Geographical distribution of two major quarantine fruit flies (*Bactrocera minax* Enderlein and *Bactrocera dorsalis* Hendel) in Sichuan Basin based on four SDMs (#81950)

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Geographical distribution of two major quarantine fruit flies (*Bactrocera minax* Enderlein and *Bactrocera dorsalis* Hendel) in Sichuan Basin based on four SDMs

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Background. Both *Bactrocera minax* and Bactrocera *dorsalis* are phytophagous insects, and their larvae are latent feeders, which cause great damage and economic losses to agricultural production and trade. It is great significance for the artificial protection and cultivation of citrus to predict the potential suitable habitat of *B. minax* and *B. dorsalis* in Sichuan Basin using niche models.

Methods. In this paper, we predicted the potential distribution area of *B. minax* and *B. dorsalis* by applying four Niche models (GARP, Bioclim, Domain, and Maxent), using 19 climate factors and elevation from the WorldClim websit and 44 species distribution records from the Chinese Herbaria, Two statistical standards, area under the receiver operating characteristic curve (AUC) and Kappa value, were used to analyze and compare the results of different models.

Results. The average AUC values of the four models were all above 0.90, and the average Kappa values were all above 0.75, indicating that the four models were suitable for predicting the potential distribution areas of *B. minax* and *B. dorsalis*. The results showed that the temperature annual range, mean temperature of driest quarter, mean temperature of warmest quarter, annual precipitation, precipitation of driest month were the key environmental factors affecting the distribution of *B. minax*, while mean diurnal range, mean temperature of driest quarter, temperature seasonality and precipitation of driest month affect the potential distribution of *B. dorsalis.* This may be the decisive factor in the current distribution pattern of *B. minax* and *B. dorsalis*,and the basis for the migration directionin the future. The suitable area of *B. minax* was mainly concentrated in the eastern of Sichuan Basin, while *B. dorsalis'* was concentrated in the southeastern. Except the Bioclim model which predicted the highly and moderately suitable area were small, the other three models predicted more than 15.94×10^4 km^2 and 13.57×10^4 km^2.

Discussion. In conclusion, the suitable areas of *B. minax* and *B. dorsalis* in Sichuan Basin is quite wide. Therefore, it is suggested that relevant departments strengthen the monitoring of human environment and do a good job in prevention and control.

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Abstract

Both *Bactrocera minax* and *Bactrocera dorsalis* are phytophagous insects, and their larvae are latent feeders, which cause great damage and economic losses to agricultural production and trade. It is great significance for the artificial protection and cultivation of citrus to predict the potential suitable habitat of *B. minax* and *B. dorsalis* in Sichuan Basin using niche models. In this paper, we predicted the potential distribution area of *B. minax* and *B. dorsalis* by applying four Niche models(GARP, Bioclim, Domain, and Maxent), using 19 climate factors and elevation from the WorldClim websit and 44 species distribution records from the Chinese Herbaria, Two statistical standards, area under the receiver operating characteristic curve(AUC) and Kappa value, were used to analyze and compare the results of different models. The average AUC values of the four models were all above 0.90, and the average Kappa values were all above 0.75, indicating that the four models were suitable for predicting the potential distribution areas of *B. minax* and *B. dorsalis* . The results showed that the temperature annual range, mean temperature of driest quarter, mean temperature of warmest quarter, annual precipitation, precipitation of driest month were the key environmental factors affecting the distribution of *B. minax*, while mean diurnal range, mean temperature of driest quarter, temperature seasonality and precipitation of driest month affect the potential distribution of *B. dorsalis* . This may be the decisive factor in the current distribution pattern of *B. minax* and *B. dorsalis* , and the basis for the migration direction in the future. The suitable area of *B. minax* was mainly concentrated in the eastern of Sichuan Basin, while *B. dorsalis* ' was concentrated in the southeastern. Except the Bioclim model which predicted the highly and moderately suitable area were small, the other three models predicted more than 15.94×10^4 km^2 and 13.57×10^4 km^2. In conclusion, the suitable areas of *B. minax* and *B. dorsalis* in Sichuan Basin is quite wide.

Therefore, it is suggested that relevant departments strengthen the monitoring of human environment and do a good job in prevention and control.

Key words: *B. minax*, *B. dorsalis* , MaxEnt, GARP, Bioclim, Domain, suitable habitat

1. Introduction

Tephritidae belongs to Diptera, commonly known as "orange maggots" and "fruit maggots" (Zhu, 2004; Tang, 2012). The common species in Chinese citrus region are *Bactrocera minax* Enderlein, *Bactrocera dorsalis* Hendel and *Tetradacus tsuneonis* Miyake, which are all international quarantine pests. *B. minax* is distributed in southern citrus regions, which can harm a variety of citrus fruits, such as sweet orange, grapefruit, lemon, bergamot and so on (Zhang, 2007). The host species of *B. dorsalis* is complex, mainly harm mango, pomegranate, lime, sweet orange, grapefruit, citrus, grape, peach, pear, plum, banana, coffee, papaya, guava, pepper, tomato, cucumber and other 46 families more than 250 kinds of fruit trees, vegetables and flowers (Meetu and Sangeeta, 2007). *B. dorsalis* is widely distributed, in addition to the southern citrus regions, the central region of China has also been found in recent years. Both *B. minax* and *B. dorsalis* are phytophagous insects, and their larvae are latent feeders, which cause great damage and economic losses to agricultural production and agricultural trade.

The ecological characteristics of crop diseases and pests, such as growth, reproduction, overwintering and distribution, are closely related to environmental conditions, especially climate conditions. Therefore, climate change will have a great impact, such as the generation of crop diseases and pests, the north boundary of overwintering and the distribution range, and the negative effects will be aggravated (Li et al., 2010). According to statistics, the area of perennial diseases and pests in China is between 200 million and 230 million square hectares, more than twice as much as arablea. Citrus is the most important fruit in Sichuan-Chongqing region, which the area and yield increases year by year. By the end of 2020, the planting area of citrus in Sichuan-Chongqing reached 3.39×10^5 hm^2 and the yield reached 4.89×10^5 t. The citrus industry has made important contributions to poverty alleviation and rural revitalization (Wang and Du, 2022). In view of the importance of citrus to Sichuan-Choingqing's economy, it is necessary to do a good job in the study of citrus. As an important factor affecting the development of citrus industry, how to control diseases and pests is the primary task.

Species distribution models (SDMs) uses certain algorithms to predict the potential survival range of species based on actual distribution and environmental factors(Gobeyn et al., 2019; Hao et al., 2019; Cvea et al., 2021). The selection of environmental factors, the migration ability of species and the types of environmental factors used have an important impact on the simulation results (William et al., 2019; Mendes et al., 2020; Yu et al., 2020). At present, the models used to predict the potential distribution of species include CLIMEX, GARP, MaxEnt, Bioclim and Domain (Peterson and Eaton, 2010; Li et al., 2013). In recent years, SDMs have been widely used to predict the potential distribution and evaluate the suitability of medicinal plants, such as *Fritillaria cirrhosa* (Zhao et al., 2018), *Cornus officinalis* (Cao et al., 2016), *Paris verticillata* (Ji et al., 2020), *Sinopodophullum hexandrum* (Zhang, 2013) and *Berberis aristata* (Ray et al., 2011), etc.

As harmful organisms affecting citrus industry, many scholars have conducted a lot of research on *B. minax* and *B. dorsalis* , such as classification and identification, biology, ecology, quarantine and treatment technology, integrated prevention and control technology, etc(Kong et al., 2008). Based on the previous study of biology and ecology, the paper analyzed the interaction between the growth of *Tephritidae* (*B. minax* and *B. dorsalis*) and environmental factors, discussed the main environmental factors affecting the geographical distribution of *Tephritidae*, and predicted the potential suitable area of *Tephritidae* with four ecological niche models, which provided the basis for further research on the risk analysis of *Tephritidae* in Sichuan Basin.

2. Materials and Methods

2.1. Sample distribution data

Occurrence records of *B. minax* and *B. dorsalis* in China were obtained from various sources, such as the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/), Centre Agriculture Bioscience International (CABI, https://www.cabi.org/), and our field survey, as well as literature reports (Zhao et al., 2006; Zhou et al., 2010; Fan et al., 2013; Wu et al., 2014; Li et al., 2017; Xu et al., 2017; Deng et al., 2018; Li et al., 2019; Zhang et al., 2019; Cui and Liu, 2020; Fang et al., 2020). The longitude and latitude of occurrence records picked up by Google Earth were converted into decimal after removing the repeated distribution points. In order to reduce the impact of spatial autocorrelation, the distance between the records and the centre were calculated by using the spatial analysis function of ArcGIS 10.0 to ensure that each censored grid contains only one distribution point closest to the centre (Wang et al., 2019; Wang et al., 2020; Liu et al., 2021) (Table S1).

2.2. Environmental factors used in the models

The growth and development of insects is closely related to the climatic conditions in which they live (Li et al., 2020). Therefore, 19 bioclimatic factors and elevation downloaded from WorldClim(https://www.worldclim.org/) were selected as the initial environmental factors. In order to screen out the environmental factors affecting the potential distribution of *B. minax* and *B. dorsalis,* the percent contribution and permutation importance of nineteen climate factors were determined by the jackknife test, and the factors with zero contribution rate were eliminated.. Then correlation analysis was performed for the retained environmental factors(Fig.1). For the pearson's correlation coefficient of two environmental factors was greater than 0.85, the one with lower percent contribution value in the jackknife test was eliminated.

After the above two steps, eleven environmental factors affecting the potential distribution of *B. minax* were retained for building forecasting models, and six environmental factors were retained for *B. dorsalis* (Table 1)(Wang et al., 2019; Liu et al., 2021; Liu et al., 2021).

2.3. Verification of model accuracy

Receiver operating characteristic (ROC) and Kappa statistics are frequently used method evaluated the accuracy of SDM model. ROC curve evaluation method uses the area under curve (AUC) enclosed by ROC curve and horizontal coordinate to evaluate the accuracy of prediction model. The value of AUC ranges from 0 to 1, and the closer the value is to 1, the more accurate the prediction result would be(Liu et al., 2021). Kappa statistics comprehensively considers the species distribution rate, sensitivity and specificity, the value ranges from - 1 to 1. When the value is higher than 0.75, it means good consistency, while lower than 0.4 means poor consistency (Wang, 2006).

3. Results

3.1. Evaluation of prediction accuracy of different models

Ten sets of training data and test data were used to conduct ROC analysis and Kappa statistics for four niche models(GARP, Maxent, Bioclim and Domain). The table 2 shows that the average AUC values of four niche models were 0.922, 0.980, 0.957 and 0.940, all of which were higher than that of random model (AUC=0.5). In addition, the average Kappa value of the four models is greater than 0.75, indicating that the four models have significant consistency and high prediction accuracy.

3.2. Potential distribution of B. minax and B. dorsalis simulated by four models.

Maxent forecast distribution map(Fig.2 A,E) shows that the suitable area of *B. minax* in Sichuan Basin was 21.61×10^4 km^2, accounting for 87.62 % of the basin area. The highly suitable area was distributed in most of the eastern parallel ridge valley (3.20×10^4 km^2), the north of the middle shallow hilly zone (2.01×10^4 km^2), the north and south of the peripheral hilly zone (0.94×10^4 km^2) and the northeast of Chengdu Plain (0.44×10^4 km^2). The moderate suitable area was distributed in the middle and east of the middle shallow hilly zone (3.86×10^4 km^2), the south of the eastern parallel ridge valley (2.25×10^4 km^2), the north of the peripheral hilly zone (2.3×10^4 km^2), and the middle and west of the Chengdu Plain (0.94×10^4 km^2). The lowly suitable area was distributed in the west and north of the peripheral hilly zone (2.2×10^4 km^2), the southwest of the middle shallow hilly zone (1.53×10^4 km^2), the north of the eastern parallel ridge valley (1.20×10^4 km^2) and the south of Chengdu Plain (0.73×10^4 km^2). The suitable area of *B. dorsalis* in Sichuan Basin was 23.49×10^4 km^2, accounting for 95.26 % of the basin area. The highly suitable area was distributed in most of the eastern parallel ridge valley (1.3×10^4 km^2), the southeast of the middle shallow hilly zone (1.28×10^4 km^2) and the eastern of the peripheral hilly zone (0.05×10^4 km^2). The moderate suitable area was distributed in the middle and east of the middle shallow hilly zone (5.23×10^4 km^2), the south of the eastern parallel ridge valley (3.51×10^4 km^2), the north of the peripheral hilly zone (1.45×10^4 km^2), and the middle and west of the Chengdu Plain (0.77×10^4 km^2). The lowly suitable area was distributed in the west and north of the peripheral hilly zone (5.41×10^4 km^2), the southwest of the middle shallow hilly zone (0.92×10^4 km^2), the north of the eastern parallel ridge valley (1.96×10^4 km^2) and the south of Chengdu Plain (1.62×10^4 km^2).

GARP forecast distribution map(Fig.2 B,F) shows that besides the west of the peripheral hilly zone, the north and south of the Chengdu Plain, the remaining areas were all highly suitable areas of *B. minax*, accounting for 73.49 % of the Sichuan Basin. The moderately suitable areas (2.28×10^4 km^2) could be divided into two parts, one part was concentrated in the north of the peripheral hilly zone and the north of Chengdu Plain, and the other part extended from the south of Chengdu Plain to the southwest of the middle shallow hilly zone in a strip shape. The lowly suitable areas (0.57×10^4 km^2) were scattered in the west of the peripheral hilly zone and the west of the Chengdu Plain. The highly suitable areas of *B. dorsalis* mainly concentrated in other areas except the northwest of middle shallow hilly zone, the north and southeast of eastern parallel ridge valley, the north of Chengdu plain and the southeast of peripheral hilly zone, and the total area was 18.12×10^4 km^2.The moderately suitable areas mainly concentrated in the southwest margin of the high suitable area, with a gross area of 2.28×10^4 km^2. The unsuitable area of *B. dorsalis* located in the peripheral hilly zone was 3.68×10^4 km^2, accounting for 15% of the basin area.

According to the Bioclim(Fig.2 C,G) and Domain(Fig.2 D,H) obtained by the modeling function of DIVA-GIS, it can be observed that the red region representing the highly suitable region accounts for a small proportion in these two models. Geographically, Bioclim predicted a small distribution range, the highly and moderately suitable areas of *B. minax* were located in the east of Sichuan Basin. The highly suitable areas (0.59×10^4 km^2) were distributed in the north of the eastern parallel ridge valley in thin strips. The moderately suitable areas (3.66×10^4 km^2) were not concentrated, pats of them were located in the eastern parallel ridge valley and adjacent middle shallow hilly zone in a south-north strip shape, while the rest were distributed in the north and south of the peripheral hilly zone in a block shape. While the highly and moderately suitable areas of *B. dorsalis* were scattered located in east of middle shallow hilly zone, west of eastern parallel ridge valley and west of peripheral hilly zone, with a gross area of 5.66×10^4 km^2. The distribution range predicted by Domain model is large, which is generally close to that of GARP model and the distribution range of highly and moderately suitable areas is similar to that of Maxent.

3.3. Relationship between probability of species and key environmental factors

3.3.1 Screening key environmental factors

The jackknife test was used again to analyze the importance of factors used for modeling, and figure. 3 was the analysis result provided by MaxEnt software. Considering the percent contribution and the permutation importance of the environmental factors, we can know from the figure. 4A that Bio9, Bio12, Bio7, Bio14 and Bio10 had higher predictive ability, which the percent contribution and permutation importance was 83.96% and 87.87%, so these five factors were identified as key environmental factors affecting the distribution of *B. minax* . Similarly, it can be seen from Figure 4B that the key environmental factors affecting the distribution of *B. dorsalis* are bio9, bio4, bio2 and bio14..

3.3.2 the suitable range of key environmental factors

Figure. 4 is the response curve between key environmental factors and distribution probability drawn by MaxEnt model, which can reflect the value range of environmental factors under different thresholds. According to Wang's(Wang et al, 2020) classification method, this paper took 0.33 as the threshold to divide the range of environmental factors suitable for the distribution of *B. minax* and *B. dorsalis* . The response curves of five key environmental factors affecting the potential distribution of *B. minax*(Fig. 4 A-E) demonstrate that the suitable ranges of temperature annual range, mean temperature of driest quarter, mean temperature of warmest quarter, annual precipitation and precipitation of driest month is 26.27–31.17 ℃, 4.58–7.07 ℃, 24.58–27.57 ℃, 1025.64–1380.34 mm and 15.2–44.65 mm, respectively. Similarly, the key environmental factors affecting the potential distribution of *B. dorsalis* (Fig. 4 F-I) is mean diurnal range, mean temperature of driest quarter, temperature seasonality and precipitation of driest month, which the threshold ranges are 2–8.61 ℃, ≥13.1 ℃, 341.88–666.67, 15.36–63.82 mm, respectively.

4. Discussion

In recent years, species distribution is a hot topic, and several available models have been developed. Through model testing, this paper concluded that the four models could accurately predict the suitable area of *B. minax* and *B. dorsalis* (AUC>0.9), but the average AUC of prediction results by GARP was the smallest and the accuracy was poor, which may be caused by the small sample data of *B. minax* and *B. dorsalis* . Yang Huifeng(Yang, 2016) tested the accuracy of GARP prediction results with different sample sizes, and found that the average AUC tended to be stable (greater than 0.9) only when the sample sizes exceeded a certain threshold. The prediction results of Domain and Bioclim are smaller than those of other models, which may be related to the information of samples. The distribution data of *B. minax* and *B. dorsalis* are mainly from the herbarium, and the samples are biased to some extent. Researchers generally sample according to their own research needs or collect specimens from herbarium, so the information of samples is relatively scattered, lack of systematic and representative (Wang et al., 2020). The prediction results of Maxent is more accurate than other models (the average AUC is 0.980), and relevant literature also proves that Maxent can predict the suitable area of species well under the condition of large and small samples.

The relationship between species and environment is an important aspect of studying the ecological needs and spatial distribution of species. The paper analyzed the relationship between the presence probability of fruit fly and the key environmental factors, and obtained the relevant feedback curve. The results showed that the presence probability of *B. minax* changed with the change of key environmental factors. Among the five key factors, mean temperature of driest quarter and annual precipitation were the most important environmental factors affecting the distribution of *B. minax,* indicating that the diffusion and reproduction process of *B. minax* was restricted by the temperature and precipitation. In this study, the suitable range of mean temperature of driest quarter for *B. minax* is 4.58–7.07 ℃, and the optimal value is 5.55 ℃. The Sichuan Basin belongs to the subtropical humid climate zone, and the driest season is from November to April of the next year, *B. minax* overwintered as the pupae during this period of time. Ma Jingyan(Ma, 2014) found that when the temperature was between 5℃ and 10℃, the pupae did not emerge and the survival time could reach 156-250 days, which was basically consistent with the temperature range of this study. The reason for the slight difference between Ma Jingyan's study and this paper may be related to the different criteria for dividing the optimal interval. The annual precipitation is related to the air and soil moisture, which has a significant effect on the emergence and survival of imago. When the soil water content is low or high, the emergence rate is significantly inhibited and the mortality rate increases. Among the four key environmental factors affecting the distribution of *B. dorsalis ,* mean temperature of driest quarter and precipitation of driest month were the most important environmental factors. Studies have shown that *B. dorsalis* is a tropical and subtropical insect, and its occurrence and distribution are greatly affected by climate conditions such as temperature and humidity. The developmental threshold temperature of pupae is 9~11℃, and the pupae cannot overwinter or eclosion safely when the temperature is too low or too high(Kong et al., 2008; Dias et al., 2018;). The influence of precipitation on *B. dorsalis* was mainly manifested in two aspects under the natural conditions. On the one hand, appropriate precipitation can maintain soil moisture and atmospheric moisture, thus reducing the mortality of mature larvae and newly emerging adults, and is conducive to the mating and spawning activities of adults. On the other hand, excessive precipitation will cause high soil moisture, which will affect the larva pupae and pupae grow up to imago. Note here that the feedback curve between presence probability of environment variable and environment factors reflects the effect of the single environment factor, but the life activities of insect is affected by a variety of environmental factors(including climate factors, host condition, natural enemy species, vegetation, etc.). Therefore, this result can be used as a reference to judge the relationship between drosophila and environmental factors, but it can not completely explain the relationship between them.

The risk of detecting exotic *Tephritidae* late or unresponsive can be illustrated by cases of eradication failure, such as *B. carambolae* in Suriname, the lag phase from the first discovery of infested fruit in 1975 to the identificaton and confirmation of specimens from South-east Asia in 1986 was 12-year(Naymã et al., 2018; Van., 2005). The prediction models of pests, such as GARP and MAXENT, can monitor fruit flies before actual problems occur, and make pre-emptive and effective pest management decisions. The research showed that the suitable area of *B. minax* was mainly concentrated in the eastern of Sichuan Basin, while the *B. dorsalis '* were concentrated in the southeastern. Except for the Bioclim model, the highly and moderately suitable area by the other three models were larger than 15.94×10^4 km^2(accounting for 55.1% of the Sichuan Basin) and 13.58×10^4(accounting for 65% of the Sichuan Basin), indicating *B. minax* and *B. dorsalis* were suitable for survival in the Sichuan Basin.

Prevention is one of the most effective strategies for the management and monitoring of drosophila, and it is crucial for determining the population dynamics, comparing infestation levels among different species, and evaluating the effectiveness of control strategies(Eliopoulos et al., 2007). A few researchers had used polymerase chain reaction (PCR) to detecte the DNA of drosophila, and this method offered a highly sensitive, rapid and accurate technique to detect pests in various biosecurity and ecological applications. Brazilian researchers had proposed a multimodal fusion approach for the classifier based on two types of images (wings and aculei), which pointed the way to identify Anastrepha. Now an algorithm had been developed to identify blotches in hyperspectral images of mangoes that had been invaded by drosophila larvae. Meanwhile, the development of automatic insect traps has been strengthened and accelerated. According to relevant study, the above methods can be used to monitor pests well. Therefor, we should strengthen the study of *B. minax* and *B. dorsalis* in Sichuan Basin on the basis of the above research.

Figure legends:

Figure 1: Potential distribution of *B. minax*(A-D) and *B. dorsalis* (E-H) simulated by MaxEnt , GARP , Bioclim and Domain. CP: Chengdu plain; MH: middle shallow hilly zone in Sichuan basin; ER: eastern parallel ridge valley in Sichuan Basin; PH, peripheral hilly zone in Sichuan basin.

Figure 2: Correlation analysis of environmental factors which may affect potential distribution of *B. minax(A)* and *B. dorsalis (B)*.

Figure 3: The importance of environmental factors affecting the distribution of *B. minax*(A) and *B. dorsalis* (B) (jackknife).

Figure 4: Response curve of *B. minax*(A-E) and *B. dorsalis* (F-I) to key environmental factors

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Author contributions

Yanli Xia and Yuxia Yang provided relevant data of *B. minax* and *D. dorsalis*, and required funds for the experiment. Jian Ding, Ke Xu and Jinpeng Zhao planned and supervised the project.

Xianjian Zhou, Mian Xiang, Huiling Xue, Huan Wang and Rulin Wang analyzed the data and performed simulations.

Competing interests

The authors declare no competing interests.

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Figure 1

Correlation analysis of environmental factors which may affect potential distribution of *B. minax*(A) and *D. dorsalis*(B).

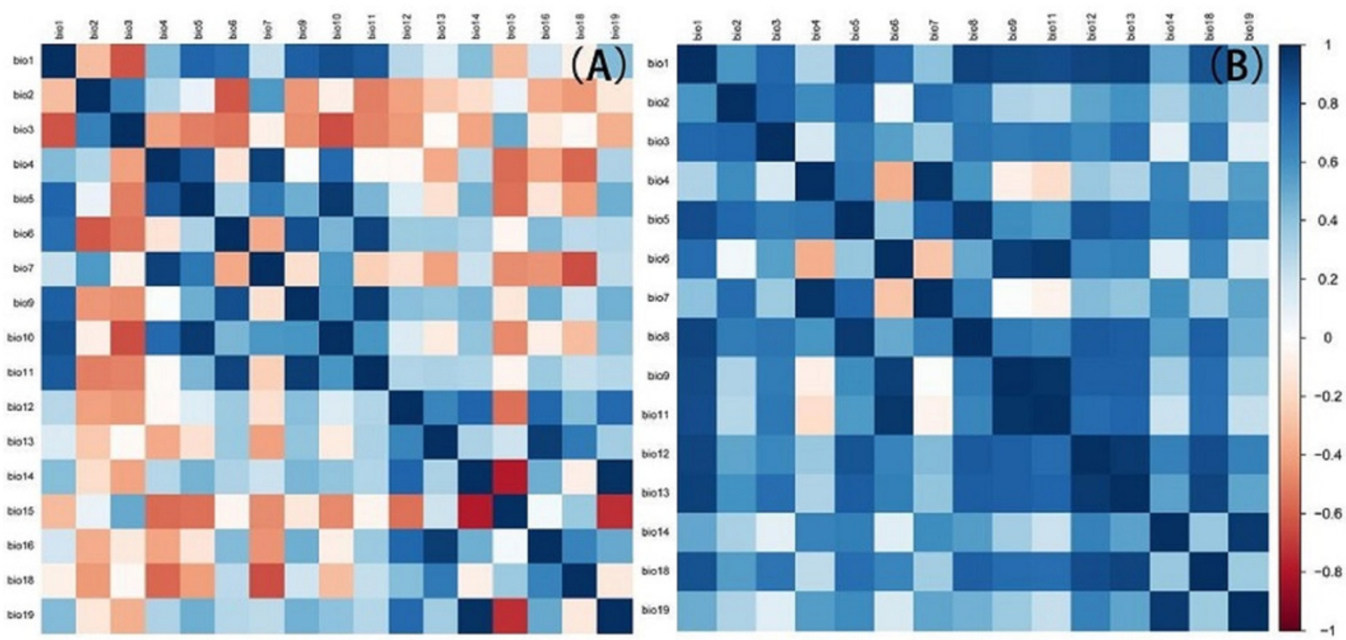
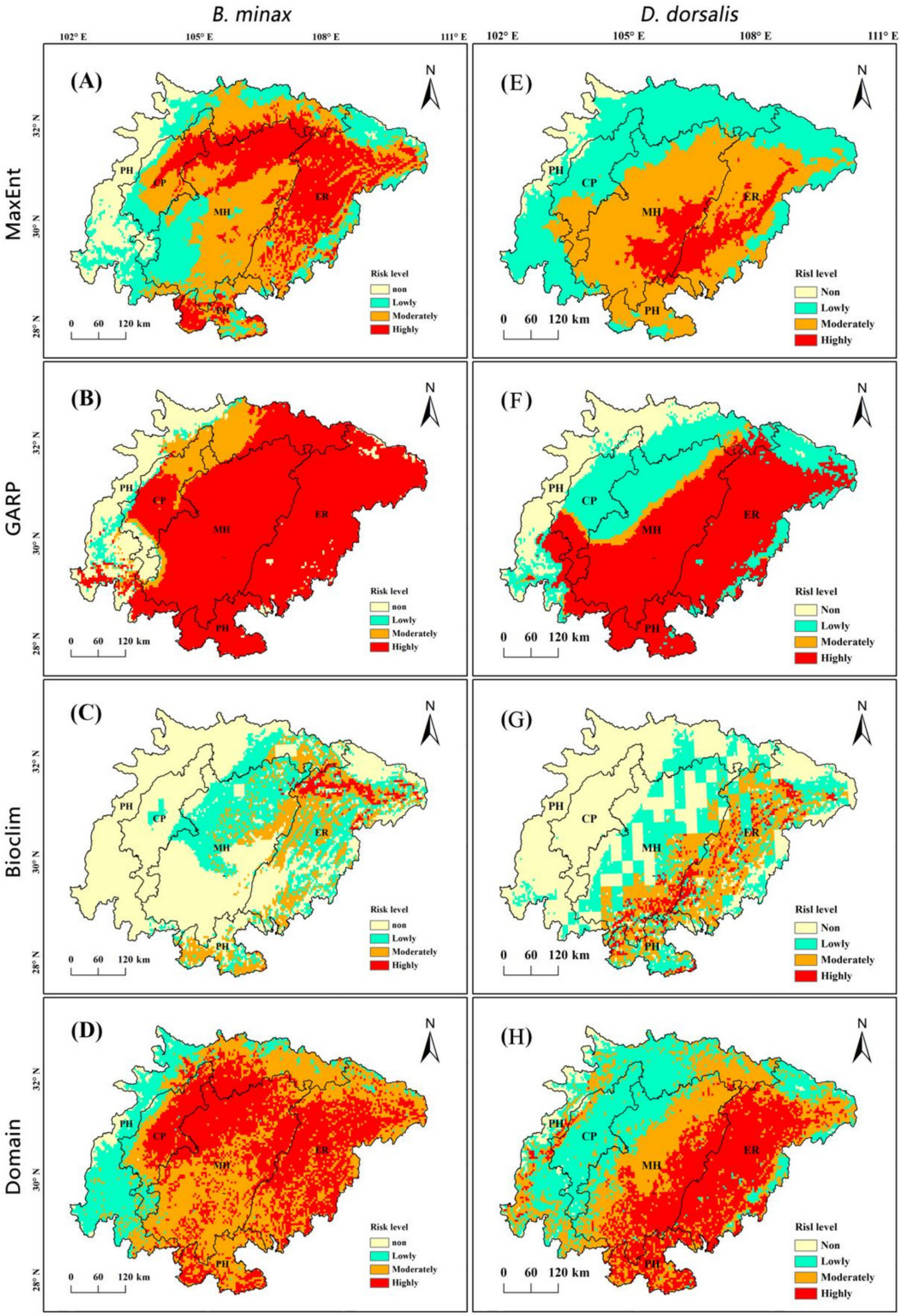


Figure 2

Potential distribution of *B. minax*(A-D) and *D. dorsalis*(E-H) simulated by MaxEnt , GARP , Bioclim and Domain



B. minax
D. dorsalis
MaxEnt
GARP
Bioclim
Domain
(A)
(B)
(C)
(D)
(E)
(F)
(G)
(H)
102° E
105° E
108° E
111° E
32° N
30° N
28° N
PH
CP
MH
ER
Risk level
non
Lowly
Moderately
Highly
Risl level
Non
Lowly
Moderately
Highly
0 60 120 km
N

Figure 3

The importance of environmental factors affecting the distribution of B. minax(A) and D. dorsalis(B) (jackknife)

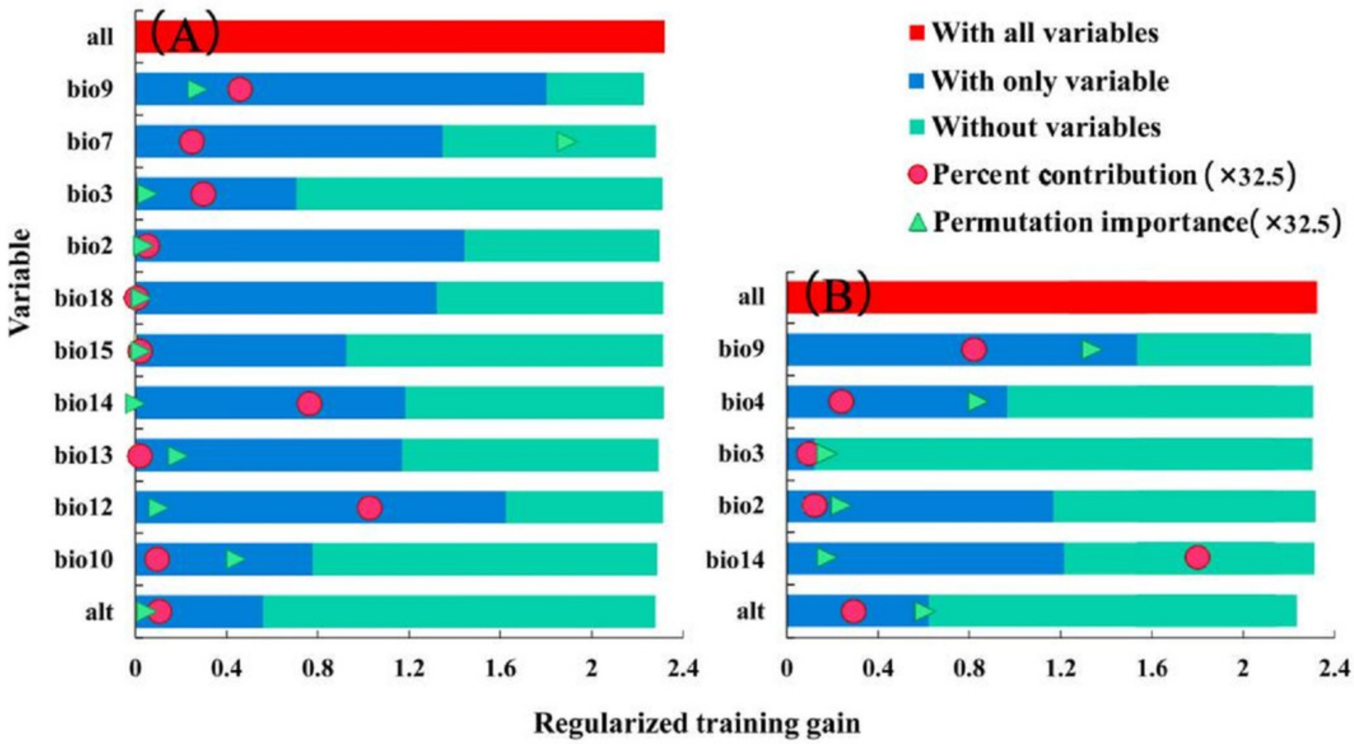


Figure 4

Response curve of B. minax(A-E) and D. dorsalis(F-I) to key environmental factors

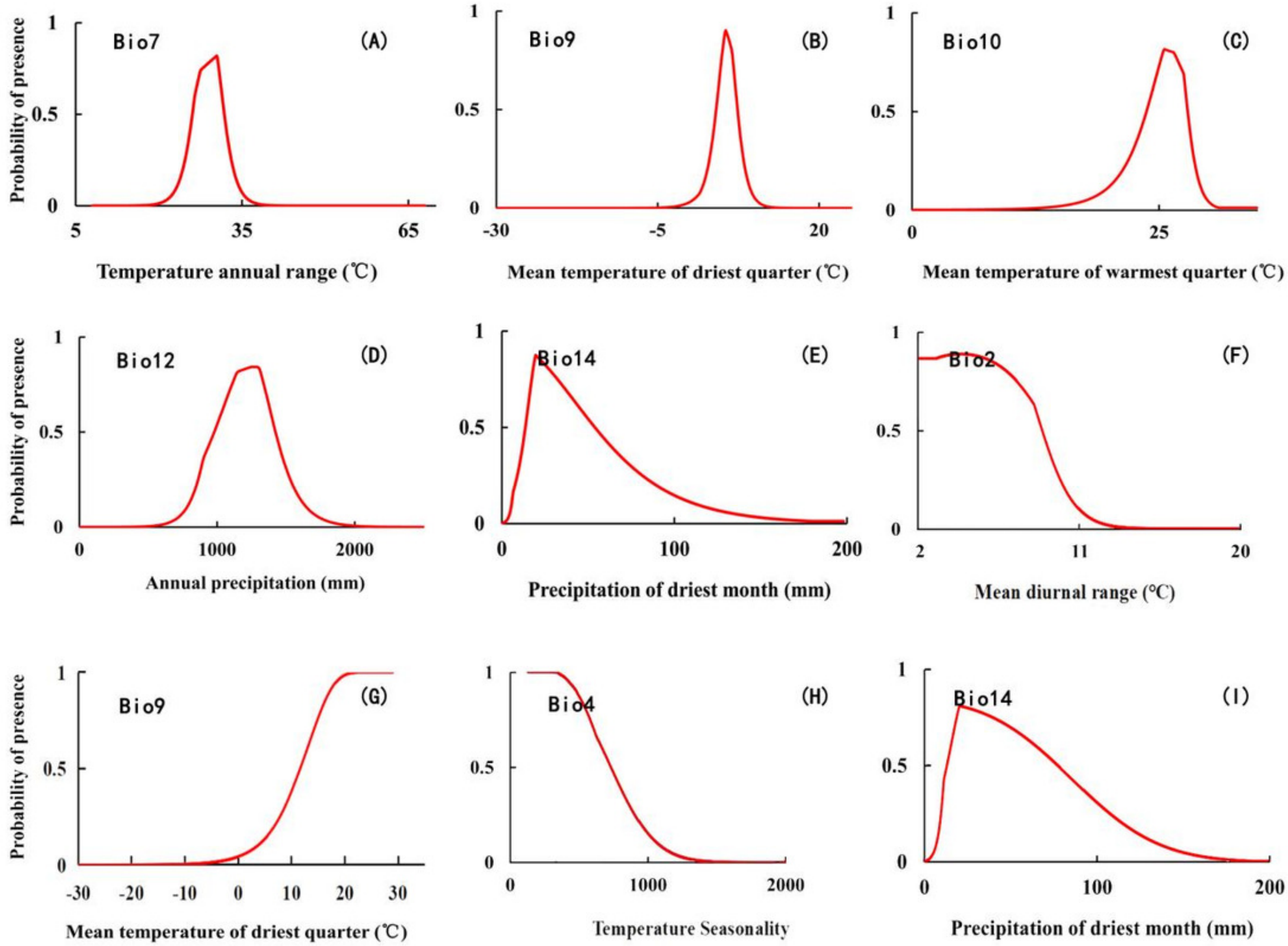


Table 1 (on next page)

Environmental factors affecting the potential distribution of *B. minax* or *D. dorsalis*

Table 1. Environmental factors affecting the potential distribution of *B. minax* or *D. dorsalis*

Environment factors			Species	
Code	Variable	Unit	*B. minax*	*D. dorsalis*
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)	℃	√	
Bio9	Mean Temperature of Driest Quarter	℃	√	√
Bio10	Mean Temperatureof Warmest Quarter	℃	√	
Bio12	Annual Precipitation	mm	√	
Bio13	Precipitation of Wettest Month	mm	√	
Bio14	Precipitation of Driest Month	mm	√	√
Bio15	Precipitation Seasonality(Coefficient of Variation)	mm	√	
Bio18	Precipitation of Warmest Quarter	mm	√	
Alt	Elevation	m	√	√

Table 2 (on next page)

The AUC and Kappa values of the four models

Table 2. The AUC and Kappa values of the four models

Groups	Area under receiver operating characteristic curve (AUC)				Consistency test statistics (Kappa)			
	Maxent	Garp	Bioclim	Domain	Maxent	Garp	Bioclim	Domain
1	0.985	0.925	0.922	0.966	0.754	0.815	0.801	0.831
2	0.981	0.923	0.944	0.955	0.720	0.794	0.796	0.821
3	0.984	0.911	0.956	0.947	0.760	0.790	0.810	0.830
4	0.977	0.907	0.968	0.934	0.751	0.768	0.821	0.856
5	0.989	0.911	0.978	0.927	0.732	0.816	0.810	0.832
6	0.992	0.928	0.964	0.947	0.744	0.827	0.814	0.801
7	0.997	0.906	0.922	0.942	0.715	0.779	0.783	0.792
8	0.981	0.913	0.937	0.927	0.806	0.792	0.788	0.827
9	0.976	0.918	0.958	0.937	0.769	0.811	0.814	0.831
10	0.988	0.922	0.949	0.945	0.774	0.785	0.792	0.828
Average	0.985	0.916	0.950	0.943	0.753	0.798	0.803	0.825