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Impacts of climate change on potential geographical cultivation areas of longan (*Dimocarpus longan*) in China

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Abstract

Longan is an economically important sub-tropical fruit tree native to southern China and southeast Asia. Its production has been affected significantly by climate change, but the underlying reasons remain unclear. Herein, the potential growing areas of longan were simulated by the Maxent model under current and future conditions. The results showed excellent prediction performance, with an area under curve of >0.9 for model training and validation. The key environmental variables identified were mean temperature of the coldest quarter, minimum temperature of the coldest month, annual mean temperature and mean temperature of the driest quarter. The optimum suitable areas of longan were found to be concentrated mainly in south-western, southern and eastern China, with a slight increase in optimum suitable areas under two different emission scenarios of three global climatic models. However, its future potential growing areas were predicted to differ among provinces or cities. Suitable growing areas in Sichuan, Jiangxi, Guangxi and Chongqing will first increase and then remain approximately unchanged between the 2050s and 2070s; those in Yunnan, Guangdong and Hainan will remain approximately unchanged from the present to the 2070s; those in Fujian and Guizhou will fluctuate slightly from the present to the 2050s and then increase to the 2070s; those in Taiwan will first decrease and then increase. In summary, the major future production areas of longan will be Guangdong, Hainan and Guangxi provinces, followed by Chongqing, Yunnan, Fujian and Taiwan. Thus, this study serves as a useful guide for the management of longan.

Introduction

Longan (*Dimocarpus longan* Lour.) belonging to the family Sapindaceae, is a subtropical fruit widely accepted by consumers all over the world for its pleasant flavour and health benefits (Wen *et al*., 2012; Lai and Lin, 2013). It is of great economic importance in southern China and southeast Asian countries, including Thailand, Vietnam, Laos, Myanmar, Sri Lanka, India, Philippines, Malaysia, Indonesia and so on (He *et al*., 2016). In China, it is widely cultivated in Fujian, Taiwan, Hainan, Guangdong, Guangxi, Yunnan, Guizhou, Sichuan, etc., with Fujian, Hainan and Guangxi provinces as its main producing areas (Yang *et al*., 2017). Modern pharmacological research shows that the longan fruit has anti-ageing and anti-cancer effects, improves immunity and promotes intellectual development, and thus has gained the attention of the whole society (Pan *et al*., 2008; He *et al*., 2016). A number of studies on longan focused on its physiological and ecological aspects (Duan *et al*., 2008; Zhao *et al*., 2014; Lu *et al*., 2017). The development of the global economy, together with improvement in people's living standards and in preservation technology, will inevitably lead to increasing demand for longan. Today, it has become the consensus of governments at all levels to cultivate longan to meet the growing demand. For example, the Municipal Government of Chongqing has recently initiated the Longan and Litchi Engineering Research Centre and Technological Innovation Platform in the upper reaches of the Yangtze River. In order to meet the growing demand of longan products for economic and social development in China, it is necessary to continuously expand the plantation area of longan. To avoid ecological damages and reduce investment risks, caused by blindly expanding its introduction and cultivation, it is very important to assess its potential cultivation areas under changing climate conditions. For longan, the optimum temperature ranges from − 2 to 18°C during the dormant stage (November–January) and from 15 to 35°C during the fruit growth and maturity stages (June–August). Because longan can grow even in barren, dry and hilly red soil, it is regarded as having wide adaptability to various soil types (Lin and Li, 1999; Duan *et al*., 2008). Therefore, climate variables have an important influence on longan and its potential growing areas.

The spatial distribution of plants is closely related to their environmental conditions, such as climate and terrain, on a regional scale (Guo *et al*., 2017). At present, species distribution models (SDMs) can infer the ecological needs of a species by using the known data (including the occurrence data and layers of environmental variables affecting its distribution) based on a specific algorithm and then map its potential distribution in the whole study area (Zhu *et al*., 2013). In recent years, with the comprehensive application of statistical tools and geographic information system (GIS), a series of ecological niche models (i.e., Bioclim, Domain, Maxent and Garp) have emerged (Wang *et al*., 2010; Lu *et al*., 2014). Out of various SDMs, Maxent (Maximum Entropy Modelling), a maximum entropy-based machine learning program, has been testified to perform better with small sample sizes or presence-only occurrence data than other models (Qin *et al*., 2017; Dong *et al*., 2019). The Maxent model has many advantages to utilize both continuous and categorical data and incorporates interactions between different variables (Phillips *et al*., 2006; Wang *et al*., 2010). Additionally, the requirements for computer configuration are lower and the operation time is shorter. The probability distribution method of the Maxent model has a concise mathematical expression amenable to the analysis of results. Besides, the model can also identify environmental factors that limit species distribution. Therefore, the Maxent model has been commonly utilized for accurately forecasting species distribution since it was released (Wang *et al*., 2010; Qin *et al*., 2017). Meanwhile, it was also used to speculate the change of species natural distributions under climate change conditions (Bradley *et al*., 2010; Xu *et al*., 2014). In our study, the Maxent model was applied to detect the cultivation area of longan by combining the known coordinates with environmental layers in China under current and future environmental conditions. Thus, our objectives in the present study were: (1) to determine the potential cultivation area of longan under current and future environmental conditions, (2) to identify the variables that have the most important influence on its potential cultivation area; (3) to analyse the change of the spatial distribution of longan in China, which will benefit the regional layout and scientific planning in China.

Material and methods

Data on species' presence

Data of longan occurrence were gathered mainly from the specimen records in the Plant Specimen Database (http://mnh.scu.edu.cn) and Chinese Digital Plant Specimen Database (http://www.cvh.org.cn), which only provide the names of small towns or villages in its growth region. The longitude and latitude of each location were obtained by using the Geographic Names Database (http://www.geonames.org/). Additionally, the latitude and longitude of longan occurrence were also collected in Chongqing Municipality from our field surveys by using a global positioning system receiver. Simultaneously, to avoid spatial autocorrelation, the duplicate database records were removed and only one record closest to the centroid of each grid was selected (Jaryan *et al*., 2013), leading to the retention of only 285 records after checking their locations. According to the Maxent software requirements, the coordinates of each point were saved in the csv format according to the species name, longitude and latitude in order.

Current environmental variables

Temperature, rainfall and other environmental factors influence species distributions on the regional and global scales (Woodward, 1987; Jia *et al*., 2017). The environmental factors, including 19 bioclimatic variables and three topographic variables (elevation, slope and aspect) were selected as the environmental data set for prediction in the present study (Table 1). The 19 bioclimatic with a spatial resolution of 30 s for our reference period (1950–2000) were downloaded from the WorldClim database (version 1.3, http://www.worldclim.org) to represent the current climatic conditions (Hijmans *et al*., 2010). These bioclimatic variables include annual trends, seasonality and extreme environmental conditions, which are considered biologically more meaningful than simple monthly or annual averages of temperature and precipitation in defining a species' eco-physiological tolerances (Kumar *et al*., 2014). The elevations of the occurrence sites (Digital Elevation Model or DEM) with the above-mentioned spatial resolution were also obtained from the WorldClim website and were used to produce the slope and aspect data using the surface analysis function of the software ArcGIS 10.2. Finally, the Chinese environmental data under GCS-WGS-1984 were obtained from all above-obtained environmental data overlaid by the administrative boundary maps of China in Environmental Systems Research Institute (ESRI) shape format in ArcGIS 10.2 and is converted into the 'asc' format in order to be compatible with the Maxent input format.

Future environmental variables

The Representative Concentration Pathways (RCPs), adopted by the IPCC (Intergovernmental Panel on Climate Change) in its fifth IPCC assessment report (AR5), express the full bandwidth of possible future emission trajectories. Moreover, the climate scenarios of the RCPs were downloaded from the WorldClim future conditions database, numbered in accordance with a possible range of radiative forcing values in the year 2100 relative to the preindustrial data (https://www.worldclim.org/data/v1.4/cmip5_30s.html) (Hijmans *et al*., 2010; Hu *et al*., 2015). Compared with the previous emission scenarios (Special Report on Emissions Scenarios, SRES), RCPs better consider the change of climate through a combination of climate, atmosphere, carbon cycle and socio-economic scenarios (Zhang *et al*., 2016; Wang *et al*., 2017). In the present study, the future potential cultivation areas of longan were predicted using three global climate models (GCMs; BCC-CSM1.1, GISS-E2-RC and CSM4) for two RCPs representing low (RCP2.6) and high (RCP8.5) greenhouse gas emission scenarios and two periods, 2050s (average for 2041–2060) and 2070s (average for 2061–2080), commonly applied in other studies (Hu *et al*., 2015; Karspeck *et al*., 2015; Bosso *et al*., 2017). Based on our assumptions, three topographic variables, including slope, aspect and altitude, would not change under different climatic scenarios. For simulations under the future climate scenarios, the 22 environmental factors (including 19 bioclimatic variables and three topographic variables) were directly used by the Maxent model and other variables were kept constant. Additionally, the 1:400 million maps of the province and country boundaries used were obtained from the National Fundamental Geographic Information System (http://nfgis.nsdi.gov.cn/).

Predicting potential cultivation areas and evaluation

The potential spatial distribution of longan was predicted by using the Maxent model (version 3.4.1, https://biodiversityinformatics.amnh.org/open_source/maxent/). According to previous

Table 1. Environmental data used in the study

Type	Code	Description	Code	Description
Climate and Terrain factors	bio-01	Annual mean temperature	bio-12	Annual precipitation
	bio-02	Mean diurnal range	bio-13	Precipitation of the wettest month
	bio-03	Isothermality	bio-14	Precipitation of the driest month
	bio-04	Temperature seasonality	bio-15	Precipitation seasonality
	bio-05	Maximum temperature of the warmest month	bio-16	Precipitation of the wettest quarter
	bio-06	Minimum temperature of the coldest month	bio-17	Precipitation of the driest quarter
	bio-07	Temperature annual range	bio-18	Precipitation of the warmest quarter
	bio-08	Mean temperature of the wettest quarter[a]	bio-19	Precipitation of the coldest quarter
	bio-09	Mean temperature of the driest quarter	alt30s1	Altitude
	bio-10	Mean temperature of the warmest quarter	slope	Slope
	bio-11	Mean temperature of the coldest quarter	aspect	Aspect

[a]Quarter = January–March, April–June, July–September, October–December.

methods (Qin *et al*., 2017), 75% of the occurrence points were used at random for model training and the remaining 25% for model validation. Furthermore, the 'do jackknife to measure variable importance' and 'create response curves' command functions were checked in the model and then it was run with other variables set as default. The model outputs in the American Standard Code for Information Interchange (ASCII) and logistic format are easy to conceptualize and interpret (Kumar *et al*., 2014). For display and further analysis, the simulation outputs were imported into ArcGIS 10.2 and then transformed into the raster format. The categories of the potential habitats used by the longan were defined as suitable and unsuitable habitats based on the maximum Youden index (Jiménez-Valverde and Lobo, 2007). The maximum Youden index (specificity + sensitivity − 1) is the threshold value defined as the sum of training sensitivity and specificity at the maximum, which is superior to other threshold methods in converting the prediction results of the continuous species habitat into 'suitable habitat' and 'unsuitable habitat' (Manel *et al*., 2001; Jiménez-Valverde and Lobo, 2007). The receiver operating characteristic curve (ROC) was built by plotting the sensitivity values and the false-positive fraction for all available probability thresholds (Wang *et al*., 2010). The model prediction performance was assessed by using the area under the curve (AUC), which can measure the ability of a model to discriminate between the sites where a species is present *v.* those where it is absent (Ward, 2007). The rough standard for assessing model performance was as follows: The model performance is considered as excellent when $0.9 < AUC < 1.0$; good when $0.8 < AUC < 0.9$; ordinary when $0.7 < AUC < 0.8$ (Swets, 1988). At the same time, all kinds of habitat areas are calculated after projection conversion.

Based on the Jackknife procedures in the Maxent model, the main dominant factors were able to be distinguished from other variables affecting the habitat suitability of a species (Wang *et al*., 2010; Kumar *et al*., 2014). Specifically, firstly, the full complement of the 22 environmental variables was applied to perform the prediction as a baseline for comparisons. Secondly, each environmental variable was removed systematically, resulting in 22 possible combinations of 21 environmental variables. Finally, the 22 possible combinations were applied to analyse the importance of each variable. The criterion was that the score of the 'with only this variable' was higher than that of the 'without this variable', indicating that this factor had a high prediction ability and significantly contributed to species distribution. Therefore, without this variable, the training score of the model decreased more, indicating that this variable had more unique information and was more important for species distribution (Lu *et al*., 2014). In addition, the Maxent-generated response curves were utilized to discuss the relationships between environmental variables and the probability of the presence of longan.

Results

Current geographic distribution and evaluation

In the model, the AUC values for model training and validation were 0.966 and 0.942, respectively, which were close to 1, showing that the model's prediction ability was excellent. Therefore, the Maxent model could provide satisfactory results for longan. According to the value of the maximum Youden index for *D. longan*, the final potential cultivation area was classified into suitable and unsuitable habitats (Fig. 1). The current suitable growing areas of longan in China are concentrated in southwestern, southern and eastern China. Specifically, these suitable growing areas are mainly in southeastern Sichuan, southwestern Chongqing, Jiangxi and Fujian, southern and eastern Yunnan, southern and central Guizhou and Guangxi, and nearly all of Hainan, Guangdong and Taiwan. According to the statistical analysis after projection conversion(Asia_North_Lambert_Conformal_Conic), the percentages of suitable and unsuitable growing regions of longan were 11.8% and 88.3% in China, respectively.

Importance of environmental variables and threshold values

In the Jackknife test, the mean temperature of the coldest quarter of the year (bio-11) had the highest score when it was used alone (Fig. 2), implying that this variable significantly affects the current distribution of longan. Moreover, the minimum temperature of the coldest month (bio-06), annual mean temperature (bio-01) and mean temperature of the driest quarter (bio-09) also determine the geographical occurrence of longan to a certain extent.

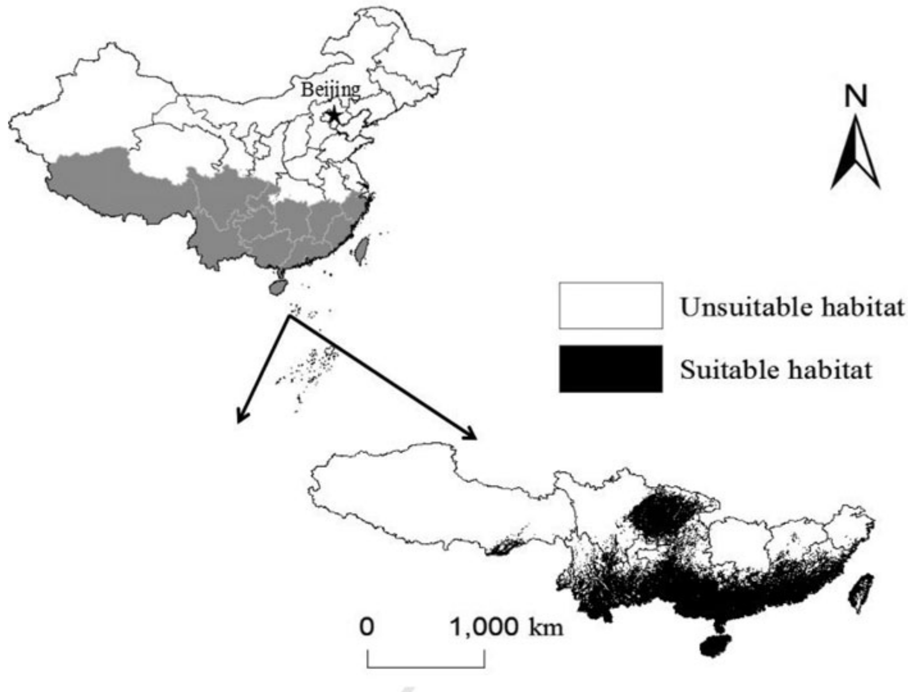

Fig. 1. Geographic distribution of *Dimocarpus longan* in the southern provinces of China based on the Maxent model.

To further clarify the environmental impacts on longan occurrence and eliminate the correlation of the above-mentioned four main influencing factors, their individual effects on longan occurrence were analysed by calculating the response curves in the Maxent model. The results of the individual response curves show that the thresholds for the main environmental variables (probability of presence >0.5) were: the mean temperature of the coldest quarter >12.3°C, minimum temperature of the coldest month >6.0°C, annual mean temperature >19.8°C and mean temperature of the driest quarter >14.5°C (Fig. 3).

Future changes in suitable habitat areas

The potential cultivation areas of longan in China under the future climate scenarios applied are described as follows. Based on the above-mentioned classification and climate projections, the potential geographical occurrence map was classified into suitable and unsuitable habitats, and the area of each class was calculated after projection. The performance of the Maxent model in the future climate scenarios was excellent, with an AUC value of >0.9 for model training and validation. The predictive occurrence maps for the applied climate scenarios indicated that longan could be grown mainly in southwestern China (Chongqing, Sichuan, Yunnan, Guizhou and Xizang), southern China (Guangxi, Guangdong and Hainan), and eastern China (Jiangxi, Fujian and Taiwan). However, the percentage of the growing areas within these regions will change to some extent in the future. Under the current conditions, 11.8% (935 352 km^2) of the suitable cultivation areas for longan were identified as suitable growing areas. However, for the 2050s period (Table 2), the percentages of suitable cultivation areas for RCP2.6 and RCP8.5, respectively, changed to 12.7% (1 007 690 km^2) and 12.0% (954 138 km^2) in BCC-CSM1.1, 12.1% (959 809 km^2) and 12.3% (977 787 km^2) in GISS-E2-R and 12.7% (1 011 100 km^2) and 12.2% (968 096 km^2) in CCSM4. In the 2070s period (Table 2), these percentages changed to 13.6% (1 084 000 km^2) and 14.4% (1 142 490 km^2) in BCC-CSM1.1, 13.1% (1 045 610 km^2) and 13.3% (1 058 570 km^2) in GISS-E2-R and 12.9% (1 026 220 km^2) and 13.2% (1 049 530 km^2) in CCSM4 under RCP2.6 and RCP8.5, respectively. The results show that the suitable growing areas in China will increase gradually in the future, even if the difference is small in a relative change of percentage.

However, for different provinces or cities (Table 3), the potential occurrence of longan shows different changing trends in the future. For example, the suitable growing areas in Sichuan, Jiangxi and Guangxi provinces and Chongqing city will first increase and then remain approximately unchanged between the 2050s and 2070s; those in Yunnan, Guangdong and Hainan provinces will remain approximately unchanged from the present to the 2070s; those in Fujian and Guizhou provinces will have small fluctuations from the present to the 2050s and then increase from the 2050s to 2070s; those in Taiwan will first decrease and then increase. Moreover, from the present to the 2070s, the percentages of the suitable habitat of longan will remain at more than 80% in Guangdong, Hainan and Guangxi provinces and at more than 50% in Chongqing, Yunnan, Fujian and Taiwan.

Discussion

Longan is a special and famous fruit of high nutritional and medicinal value in southern China and southeast Asia (Wen *et al.*, 2012). In China, it is presently grown in Fujian, Taiwan, Hainan, Guangdong, Guangxi, Yunnan, Guizhou and Sichuan provinces, with Fujian, Taiwan and Guangxi provinces as its main production areas (Yang *et al.*, 2017). However, so far, very little is known about the potential growing areas of longan and its affecting factors. Fortunately, with the development of applied ecology, several SDMs have been developed as important tools for evaluating and predicting changes in the potential distribution of a species (Wang *et al.*, 2010; Qin *et al.*, 2017). Among them, the Maxent model has been increasingly used by biologists to estimate

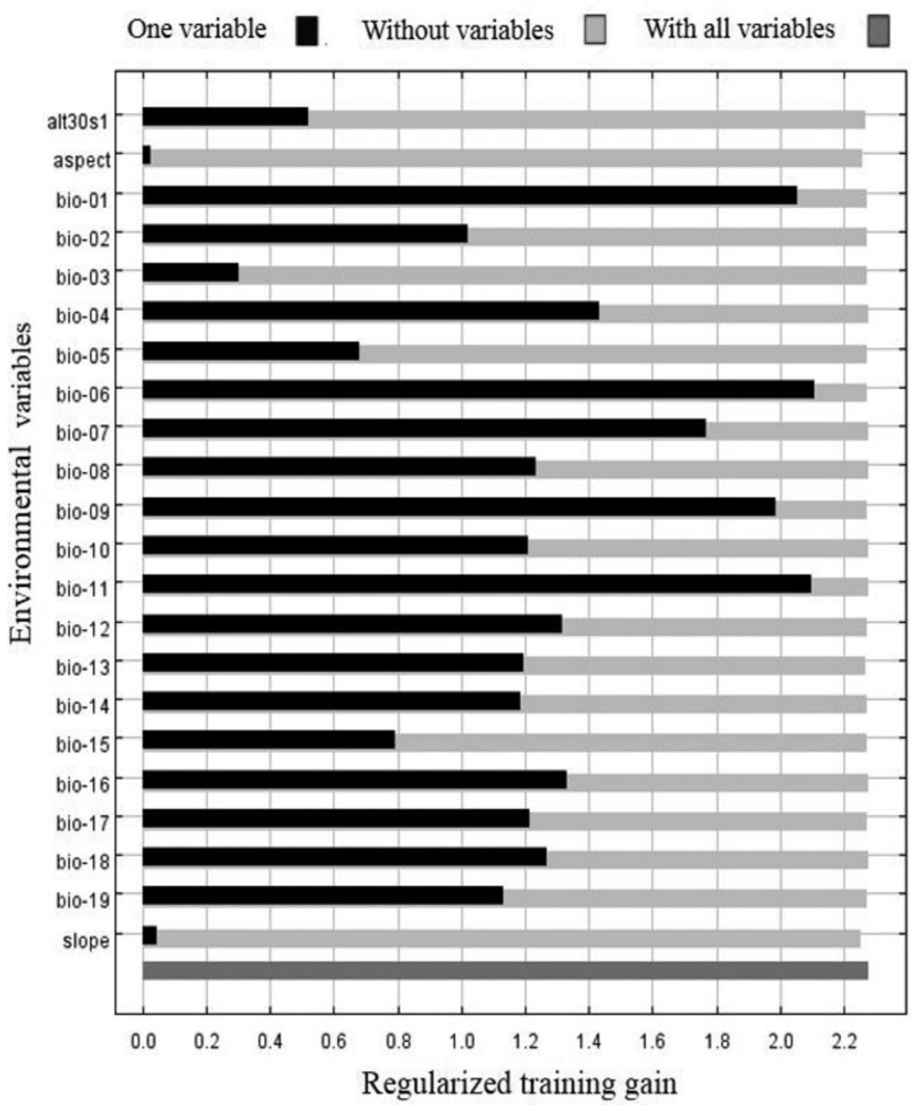

Fig. 2. Effects of climatic variables on the gain of distribution using the Jackknife test. Please see Table 1 for descriptions of the environmental variable codes.

the distribution of a species by finding the probability dispersal of maximum entropy (Phillips *et al.*, 2006; Qin *et al.*, 2017). The principle of the Maxent model is that species are present in areas with suitable environmental conditions but are absent in unsuitable climates (Guisan and Zimmermann, 2000; Hu *et al.*, 2015). In the present study, the Maxent model for *D. longan* provided satisfactory results, with an AUC value of more than 0.9 for model training and validation, which is higher than 0.5 of a random model. Only minor deviations occur, probably because of the biological routes of transmission and interactions between organisms (Svenning *et al.*, 2008; Hu *et al.*, 2015). However, human cultivation activities for longan have overcome these two restrictions. Therefore, it was concluded that the model performances were excellent based on the simulation of the potential distribution areas of longan. The result shows that the suitable growing areas of longan under the future climate scenarios will be similar as under current environmental conditions and their suitable areas will be concentrated mainly in southwestern, southern and eastern China. In the future (Table 2), the suitable growing areas were predicted to increase gradually from 935 352 to 954 138 ~1 011 100 km^2 in the 2050s and to 1 142 490 ~1 026 220 km^2 in the 2070s under the two scenarios of RCP2.6 and RCP8.5, respectively, of the three GCMs. We can, therefore, conclude that the suitable growing areas of longan in China will increase gradually in the future (Table 2). Fortunately, this trend was consistent with the development of the longan processing industry in China. However, the growing areas of longan showed different trends at smaller spatial units such as different provinces or cities (Table 3). In Sichuan, Jiangxi, Guangxi and Chongqing, the suitable growing areas simulated in our study will increase at first and then remain approximately unchanged between the 2050s and 2070s; therefore, the growing areas for longan in these provinces or cities may be expanded in the future. The growing areas in Yunnan, Guangdong and Hainan provinces should be expanded cautiously because the suitable growing areas in these provinces will remain approximately unchanged from the present to the 2070s. In Fujian and Guizhou provinces, the suitable growing areas will have small fluctuations from the present to the 2050s and then increase from the 2050s to the 2070s. This information reminds us that we may maintain the current scale from the present to the 2050s and expand suitable growing areas during the period of 2070s. The suitable growing areas in Taiwan will first decrease and then increase from the present to the 2070s. Based on the results of our study, the local varieties

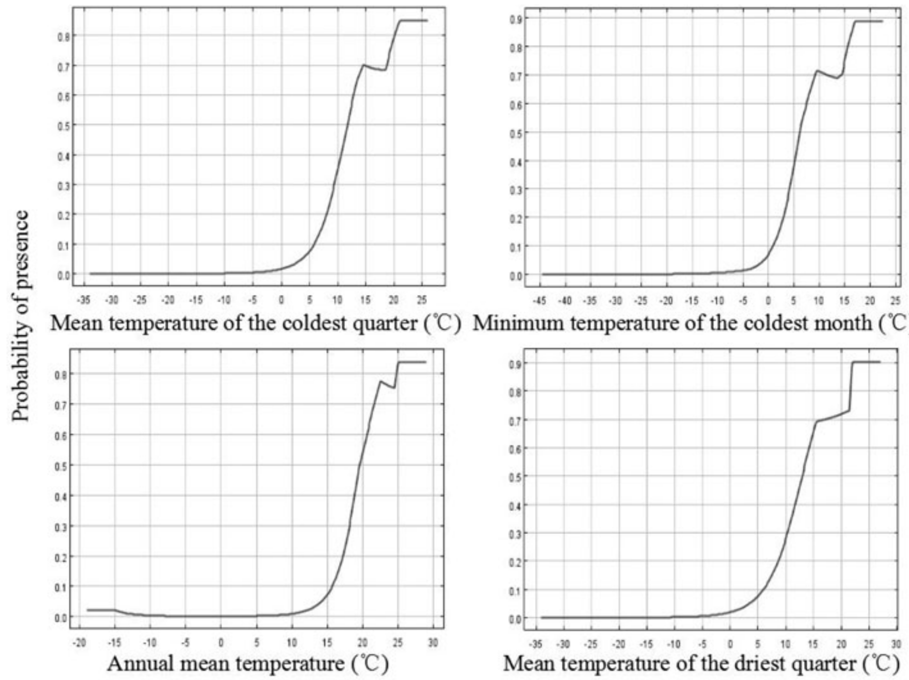

Fig. 3. Relationship of each dominant factor and the distribution probability of *Dimocarpus longan* under current environmental conditions.

Table 2. Baseline and potential increase in suitable areas for the production of *Dimocarpus longan* under future different environmental conditions

		BCC-CSM1.1		GISS-E2-R		CCSM4	
Climate change scenario	Year	Suitable area (km^2)	Increased area (km^2)	Suitable area (km^2)	Increased area (km^2)	Suitable area (km^2)	Increased area (km^2)
RCP2.6	2050s	1 007 690	72 338	959 809	24 457	1 011 100	75 748
	2070s	1 084 000	148 648	1 045 610	110 258	1 026 220	90 868
RCP8.5	2050s	954 138	18 786	977 787	42 435	968 096	32 744
	2070s	1 142 490	207 138	1 058 570	123 218	1 049 530	114 178

Note: Areas above 935 352 km^2 were identified as the increased suitable areas under the future environmental conditions.

should be domesticated in Taiwan to ensure that the yield of longan does not decrease even if the suitable growing areas in Taiwan decrease in the 2050s. Moreover, more than 80% of the area in Guangdong, Hainan and Guangxi provinces and more than 50% of the area in Chongqing, Yunnan, Fujian and Taiwan were found suitable for the cultivation of longan from the present to the 2070s, indicating that the main production regions would be Guangdong, Hainan and Guangxi provinces, followed by Chongqing, Yunnan, Fujian and Taiwan in the future.

The geographical distribution of species mainly depends on its adaptability to climate, topography and other environmental factors (Woodward, 1987; Jia *et al.*, 2017). The result of the Jackknife test in the Maxent model showed that the main determining environmental variables were mean temperature of the coldest quarter, minimum temperature of the coldest month, annual mean temperature and mean temperature of the driest quarter, with the threshold values >12.3, 6.0, 20.3 and 14.5°C, respectively. The above-mentioned four main factors are closely related to temperature, indicating that temperature is the dominant factor affecting the growing conditions of longan in China. This is in agreement with the result of a previous study that reported longan to be very sensitive to temperature changes in different periods (Duan *et al.*, 2008). In this study, among the above-mentioned four main factors, the mean temperature of the coldest quarter and the minimum temperature of the coldest month with the threshold values >12.3 and 6.0°C, respectively, showed the highest impact on longan and can be regarded as the most important factors affecting the growth of longan under the current climate conditions in China. In southern China, the dormancy stage occurs in winter, where lower temperatures can preserve nutrients and increase the rate of flowering and fruit-bearing; however, temperatures below critical temperature cause cold damage (Duan *et al.*, 2008). This is in agreement with our results. The annual mean temperature with the threshold value >19.8°C was found most beneficial for longan to bloom, pollinate, bear fruit and promote the growth of autumn shoots in order to lay the foundation for the next year's flowering and fruiting. This proves the fact that longan is suitable to thrive in the warm climate of south China (Lin and Li, 1999). The mean temperature of the driest quarter corresponds to the ripening period of the longan fruit and its threshold value >14.5°C is good for fruit development.

As temperature, rainfall and other environmental factors significantly affect the species distributions on the regional and global scales, we analysed the effects of only bioclimatic and

Table 3. Percentage of suitable habitat distribution of *Dimocarpus longan* under current and future climate conditions in different provinces, cities and in Taiwan

Region[a]	1950–2000	BCC-CSM1.1 (2050s)		GISS-E2-R (2050s)		CCSM4 (2050s)		BCC-CSM1.1 (2070s)		GISS-E2-R (2070s)		CCSM4 (2070s)	
		RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5	RCP2.6	RCP8.5
Sichuan	28.0	33.1	34.5	28.0	32.0	32.4	30.0	30.4	36.3	32.1	31.8	31.8	33.2
Chongqing	53.2	56.6	62.3	54.2	54.0	54.8	58.6	59.4	58.9	56.5	61.4	56.5	55.9
Yunnan	60.1	58.7	59.2	60.2	59.1	61.4	60.2	64.8	66.7	58.8	64.4	57.7	58.8
Guizhou	44.4	46.0	44.6	42.2	47.8	44.4	49.6	60.0	54.6	61.0	62.5	64.9	55.9
Guangxi	86.9	89.2	92.9	88.0	89.4	93.5	91.7	91.4	91.8	90.3	91.5	91.2	92.5
Guangdong	94.8	95.7	95.9	93.9	96.7	93.9	96.6	95.8	94.0	96.8	96.8	96.7	94.0
Fujian	58.8	60.9	57.8	54.8	62.8	54.8	59.9	74.2	67.8	68.5	69.2	66.0	70.8
Jiangxi	19.3	28.0	33.6	40.5	41.6	24.0	27.6	43.7	39.5	31.5	28.1	30.1	25.9
Hainan	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	99.6
Taiwan	80.2	54.1	70.9	62.8	70.7	75.2	74.5	82.6	78.4	79.9	78.5	81.0	78.4

[a]Provinces: Sichuan; Yunnan; Guizhou; Guangxi; Guangdong; Fujian; Jiangxi; Hainan; City: Chongqing.

topographic variables for the production of longan. Other environmental variables, such as soil, solar radiation, wind speed, extreme weather, disease and human deforestation, were not considered in this study. These variables may have non-negligible effects on the habitat distribution of longan. Compared to one-variable models, the multivariable SDMs may be more suitable (Dai and Cao, 2014). Therefore, in the future, more environmental factors should be considered in order to improve the prediction accuracy of the SDMs. Furthermore, in recent years, numerous ecological niche models have emerged with their own advantages (Lu *et al*., 2014), suggesting that these models may be applied simultaneously and compared for their prediction accuracy to find the best solution for specific applications.

Conclusions

(1) In our study, we show that the most suitable growing areas of longan in China are mainly concentrated in southwestern, southern and eastern China under current and future environmental conditions. (2) The main environmental variables affecting the production and potential growing areas of longan were the mean temperature of the coldest quarter, minimum temperature of the coldest month, annual mean temperature and mean temperature of the driest quarter, with a certain threshold range. (3) The suitable cultivation areas were predicted to increase gradually under two different emission scenarios of the three GCMs. However, for different provinces or cities, the potential occurrence of longan showed different changing trends in the future. Moreover, our results showed that the main producing areas of longan would be Guangdong, Hainan and Guangxi provinces, followed by Chongqing, Yunnan, Fujian and Taiwan in the future under the expected changing climate conditions.

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Conflict of interest. The authors declare that there is no conflict of interest.

Ethical standards. Not applicable.

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