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Maximum Entropy Model Prediction of the Distributions of Two Sympatric Bean Weevil Species, *Megabruchidius dorsalis* (Fahraeus, 1839) and *Bruchidius coreanus* (Chûjô, 1937), under Various Climate Scenarios in Guizhou Province, China

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Abstract: *Megabruchidius dorsalis* and *Bruchidius coreanus* are sympatric bean weevil species that bore into *Gleditsia sinensis* seeds, seriously affecting the commercial development of this plant. Here, we aimed to understand potential changes in the distribution of these two sympatric pests under current and future climate conditions to provide a reference for the prediction of their occurrence and facilitate their prevention and control. Based on empirical field data, we predicted the potential distribution of *M. dorsalis* and *B. coreanus* in suitable habitat areas using the MaxEnt model and explored the relationships among different spatiotemporal distributions using change analysis. Our findings showed that compared with the current situation, the suitable areas for *M. dorsalis* and *B. coreanus* were predicted to increase by 4.8141% and 3.1009%, respectively, in the future. Isothermality (BIO3), min temperature of coldest month (BIO6), and variance in precipitation (BIO15) in the coldest month were determined to be the main factors restricting the current distribution of *M. dorsalis* and *B. coreanus*. Areas currently suitable for the two species are mainly in the central region of Guizhou and are predicted to move eastward in the future. Significant area under the receiver operating characteristics curve values for *M. dorsalis* (0.878) and *B. coreanus* (0.833) indicated that MaxEnt could be used to predict the potential habitats of these weevils, providing valuable information to inform their control in Guizhou Province.

Keywords: *Megabruchidius dorsalis*; *Bruchidius coreanus*; MaxEnt model; environmental variables; potential distribution; suitable areas

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Citation: Ma, G.; Peng, Q.; Pan, X.; Xie, M.; Liao, J.; Wu, C.; Yang, M. Maximum Entropy Model Prediction of the Distributions of Two Sympatric Bean Weevil Species, *Megabruchidius dorsalis* (Fahraeus, 1839) and *Bruchidius coreanus* (Chûjô, 1937), under Various Climate Scenarios in Guizhou Province, China. *Forests* **2024**, *15*, 300. https://doi.org/10.3390/f15020300

Academic Editor: Zoltán Elek

Received: 10 December 2023
Revised: 21 January 2024
Accepted: 26 January 2024
Published: 4 February 2024

1. Introduction

Climate change is a crucial factor affecting species distribution. According to a report from the Intergovernmental Panel on Climate Change, the global surface temperature in 2011–2020 was 1.09 °C higher than that in 1850–1900, with larger increases over land (1.59 °C) than over the ocean (0.88 °C) [1]. The climate of China has also been affected to some extent by global climate change in the past century [2]. The annual average surface temperature in China increased significantly from 1951 to 2020, at a rate of 0.26 °C/decade, while the average rainfall also rose [3,4]. Global climate change, particularly the rise in average temperature, poses a serious threat to the sustainability of global ecosystems, will significantly influence species distribution and biological diversity [5–7], and is expected to be a key factor leading to significant economic losses [8].

Guizhou Province is located in the subtropical low latitude of the Yunnan–Guizhou Plateau, which has a humid monsoon climate. The area is also mountainous, with high-altitude, low-latitude, and typical karst landforms, with distinct changes in microclimate, colloquially referred to as "four seasons in one mountain, different weather within 10 km". In addition, physical and chemical changes in the soil properties due to the karst rocky desertification environment and the deepening impact of humans on ecology may be influencing the biodiversity of microclimate conditions in this area. In particular, in the context of global warming, since the beginning of the 21st century, extreme weather events, such as droughts, floods, and heatwaves have occurred frequently [2]. Climate-driven adaptive changes in spatial species distribution are of great significance for the development of appropriate conservation plans. Therefore, understanding the dynamic changes in species distribution under climate change is crucial [6]. Suitable habitats provide necessary conditions for the survival and reproduction of species and their natural enemies. Predicting distribution dynamics during changes in the microclimates of suitable habitats using the MaxEnt model for species has become increasingly important in many fields, particularly conservation biology [6,9,10], and the prevention and control of pest species can be managed according to their areas of distribution.

Species distribution models (SDMs) are the most powerful and widely used tools for evaluating geographical distributions in space and time and predicting species habitat preferences [11]. Among SDMs, the Bioclimate Analysis and Prediction System (BIOCLIM), the Ecological Niche Factor Analysis (ENFA), the Genetic Algorithm for Rule-Set Production (GARP), and Maximum Entropy Modeling (MaxEnt) have been commonly used in recent years [12]. Compared with other models, the MaxEnt model can generate results with high prediction accuracy based on relatively few species distribution points. Further, MaxEnt was reported to be the most reliable SDM model based on its predictive power, accuracy, and ease of operation [6]. In recent years, the MaxEnt model has been widely used in agroforestry [13,14], fisheries [15,16], animal and plant protection [6,9], and pest prediction and control [8,17,18], among other applications.

Gleditsia sinensis Lam. is a small deciduous tree of the Fabaceae family. A recent survey showed that in Guizhou Province, *G. sinensis* seeds have been seriously damaged by two sympatric bean weevils, *Megabruchidius dorsalis* (Fahraeus, 1839) (Coleoptera, Bruchinae) and *Bruchidius coreanus* (Chûjô, 1937), which are both oligophagous insects [19]. *M. dorsalis* is widely distributed in Japan, India, and China (Table A1), where it is mainly found in Gansu, Qinghai, Xinjiang, Hebei, Guizhou, and Fujian, as well as some other regions of China [20]. *B. coreanus* is mainly distributed in Japan, South Korea, and the Guizhou Province of China, among other regions [21]. These two species primarily feed on the seeds of the *G. sinensis* plant and damage the seeds by boring, thus impairing seed vitality, which is extremely destructive to *G. sinensis* and seriously restricts the commercial development of this plant [22,23]. So, the model mapped the current spatial distribution of the two species, then predicted future spatial distributions under climate change scenarios, and then assessed spatial distribution changes between current and future models, which provided a reference for the planting area of this plant.

To date, research into *M. dorsalis* has primarily focused on its biological characteristics, pesticides, and genetics in China and other countries [24–26], and no report describing MaxEnt modeling of the distribution of these two sympatric pests has been published. In this study, we predicted the potential distribution of *M. dorsalis* and *B. coreanus* in Guizhou Province under multiple microclimate change scenarios. Our findings provide a reference for future research into *M. dorsalis* and *B. coreanus* and their control.

2. Materials and Methods

2.1. Species Occurrence Data Collection and Processing

M. dorsalis and *B. coreanus* distribution-point data were mainly collected via field survey. *G. sinensis* seeds from plants in Guizhou Province, China, were collected and their longitude and latitude instantaneously recorded using a GPS tool (v.2.7.2, China). Seeds were transported to the laboratory in sealed, breathable bags. Samples were collected each week and the species and quantity recorded. Some occurrence datapoints were also obtained from the Global Biodiversity Information Facility (https://www.gbif.org/zh/, accessed on 12 September 2022) or relevant literature related to *M. dorsalis* and *B. coreanus* until 2022. All longitude and latitude coordinate data were input into Excel (2010, USA) and then saved in CSV format, with fields including species name, longitude, and latitude. Totals of 56 and 31 accurate distribution points of *M. dorsalis* and *B. coreanus*, respectively, in Guizhou Province, China, were obtained. Among them, the background points that were generated against the presence records of *M. dorsalis* and *B. coreanus* in Guizhou province, China, were all 1.

The buffer-zone-analysis method was used to check and screen the distribution points of the two sympatric species, and the influence of overfitting, caused by substantial spatial correlation and duplicate distribution points, was excluded. Since the spatial resolution of environmental variables was 2.5 arc min (approximately 4.5 km^2), the buffer radius was set to 1.5 km. When the distance between distribution points was <3 km, only one of them was retained [17]. Finally, 46 and 26 distribution points of *M. dorsalis* and *B. coreanus* were included in the analysis (Figure 1).

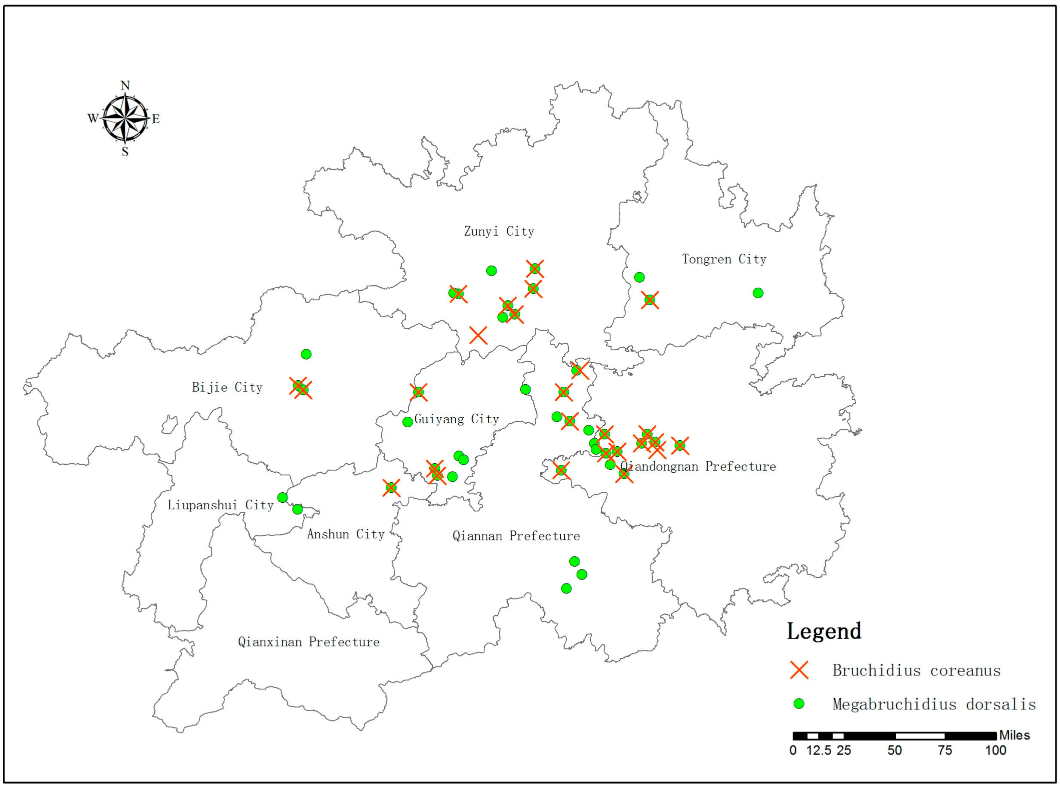

Figure 1. *Megabruchidius dorsalis* and *Bruchidius coreanus* distribution points in Guizhou Province, China.

2.2. Environmental Variable Selection and Processing

A total of 20 environmental factors, classified into three types, were selected for analysis in this study (Table 1). Current and predicted future climate and environmental data were downloaded from the WorldClim website (https://www.worldclim.org/, accessed on 20 September 2022), with a spatial resolution of 2.5 min. The 19 bioclimatic variables (BIO1–BIO19) and the elevation variable (ELEV) from 1970 to 2000 were used as current climate factors (Table 1). Future bioclimatic data were divided into four periods: 2021–2040, 2041–2060, 2061–2080, and 2081–2100, including 245 Shared Socioeconomic Pathways. The Guizhou Province base map was from the National Basic Geographic Information System (https://www.ngcc.cn/ngcc/, accessed on 20 September 2022).

Table 1. Environmental factors analyzed in this study.

Type	Variable Abbreviation	Description	Contribution Rate (%)	
			M. dorsalis	*B. coreanus*
Temperature	Bio1	Annual mean temperature	14.5	12
	Bio2	Mean diurnal range	4.6	0.7
	Bio3	Isothermality	5.2	9.1
	Bio4	Temperature seasonality		
	Bio5	Max temperature of warmest month		
	Bio6	Min temperature of coldest month	35.6	20.1
	Bio7	Temperature annual range	9.6	25.4
	Bio8	Mean temperature of wettest quarter	10.4	
	Bio9	Mean temperature of driest quarter		
	Bio10	Mean temperature of warmest quarter		
	Bio11	Mean temperature of coldest quarter		
Precipitation	Bio12	Annual precipitation	4.2	10.6
	Bio13	Precipitation of wettest month		0.1
	Bio14	Precipitation of driest month		
	Bio15	Precipitation seasonality	8.5	22.1
	Bio16	Precipitation of wettest quarter		
	Bio17	Precipitation of driest quarter	7.4	
	Bio18	Precipitation of warmest quarter		
	Bio19	Precipitation of coldest quarter		
Terrain	ELEV	Elevation variable		

Environmental factor data were first preprocessed. First, the Extract by Mask (Folder) of the Raster Tools (Basic Tools) option in Arcgis (10.8, USA) was used to bulk crop the Guizhou environmental data. Then, the Raster to ASCII (Folder) tool in Raster Tools was used to convert the cropped environmental data into ASCII format for subsequent MaxEnt model analysis. To avoid the effect of cross-correlation of bioclimatic variables, based on *M. dorsalis* and *B. coreanus* sample data, selected environmental factors were input into the MaxEnt model. The output format was "Logistic" (file type, "asc"). Since training data and training sample numbers were between 15 and 79, linear, quantitative, and hinge were used for feature setting. Prediction images were generated by selecting "Create response curves", and the jackknife method was applied to determine variable importance [27]. Seventy-five percent of the data were randomly selected as the training set for model construction, and the remaining twenty-five percent were chosen as the test set for model evaluation. And the model's default regularization multiplier (RM) (β), which was "1", was used. The number of training repeats was set to 10 to reduce the uncertainty caused by abnormal values. Optimal environmental variables with impact factors > 0.8 were selected, and jackknife was used to determine the contribution rate of environmental variables.

Correlation analysis was then performed using SPSS software version 26.0 to eliminate highly correlated variables. If two or more environmental factor correlation coefficients ($|r|$) were $\geq$0.8, variables with more clear ecological significance were retained. Finally, nine and eight environmental factors were screened for *M. dorsalis* and *B. coreanus*, respectively (Table 1); filtered environmental factors were included in MaxEnt model analysis, with all parameters set as described above.

2.3. MaxEnt Model Construction

Receiver operating characteristic (ROC) curves were used to evaluate the contribution rate of each environmental factor, and the influence of each environmental variable on *M. dorsalis* and *B. coreanus* distribution was evaluated with non-parametric estimation using the jackknife method. The area under the ROC curve (AUC) value was used to evaluate the model's prediction accuracy [28]. AUC values ranged from 0.5 to 1, and model accuracy was classified into five grades, as follows: fail (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good

(0.8–0.9), and excellent (0.9–1.0). The closer the AUC value was to 1, the farther away it was from a random distribution, the greater the correlation was between environmental variables and the predicted geographical distribution of species, and the more accurate the model performance was [29]. To determine the main environmental factors affecting the geographical distribution of *M. dorsalis* and *B. coreanus*, the relative contribution of each environmental factor to the model was evaluated according to the contribution percentage of environmental factors output by the MaxEnt model.

2.4. Classification of Suitable Areas

Habitat suitability was optimized according to Jenks' natural breaks classification and empirical data on *M. dorsalis* and *B. coreanus* distributions. The current and future of *M. dorsalis* habitat suitability were also divided into four categories, as follows [8]: unsuitable growth areas ($p < 0.12$), poorly suitable growth areas ($0.12 \leq p < 0.30$), moderately suitable growth areas ($0.30 \leq p < 0.50$), and highly suitable growth areas ($0.50 \leq p < 0.87$). Similarly, current and future *B. coreanus* habitat suitability was also classified as follows: unsuitable growth area ($p < 0.12$), poorly suitable growth area ($0.12 \leq p < 0.30$), moderately suitable growth areas ($0.30 \leq p < 0.50$), and highly suitable growth areas ($0.50 \leq p < 0.85$). Geographic distribution maps of *M. dorsalis* and *B. coreanus* under current and predicted future climate conditions were drawn according to current and predicted future climate change scenarios, and the differences between distributions under current and future climate conditions compared.

3. Results

3.1. Model Accuracy Evaluation

After tenfold cross-validation, the mean AUC values for *M. dorsalis* and *B. coreanus* were 0.833 and 0.878 (the standard deviations were 0.086 and 0.073), respectively, demonstrating that the MaxEnt models had good accuracy and could be used to accurately simulate the potential geographical distributions of *M. dorsalis* and *B. coreanus* (Figure A1).

3.2. Analysis of the Contributions of Environmental Variables

The jackknife method was used to evaluate the impact of various environmental factors on the prediction of *M. dorsalis* and *B. coreanus* distributions (Figure 2). Our experimental results showed that among the analyzed environmental factors, isothermality (BIO3) was the bioclimatic variable with the largest effect on the potential distribution of *M. dorsalis* and *B. coreanus*, indicating that this variable carries the most valuable modeling information. The minimum temperature of the coldest month (BIO6) and variance of precipitation change (BIO15) also had important impacts on the models.

From the predicted response curves of the major climate variables (Figure 3), the optimal values of the major climate variables were Bio3 = 28 °C, Bio6 = 1 °C, and Bio15 = 64 mm, respectively; the distributions of the niches of the two species were predicted using the maximum entropy model; the probabilities of the distributions were highest when the isothermality was 28 °C, min temperature of coldest month was 1 °C, and precipitation seasonality was 64 mm.

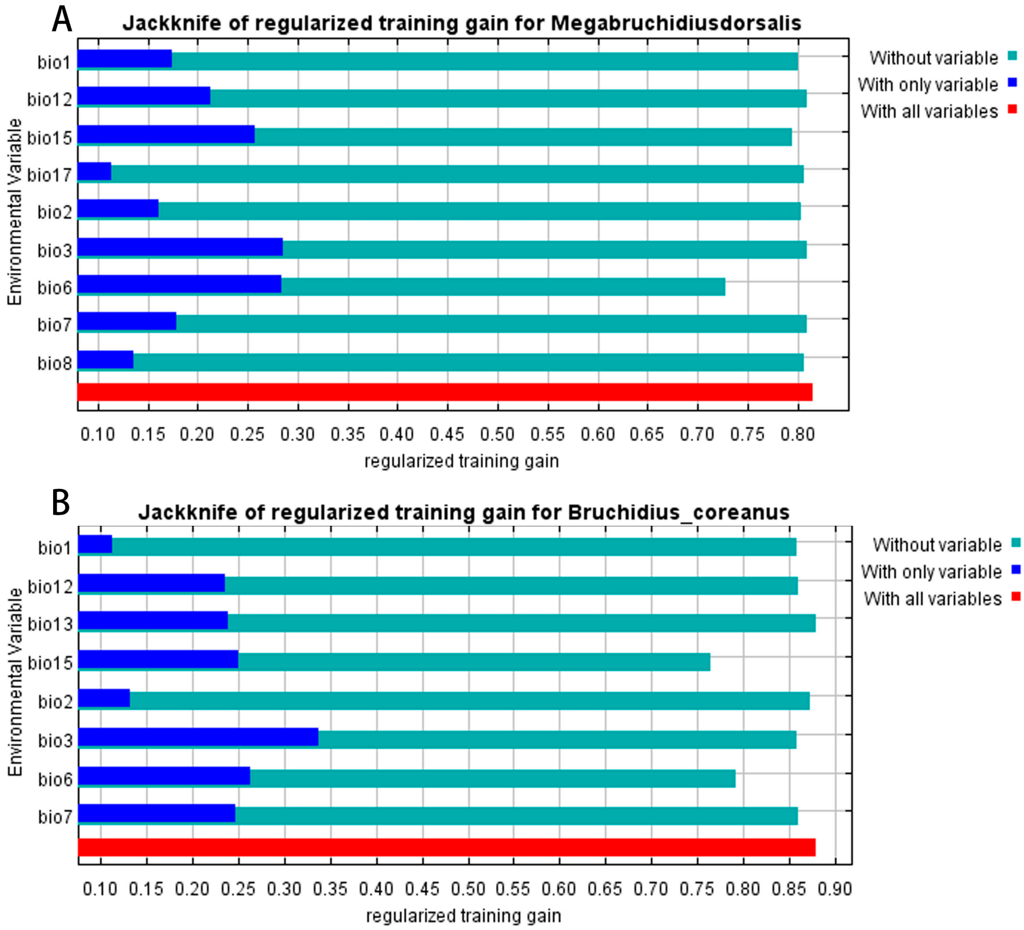

Figure 2. Jackknife test evaluation of the relative importance of major bioclimatic variables on distributions of the species *Megabruchidius dorsalis* (**A**) and *Bruchidius coreanus* (**B**).

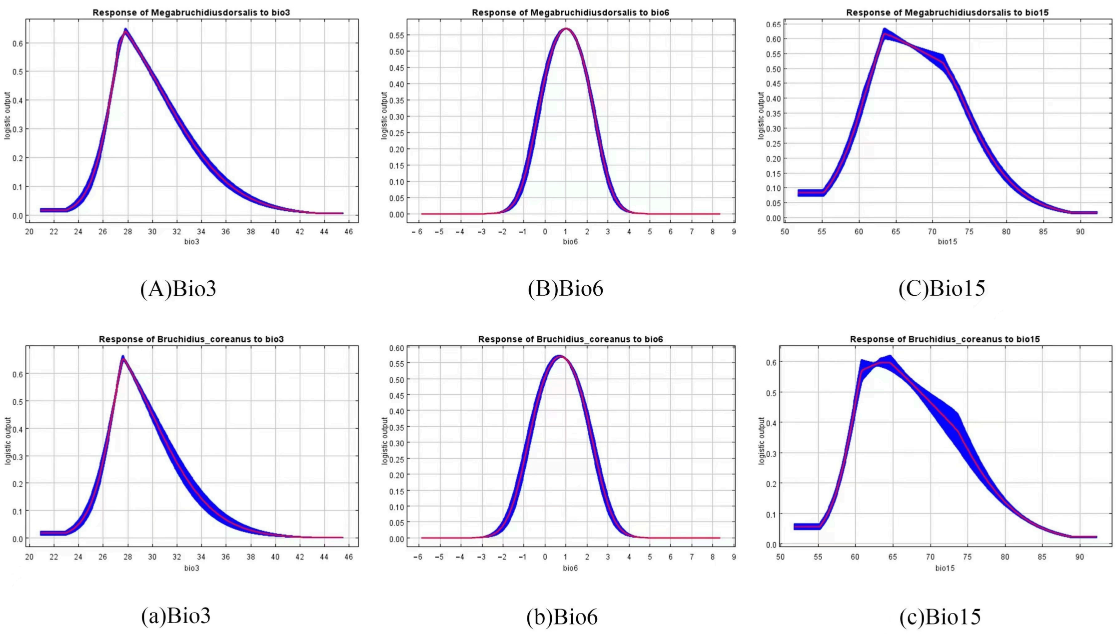

Figure 3. Response curves of main bioclimatic variables in predictions of suitable areas for *Megabruchidius dorsalis* (**A**–**C**) and *Bruchidius coreanus* (**a**–**c**).

3.3. Current and Potential Future Distributions of *M. dorsalis* and *B. coreanus* in Guizhou

3.3.1. Predicted Current Distributions

The MaxEnt model was used to predict the current distributions of *M. dorsalis* and *B. coreanus* (Figure 4, Table 2). The distribution trends of suitable areas for the two species were the same, with all concentrated in Guiyang City, Zunyi City, Qiannan Prefecture, and Qiandongnan Prefecture. Qianxinan Prefecture was identified as an unsuitable area for these two species. Highly suitable areas for *M. dorsalis* comprised approximately 2.4927×10^4 km^2, with moderately suitable areas comprising 3.4897×10^4 km^2. Areas highly suitable for *B. coreanus* comprised around 2.3208×10^4 km^2, with moderately suitable areas of 3.0848×10^4 km^2.

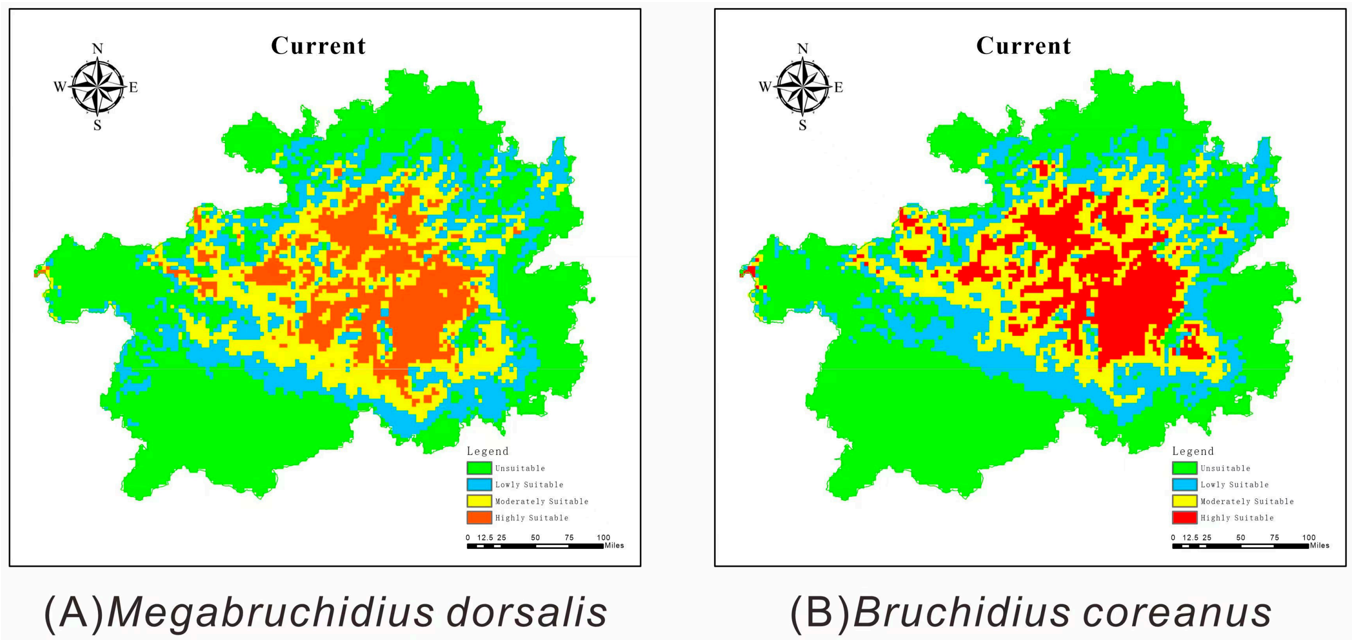

Figure 4. Potential distributions of *Megabruchidius dorsalis* (**A**) and *Bruchidius coreanus* (**B**) under current climatic conditions.

Table 2. Predicted potential distributions of *Megabruchidius dorsalis* and *Bruchidius coreanus* under different climate scenarios.

Species	Climate Scenario	Unsuitable Area		Poorly Suitable Area		Moderately Suitable Area		Highly Suitable Area	
		Area ($\times 10^4$ km^2)	Trend (%)	Area ($\times 10^4$ km^2)	Trend (%)	Area ($\times 10^4$ km^2)	Trend (%)	Area ($\times 10^4$ km^2)	Trend (%)
Megabruchidius dorsalis	Current	8.0606	45.7552	3.5738	20.2862	3.4897	19.8092	2.4927	14.1494
	2021–2040	7.5041	42.5964	4.3884	24.9104	3.2918	18.6855	2.4325	13.8077
	2041–2060	7.5555	42.8881	4.3253	24.5525	3.2798	18.6178	2.4561	13.9416
	2061–2080	7.3906	41.9523	4.1424	23.5141	3.4947	19.8373	2.5890	14.6963
	2081–2100	7.2125	40.9411	4.4581	25.3063	3.1765	18.0310	2.7696	15.7216
Bruchidius coreanus	Current	8.5362	48.4549	3.6750	20.8609	3.0848	17.5106	2.3208	13.1736
	2021–2040	8.3806	47.5720	4.1281	23.4329	2.6851	15.2417	2.4229	13.7534
	2041–2060	8.3162	47.2062	4.2164	23.9340	2.8517	16.1875	2.2324	12.6722
	2061–2080	8.2313	46.7245	4.2093	23.8937	2.7839	15.8026	2.3922	13.5792
	2081–2100	7.9899	45.3540	4.2805	24.2980	3.0007	17.0335	2.3456	13.3145

Under current climate conditions, the area classified as highly suitable *M. dorsalis* habitat accounted for 14.1494% of Guizhou Province, mainly in the southern part of Zunyi City, the northeast of Qiannan Prefecture, the area throughout Guiyang City, the northwest of Qiandongnan Prefecture, the eastern and central regions of Bijie City, Pingba District in the northeast part of Anshun City, and various areas in the southwest of Tongren City.

Areas of moderately suitability made up 19.8092% of Guizhou Province, mainly distributed in Qingzhen City of Guiyang City, Fenggang County of Zunyi City, Qianxi County of Bijie City, Pingtang County of Qiannan Prefecture, Rongjiang County of Qiandongnan Prefecture, Pingba District of Anshun City, Shiqian County of Tongren City, and Liuzhi Special Zone of Liupanshui City. Poorly suitable and unsuitable areas were 20.2862% and 45.7552% of Guizhou, respectively, distributed in the peripheral areas of the province; Qianxinan Prefecture was an unsuitable area.

Highly suitable habitats for *B. coreanus* accounted for 13.1736% of the Guizhou Province area and were in similar areas to those for *M. dorsalis*, except that the areas highly suitable for *B. coreanus* did not include Anshun City. Areas with moderately suitable conditions accounted for 17.5106% of Guizhou Province, mainly distributed in areas also designated as moderately suitable for *M. dorsalis*. Poorly suitable and unsuitable areas accounted for 20.8609% and 48.4549%, respectively, and were also distributed in the peripheral areas of Guizhou, with Qianxinan Prefecture as an unsuitable area.

3.3.2. Potential Future Distribution of *M. dorsalis* and *B. coreanus*

In the future climate scenarios, areas highly suitable for *M. dorsalis* were predicted to first decrease (2021–2040) and then increase (2061–2100). Compared with the current climate, areas highly suitable for *M. dorsalis* were predicted to increase by 1.5722% by 2081. During the 2100s, the area highly suitable for *M. dorsalis* was predicted to expand overall, spreading from the Bijie area in the west of Guizhou Province to the central area. By 2100, the Weining and Hezhang counties of Bijie City were predicted to have no areas highly suitable for *M. dorsalis*, while highly suitable areas in Tongren City could gradually decrease close to its southwest borders with Zunyi City and Qiandongnan Prefecture. Areas highly suitable for *B. coreanus* were predicted to alternately increase and decrease, increasing during 2021–2040 and 2061–2080 and decreasing during 2041–2060 and 2081–2100. Compared with the current climate, areas highly suitable for *B. coreanus* were predicted to have decreased by 0.1410% in 2081. Unlike *M. dorsalis*, Anshun City was not predicted to be a highly suitable habitat for *B. coreanus*, and the total area of the suitable *B. coreanus* habitat was predicted to decrease overall until the year 2100; however, similar to *M. dorsalis*, *B. coreanus* was predicted to spread from the Bijie area in the west of Guizhou Province to the central area and be concentrated in the central area of Guizhou Province.

Habitats moderately suitable for *M. dorsalis* and *B. coreanus* were predicted to reduce by 1.7782% and 0.4771%, respectively, relative to the current climate. Areas with poor suitability for *M. dorsalis* were predicted to first increase (2021–2060), then decrease (2061–2080), and finally increase again (2081–2100), with a total increase of 5.0201%. Areas of poor suitability for *B. coreanus* were predicted to first increase (2021–2040), then remain stable (2041–2080), and finally increase (2081–2100), with a total increase of 3.4371%.

Areas of unsuitable habitat for *M. dorsalis* and *B. coreanus* were predicted to decrease, by 4.8141% and 3.1009%, respectively, from 2021 to 2100. The whole area of Qianxinan Prefecture was predicted to be an unsuitable habitat for both *M. dorsalis* and *B. coreanus*, indicating that this area cannot support their survival (Figure 5).

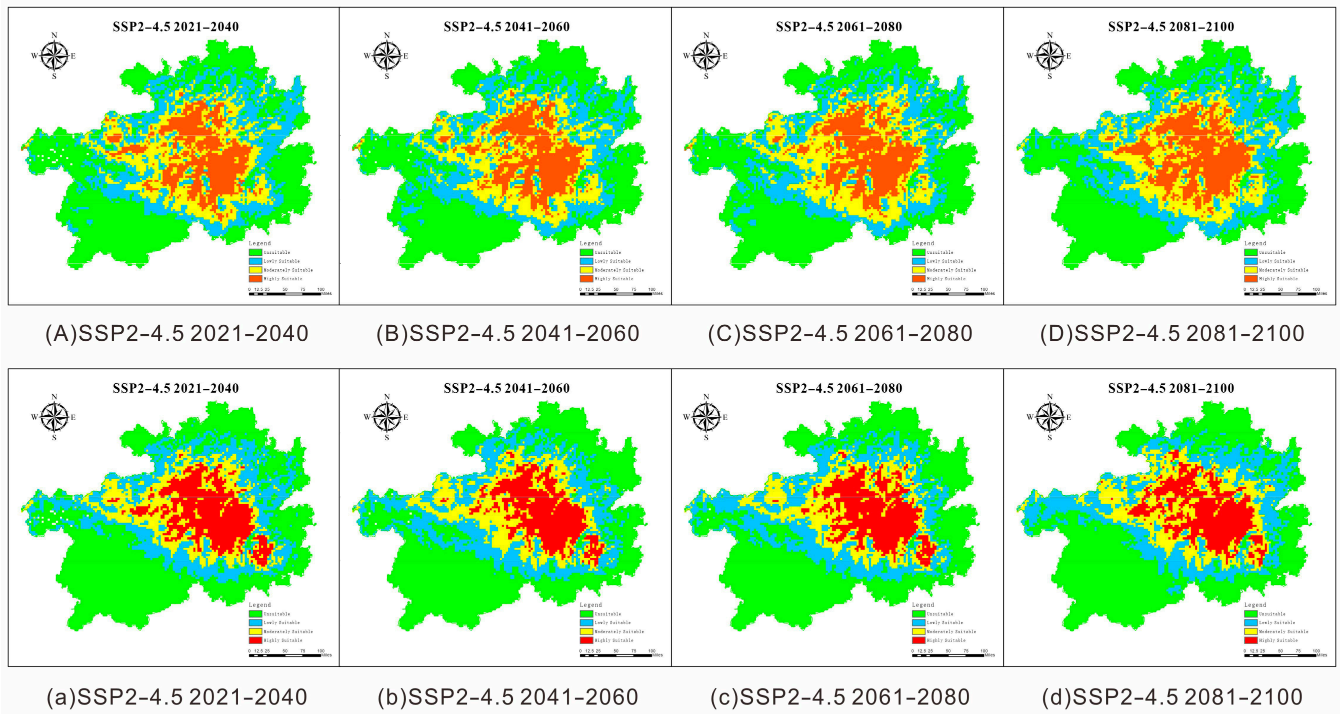

Figure 5. Potential distributions of (**A**–**D**) *Megabruchidius dorsalis* and (**a**–**d**) *Bruchidius coreanus* under future climate conditions.

4. Discussion

We used the jackknife method to predict the habitat suitability for *M. dorsalis* and *B. coreanus*. The average AUC value showed that the MaxEnt model had good accuracy and could be used to predict *M. dorsalis* and *B. coreanus*. And the results showed that temperature and precipitation were the main environmental factors influencing the distributions of both species. These findings are consistent with the results of Yang et al. [18], who reported that isothermality (BIO3), annual average temperature (BIO1), and the coldest month (BIO6) had important effects on the distribution of *Acanthoscelides macrophthalmus* (Schaeffer, 1999). Wang et al. [17] found that altitude, mean rainfall, and temperature were the main environmental variables affecting the potential distribution of *Locusta migratoria tibetensis* (Chen, 1963). Species–environment relationships are an important aspect of studying the ecological needs and spatial distributions of species. This study analyzed the relationship between the probability of existence of *M. dorsalis* and *B. coreanus* and the dominant environmental variables and obtained relevant feedback curves. The results showed that the probability of existence of the two species varied with the dominant environmental variables (BIO3, BIO6, and BIO15). And when the isothermality is 28 °C, min temperature of coldest month is 1 °C, and precipitation seasonality is 64 mm, they can exist. This is consistent with previous studies on indoor breeding conditions [24]. Temperature and humidity may affect the growth and reproduction of insects (such as oviposition, developmental stage, pupal stage, etc.), but high temperatures in summer are not the limiting factor, and low temperatures in winter can affect the safety of overwintering [17]. However, it should be noted that the life activities of insects are affected not only by single environmental conditions, but also by a variety of environmental variables (including human activities, climate factors, soil, vegetation conditions, etc.); therefore, these results can be used as a reference to judge the relationship between *M. dorsalis* and *B. coreanus* and environmental variables.

ROC curve analysis conducted by Wang et al. [17] on five models (GARP, BIOCLIM, Climex, MaxEnt, and Domain) indicated that MaxEnt models generated the highest AUC values, suggesting that its results are superior. However, environment variables are selected according to different requirements (such as species, climate, region, etc.), which may lead to problems such as autocorrelation and multicollinearity among these variables, thus negatively affecting the simulation results [6,29]. So, the results of the present study are the maximum possible distribution range under ideal conditions, which does not mean that the suitable area is completely consistent with the actual distribution area. Previous studies have shown that the success rate of model predictions may increase with increasing the sample size [18]. However, due to the limitations of data and the investigation environment, the distribution of species is affected not only by climate factors, but also by topography, soil, socioeconomic development, and human intervention. Therefore, as much data as possible on the distribution of species should be collected in order to reduce inaccurate predictions caused by incomplete data. Although there are many assumptions and uncertainties in the distribution model of *M. dorsalis* and *B. coreanus*, the model is still a key data source for future suitability prediction. Generally, researchers have focused on predicting the distribution of a single species, while in this study we predicted the distribution patterns of two insects, both of which have been the subject of relatively little research to date. In summary, this study provides valuable reference information and could guide future research on the occurrence of *M. dorsalis* and *B. coreanus*, as well as providing a method to generate early warnings of the occurrence of these pests and data that can inform their prevention.

Our results showed that areas highly suitable for the growth of *M. dorsalis* and *B. coreanus* corresponded strongly with points of their recorded occurrence in Suiyang County, Huichuan District and Honghuagang District of Zunyi City, Weng'an County and Fuquan City of Qiannan Prefecture, Huaxi District and Kaiyang County of Guiyang City, Majiang County and Kaili City of Qiandongnan Prefecture, Qianxi County of Bijie City, and Shiqian County of Tongren City. In general, suitable habitat areas for these two invasive species were predicted to decrease somewhat in the future; however, over the years until 2100, the areas suitable for *M. dorsalis* and *B. coreanus* are predicted to spread from the Bijie area in the west of Guizhou Province to the central area. There was no area highly suitable for *M. dorsalis* and *B. coreanus* distribution in Qianxinan Prefecture. Unlike *M. dorsalis*, there were no highly suitable areas for *B. coreanus* in Anshun City, which may be related to local climate characteristics. The true distribution of insects is also related to their hosts, the characteristics of the insects themselves, the surrounding microclimate, and occasional extreme climate events, so results predicting suitable habitats may not be completely accurate [18]. Therefore, there should be a focus on empirical investigations, particularly into the landforms of the province, which can be summarized into four basic types: plateau, mountain, hill, and basin, with plateau and mountainous areas comprising the majority, leading to the diverse range of temperatures experienced in Guizhou province.

5. Conclusions

This research will expand the understanding of the potential distribution areas of *M. dorsalis* and *B. coreanus* in Guizhou Province. There should be a focus on the defense of highly suitable habitat areas (8.0606×10^4 km^2 for *M. dorsalis* and 8.5362×10^4 km^2 for *B. coreanus*), and particularly on moderately suitable areas, to protect tree resources by using appropriate quarantine measures and comprehensive management to prevent *M. dorsalis* and *B. coreanus* occurrence and consequent serious damage. Therefore, in the future, we intend to collect additional geographical location information and predict the suitable habitats of *G. sinensis*, as well as collecting more environmental data, such as soil, slope, aspect, etc., to better predict the distribution range of these two harmful species in Guizhou Province.

Author Contributions: Conceptualization, G.M. and Q.P.; methodology, C.W.; software, G.M. and Q.P.; validation, X.P. and M.X.; formal analysis, G.M.; investigation, J.L., M.Y. and C.W.; resources, C.W. and J.L.; data curation, C.W.; writing—original draft preparation, G.M. and Q.P.; writing—review and editing, C.W., G.M. and M.Y.; visualization, G.M.; supervision, G.M.; project administration, C.W.; funding acquisition, C.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Guizhou Provincial Science and Technology Projects (Qian Ke He Ji Chu-ZK [2022] General 120); the Forestry Science and Technology Research Project of Guizhou Province, grant/award number [2021] (06); and the Characteristic Forestry Industry Scientific Research Project of Guizhou Province, grant/award number: GZMC-ZD20202098. Scientific and Technological Innovation Talent Team Construction Project of Expanding and Application of Natural Enemies of Important Crop Pests in Guizhou Province: Qian Ke He Platform Talent-CXTD:[2021] 004, under the construction project of the natural enemy expansion breeding room in Guizhou province: Guizhou Development and Reform Investment [2021] 318.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

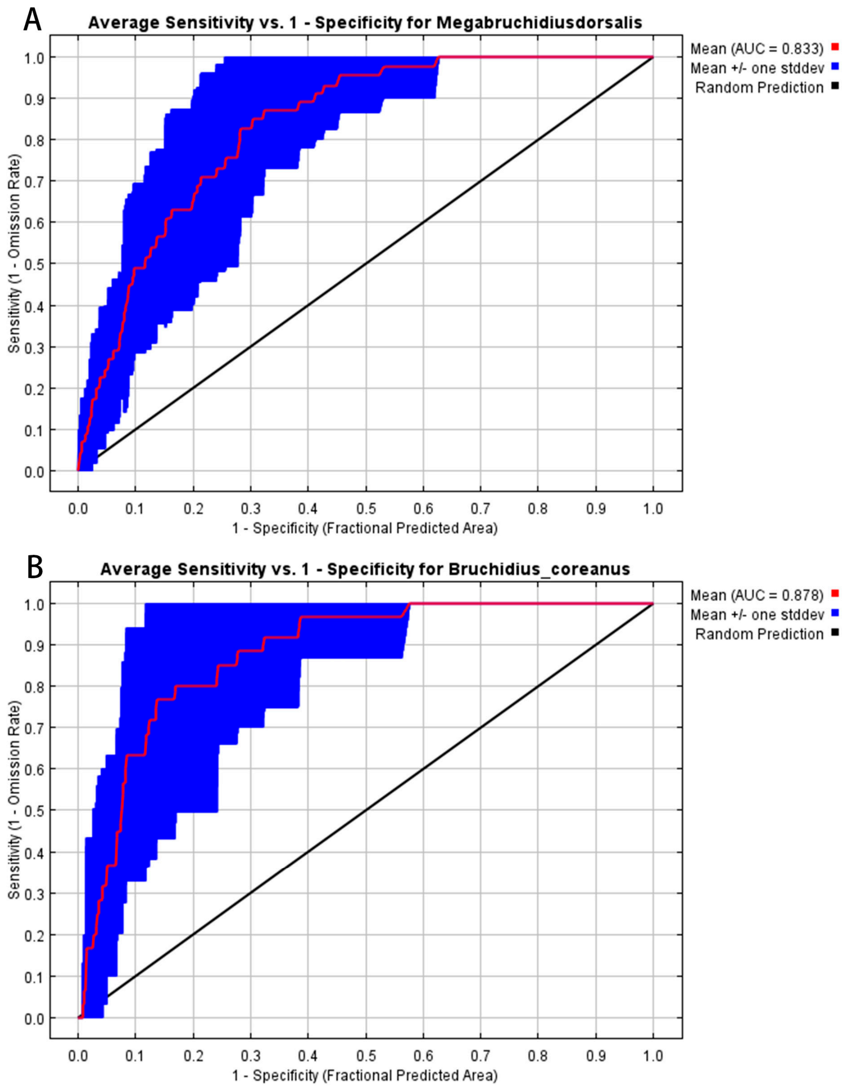

Figure A1. Receiver operating characteristic curves with area under the curve (AUC) values for (**A**) *Megabruchidius dorsalis* and (**B**) *Bruchidius coreanus*.

Table A1. The domestic and international distribution of *Megabruchidius dorsalis* and *Bruchidius coreanus*.

Species	Location	Reference	Location (China)	Reference
Megabruchidius dorsalis	Japan	Li et al. (2014) [24]	Taiwan, China	György and Tuda (2020) [30]
Megabruchidius dorsalis	Europe	György and Tuda (2020) [30]	Fujian, China	Říha and Bezděk (2015) [31]
Megabruchidius dorsalis	China	Li et al. (2014) [24]	Hongkong, China	Říha and Bezděk (2015) [31]
Megabruchidius dorsalis	Mongolia	Říha and Bezděk (2015) [31]	Xinjiang, China	Li et al. (2014) [24]
Megabruchidius dorsalis	Turkmenistan	Říha and Bezděk (2015) [31]	Dongling, Shenyang, Liaoning provinces, China	Wang (1984) [32]
Megabruchidius dorsalis	Hungary	Ramos (2009) [23]; György and Tuda (2020) [30]	Beiling, Shenyang, China	Wang (1984) [32]
Megabruchidius dorsalis	Switzerland	Ramos (2009) [23]	Yiwulushan Nature Reserve, Beizhen County, Liaoning Province, China	Wang (1984) [32]
Megabruchidius dorsalis	Papua New Guinea	Li et al. (2014) [24]	Xiong Yue Botanical Garden, Gai County, Liaoning Province, China	Wang (1984) [32]
Megabruchidius dorsalis	Italy	Li et al. (2014) [24]	Zhengzhou, Henan Province, China	Yang and Zhou (1974) [33]
Megabruchidius dorsalis	Greece	Yus Ramos et al. (2014) [34]	Luoyang, Henan Province, China	Yang and Zhou (1974) [33]
Megabruchidius dorsalis	Argentina	György and Tuda (2020) [30]	Kaifeng, Henan Province, China	Yang and Zhou (1974) [33]
Megabruchidius dorsalis	France	György and Tuda (2020) [30]	Anyang, Henan Province, China	Yang and Zhou (1974) [33]
Megabruchidius dorsalis	Russia	György and Tuda (2020) [30]	Hebei Province, China	Li et al. (2014) [24]
Megabruchidius dorsalis	Ukraine	György and Tuda (2020) [30]	Qinghai Province, China	Li et al. (2014) [24]
Megabruchidius dorsalis	Slovakia	Říha and Bezděk (2015) [31]	Gansu Province, China	Li et al. (2014) [24]
Megabruchidius dorsalis	Crimea	Korotyaev (2016) [35]	Fencheng town, Xiangfen County, Shanxi Province, China	Xin (2016) [36]
Megabruchidius dorsalis	Germany	Korotyaev (2016) [35]	South Campus of Guizhou University, Huaxi District, Guiyang City, Guizhou Province, China	Li et al. (2014) [24]
Megabruchidius dorsalis	Croatia	György and Tuda (2020) [30]	Suiyang County, Zunyi, China	This study
Megabruchidius dorsalis	Romania	György and Tuda (2020) [30]	Huichuan District, Zunyi, China	This study
Megabruchidius dorsalis	Austria	Sajna (2019) [37]	Bozhou District, Zunyi,China	This study
Megabruchidius dorsalis	Kazakhstan	Temreshev and Makezhanov (2019) [38]	Honghuagang District, Zunyi, China	This study
Megabruchidius dorsalis	South Kazakhstan	Temreshev and Makezhanov (2019) [38]	Sinan County, Tongren, China	This study
Megabruchidius dorsalis	Turkey	Temreshev and Makezhanov (2019) [38]	Jiangkou County, Tongren City, Guizhou Province, China	This study
Megabruchidius dorsalis	S. Korea	Cho and An (2020) [39]	Weng 'an County, Qiannan Prefecture, Guizhou Province, China	This study
Megabruchidius dorsalis	Republic of Moldova	Pintilioaie et al. (2018) [40]	Fuquan City, Qiannan Prefecture, Guizhou Province, China	This study
Megabruchidius dorsalis	S.W. Poland	Ruta et al. (2017) [41]	Dushan County, Qiannan Prefecture, Guizhou Province, China	This study
Megabruchidius dorsalis	Slovenia	Sajna (2019) [37]	Majiang County, Qiandongnan Prefecture, Guizhou Province, China	This study
Megabruchidius dorsalis	Caucasus	Korotyaev (2016) [35]	Kaili City, Qiandongnan State, Guizhou Province, China	This study
Megabruchidius dorsalis	Indian	Li et al. (2014) [24]	Liupanshui special administrative region of Guizhou Province, China	This study
Megabruchidius dorsalis	Bangladesh	György and Tuda (2020) [30]	Qingzhen County, Guiyang City, Guizhou Province, China	This study

Table A1. *Cont.*

Species	Location	Reference	Location (China)	Reference
Megabruchidius dorsalis	Bulgaria	Li et al. (2014) [24]	Nanming District, Guiyang, China	This study
Megabruchidius dorsalis	Turkmenistan	Li et al. (2014) [24]	Dafang County, Bijie City, Guizhou Province, China	This study
Megabruchidius dorsalis	Indonesia	Li et al. (2014) [24]	Pingba District, Anshun, Guizhou Province, China	This study
Bruchidius coreanus	Kyoto, Japan	Morimoto (1990) [42]	Suiyang County, Zunyi, China	This study
Bruchidius coreanus	Kumamoto, Japan	Morimoto (1990) [42]	Huichuan District, Zunyi, China	This study
Bruchidius coreanus	Guizhou province, China	Peng et al. (2024) [21]	Bozhou District, Zunyi, China	This study
Bruchidius coreanus	Korea	Peng et al. (2024) [21]; Cho and An (2020) [39]	Honghuagang District, Zunyi, China	This study
Bruchidius coreanus			Sinan County, Tongren, China	This study
Bruchidius coreanus			Weng'an County, Qiannan Prefecture, Guizhou Province, China	This study
Bruchidius coreanus			Fuquan City, Qiannan Prefecture, Guizhou Province, China	This study
Bruchidius coreanus			Majiang County, Qiandongnan Prefecture, Guizhou Province, China	This study
Bruchidius coreanus			Kaili City, Qiandongnan State, Guizhou Province, China	This study
Bruchidius coreanus			Dafang County, Bijie City, Guizhou Province, China	This study
Bruchidius coreanus			Pingba District, Anshun, Guizhou Province, China	This study
Bruchidius coreanus			Huaxi District, Guiyang City, Guizhou Province, China	This study

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