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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Both *Bactrocera minax* and *Bactrocera dorsalis* are phytophagous insects, and their larvae are latent feeders, which cause great damage and economic losses to agriculture production and trade. This study aimed to provide a scientific reference for researching and developing the feasible countermeasures against these two pests. Based on the distribution data of *B. minax* and *B. dorsalis* in China, obtained from the Chinese herbaria, investigation and literature. Four Niche models (Garp, Bioclim, Domain, and Maxent) were used to analyze the key environmental factors affecting the distribution of both pests and to build prediction models of the potential distribution in Sichuan Basin. Combined with two statistical standards, area under the receiver operating characteristic curve (AUC) and Kappa, the validity of prediction models were analyzed and compared.

The results show that: the average AUC values of the four models are all above 0.90, and the average Kappa values are all above 0.75, indicating that the four models are suitable for predicting the potential distribution area of *B. minax* and *B. dorsalis*. The annual range of temperature, the mean temperature in the driest quarter, the mean temperature in the warmest quarter, the annual precipitation, and the precipitation in driest month are the key environmental factors affecting the distribution of *B. minax*, while the mean diurnal temperature range, the mean temperature in the driest quarter, the seasonal temperature variations and the precipitation in driest month affect the potential distribution of *B. dorsalis*. The suitable areas for *B. minax* are mainly concentrated in the eastern of Sichuan Basin, while the suitable areas for *B. dorsalis* are concentrated in the southeastern. Except for the Bioclim model, the highly-suitable area for both pests predicted by the other three models are all greater than 15.94×10^4 km^2 and the moderately-suitable areas are greater than 13.57×10^4 km^2. In conclusion, the suitable areas for both pests in Sichuan Basin are quite wide.

Therefore, the relevant authorities should be given strengthened monitoring of both pests, especially in areas with high incursion rates.

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16 **Abstract**

17 Both *Bactrocera minax* and *Bactrocera dorsalis* are phytophagous insects, and their larvae

18 are latent feeders, which cause great damage and economic losses to agriculture production and

19 trade. This study aimed to provide a scientific reference for researching and developing the

20 feasible countermeasures against these two pests. Based on the distribution data of *B. minax* and

21 *B. dorsalis* in China, obtained from the Chinese herbaria, investigation and literature. Four Niche

22 models (Garp, Bioclim, Domain, and Maxent) were used to analyze the key environmental

23 factors affecting the distribution of both pests and to build prediction models of the potential

24 distribution in Sichuan Basin. Combined with two statistical standards, area under the receiver

25 operating characteristic curve (AUC) and Kappa, the validity of prediction models were analyzed

26 and compared. The results show that: the average AUC values of the four models are all above

27 0.90, and the average Kappa values are all above 0.75, indicating that the four models are suitable

28 for predicting the potential distribution area of *B. minax* and *B. dorsalis*. The annual range of

29 temperature, the mean temperature in the driest quarter, the mean temperature in the warmest

30 quarter, the annual precipitation, and the precipitation in driest month are the key environmental

31 factors affecting the distribution of *B. minax*, while the mean diurnal temperature range, the mean

32 temperature in the driest quarter, the seasonal temperature variations and the precipitation in

33 driest month affect the potential distribution of *B. dorsalis*. The suitable areas for *B. minax* are

34 mainly concentrated in the eastern of Sichuan Basin, while the suitable areas for *B. dorsalis* are

35 concentrated in the southeastern. Except for the Bioclim model, the highly-suitable area for both
36 pests predicted by the other three models are all greater than $15.94×10^4$ km^2 and the moderately-
37 suitable areas are greater than $13.57×10^4$ km^2. In conclusion, the suitable areas for both pests in
38 Sichuan Basin are quite wide. Therefore, the relevant authorities should be given strengthened
39 monitoring of both pests, especially in areas with high incursion rates.
40
41 **Key words:** species distribution models, MaxEnt, Garp, Bioclim, Domain, suitable habitat,
42 *Bactrocera minax* (Enderlein)*, Bactrocera dorsalis* (Hendel)
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45 **1. Introduction**

46   Fruit flies are insects belonging to the order Diptera and the family Tephritidae,
47 characterized by one pair of functional wings and one pair of reduced halteres, a diverse range of
48 habitats and feeding behaviors, and a significant impact on various ecosystems and human
49 activities (*Elekçioğlu, 2013*). The common species in China are *Bactrocera minax* Enderlein,
50 *Bactrocera dorsalis* Hendel and *Tetradacus tsuneonis* Miyake, which are all international
51 quarantine pests *(Wang & Zhang, 2009). B. minax* is a native species *(Liang, Zhang & Xu, 1989),*
52 mainly distributed in southern citrus regions, which can harm a variety of citrus fruits, such as
53 sweet orange, grapefruit, lemon, bergamot (*Zhang, 2007*). The host species of *B. dorsalis* is
54 complex, including more than 250 kinds of trees, vegetables and flowers, such as mango,
55 pomegranate, lime and so on (*Liang et al., 2003*). *B. dorsalis* is a non-native species *(Zhang et*
56 *al., 2022),* but it's widely distributed. In addition to the southern citrus regions, it has also been
57 found in central China in recent years. Both *B. minax* and *B. dorsalis* are invasive and
58 polyphagous pests of horticultural crops, which have caused great damage and economic losses
59 to agricultural production and agricultural trade (*Ye et al., 2022*).
60   *B. minax* occurs one generation a year and overwinters in the soil as a pupae. The eclosion
61 time of adult insects varies with year and place, mainly affected by the mild atmosphere and soil
62 moisture, the optimal temperature is about 22℃ and the soil moisture is between 15% and 20%.
63 In Sichuan Basin, the eclosion time of *B. minax* begins in late April, and gradually ends in mid-
64 June, which is generally consistent with the phenological period from flowering to fruiting (*Tang,*
65 *2012*). *B. dorsalis* usually occurs three to five generations a year in subtropical areas and
66 overwinters in the soil as an old larvae or pupae (*Liang et al., 2003*). The development stage and
67 the hatching rate of eggs are affected by temperature and humidity, and it is very poor when the
68 temperature is lower than 16℃ or higher than 36℃, and the relative humidity is lower than 40%.
69 The larval stage is related to temperature and host, ranging form five to ten days at 28±1℃ and
70 eight to eleven days at 25±1℃. The pupal stage is greatly affected by soil water content and
71 temperature, the mortality rate is higher when the soil water content is lower than 40% or higher
72 than 80%, and the pupal stage doubles and the emergence rate decreases when the temperature is
73 lower than 18℃ (*Zhou, 2016*).

74   The ecological characteristics of crop diseases and pests, such as growth, reproduction,
75 overwintering and distribution, are closely related to environmental conditions, especially climate
76 conditions. Therefore, climate change have a great impact on the generation, wintering northern
77 boundaries and the distribution range of crop diseases and pests (*Li et al., 2010*). According to
78 previous studies, the annual area of pests in China is between 200 million and 230 million square
79 kilometers, more than twice as much as arable (*Zhou et al., 2013*). Citrus is the most important
80 fruit in Sichuan Basin, its area and yield are increasing year by year. By the end of 2020, the
81 citrus planting area reached $3.39×10^5$ hectares and the yield reached $4.89×10^6$ tons (*Wang & Du,*
82 *2022*). In view of the importance of citrus to the economy of Sichuan Basin, it is vital to control
83 pests.

84   Species distribution models (SDMs) use certain algorithms to predict the potential
85 distributional range of species based on actual distribution points and environmental factors. The
86 selection of environmental factors, the migration ability of species and the types of environmental
87 factors have an important impact on the simulation results (*Gobeyn et al., 2019; Cvea et al.,*
88 *2021*). At present, The SDMs used to predict the potential distribution of species include Climex,
89 Garp, MaxEnt, Bioclim and Domain (*Li et al., 2013; Xu, Peng & Peng, 2015*), many scholars
90 used these models to predict the potential distribution of pests, such as *Bemisia tabaci (Li et al.,*
91 *2023), Wasmannia auropunctata (Xu et al., 2023), Locusts (Ju et al., 2022)*, etc.

92   Recently, some scholars have studied *B. minax* and *B. dorsalis*, mainly focuses on biology
93 (*Mayren et al., 2022; Akami et al., 2022*), ecology (*Diesner et al., 2022*), quarantine and
94 treatment technology (*Grazielle, Beatriz & Henrique, 2021; Hou et al., 2021*), integrated
95 prevention and control technology (*Todd et al., 2022; Yukihiro et al., 2021*), but there is no
96 research on theirs geographical division in China. In this paper, we predicted the distribution of
97 *B. minax* and *B. dorsalis* with SDMs, obtained the key environmental factors affecting theirs
98 geographical distribution, and delimited theirs suitable area. This study aimed to provide a
99 scientific reference for researching and developing the feasible countermeasures against *B. minax*
100 and *B. dorsalis*, reduce the serious economic loss caused by the them, and ensure the steady
101 development of the fruit, vegetable and flower industry in China.

102 **2. Materials and Methods**

103 *2.1. Sample distribution data*

104   Occurrence records of *B. minax* and *B. dorsalis* in China were obtained from various
105 sources, such as the Global Biodiversity Information Facility (*GBIF, 2023*), Centre Agriculture
106 Bioscience International (*CABI, 2023*) and literature *(Zhao et al., 2006; Zhou et al., 2010; Fan,*
107 *Yang & Yin, 2013; Wu et al., 2014; Li et al., 2017; Xu et al., 2017; Deng, Huang & Dong, 2018;*
108 *Li et al., 2019; Zhang, Mao & Du, 2019; Cui and Liu, 2020; Fang et al., 2020)*. The longitude
109 and latitude of occurrence records picked up by Google Earth were converted into decimal after
110 removing the repeated distribution points. In order to reduce the impact of spatial self-correlation,

111   ENMTOOL software was applied to process occurrence records to ensure that each grid (size: 30
112   arc-seconds) contains only one distribution point (*Wang et al., 2019; Wang et al., 2020*). After the
113   above steps, two hundred and fifty-one valid records were retained to build the prediction model
114   for *B. minax,* and fifty-seven valid records were retained for *B. dorsalis* (Fig. 1).

115   *2.2. Environmental factors used in models*

116   The growth and development of insects are closely related to the climatic conditions in
117   which they live (*Li et al., 2020*). Therefore, nineteen bioclimatic factors and elevation
118   downloaded from WorldClim (https://www.worldclim.org/) were selected as initial environmental
119   factors. In order to eliminate the correlation among the nineteen bioclimatic factors, the following
120   operations were carried out. First, ArcGIS was used to extract the attribute values of nineteen
121   bioclimate factors corresponding to the occurrence records of *B. minax* and *B. dorsalis*. Second,
122   the percent contribution of nineteen bioclimatic factors was tested by the jackknife method, and
123   the factors with zero contribution rate were excluded. Third, correlation analysis was performed
124   for the retained bioclimatic factors (Fig. 2). For the two bioclimatic factors with pearson
125   correlation coefficient greater than 0.85, the factor with lower percent contribution value in the
126   jackknife test was excluded. After the above three steps, thirteen environmental factors were
127   retained to build the prediction model for *B. minax,* and six environmental factors were retained
128   for *B. dorsalis* (Table 1).

129   *2.3. Verification of model accuracy*

130   Receiver operating characteristic (ROC) and Kappa statistics are common methods for
131   evaluating the accuracy of SDMs (*Xu, Peng & Peng, 2015*). ROC curve evaluation method uses
132   the area under curve (AUC) enclosed by ROC curve and horizontal coordinate to evaluate the
133   prediction precisions. The value of AUC ranges is 0 to 1, and the closer the value is to one, the
134   more accurate the prediction result will be (*Liu et al., 2021*). Kappa statistics comprehensively
135   considers the species distribution rate, sensitivity and specificity, and the value ranges is - 1 to 1.
136   When the value is greater than 0.75, the consistency is good, and when it is less than 0.4, the
137   consistency is poor (*Wang, 2006*).

138   *2.4 Prediction model and modeling process*

139   2.4.1 Maxent model
140   MaxEnt software running Maxent model was downloaded from official website
141   (https://biodiversityinformatics.amnh.org/open_source/maxent/). In order to improve the
142   accuracy of Maxent model, we optimized the model by adjusting regularization multiplier (RM)
143   and feature combinations (FCs). The FCs contains five characteristics, such as linear (L),

144 quadratic (Q), hinge (H), product (P) and threshold (T). The operations were as follows: The RM
145 range was set to 0.5 to 4, and the step was 0.5. The FCs was set as L, LQ, H, LQH, LQHP and
146 LQHPT, respectively. Therefore, 48 different combinations of RM and FCs were established and
147 the combination with the smallest AICc value was selected as the optimal model. Meanwhile,
148 other parameters of the optimal model were set as follows: 25% distribution points were selected
149 as the test set, 75% distribution points were selected as the training set, the maximum number of
150 iterations was set to 500, the maximum number of background points was set to 10,000, and the
151 number of repetitions was set to 10 (*Zhao et al., 2022; Guo et al., 2022*).
152 2.4.2 Garp model
153   Desktop Garp was downloaded from website (http://www.lifemapper.org). Retaining the
154 default settings except that the number of runs was set to 20 times, that was, the convergence
155 limit and the max iterations was set to 0.01 and 1000 (*Peterson, Papes & Eaton, 2007*),
156 respectively. By superimposing the result of 10 optimal models in ArcGIS, the geographical
157 distribution prediction map of species can be obtained (*Anderson, Lew & Peterson, 2003.*) .
158 2.4.3 Bioclim and Domain model
159   DIVA-GIS software running Bioclim and Domain model was downloaded from DIVA-GIS
160 official website (http://swww.diva-gis.org/). The training data set in shp format was added to
161 DIVA-GIS, then environmental factors were converted into grd format to generate stack data set.
162 Added a stack file in the modeling Bioclim / Domain module and selected the two models for
163 prediction (*Wang et al., 2020*).

164 *2.5 Suitable area division and area calcultaion*

165   The natural break point method was used to classify the predicted results, and the potential
166 distribution was divided into four types of suitable area: the unsuitable area, the lowly-suitable
167 area, the moderately-suitable area, the highly-suitable area (*Zhang, 2023*). In order to avoid over-
168 interpretation the prediction results of Domain model with natural break point method, research
169 referenced Carpenter (*1993*) and combined with the matching degree between the output of
170 Domain and the actual distribution of *B. minax* and *B. dorsalis* to adjust the suitable areas
171 predicted by Domain model. After reclassification, the pixel counts of different suitable areas
172 were counted through "attribute-symbol system-unique value", then the area of each suitable area
173 in Sichuan Basin was calculated base on the number of pixels.

174 **3. Results**

175 *3.1. Evaluation of prediction accuracy of different models*

176   Ten sets of training data and test data were used to conduct ROC analysis and Kappa
177 statistics for four niche models. As can be seen from table 2, the average AUC values of four

178 niche models (Maxent, Garp, Bioclim and Domain) are 0.985, 0.916, 0.933 and 0.950, all of
179 which are higher than those of random model (AUC=0.5). The Kappa values are 0.825, 0.753,
180 0.768 and 0.803, all of which are greater than 0.75, indicating that the four models have
181 significant consistency and high prediction accuracy.

182 *3.2. Potential distribution of B. minax and B. dorsalis simulated by four models.*

183   The prediction results of four ecological niche models on the potential distribution of *B.*
184 *minax* and *B. dorsalis* in Sichuan Basin are shown in Figure 3. The MaxEnt model simulation
185 (Fig.3 A) shows that the total suitable area for *B. minax* in Sichuan Basin is 21.61×10^4 km^2,
186 accounting for 87.62 % of the basin. Specifically, the highly-suitable area is 6.61×10^4 km^2,
187 including most of the eastern parallel ridge valley, the north of the middle shallow hilly zone, the
188 north and south of the peripheral hilly zone and the northeast of the Chengdu Plain. The
189 moderately-suitable area is 9.34×10^4 km^2, including the middle and east of the middle shallow
190 hilly zone the south of the eastern parallel ridge valley, the north of the peripheral hilly zone, and
191 the middle and west of the Chengdu Plain. The rest is lowly-suitable area, which is mainly
192 distributed in the west and north of the peripheral hilly zone, the southwest of the middle shallow
193 hilly zone, the north of the eastern parallel ridge valley and the south of the Chengdu Plain. As
194 can be seen from Fig.3 E, the total suitable area for *B. dorsalis* in Sichuan Basin is 23.49×10^4
195 km^2, accounting for 95.26 % of the basin. Specifically, the highly-suitable area is 2.62×10^4 km^2,
196 including most of the eastern parallel ridge valley, the southeast of the middle shallow hilly zone
197 and the eastern of the peripheral hilly zone. The moderately-suitable area is 10.95×10^4 km^2,
198 including the middle and east of the middle shallow hilly zone, the south of the eastern parallel
199 ridge valley, the north of the peripheral hilly zone, and the middle and west of the Chengdu Plain.
200 The rest is lowly-suitable area, which is mainly distributed in the west and north of the peripheral
201 hilly zone, the southwest of the middle shallow hilly zone the north of the eastern parallel ridge
202 valley and the south of Chengdu Plain.
203   The forecast distribution map (Fig.3 B, F) using Garp model shows that besides the west of
204 the peripheral hilly zone, the north and south of the Chengdu Plain, the remaining area is highly-
205 suitable area for *B. minax*, accounting for 73.49 % of the Sichuan Basin. The moderately-suitable
206 area is 2.28×10^4 km^2, which can be divided into two parts, one part is concentrated in the north of
207 the peripheral hilly zone and the north of the Chengdu Plain, and the other part extends from the
208 south of the Chengdu Plain to the southwest of the middle shallow hilly zone in a strip shape. The
209 lowly-suitable area is 0.57×10^4 km^2, which is scattered in the west of the peripheral hilly zone
210 and the west of the Chengdu Plain. The highly-suitable area for *B. dorsalis* mainly concentrate in
211 other areas except the northwest of middle shallow hilly zone, the north and southeast of eastern
212 parallel ridge valley, the north of Chengdu plain and the southeast of peripheral hilly zone, and
213 the total area is 18.12×10^4 km^2. The moderately-suitable area is mainly in the southwest margin
214 of the high suitable area, with a gross area of 2.28×10^4 km^2. The unsuitable-area for *B. dorsalis*
215 located in the peripheral hilly zone is 3.68×10^4 km^2, accounting for 15% of the basin.
216   According to the Bioclim (Fig.3 C, G) and Domain (Fig.3 D, H) obtained by the DIVA-GIS

217 software, it can be observed that the red region representing the highly-suitable area accounts for
218 a small proportion in these two models. Geographically, Bioclim predicted a small distribution
219 range, the highly-suitable area and moderately-suitable area for *B. minax* are located in the east of
220 Sichuan Basin. The highly-suitable area (0.59×10^4 km²) is distributed in the north of the eastern
221 parallel ridge valley in thin strips. The moderately-suitable area (3.66×10^4 km²) is not
222 concentrated, one part is locate in the eastern parallel ridge valley and adjacent middle shallow
223 hilly zone in a south-north strip shape, and the other is distributed in the north and south of the
224 peripheral hilly zone in a block shape. While the highly-suitable area and moderately-suitable
225 area for *B. dorsalis* are scattered located in east of middle shallow hilly zone, west of eastern
226 parallel ridge valley and west of peripheral hilly zone, with a gross area of 5.66×10^4 km². The
227 distribution range predicted by Domain model is large, which is generally close to that of Garp
228 model and the distribution range of highly and moderately suitable area are similar to that of
229 Maxent.

3.3. Relationship between probability of species and key environmental factors

231 3.3.1 Screening key environmental factors
232   The importance of factors used in the modeling was analyzed again by the tool of jackknife
233 test, and the analysis results are shown in Fig.4. Considering the percent contribution and the
234 permutation importance of environmental factors, it can be seen from the Fig.4 A that mean
235 temperature of driest quarter (Bio9), annual precipitation (Bio12), temperature annual range
236 (Bio7), precipitation of direst month (Bio14) and mean temperature of warmest quarter (Bio10)
237 have high predictive ability, which the percent contribution and permutation importance are
238 83.96% and 87.87%, respectively. Therefore, these five factors are identified as the key
239 environmental factors affecting the distribution of *B. minax*. Similarly, it can be seen from Fig.4
240 B that the key environmental factors affecting the distribution of *B. dorsalis* are mean
241 temperature of driest quarter (Bio9), temperature seasonality (bio4), mean diurnal range (bio2)
242 and precipitation of direst month (Bio14).
243
244 3.3.2 The suitable range of key environmental factors
245   Figure. 5 is the response curve between key environmental factors and distribution
246 probability drawn by Maxent model, which can reflect the value range of environmental factors
247 under different thresholds. According to Wang's (Wang et al, 2020) classification method, the
248 paper took 0.33 as the threshold to divide the range of environmental factors suitable for *B.*
249 *minax* and *B. dorsalis.* The response curves of five key environmental factors affecting the
250 potential distribution of *B. minax* (Fig. 5 A-E) demonstrate that the suitable ranges of temperature
251 annual range, mean temperature of driest quarter, mean temperature of warmest quarter, annual
252 precipitation and precipitation of driest month are 26.27–31.17 ℃, 4.58–7.07 ℃, 24.58–27.57
253 ℃, 1025.64–1380.34 mm and 15.2–44.65 mm, respectively. Similarly, the key environmental
254 factors affecting the potential distribution of *B. dorsalis* (Fig. 5 F-I) are mean diurnal range, mean
255 temperature of driest quarter, temperature seasonality (standard deviation ×100) and precipitation

256 of driest month, which the threshold ranges are 2–8.6 ℃, ≥13.1 ℃, 341.88–666.67, 15.4–63.9
257 mm, respectively.

4. Discussion

259   By comparison, it is found that Maxent model can fit the distribution of *B. minax* and *B.*
260 *dorsalis* in Sichuan Basin well, which the average value of AUC and Kappa are higher than other
261 models. Relevant literature also proves that Maxent could predict the suitable area of species well
262 under both large or small sample conditions *(Xu, Peng & Peng, 2015)*. The Garp model predicts a
263 wide range of highly-suitable area for *B. minax* and *B. dorsalis*, which is similar to what other
264 scholars have done in predicting other species (*Wang et al., 2020; Zhang et al., 2023*). This may
265 be due to two reasons, one is that the output type of Garp is boolean, and the result is suitable as
266 long as species shows adaptation somewhere, another may be due to insufficient repetitive
267 Settings, the classification is not obvious. The Domain model uses Gower algorithm to calculate
268 the similarity between points, and uses similarity matrix to classify the study region *(Carpenter,*
269 *Gillison & Winter, 1993)*. The prediction results of Domain model are greatly affected by the
270 distribution points, and almost all the places with distribution points have certain suitable regions
271 *(Zhang et al., 2017)*. Based on the above reasons, the range of suitable area predicted by Domain
272 model is also large. The Bioclim defines the environmental envelope as the volume of a straight
273 line in Euclidean space and treats each climate axis independently depending on the range, which
274 can lead to ecologically unreasonable predictions *(Zhang et al., 2023)*.Therefore, the Bioclim
275 model is poor in predicting the distribution of *B. minax* and *B. dorsalis*.
276   The relationship between species and environment is an important aspect to study the
277 ecological needs and spatial distribution of species. The paper analyzes the relationship between
278 the presence probability of *B. minax* and *B. dorsalis*, and the key environmental factors affecting
279 the potential distribution of these two pests, and obtains the feedback curve. Among the five key
280 factors affecting the distribution of *B. minax*, mean temperature of driest quarter and annual
281 precipitation are the most important environmental factors, indicating that the diffusion and
282 reproduction process of *B. minax* is restricted by the temperature and precipitation. In this study,
283 the suitable range of mean temperature of driest quarter for *B. minax* is 4.58–7.07 ℃, and the
284 optimal value is 5.55 ℃. The Sichuan Basin belongs to the subtropical humid climate zone, and
285 the driest season is from November to April of the next year, *B. minax* overwinters as the pupae
286 during this period. Ma (*2014*) found that when the temperature was between 5℃ and 10℃, the
287 pupae did not emerge and the survival time could reach 156-250 days, which was basically
288 consistent with the temperature range in this study. The annual precipitation is related to the air
289 and soil moisture, which has a significant effect on the emergence and survival of imago. When
290 the soil water content is low or high, the emergence rate is significantly inhibited and the
291 mortality rate increases. Among the four key environmental factors affecting the distribution of
292 *B. dorsalis*, mean temperature of driest quarter and precipitation of driest month are the most
293 important environmental factors. Studies have shown that *B. dorsalis* is a tropical and subtropical
294 insect, and its occurrence and distribution are greatly affected by climate conditions such as

295 temperature and humidity. The developmental threshold temperature of pupae is 9~11℃, and
296 neither too low nor too high temperature can make pupae survive or emerge safely (*Kong et al.,*
297 *2008;*). The influence of precipitation on *B. dorsalis* is mainly manifested in two aspects under
298 the natural conditions. On the one hand, appropriate precipitation can maintain soil moisture and
299 atmospheric moisture, thus reducing the mortality of mature larvae and newly emerging adults,
300 which is conducive to the mating and spawning activities of adults. On the other hand, excessive
301 precipitation will cause high soil moisture, which will affect the larva pupae and pupae grow up
302 to imago. It should be noted that the feedback curve between presence probability of pests and
303 environment factors reflects the effect of the single environment factor, but the life activities of
304 pests is affected by a variety of environmental factors (including climate factors, host condition,
305 natural enemy species, vegetation, etc.). Therefore, this result can be used as a reference to judge
306 the relationship between pests and environmental factors, but it can not completely explain the
307 relationship between them.
308   The risk of detecting exotic pests late or unresponsive can be illustrated by cases of
309 eradication failure, such as *B. carambolae* in Suriname, the lag phase from the first discovery of
310 infested fruit in 1975 to the identificaton and confirmation of specimens from South-east Asia in
311 1986 was 12-year (*Naymã et al., 2018; Alies, 2005*). SDMs can predict the possible range of pests
312 before actual problems occur, and make pre-emptive and effective pest management decisions.
313 The research shows that the suitable area for *B. minax* is mainly concentrated in the eastern of the
314 Sichuan Basin, while the *B. dorsalis ʼ* is concentrated in the southeastern. Except for the Bioclim
315 model, the highly-suitable area and moderately-suitable area predicted by the other three models
316 are larger than $15.94×10^4$ km^2 (accounting for 55.1% of the Sichuan Basin) and $13.58×10^4$ km^2
317 (accounting for 65% of the Sichuan Basin), indicating *B. minax* and *B. dorsalis* are suitable for
318 survival in the Sichuan Basin.
319   Prevention is one of the most effective strategies for controlling and monitoring of pests, and
320 is crucial for determining the population dynamics, comparing infestation levels among different
321 species, and evaluating the effectiveness of control strategies(*Eliopoulos, 2007*). With the
322 continuous development and improvement of analytical biotechnology and biochemical
323 technology, many new techniques have been applied in the identification of insect classification.
324 Brazilian researchers had proposed a multimodal fusion method based on two types of images
325 (wings and aculei), which pointed the way to identify *Anastrepha*. Now an algorithm had been
326 developed to identify blotches in hyperspectral images of mangoes that had been invaded by
327 tephritidae larvae. Meanwhile, the development of automatic insect traps has been strengthened
328 and accelerated. According to relevant studies, the above methods can be used to monitor pests
329 well. Therefor, we should strengthen the study of *B. minax* and *B. dorsalis* in the Sichuan Basin
330 on the basis of the above research.
331   The spatial distribution of species reflects the inter-relationship between population
332 individuals in horizontal space, and is the result of long-term adaptation and selection between
333 population and environment. The study of population spatial pattern can reflect a series of
334 ecological processes that plant populations have experienced in the past. Therefore, the prediction
335 of the potential geographical distribution of *B. minax* and *B. dorsalis* by four models can
336 understand the population characteristics, the intra-specific and inter-specific relationships, and
337 the relationship between the population and the environment, so as to study and develop feasible

338   quarantine pest control countermeasures. It is great significance to reduce the serious economic
339   losses caused by quarantine pests and ensure the stable development of China's fruit, vegetable
340   and flower industry. The combined results of the four models find that the northern part of middle
341   shallow hilly zone and the eastern part of parallel ridge valley in Sichuan basin are high risk area
342   for the occurrence of *B. minax*, while the eastern part of middle shallow hilly zone and the
343   western part of parallel ridge valley in Sichuan basin are high risk area for the occurrence of *B.*
344   *dorsalis*, so these areas should take preventive measures to prevent *B. minax* and *B. dorsalis*
345   further spread and outbreak. The prediction results show that there are scattered distribution
346   records of *B. minax* and *B. dorsalis* in peripheral hilly zone of the Sichuan basin, so it is
347   recommended to carry out census work to find out the actual distribution and establish early
348   monitoring and warning system. At the same time, the establishment of a rapid response and real-
349   time control system for the epidemic and the strengthening of popular science publicity are also
350   conducive to "early detection, early warning and early response".
351   As the main group of animals, the distribution of insects is greatly affected by the
352   environment and host distribution (*Xin, 2019*). Due to data limitations, the study only considered
353   meteorology and altitude affecting the suitable areas of *B. minax* and *B. dorsalis*, which might
354   cause the predicted ecological niche to be larger than the actual ecological niche. In the next step,
355   we will focus on considering the reliable expression of the interaction of various factors to
356   improve the prediction effect of the model.
357   **Figure legends:**

358   Figure 1: Existence record of *B. minax* and *B. dorsalis* in China
359   Figure 2: Potential distribution of *B. minax* (A-D) and *B. dorsalis* (E-H) simulated by Maxent , Garp , Bioclim and
360   Domain. CP: Chengdu plain; MH: middle shallow hilly zone in Sichuan basin; ER: eastern parallel ridge valley in
361   Sichuan Basin; PH, peripheral hilly zone in Sichuan basin.
362   Figure 3: Correlation analysis of environmental factors which may affect potential distribution of *B. minax (A)* and
363   *B. dorsalis (B)*.
364   Figure 4: The importance of environmental factors affecting the distribution of *B. minax* (A) and *B. dorsalis* (B)
365   (jackknife).
366   Figure 5: Response curve of *B. minax* (A-E) and *B. dorsalis* (F-I) to key environmental factors
367

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375

Author contributions

Yanli Xia and Yuxia Yang provided relevant data of *B. minax* and *B. dorsalis*, and required funds for the experiment. Jinpeng Zhao, Jian Ding and Ke Xu 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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538

Figure 1

Existence records of *B. minax* and *B. dorsalis* in China

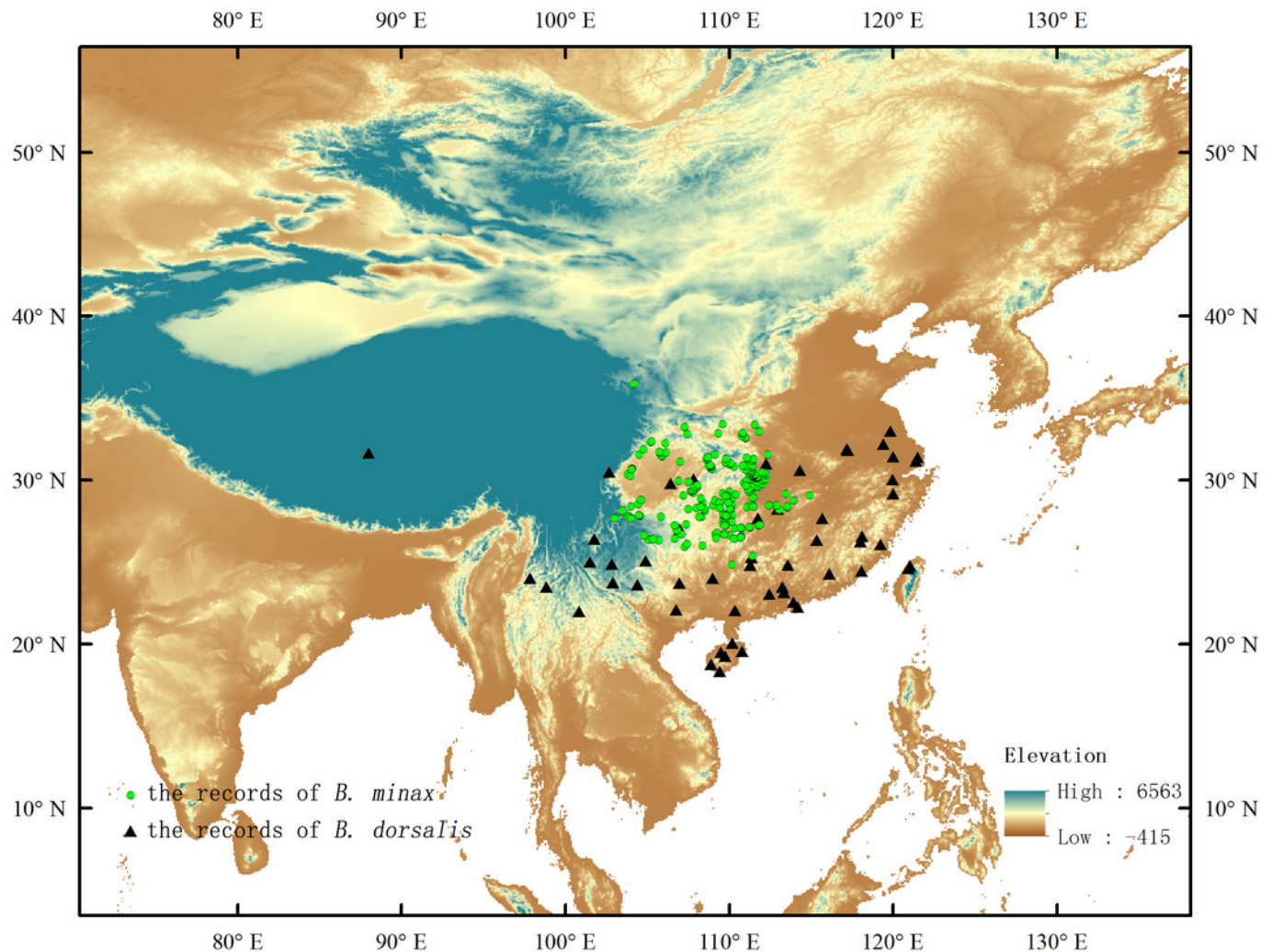



Figure 2

Correlation analysis of environmental factors affecting potential distribution of *B. minax*(A) and *B. dorsalis*(B).

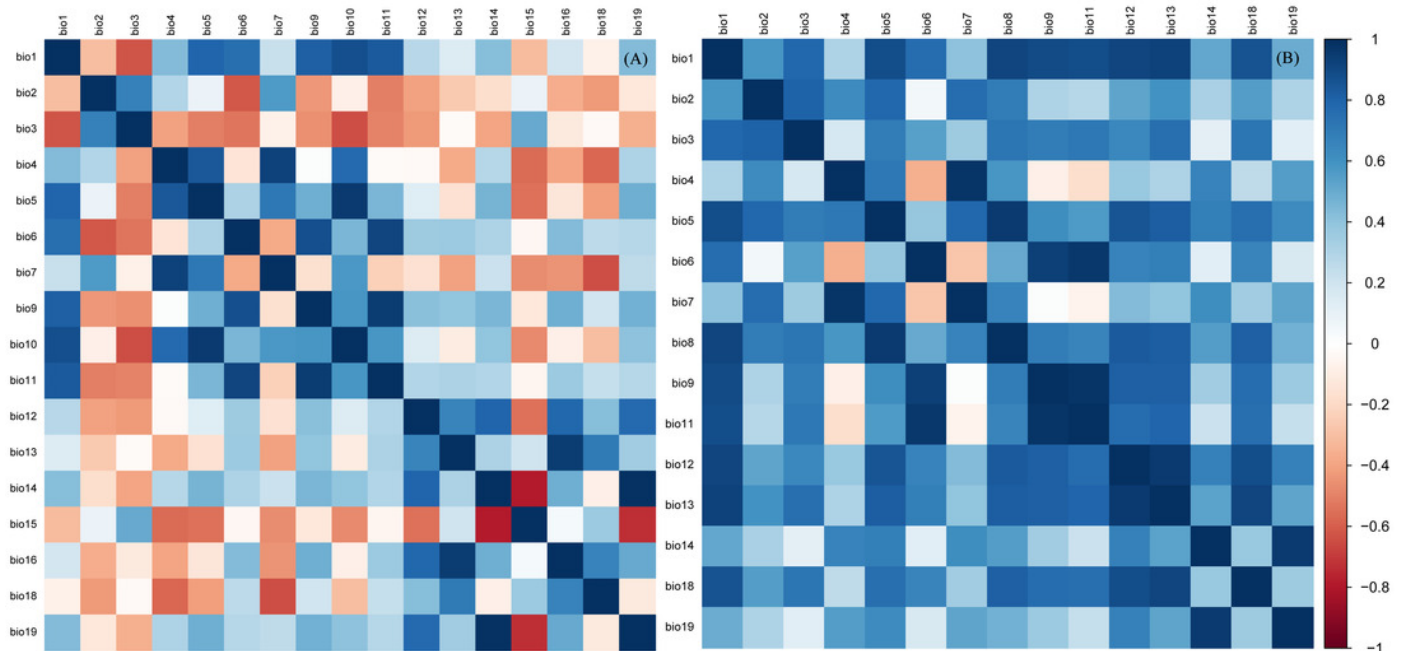



Figure 3

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.

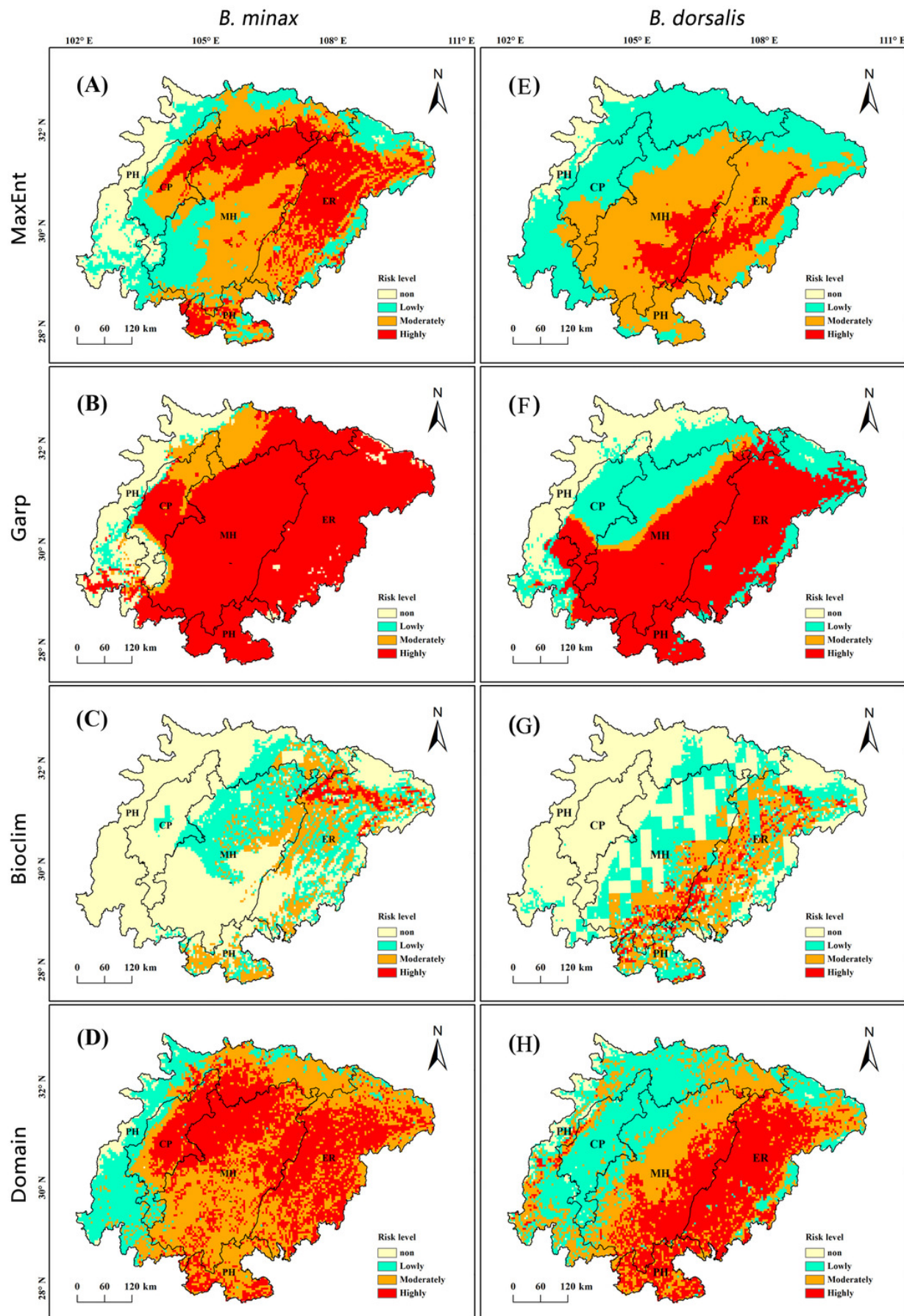



Figure 4

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

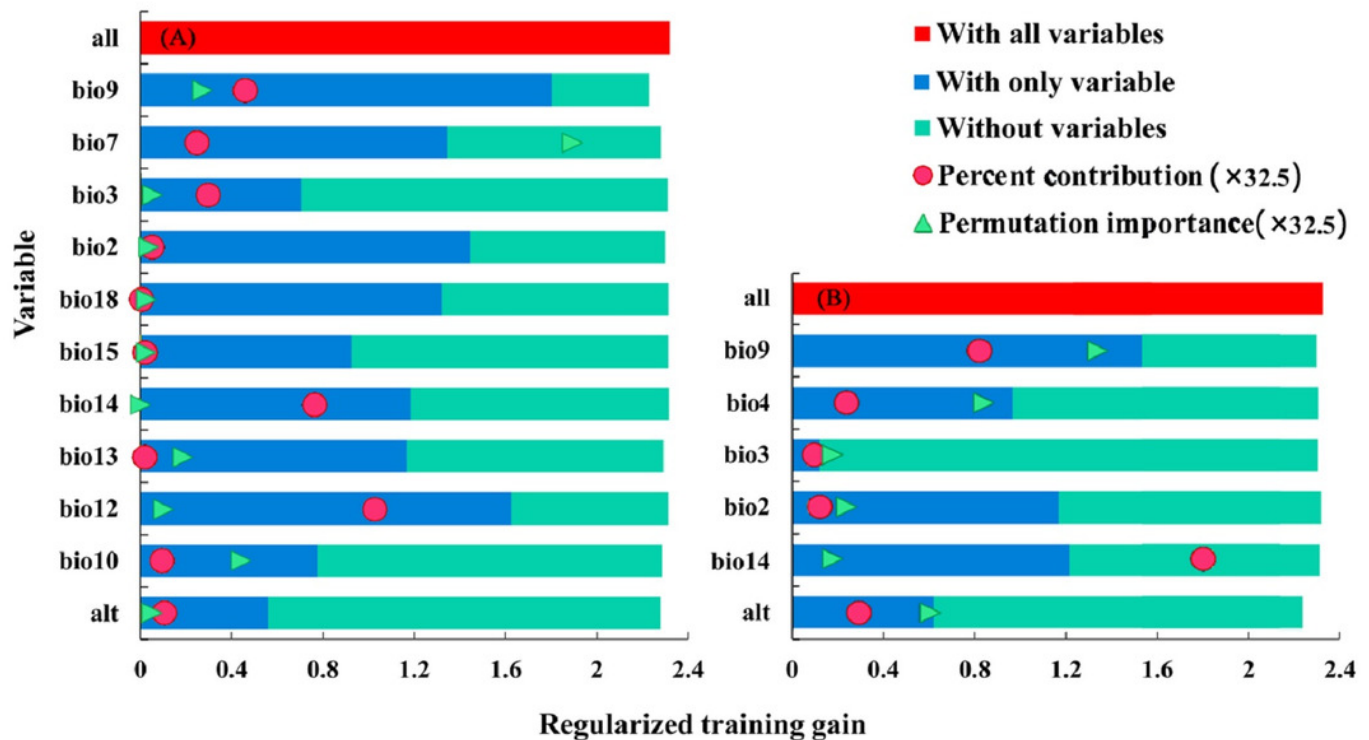
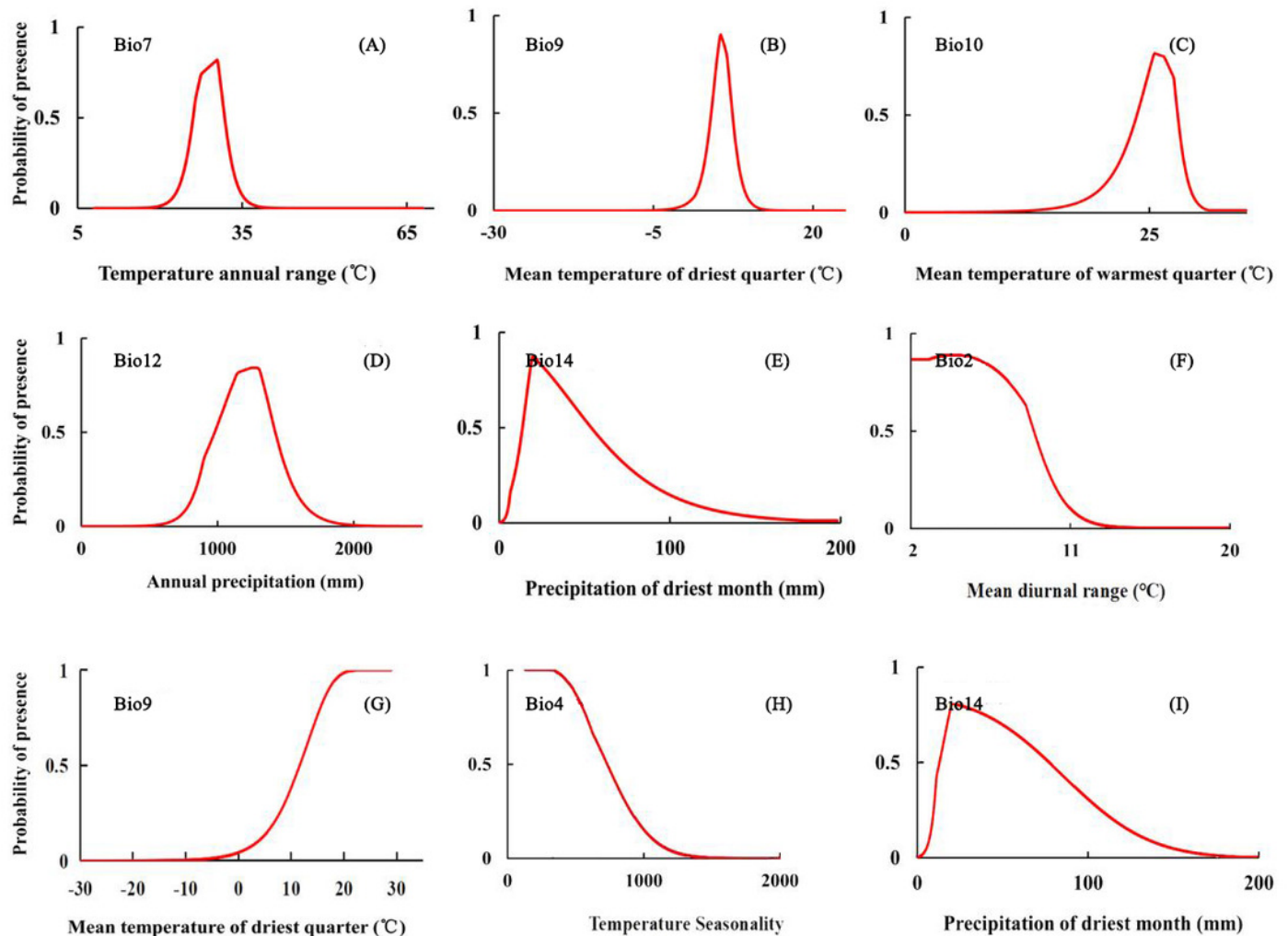



Figure 5

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

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

Environment factors			Species	
Code	Variable	Unit	*B. minax*	*B. 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	√	√

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

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	0.916	0.922	0.831	0.754	0.815	0.801
2	0.981	0.923	0.935	0.944	0.821	0.72	0.754	0.796
3	0.984	0.911	0.947	0.956	0.83	0.76	0.763	0.81
4	0.977	0.907	0.934	0.968	0.856	0.751	0.768	0.821
5	0.989	0.911	0.927	0.978	0.832	0.732	0.746	0.81
6	0.992	0.928	0.917	0.964	0.801	0.744	0.757	0.814
7	0.997	0.906	0.942	0.922	0.792	0.715	0.779	0.783
8	0.981	0.913	0.927	0.937	0.827	0.806	0.782	0.788
9	0.976	0.918	0.937	0.958	0.831	0.769	0.743	0.814
10	0.988	0.922	0.945	0.949	0.828	0.774	0.775	0.792
Average	0.985	0.916	0.933	0.950	0.825	0.753	0.768	0.803