilization of the *Gnetum* L. resources in China.

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