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Forecast of Current and Future Distributions of *Corythucha marmorata* (Uhler) under Climate Change in China

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Abstract: *Corythucha marmorata* (Uhler) emerged as an invasive pest in China around 2010, posing a significant threat to plants within the Asteraceae family. Employing the MaxEnt model, this study endeavors to anticipate the potential geographic distribution of *Corythucha marmorata* amid present and forthcoming climatic conditions, utilizing a dataset of 60 distributional occurrences alongside environmental parameters. The results revealed that presently, suitable regions span from 18–47° N to 103–128° E, with pronounced suitability concentrated notably in Jiangsu, Shanghai, Anhui, Hubei, Jiangxi, Hunan, Guangdong, Guangxi, Chongqing, and Sichuan. Projections suggested a general expansion of suitable habitats, albeit with exceptions noted in SSP1–2.6 and SSP2–4.5 scenarios in the 2050s and SSP5–8.5 in the 2070s. The potential suitability of areas for *Corythucha marmorata* was influenced by major factors such as precipitation in the warmest quarter (bio18), mean temperature in the warmest quarter (bio10), mean temperature in the wettest quarter (bio8), and annual precipitation (bio12). Notably, temperature and precipitation emerge as primary determinants affecting both current and future ranges. In comparison with the current distributional area, there was a trend towards increasing the potentially suitable areas in the future. Moreover, there was a greater risk of spreading to the north of China in the future. This study serves as a pivotal resource for guiding future endeavors in monitoring, early detection, and preventative management strategies targeting *Corythucha marmorata*.

Keywords: MaxEnt model; climate change; environmental variables; potential suitable area; biological invasions

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1. Introduction

Biological invasion, defined as the introduction of non-native species into new environments through human activities or other mechanisms, represents a critical challenge, endangering indigenous species and ecosystems [1]. Invasive alien species present a formidable menace to global biodiversity, human well-being, and economic progress [2], thereby prompting concerted research efforts on alien invasions worldwide.

Climate change exerts profound impacts on species and their habitats, consequently disrupting ecosystem structure and function and amplifying the risks associated with invasive species, pest outbreaks, and habitat loss [3]. Moreover, climate change significantly influences insect diversity, distribution, and incidence rates, as well as various physiological aspects such as reproduction, growth, and development [4], thereby potentially reshaping community dynamics and composition [5]. The proliferation of invasive insects, particularly under the influence of climate change, has garnered international attention, with numerous studies employing modeling techniques to assess the geographic range shifts of invasive species in response to changing climatic conditions [6–12]. Notably, temperature increases have been linked to higher populations of *Corythucha marmorata* (Uhler) (Hemiptera: Tingidae) and *Solidago canadensis* Linnaeus (Asteraceae) [13].

Corythucha marmorata, depicted in Figure 1, represents a formidable invasive pest—a spiny-sucking insect—primarily targeting plants within the Asteraceae family, including *Solidago canadensis*, *Ambrosia artemisiifolia* Linnaeus (Asteraceae), *Erigeron canadensis* Linnaeus (Asteraceae), *Helianthus tuberosus* Linnaeus (Asteraceae), *Erigeron sumatrensis* Retz. (Asteraceae), *Artemisia argyi* H. Lév. & Vaniot (Asteraceae), *Artemisia princeps* Pampanini (Asteraceae), and *Rudbeckia bicolor* Nutt. (Asteraceae), often found in ornamental plants [14–17]. Additionally, economic crops such as *Ipomoea batatas* (Linnaeus) Lamarck (Convolvulaceae), *Helianthus annuus* Linnaeus (Asteraceae), and *Solanum melongena* Linnaeus (Solanaceae) are among its hosts [15,18,19]. In China, *Corythucha marmorata* inflicts damage by congregating on the undersides of leaves, causing yellow–white spots on the leaf surface accompanied by blackened excrement, eventually leading to leaf yellowing and withering [20].

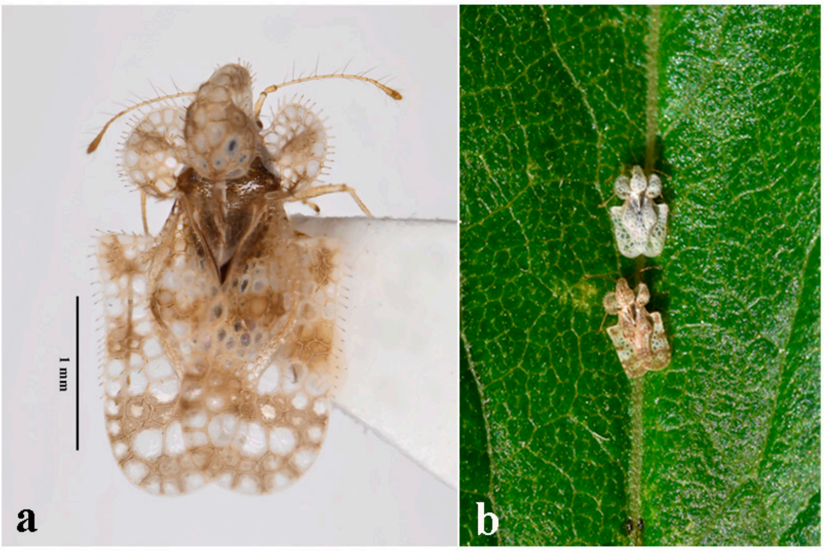

Figure 1. Habitus of *Corythucha marmorata* (Uhler) (photographed by Xinqian Liang and Linyou Gu); (**a**) adults of *Corythucha marmorata*; (**b**) adults of *Corythucha marmorata* on *Solidago canadensis*.

Originally widespread in North America (Canada, USA, Jamaica, and Mexico) [21], *Corythucha marmorata* has expanded to Europe [22] and Asia, including Japan since 2000 [23], Korea since 2011 [24], and China since 2010. Since its first detection in Shanghai [25], it has rapidly spread across multiple provinces in China, including Hebei, Shaanxi, Henan, Shandong, Jiangsu, Shanghai, Anhui, Zhejiang, Jiangxi, Hubei, Hunan, Fujian, Chongqing, Guizhou, Sichuan, and Taiwan, causing significant damage, according to our field investigations and relevant literature [26–29].

Utilizing species distribution models (SDMs) to forecast suitable habitats for significant pests has emerged as a vital tool for devising effective management and control strategies. SDMs employ statistical learning techniques to correlate species distribution data with relevant environmental variables, thereby discerning the relationship between a species' geographic range and its environmental context to anticipate distributional shifts under diverse climatic conditions [30,31]. Among the prevailing niche models, MaxEnt, GARP, and Bioclim stand out as widely utilized approaches [32,33]. Rooted in maximum entropy theory, the MaxEnt model utilizes species distribution data and environmental factors to ascertain the maximum entropy of distributional trends, offering stable performance, superior precision, and minimal susceptibility to sample biases [34]. Consequently, the MaxEnt model has witnessed increasing adoption in recent years owing to its user-friendly interface and robust predictive capabilities [35–37].

This study delves into the current and future distributions of *Corythucha marmorata*, indicating highly suitable, moderately suitable, poorly suitable, and unsuitable areas based on predicted distribution patterns. By simulating future diffusion scenarios, it furnishes valuable insights for monitoring and preventive measures against *Corythucha marmorata* proliferation.

2. Materials and Methods

2.1. Collection and Treatment of Species Geographic Distribution Records

Distributional records for *Corythucha marmorata* were sourced primarily from online databases, relevant literature, and field investigations. The Global Biodiversity Information Facility (GBIF): https://www.gbif.org/ (accessed on 26 October 2023) and the iNaturalist website: https://www.inaturalist.org/ (accessed on 26 October 2023) served as key repositories for data retrieval. Through searches on these platforms, latitude and longitude coordinates were extracted, and the pest in the record photos was reidentified as *Corythucha marmorata*. Additionally, a comprehensive review of published papers related to *Corythucha marmorata* augmented the dataset, supplemented by GPS−guided field surveys across various provinces, including Hebei, Shaanxi, Henan, Shandong, Jiangsu, Shanghai, Anhui, Zhejiang, Jiangxi, Hubei, Hunan, Fujian, Chongqing, and Sichuan (Figure 2). The amalgamation of data sources yielded a total of 294 distribution points (Table S2). The 294 distributional data collected were imported into ArcGIS 10.8 to eliminate duplicates, which meant that only one of the species' distribution points on a 10 km × 10 km grid was retained, resulting in a total of 60 distribution points (Figure 3; Table S1).

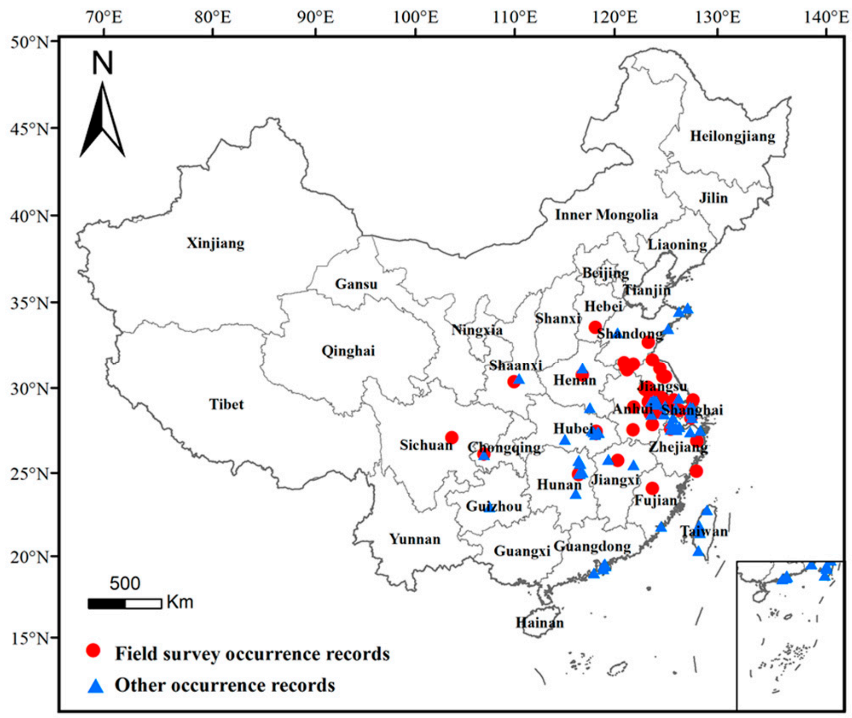

Figure 2. A total of 294 records of *Corythucha marmorata* from China. A total of 206 records are from our field survey, and 88 records are from other occurrences, including websites and the literature.

2.2. Screening of Environmental Variables

The environmental variables deemed relevant for this study encompassed bioclimatic factors and elevation. Climate data utilized in the analysis were sourced from the World Climate Database (World Clim version 2.1): http://www.worldclim.org/bioclim (accessed on 7 November 2023), featuring a comprehensive dataset comprising 19 environmental climate variables, including temperature and precipitation, spanning three distinct periods: the current epoch (1970–2000), the 2050s (2041–2060), and the 2070s (2061–2080) [38]. Future climate projections were delineated across four scenarios: SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5, and we chose SSP1–2.6, SSP2–4.5, and SSP5–8.5 for the modeling prediction analysis [39].

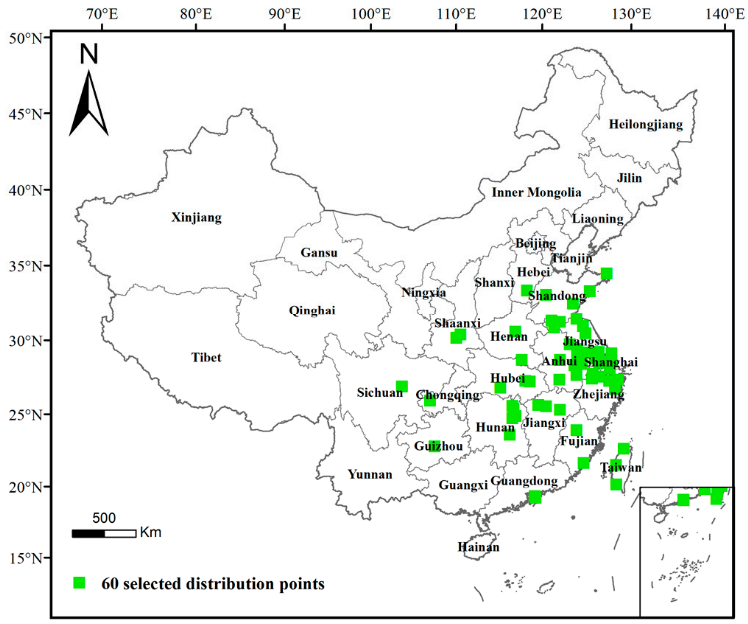

Figure 3. A total of 60 selected distribution points in China.

In forecasting species distribution, the identification of key environmental factors significantly shaping its habitat is important. Hence, a rigorous selection process was undertaken, eliminating variables with minimal impact on species distribution. The MaxEnt was used to conduct the Jackknife test to discern the individual contribution of each environmental factor to model construction, pinpointing the dominant variable. To avoid overfitting the model due to the multicollinearity of environmental variables, variables with correlation coefficients (r) greater than or equal to 0.85 were selected to construct the model [40]. The maximum entropy model for the distribution of *Corythucha marmorata* was constructed using several environmental factors, including bio2, bio3, bio4, bio8, bio10, bio12, bio15, bio18, bio19, and elev (Table 1; Figure S1). Notably, bio18, bio10, bio8, and elev emerged as major factors under current climatic conditions, and the cumulative contribution of these four factors reached 70% (Table 1). The accuracy of the simulation results was evaluated.

Table 1. Significance of each dominant environment variable in the MaxEnt model.

Variable	Percent Contribution	Permutation Importance
bio18	54.5	2.3
bio4	18.5	1.3
elev	10.4	0.1
bio2	5.8	14.7
bio15	3.5	0.1
bio10	3.2	10.8
bio3	1.9	15.8
bio8	1.9	54.7
bio19	0.1	0.1
bio12	0.1	0.1

2.3. MaxEnt Model Construction and Parameter Optimization

The environmental data alongside *Corythucha marmorata* distribution points were imported into MaxEnt (version 3.4.4), with parameters configured as follows: 75% of the distribution data served as the training set, while the remaining 25% constituted the test set. The Jackknife test was subsequently conducted to evaluate the significance of principal environmental factors, generating response curves indicating the logical relationship between occurrence probability and climate variables.

To ascertain the precision of species distribution prediction, the receiver operating characteristic (ROC) curve and the corresponding area under the curve (AUC) were tested. AUC quantifies the precision of MaxEnt predictions by measuring the area under the ROC curve, with values ranging from 0 to 1. A higher AUC value indicates a stronger correlation between environmental variables and the distribution model, thereby yielding more accurate prediction outcomes [41].

2.4. Classification of Suitable Grades

The MaxEnt model was employed to estimate the probability of *Corythucha marmorata* occurrence in China, while ArcGIS was used to develop a map showing the probability distribution of the occurrence of *Corythucha marmorata* in China. The results exported from MaxEnt were imported into ArcGIS and classified into four classes of potential habitat for *Corythucha marmorata* by using the Jenks' natural breaks in the "Reclassify" function of the "Spatial Analyst Tools" in ArcGIS [42]. The classification criteria were as follows: $p < 0.09$ (unsuitable area); $0.09 \leq p < 0.29$ (poorly suitable area); $0.29 \leq p < 0.50$ (moderately suitable area); and $p \geq 0.50$ (highly suitable area). The resulting map depicted diverse colors corresponding to varying probability ranges, providing a visual representation of potential habitat suitability for *Corythucha marmorata*.

3. Results

3.1. Model Performance

The AUC value served as a metric for assessing the efficacy of the MaxEnt model. A higher AUC value signifies a stronger correlation between bioclimatic variables and the predicted distribution area, indicating superior model performance. Notably, the average AUC value across 10 iterations for *Corythucha marmorata* stood at 0.994, affirming the model's high reliability in forecasting potential distribution outcomes (Figure 4). A comprehensive distribution survey of *Corythucha marmorata* conducted from 2022 to 2023 confirmed these estimations, with the species observed across all surveyed areas aligning consistent with the model's projections.

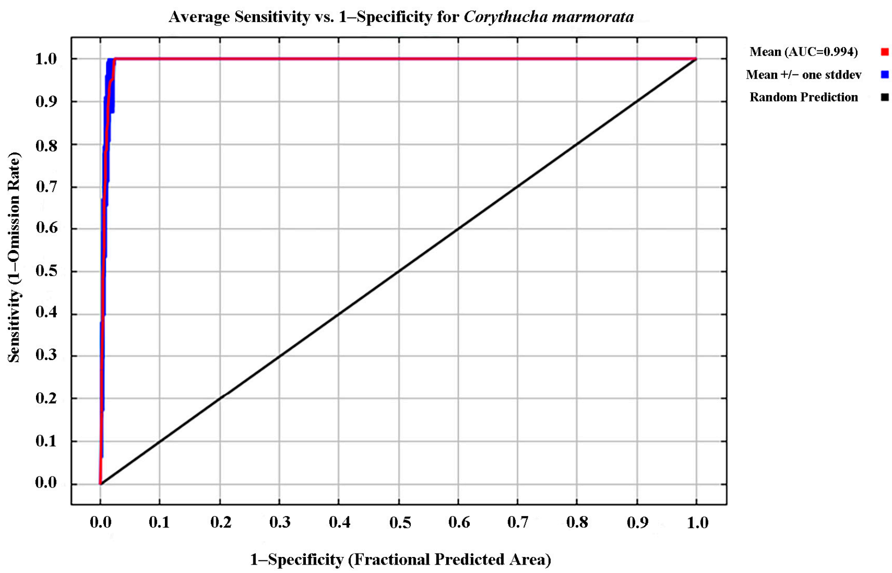

Figure 4. AUC results of the initial model.

3.2. Environmental Variable Analysis

The Jackknife test emphasized the key role of dominant environmental variables in shaping the distribution patterns of *Corythucha marmorata* (Figure 5). Results from this analysis revealed that precipitation of the warmest quarter (bio18), mean temperature of the warmest quarter (bio10), mean temperature of the wettest quarter (bio8), annual precipitation (bio12), and elevation (elev) emerged as the most influential factors, each contributing significantly to the model with values exceeding 1.0. Notably, precipitation in the warmest quarter (bio18) exhibited the highest contribution to the model, characterized by a substantial regularization gain, closely followed by the mean temperature in the warmest quarter (bio10). This observation suggested that these two variables provided the most pertinent effect for model simulation and held considerable significance in delineating species distribution. Overall, the results indicated the significant influence of temperature and precipitation as the principal drivers shaping the distribution of *Corythucha marmorata*.

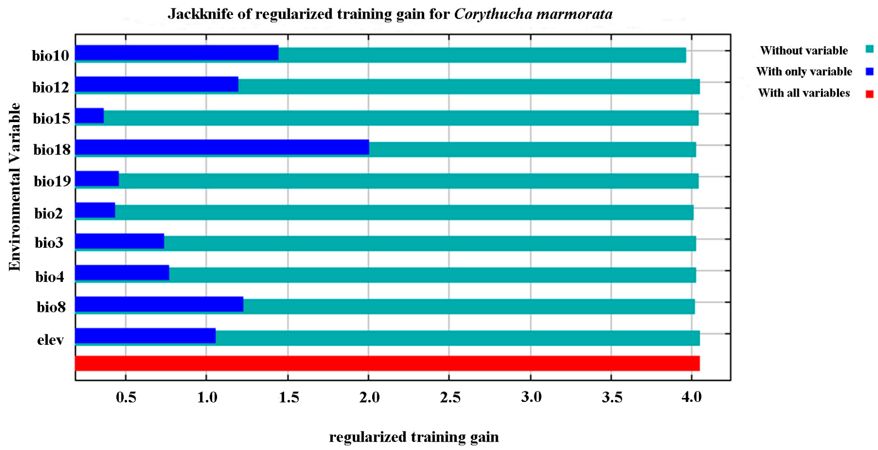

Figure 5. Importance of environmental variables to *Corythucha marmorata* is determined by the Jackknife test.

3.3. Response Curve Analysis of Climate Variables

In this study, the interplay between the likelihood of *Corythucha marmorata* presence and environmental factors was scrutinized through the analysis of MaxEnt model response curves, aiming to determine the influence of key environmental parameters on species distribution within suitable habitats (Figure 6). The optimal ranges for bio8, bio10, bio12, and bio18 were found to be approximately 20.73–29.18 °C, 24.23–28.94 °C, 687.61–2470.73 mm, and 392.43–660.63 mm, respectively. Within these defined ranges, fluctuations in primary environmental variables are poised to impact the occurrence of *Corythucha marmorata*, while conditions beyond these bounds are likely to constrain the species' distribution.

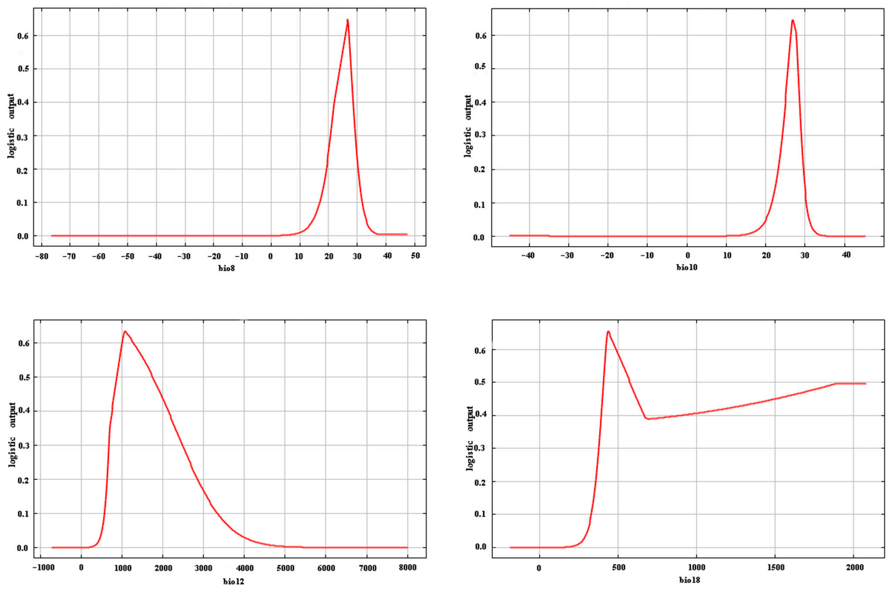

Figure 6. Relationship between potential habitat areas and single-factor response variables.

3.4. Current Distribution Forecast

The present distribution of *Corythucha marmorata* was charted based on simulation outcomes (Figure 7). Utilizing a model constructed from 10 key environmental variables, the projected suitable distribution range for *Corythucha marmorata* encompassed coordinates between 103°–128° E and 18°–47° N under current climatic conditions. The total estimated suitable distribution area spanned approximately 205.98265 × 10^4 km^2, constituting 21.4% of the total suitable territory. Among these, regions categorized as poorly, moderately, and highly suitable covered approximately 68.11459 × 10^4 km^2, 72.5816 × 10^4 km^2, and 65.28646 × 10^4 km^2, respectively, accounting for 33.1%, 35.2%, and 31.7% of the overall suitable area. Notably, areas classified as highly suitable were predominantly concentrated in the northwest of Shandong, extensive portions of Jiangsu and Shanghai, significant portions of Anhui, southern Hubei, central Hunan, southern Guangdong, most of Guangxi, western Chongqing, and eastern Sichuan. This indicates a significant increase in invasions across these regions.

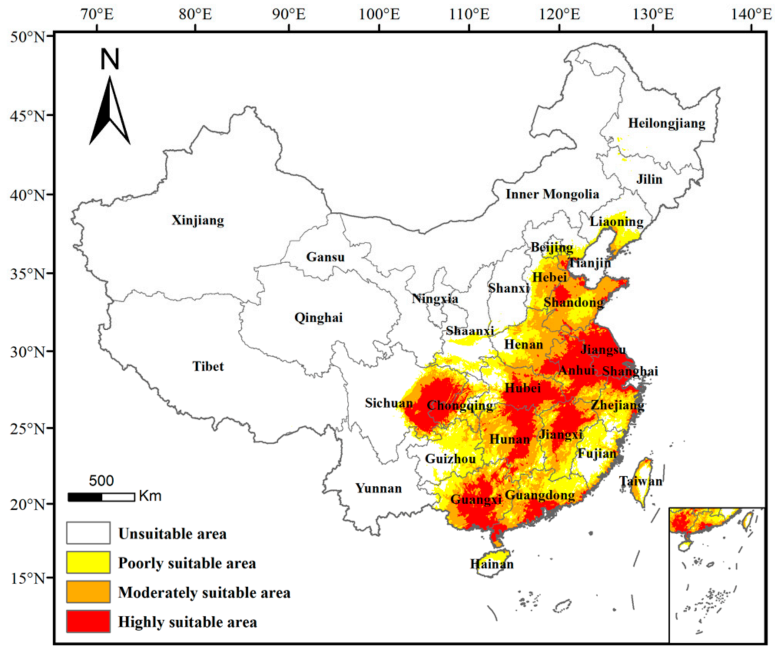

Figure 7. Current suitable climatic distribution of *Corythucha marmorata* in China.

3.5. Future Distribution Forecast

In comparison to suitable regions under the current climate, future projections indicated an obvious shift in the overall distribution of suitable habitats for *Corythucha marmorata*, particularly towards the central and southern regions of China. In particular, the central region emerged as a focal point for highly suitable areas (Figure 8). The areas of suitable habitat changed to varying degrees (Figure 9).

In the 2050s, the unsuitable habitat area experienced a marginal increase of 0.34% and 0.17% in SSP1–2.6 and SSP2–4.5, respectively, while decreasing by 0.52% in SSP5–8.5 compared to the current unsuitable distribution. The proportion of poorly suitable areas expanded by 1.24%, 8.19%, and 10.35% in SSP1–2.6, SSP2–4.5, and SSP5–8.5, respectively, relative to the present poorly suitable distribution. Moderately suitable areas showed an increase of 2.63% and 5.93% in SSP2–4.5 and SSP5–8.5, respectively, alongside a decline of 7.02% in SSP1–2.6 compared to current levels. Similarly, in contrast to current highly suitable regions, SSP1–2.6 had an increase of 2.61%, while SSP2–4.5 and SSP5–8.5 had reductions of 13.45% and 11.41%, respectively.

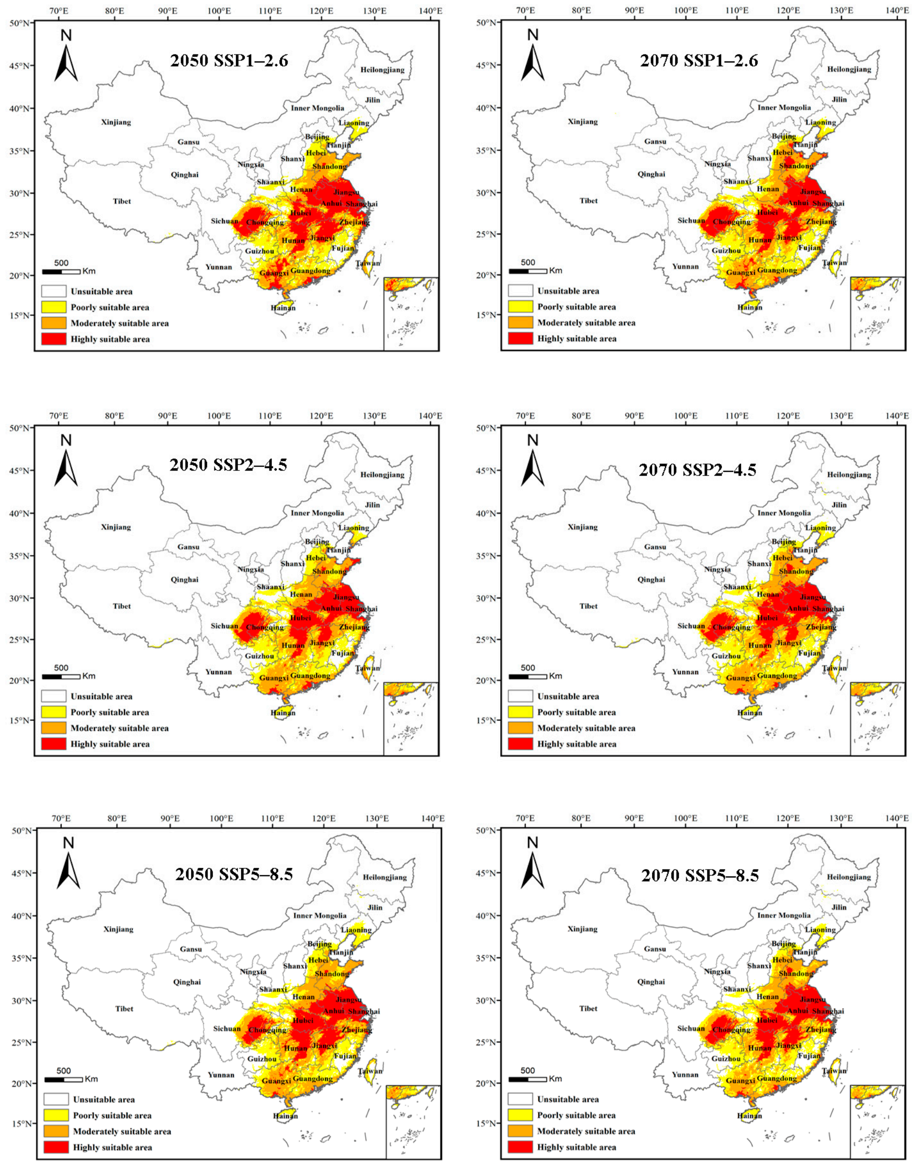

Figure 8. Potential range of *Corythucha marmorata* in China under different climate change scenarios.

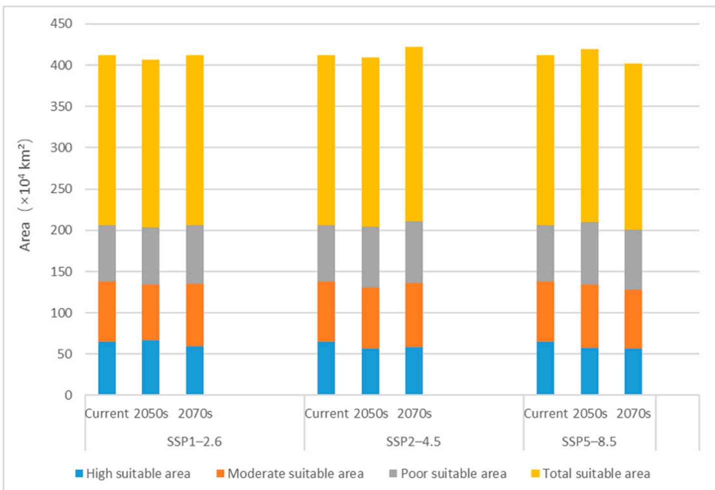

Figure 9. The areas of suitable habitat under SSP1–2.6, SSP2–4.5, and SSP5–8.5 are shown.

In the 2070s, unsuitable areas increased by 0.68% under SSP5–8.5, with slight decreases of 0.02% and 0.69% under SSP1–2.6 and SSP2–4.5, respectively. Poorly suitable regions expanded by 3.69%, 9.69%, and 7.06% under SSP1–2.6, SSP2–4.5, and SSP5–8.5, respectively, compared to current poorly suitable distributions. Moderately suitable areas expanded by 4.25% and 7.08% in SSP1–2.6 and SSP2–4.5, respectively, and decreased by 1.6% in SSP5–8.5. Highly suitable areas declined by 8.32%, 9.88%, and 13.49% under SSP1–2.6, SSP2–4.5, and SSP5–8.5, respectively, relative to current highly suitable distributions.

3.6. Diffusion Tendency

The centroid of suitable habitat for *Corythucha marmorata* exhibited a northward migration trend across both current and projected future climate scenarios (Figure 10).

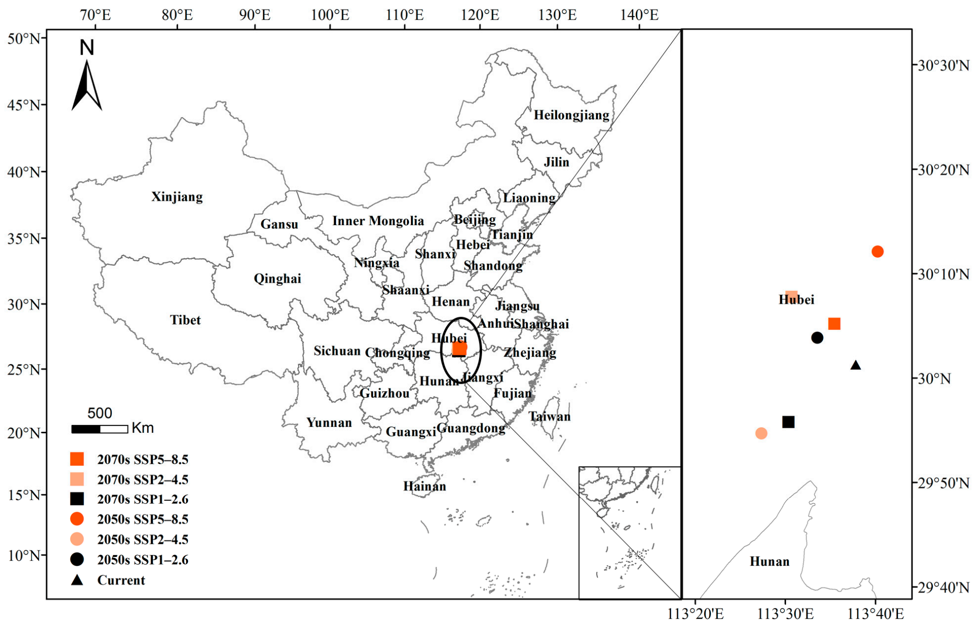

Figure 10. Centroid migration of potentially suitable areas of *Corythucha marmorata* under current and future climatic scenarios. Point 1: current; point 2: 2050s SSP1–2.6; point 3: 2050s SSP2–4.5; point 4: 2050s SSP5–8.5; point 5: 2070s SSP1–2.6; point 6: 2070s SSP2–4.5; point 7: 2070s SSP5–8.5.

Initially, the centroid of the current potentially suitable area was pinpointed at point 1 (113.6684° E, 30.02938° N) in Hubei Province. In the 2050s and 2070s, under various climate scenarios, notable shifts in the centroid were observed. Under the SSP1–2.6 climatic scenario, the center of mass migrated to point 2 (113.6017° E, 30.07793° N) and point 3 (113.5343° E, 29.94702° N). Under the SSP2–4.5 climatic scenario, the center of potential distribution migrated to point 4 (113.4824° E, 29.93281° N) and point 5 (113.5602° E, 30.1467° N). Under the SSP5–8.5 climatic scenario, the center of mass migrated to point 6 (113.7284° E, 30.2069° N) and point 7 (113.6357° E, 30.09785° N). Notably, the spatial concentration of the habitable zone remained predominantly in the southeastern region of Hubei Province.

Under the SSP1–2.6 climatic scenario, the habitable zone's centroid would shift northwestward in the 2050s, covering a distance of 8387.573 m. Conversely, in the SSP2–4.5 climatic scenario, it would shift southwestward, spanning 20,897 m. Moreover, the habitable zone in the SSP2–4.5 climatic scenarios exhibited a southern shift compared to the SSP1–2.6 and SSP5–8.5 scenarios, with faster spread rates observed. In the SSP5–8.5 climatic scenario, the centroid shifted northeastward by 20,490.34 m. Compared to the current climate scenario, in the 2070s, the centroid of the SSP1–2.6 scenario is projected to shift southwestward by 15,836.21 m, while the SSP2–4.5 and SSP5–8.5 climatic scenarios would show southwestward shifts of 16,668.26 m and 8215.312 m, respectively. Overall, these shifts indicated a northward trend in the centroid of potentially suitable areas.

3.7. Simulation of Changes in the Distribution Pattern of Corythucha marmorata in Different Periods of Time

With climate change, species often migrate to more favorable habitats conducive to their growth. Analyzing the spatial alterations in potentially suitable areas for *Corythucha marmorata* under future climate conditions involved assessing areas increased, lost, and reserved (Figure 11; Table 2).

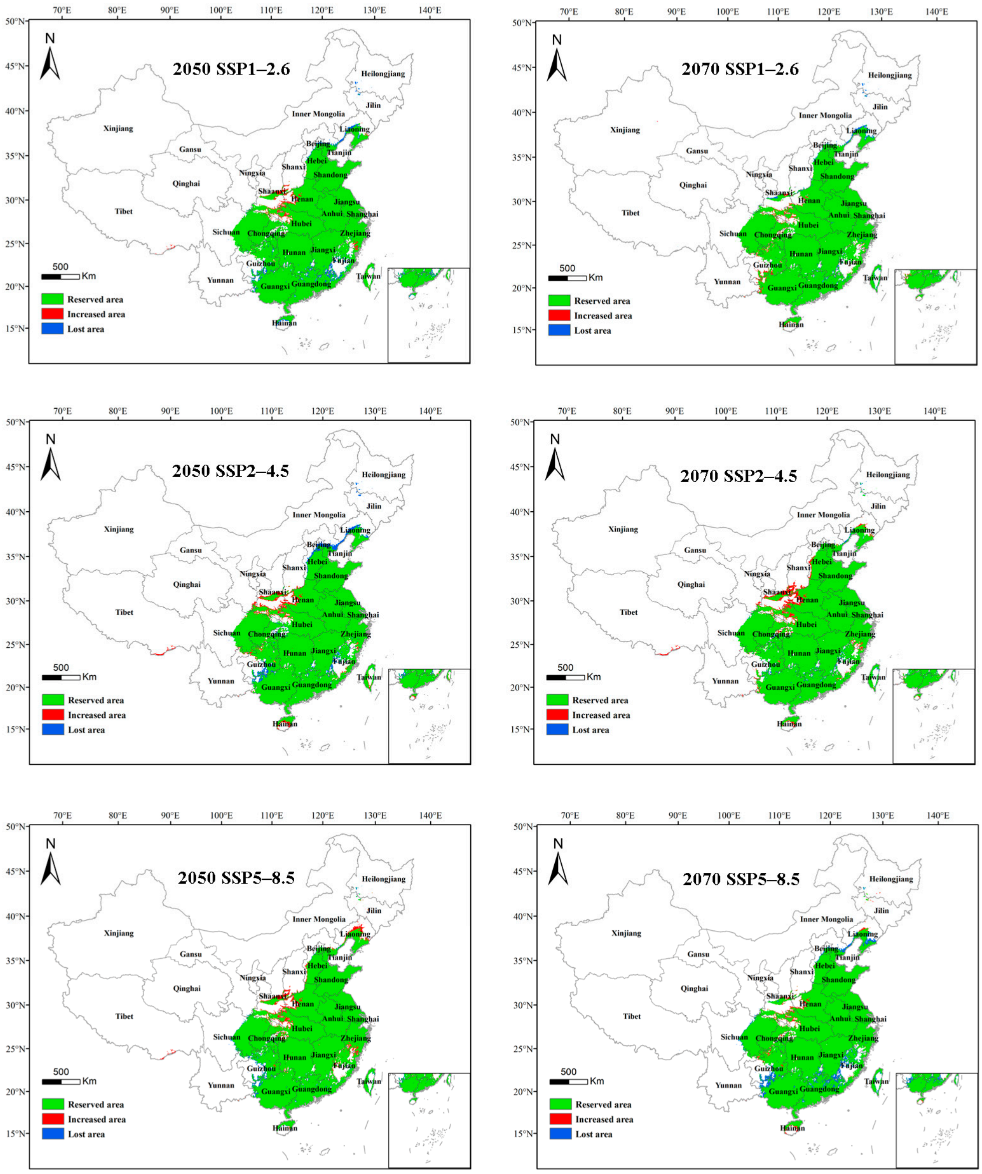

Figure 11. Changes in the suitable distribution of *Corythucha marmorata* under different climate change scenarios.

Relative to the current climate, the SSP5–8.5 climatic scenario in the 2050s and the SSP2–4.5 climatic scenario in the 2070s exhibited the largest increments in additional suitable areas, measuring 7.31 × 10^4 km^2 and 8.34 × 10^4 km^2, respectively, with additional rates of 3.54% and 4.04%. These areas were primarily concentrated in Liaoning, Shaanxi, Hubei, and Zhejiang, reflecting substantial changes totaling 1.94% and 2.6%, respectively. Conversely, SSP2–4.5 climatic scenario in the 2050s and SSP5–8.5 climatic scenario in the 2070s had the greatest loss in suitable areas, totaling 7.32 × 10^4 km^2 and 8.53 × 10^4 km^2, respectively, with loss rates of 3.55% and 4.14%. These losses predominantly occurred in Liaoning, Beijing, and Guizhou. SSP2–4.5 climatic scenario in the 2050s and SSP1–2.6 climatic scenario in the 2070s exhibited the lowest rates of change, at 0.58% and 0.08%, respectively, suggesting minimal climate impact during these periods on *Corythucha marmorata*'s potential suitable habitat.

Table 2. Changes in the habitat range of *Corythucha marmorata* (Uhler) under different climate scenarios.

Period	Area/($\times 10^4$ km ^{2})				Change Rate/%			
	Increased	Reserved	Lost	Change	Increased	Reserved	Lost	Change
2050s SSP1–2.6	4.09	199.53	6.67	−2.58	1.98	96.9	3.24	−1.25
2050s SSP2–4.5	6.12	198.89	7.32	−1.20	2.97	96.6	3.55	−0.58
2050s SSP5–8.5	7.31	202.90	3.30	4.00	3.54	98.5	1.6	1.94
2070s SSP1–2.6	3.60	202.78	3.41	0.18	1.75	98.4	1.66	0.08
2070s SSP2–4.5	8.34	203.23	2.98	5.36	4.04	98.7	1.45	2.6
2070s SSP5–8.5	3.34	197.67	8.53	−5.19	1.62	96	4.14	−2.52

Overall, future climate scenarios are projected to expand the potential distribution areas of *Corythucha marmorata*. Losses in distribution areas were concentrated in Liaoning, Beijing, Hebei, Guizhou, Fujian, Guangxi, and Guangdong, while increases were observed in Shaanxi, Henan, Hubei, Zhejiang, and Hainan. The results imply potential sensitivity to future *Corythucha marmorata* distribution patterns in these regions, warranting close monitoring.

4. Discussion

In this investigation, the MaxEnt model served as a tool to forecast the potential habitat of *Corythucha marmorata* and to scrutinize the influence of both current and future climate scenarios on its potential distribution. MaxEnt utilizes the known species distribution and the environmental constraints shaping it to establish a connection between the species' potential distribution and specific environmental factors [43]. For this study, only the influence of climate and elevation factors was factored in, while other potential factors, such as topography, intraspecific and interspecific relationships, and human activities, which might influence model accuracy, were omitted [44,45]. Moreover, the environmental data used for prediction were confined to the period from 1970 to 2000, failing to encompass the significant climate changes observed over the past two decades due to heightened greenhouse gas emissions. Consequently, the predictive accuracy of this study might have been impacted by this dearth of contemporary data. Subsequent research should delve into refining the model's representation of the intricate interplay among various factors to enhance its predictive efficacy.

Climate stands out as the primary factor shaping species distribution [46]. Alterations in climate exert a direct influence on the life activities of insects, spanning growth, reproduction, survival, and interactions with host plants. The distribution of *Corythucha marmorata* proved to be significantly influenced by two pivotal environmental variables: bio18 and bio10. Recent years have witnessed environmental shifts attributed to global warming, wherein alterations in moisture content and rainfall patterns directly impinge on insect dynamics. China, subject to the influence of the East Asian monsoons and western circulation, experiences seasonal and regional variations in dryness and precipitation [47]. Moreover, environmental moisture profoundly impacts the timing, abundance, and geographical range of forestry and agricultural pests [48]. It highlights the significance of bio18 and bio10 in influencing the distribution of *Corythucha marmorata.* It is likely that changes in temperature and precipitation will continue to drive the expansion of this pest, as studies have confirmed the influence of changing climates on spreading pests [49,50]. Notably, most of the overall suitable area is anticipated to enlarge, barring SSP1–2.6 and SSP2–4.5 climatic scenarios in the 2050s and SSP5–8.5 climatic scenarios in the 2070s. This suggests that climate change will affect the size of suitable areas for *Corythucha marmorata*. Over time and across diverse climate scenarios, a discernible trend of decline emerged in the overall highly suitable area for *Corythucha marmorata*. Excessive temperatures tend to render habitats unsuitable for this species. Nevertheless, there were some variations between the various time periods and climate scenarios, which may be related to changes in temperature and rainfall under different scenarios. In the context of escalating global temperatures, regions previously deemed unsuitable for *Corythucha marmorata* may undergo a transition to suitability. Hence, forestry departments operating in areas lying beyond the species' natural range should remain vigilant, instituting diligent monitoring and control measures for *Corythucha marmorata* as deemed necessary.

The ongoing spread of *Corythucha marmorata* necessitates heightened monitoring efforts. Prompt action must be taken upon the detection of infestations to curtail their dissemination. Preliminary inspection and stringent quarantine protocols in regions forecasted for future expansion are imperative. Areas forecasted for sustained proliferation demand a comprehensive prevention strategy. Conversely, in regions expected to transition gradually from suitable to unsuitable, a phased reduction in control measures can mitigate undue economic losses. In areas where *Helianthus annuus*, *Ipomoea batatas*, and other cash crops are grown, weeds in the vicinity should be eradicated in a timely manner to control the density of the *Corythucha marmorata* population and reduce the possibility of the insect damaging cash crops. Chemical methods offer another way for prevention and control. Studies have shown that *Corythucha marmorata*'s propensity for outdoor migration and spread is limited. Consequently, following chemical intervention, insect populations on treated plants tend to remain low for extended periods. Hence, early-stage prevention and control are recommended, with spraying commencing towards late March, repeated 3–4 times at 2–3 week intervals. This approach not only effectively reduces insect population density and prevents further spread and proliferation but also minimizes pesticide usage, thereby mitigating environmental pollution. Acetamiprid 10% ME emerges as a relatively effective pesticide for *Corythucha marmorata* control. Notably, this insecticide is environmentally benign and suitable for widespread application [51]. Furthermore, the eradication of wild weeds belonging to the Asteraceae family can serve to diminish pest populations [52].

The spread of *Corythucha marmorata* is intricately linked to its host plants, necessitating a comparative analysis of their future habitats. Previous studies have focused on *Solidago canadensis* and *Ambrosia artemisiifolia*, the main host plants of *Corythucha marmorata*, to forecast potential suitable areas in China. Results indicate a similarity between the projected distribution areas of *Solidago canadensis* and our predictions, except that Hainan Island may not be included in the future distribution of *Solidago canadensis* [53–55]. However, our predictive results identify Hainan Island as a poorly suitable zone for *Corythucha marmorata* that needs to be monitored in the future (Figures 7 and 8). Despite its isolation from the mainland, the potential spread of *Solidago canadensis* to Hainan Island remains plausible. Notably, *Solidago canadensis* is considered an invasive species, and monitoring its spread holds crucial implications for *Corythucha marmorata* prevention and control efforts. Meanwhile, there exist disparities in the potential habitats of *Corythucha marmorata* and *Ambrosia artemisiifolia*. While *Ambrosia artemisiifolia* is prevalent in northeastern and southeastern China, northeastern regions do not serve as habitats for *Corythucha marmorata* [56]. Additionally, our studies suggest a heightened risk of *Corythucha marmorata* spreading northward in the future, underscoring the need for continued monitoring and preventive measures.

5. Conclusions and Future Prospects

In this study, we forecasted the habitat distribution of *Corythucha marmorata* based on 60 distribution records and 10 variables. Achieving an AUC value of 0.994, the MaxEnt model demonstrated high reliability. Among the significant parameters associated with *Corythucha marmorata* were bio18 and bio10. Current habitats predominantly lie in central and southern China, indicating a preference for temperate climates by *Corythucha marmorata*. However, under future climate conditions, there appears to be a northward expansion trend in its habitat range. While this study primarily analyzed the influence of climate and elevation on *Corythucha marmorata* distribution in China, future research could delve into additional factors, such as topography and anthropogenic influences.

In summary, this study lays a theoretical foundation for the management and monitoring of *Corythucha marmorata*. Vigilant prevention and quarantine measures are essential, particularly in areas predicted for future expansion, to reduce risks effectively. Furthermore, ongoing monitoring of host plants, especially *Solidago canadensis*, is imperative, with prompt eradication of infested plants crucial for containment efforts.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f15050843/s1, Figure S1: Rplot of *Corythucha marmorata*; Table S1: 60 Selected distribution points of *Corythucha marmorata* in China; Table S2: 294 distribution points of *Corythucha marmorata* in China.

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Data Availability Statement: The data are included in the article. For the data provided in this study, see Sections 2.1 and 2.2 in the text.

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