# Obolodiplosis robiniae Will Infect All Black Locust In Eurasia Under Climate Change

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## Abstract

Obolodiplosis robiniae was discovered in Eurasia at the beginning of the 21st century and was then spread at an explosive rate. Here, we explore the current and future (in years 2050 and 2070) trends in the potential distribution of O. robiniae in Eurasia under diverse climate change scenarios based on a maximum entropy (MaxEnt) model. Our results showed that the current potential distribution area of O. robiniae is within the range of 21.58°-65.66°N in the Eurasian continent. The total current potential distribution (CPD) area of O. robiniae in Eurasia was 10,896,309.16 km2 , with suitable areas covering a substantial section of Europe. The Annual Mean Temperature (Bio1), Annual Precipitation (Bio12), and the Precipitation of the Driest Month (Bio14) are the most important bioclimatic variables determining the potential distribution of O. robiniae. The future area suitable for habitat of O. robiniae is characterized by a large-scale northward expansion trend with temperature elevation. The marginally suitable and highly suitable areas would thus increase, whereas the southern appropriate areas would shrink. Under the SSP585 scenario, in 2070, the suitable area of O. robiniae would be the largest, up to 14,696,253.77 km2, which is 34.87% more than the current suitable area. This information would facilitate the provision of early warning on the potential distribution areas of O. robiniae issued by the forestry quarantine departments of Asian and European countries and provide a scientific basis for the prevention and control of O. robiniae spread and outbreaks.

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# *Obolodiplosis robiniae* Will Infect All Black Locust In Eurasia Under Climate Change

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## Key Points:

- Temperature is the key determinant factor driving the distribution of *O. robiniae.*
- Potential distribution will expand to the north and the south will shrink.
- The trend in the potential distribution is consistent with that of the host.

**Abstract**

*Obolodiplosis robiniae* was discovered in Eurasia at the beginning of the $21^{st}$ century and was then spread at an explosive rate. Here, we explore the current and future (in years 2050 and 2070) trends in the potential distribution of *O. robiniae* in Eurasia under diverse climate change scenarios based on a maximum entropy (MaxEnt) model. Our results showed that the current potential distribution area of *O. robiniae* is within the range of 21.58°-65.66°N in the Eurasian continent. The total current potential distribution (CPD) area of *O. robiniae* in Eurasia was 10,896,309.16 $km^2$ , with suitable areas covering a substantial section of Europe. The Annual Mean Temperature (Bio1), Annual Precipitation (Bio12), and the Precipitation of the Driest Month (Bio14) are the most important bioclimatic variables determining the potential distribution of *O. robiniae*. The future area suitable for habitat of *O. robiniae* is characterized by a large-scale northward expansion trend with temperature elevation. The marginally suitable and highly suitable areas would thus increase, whereas the southern appropriate areas would shrink. Under the SSP585 scenario, in 2070, the suitable area of *O. robiniae* would be the largest, up to 14,696,253.77 km2, which is 34.87% more than the current suitable area. This information would facilitate the provision of early warning on the potential distribution areas of *O. robiniae* issued by the forestry quarantine departments of Asian and European countries and provide a scientific basis for the prevention and control of *O. robiniae* spread and outbreaks.

**Plain Language Summary**

*Obolodiplosis robiniae* originated in the eastern United States. This species has now become a common pest on black locust trees, with high infestations causing severe defoliation of black locust and consequent serious ecological and economic damage. We collected the occurrence records assessed from surveys conducted in China, the Global Biodiversity Information Facility (GBIF) database, and the literature. Bioclimatic modeling was being used to estimate the current and future potential distribution of *O. robiniae*. Our results showed that the temperature is the key determinant factor driving the distribution of *O. robiniae.* The highly and moderately suitable areas are mainly distributed in the semi-humid and semi-arid and warm areas, which also coincides with the distribution areas of the optimum growth of the host black locust (*Robinia pseudoacacia* L.). The prediction of the future potential distribution area of *O. robiniae* revealed that global warming will benefit the species. The future spread tendency of *O. robiniae* in Eurasia aims to attract the attention of governments, and quarantine management should be implemented as soon as feasible, otherwise the expense of later management will be very expensive.

## 1 Introduction

Due to the globalization of trade and the increasing tourist traffic between continents, the yearly introduction and spread of new species have been increasing each year (Essl *et al.*, 2020; Seebens *et al.*, 2021). Invasive alien species (IAS) can cause significant negative ecosystem-level, economic, and human health effects in the area of their introduction (Diagne et al., 2021; Mack and Smith, 2011; Vanbergen et al., 2018). In fact, because of their impact on the environment, invasive species are predicted to among the biggest driving forces of global change (Vilà et al., 2007). In addition, the elevated temperature of the global climate is expected to increase the suitability for living of increasingly more new areas that have been previously unsuitable habitats of such species (Descombes et al., 2020; McCain and Garfinkel, 2021). Insects, in particular, are more harmful as invasive species due to their high reproductive rate and abundance, as well as their remarkable physiological tolerance to temperature extremes and ability to fly, giving them the leverage to spread faster and farther (Kenis and Branco, 2010). A previous investigation revealed that 940 of 1600 insects species were significantly affected by global warming, including its effects on the number of insect populations, the acceleration of insect development, the increase of alien invasive insect species range, the migration of insects to high altitude areas, the increase in the probability of insect outbreaks, and the reduced insect population diversity (Raza *et al.*, 2015).

Locust gall midge, *Obolodiplosis robiniae* Haldeman (Diptera: Cecidomyiidae) , is a Nearctic pest with similar body color, size and morphology to the adult *Anopheles* mosquito (Tóth et al., 2009). *O. robiniae* is a monophagous species, with specialized feeding on *Robinia* species, such as, *R.*

*pseudoacacia* L, *R. hisqida* L, *R. pseudoacacia* Aurea. The gregariously feeding larvae cause the margins of the leaflets to thicken and to bend downwards, forming the characteristic leaf margin roll galls (Shao et al., 2010; Wermelinger and Skuhrava, 2007; Zang, 2015). This insect causes harm throughout the year, from the initial leaf development of the black locust (*Robinia pseudoacacia*) to the fall of its leaves in winter, hindering leaf photosynthetic processes and causing early leaf abscission. Consequently, this leads to a decline in the tree growth and productivity, thus affecting the economic, ecological efficiency, and ornamental value of the black locust. Moreover, these injuries facilitate the attack by secondary pests such as longhorn beetles and jewel beetles, which eventually causes the death of trees (Glavendekić et al., 2009; Yao et al., 2015).

In the 19$^{th}$ century, *O. robiniae* was first described as *Cecidomyia robiniae* in Pennsylvania (USA) (Haldeman, 1847). Its habitat was restricted to North America, and *O. robiniae* did not receive much attention until its discovery in Asia in 2002 (in Japan and Korea) and later in Europe (Italy) in 2003 (Duso et al., 2005; Kodoi et al., 2003; Uechi et al., 2005; Woo et al., 2003). In Europe, *O. robiniae* has been spreading faster than expected, with 26 European countries recently reporting infestations (Bálint et al., 2010). From 2003 to 2006, *O. robiniae* moved approximately 2000 kilometers eastward from Veneto in Italy to Donetsk, Ukraine (Berest and Titar, 2007). In 2007, it reportedly crossed the English Channel to Oxford, England (UK) in Western Europe (Skuhravá et al., 2007). A year later, in 2008, it was found in Sweden's Lund in Northern Europe, showing a tendency for *O. robiniae* spread eastward (Molnar et al., 2009). In China, *O. robiniae* was discovered in Qinhuangdao, Hebei Province in 2004 (Yang *et al.*, 2006). After that, an explosive spread occurred throughout China, and the species was detected in Northeast Liaoning in 2005 (Wang et al., 2006); it also spread to Jilin, Beijing, and Shandong in 2006 (Mu et al., 2010; Yan et al., 2007; Zhang et al., 2008). Currently, it has been detected in 17 provinces (municipalities/ autonomous regions) of China, which are roughly distributed within the range of 26.59°-43.98°N and 103.80°-121.25°E, at an altitude of 8.05m-1561.33 m.

Zhang *et al.* used the CLIMEX model to predict and analyze the potential geographic distribution of *O. robiniae* in China. The quantitative analysis of the pest risk conducted by these researchers predicted that the risk value in China was 2.26, which represented a highly dangerous organism according to the International Plant Protection Convention (IPPC) of risk values (Zhang et al., 2009). Zhao *et al.* analyzed the current and future (2050s) changes in the areas suitable as *O. robiniae* habitat in China by using the maximum entropy model. They found that the future habitat is larger than the total habitat range under the current climatic conditions, and the main factor for this increase was the expansion of the highly and moderately suitable areas (Zhao and Shi, 2019). Due to the limited previous research and scarce data of its real spread, *O. robiniae* was then considered to be still in a state of diffusion. Here, we present our survey of the occurrence of *O. robiniae* in China, with more complete occurrence records and updated global climate data collected from v1.4 to v2.1 of the WorldClim database in 2020 (Fick and Hijmans, 2017; Hijmans et al., 2005). The most significant feature of the WorldClim v2.1 is that it contains historical climate data from 1970 to 2000. The prediction future climate data adopts the Coupled Model Intercomparison Project Phase 6 (CMIP6), which adopts four shared socio-economic pathways (SSPs) for climate change scenarios. SSPs can determine accurately the correlation between socio-economic development and climate scenarios; furthermore, the novel SSP370 program was recently created, which considerably facilitates the achieving of this purpose (Jiang and O'Neill, 2017; Kriegler et al., 2012; Moss et al., 2010). The CMIP6 model is better than CMIP5 in many aspects (Saha et al., 2021), such as improved prediction accuracy of the temperature variables by 5%–15%. The following global cross-validation correlation values were determined: temperature and humidity ≥ 0.99, precipitation = 0.86, and wind speed = 0.76, The simulation results of CMIP6 were closer to the data of the actual observations (Fan et al., 2020; Nie et al., 2020), which provided an opportunity for the update and improvement of the prediction of the potential distribution range of *O. robiniae*.

Using the maximum entropy model and new climate data, combined with the results of our observations in China, in this study, we aimed to predict the current potential distribution (CPD) of *O. robiniae* in Eurasia and its future (years 2050s and 2070s) potential distribution (FPD) change trend. Furthermore, we determined the dominant climate factors influencing the distribution of *O. robiniae*. Our findings provide an important reference and guidance for the current and future control and quarantine of *O. robiniae* by forestry and customs quarantine authorities.

## 2 Material and methods

### 2.1 Species occurrence data and environmental variables

We identified the availability of 1008 occurrence records of *O. robiniae* in the Eurasia: (1) All occurrence records collected in China originated from our field survey; finally, 125 occurrence data of *O. robiniae* were recorded in 26 cities in 15 provinces (municipalities/ autonomous regions); (2) The data of the distribution points outside China were derived from the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/) (648 records) and published in the literature statistics (236 records) (Figure S1).

The climate data were downloaded from the WorldClim website (http://www.worldclim.org). The Global Climate Data Version 2.1 with a resolution of 2.5 minutes was employed. It included a total number of 19 bioclimatic variables (Table S1). The bioclimatic variables were derived from analyses of the annual trends and biologically significant parameters obtained from seasonal temperature and rainfall data values, which are essential for the species survival in a habitat. These climatic parameters were used ecological research to assess the impact of climatic conditions and their possible distribution (Ashoori *et al.*, 2018; Fois *et al.*, 2018).

To comprehensively evaluate the changes in the potential suitable areas of *O. robiniae* in the future periods, namely years 2041-2060 (2050s) and 2061-2080 (2070s), we used three different global climate models (GCMs): BCC-CSM2-MR, CNRM -CM6-1, and IPSL-CM6A-LR(Tang et al., 2022). We implemented the GCMs from the CMIP6 of the sixth assessment report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). Three Shared Socio-economic Pathways (SSPs) were selected for each of the GCMs: SSP245 (Fricko *et al.*, 2017), SSP370 (Fujimori *et al.*, 2017), and SSP585 (Kriegler *et al.*, 2017). Then, these three SSPs emission scenarios were considered to represent a low-forcing, medium-forcing, and high-forcing scenario of climate change with economic development.

## 2.2. Optimization of the model parameter

MaxEnt software is an ecological niche model based on environmental variable layers and species occurrence records. It integrates machine learning and the principle of maximum entropy to simulate the potential geographic distribution of species (Phillips et al., 2006). To reduce the sampling bias due to oversampled areas, we calibrated the CPD for each species by filtering the specimen records to the spatial resolution of the environmental layers used (2.5 arc-minutes), resulting in one record per cell (Martínez-López *et al.*, 2021). By this approach, we obtained 659 points after filtering.

There is a certain correlation among the 19 bioclimatic variables, and too many variables increase the dimensionality of the ecological niche, thereby affecting the prediction performance and accuracy of the maximum entropy model (Sillero, 2011; Verbruggen *et al.*, 2013). Next, we used the ArcMap version 10.3 (ESRI, Redlands, CA, USA) software to couple the 19 bioclimatic variables with 659 occurrence records to perform Pearson's correlation analysis (Figure S2); we removed the climate layer with a low biological significance in the high-correlation variable group, and filtered out 10 environment layers (Table S1).

Further, we conducted our first exploratory analysis using MaxEnt version 3.4.4 (results not shown) and the “ENMTools” package in R, version 4.0.5 (https://www.r-project.org/), to adjust and optimize the feature combination (FC) of the MaxEnt and regularization multiplier (RM) β parameters. Hence, we effectively reduced the complexity of the model and improved the degree of fit between the predicted and actual results. The β multiplier settings of 0.1-5, and 0.5 gradually increased. The FC included linear (L), quadratic (Q), hinge (H), product (P), and threshold (T).We tested eight different FC combinations, including L, LQ, LQP, QHP, LQH, LQHP, QHPT, and LQHP (Martínez-López et al., 2021; Merow et al., 2013; Radosavljevic and Anderson, 2014), and obtained the corrected Akaike Information Criterion (AICc) of different parameter combinations. We then selected the minimum value of the AICc as the optimal setting and established the model (Figure S3a) (Warren and Seifert, 2011).

To assess its predictive performance, the species occurrence records were utilized for model calibration by their division into a training set (75% of the total occurrence records) and a test set (25% of the total occurrence records). The relative probability calculated for each grid is used here as the relative habitat suitability of *O. robiniae*. To improve the accuracy of the prediction results and reduce the level of uncertainty, subsample validation was set up in the model, and 10-fold repetitions were performed to obtain average results. Then, the response curves and jackknife were created to measure the importance of the variables, removing climate variables with low contributions to obtain the final six climate variables (Table S1) (Negrete et al., 2020).

To minimize model overfitting, Principal-component analysis (PCA) of the climate variables was performed to estimate the heterogeneity of six bioclimatic variables using ArcMap software (ArcToolbox: SDM Tools). We aimed to ensure that the occurrence records were spatially independent, thereby reducing the over-fitting of the model to environmental biases. Next, we performed spatial filtering based on the value of the environmental heterogeneity, and finally obtained the occurrence records (Figure S1) (Boria et al., 2014; Brown et al., 2017).

The performance of the Maxent model was evaluated by the Receiver operating characteristic (ROC) method and the area under the curve (AUC) was calculated as a measure of the prediction accuracy. The AUC values >0.5 imply a better than random fit, with $0.9 < AUC < 1$ representing high predictive ability.

### 2.3. Classification of CPD and FPD

A second construction of the model using the selected occurrence records and bioclimatic variables was used for the development of CPD maps and 18 FPD maps for the prediction of *O. robiniae* spread (Figure S4 and S5). To balance the differences between GCMs and present a trend for a higher likelihood of FPD occurrence (Zhou *et al.*, 2021), we averaged the results of these three GCMs for SSP126, SSP370, and SSP585, respectively, and finally obtained six CPD maps (years 2050 and 2070) for different SSPS scenarios of *O. robiniae* spread.

We used the lowest presence threshold (LPT) to define the suitable and non-suitable areas (Pearson et al., 2007). The potential area distribution was divided into four categories, including unsuitable (0-LPT), marginally suitable (LPT-0.4), moderately suitable (0.4–0.6), and highly suitable (0.6–1.0) areas. We used the ArcMap 10.3 software "ArcToolbox: Spatial Analyst Tools" to analyze the changes in the CPD and FPD areas and the centroid movement trend.

## 3. Results

We constructed the current model using 248 occurrence records of 6 bioclimatic variables, FC for LQHP and RM of 0.5 (Figure S3c), which showed very good performance (AUC = 0.952 ± 0.005) (Figure S6b) and the LPT of

0.043.

The most important bioclimatic variables that determined the potential distribution of *O. robiniae* were the Annual Mean Temperature (Bio1), Annual Precipitation (Bio12), and the Precipitation of the Driest Month (Bio14). The total contribution of these three climatic factors was 86.6% (Table 1). The response curve (Figure S7b-d) showed that the climatic suitability of *O. robiniae* had a unimodal relationship with BIO1 and BIO12, while the BIO14 had two peaks at 2.80mm and 46.93mm. For the BIO1, the range of the highly suitable for *O. robiniae* was 8.31°C -12.31°C, with the standard deviation was 1.17°C. For the BIO12, the range of the highly suitable was 632.99mm - 1392.57mm, the standard deviation of the BIO14 was 18.5mm. The future values of these three layers were larger than the current values, with a wider range and an average increase of 9.7% (Table S2). According to Jackknife (Figure S7a), a shorter green band indicates that the environmental variable has more information than other variables; in this case, the influence on the species distribution is greater. As can be seen in the figure, Bio1, Bio3, and Bio15 provided more information specific to the prediction of the distribution area of *O. robiniae* and were thus indispensable.

Table 1. MaxEnt results of the percentage contribution and permutation importance of Bioclimatic variables for the selected model developed for *O. robiniae.*

| Code | Environmental variables | Percent contribution | Permutation importance | AUC |
|---|---|---|---|---|
| BIO1 | Annual Mean Temperature | 59.2 | 59.4 | 0.91 |
| BIO12 | Annual Precipitation | 14.3 | 8.1 | 0.84 |
| BIO14 | Precipitation of Driest Month | 13.1 | 0.9 | 0.84 |
| BIO3 | Isothermality | 5.5 | 15.2 | 0.84 |
| BIO15 | Precipitation Seasonality | 4.9 | 7.9 | 0.74 |
| BIO6 | Min Temperature of Coldest Month | 3.0 | 8.5 | 0.89 |

The total CPD area of *O. robiniae* in Eurasia was 10,896,309.16 km$^2$ (Figure 1 and 3), with suitable areas covering a substantial section of Europe. The moderately and highly suitable areas (orange and red) were predominant, reaching 38.91% of the total European land, including most of Western Europe (the central and southern parts of the United Kingdom, the north of Spain, France, Germany, *etc.*), the southwestern region of Central Europe (southwestern Poland, Hungary, *etc.*), the north of Southern Europe (the south of Romania, the north of Greece, Serbia, *etc.*), a small part of Northern Europe (Denmark and south of Sweden), and Eastern Europe, mainly in the plain area on the east side of the Black Sea . In Asia, Turkey and northern Iran in West Asia, and southern Kazakhstan and eastern Uzbekistan in Central Asia, were suitable areas, but with a relatively low degree of fitness. The highly and moderately suitable areas were distributed mainly in East Asia, the eastern part of Japan, the southwest of the Korean Peninsula, and in northeast China (Liaoning Province), north China (Beijing, Tianjin, Hebei, Shandong, *etc.*), and southwest China (Guizhou Province, Sichuan Province, *etc.*). The *O. robiniae* suitable area in West Asia was closely associated with that in Europe. To assist our research and minimize fragmentation of the suitable areas, our next study divides the potential distribution areas into two categories, namely, the suitable areas in Europe and Western Asia ( EWA ) are divided into one category, and the other is composed of East Asian countries.

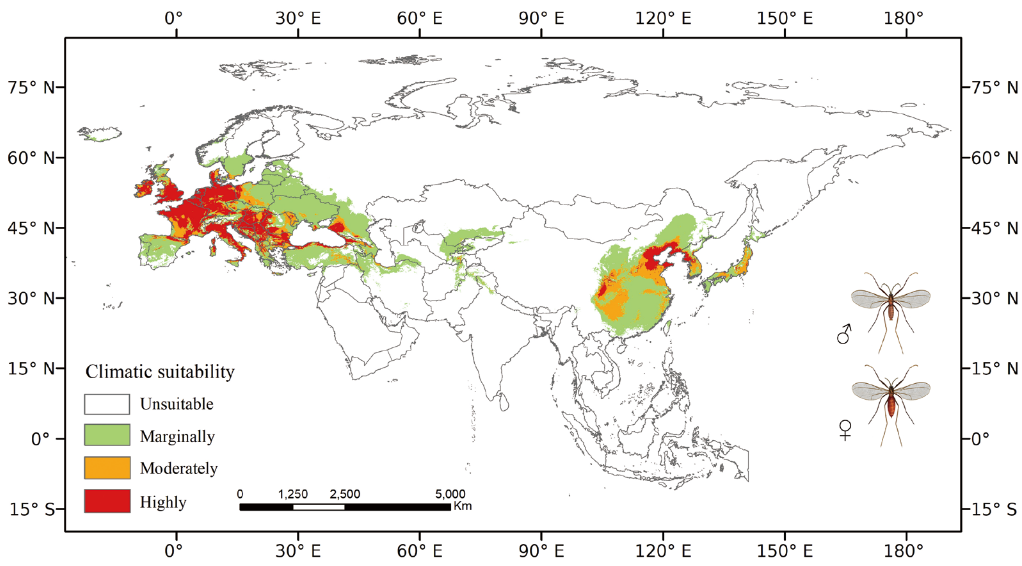


Figure 1. Prediction of the current potential distribution area of O. robiniae in Eurasia. Colours indicate the probability of climatic suitability: unsuitable area (0-0.043), marginally suitable area (0.043-0.4), moderately suitable area (0.4-0.6) and highly suitable area (0.6-1.0). Spatial resolution: 2.50 minutes; Geographic Coordiante System: WGS 84

The results of the MaxEnt model obtained under the future climate change scenarios SSP245, SSP375, SSP585 for 2050s and 2070s are presented in Figure 2. It can be seen that, compared with CPD, in the same year of FPD, the total suitable area of *O. robiniae* becomes larger with the increase in the radiative force in the SSPs emission scenario. Similarly, in the same SSPs emission scenario, the suitable area in 2070 would be larger than that in 2050 (Figure 3). The marginally suitable area occupied the main part, followed by the highly suitable area. Except for 2070-SSP370 and 2070-SSP585, the moderately suitable area was more than the highly suitable area. The largest FPD area was under the scenario of SSP585 in 2070. The total area was 34.87% larger than that of CPD, reaching 14,696,253.77 $km^2$, mainly due to the expansion of the marginally and moderately suitable areas, which increased by 43.15% and 35.91%, respectively. As can be seen in Figure 2 in the future, the moderately and highly suitable areas for *O. robiniae* habitats would continue to spread northwards in Eurasia. In EWA, the west coast of Norway, Poland, the central and western parts of Ukraine, and the southern part of Belarus and Sweden would become the new worst-hit areas by *O. robiniae* spread. In East Asia, Japan and South Korea would gradually become marginally suitable areas as *O. robiniae* habitats. In China, the moderately and highly suitable areas would gradually decrease in the southwest, and the three northeastern provinces would gradually become the worst-hit areas. Although the CPD of *O. robiniae* generally tended to spread northwards, subtle differences existed between EWA and East Asia. In EWA, the expansion of the moderately and highly suitable areas was predominant, whereas in East Asia, the growth of the marginally suitable sites was dominant, and the moderately suitable areas were declining.

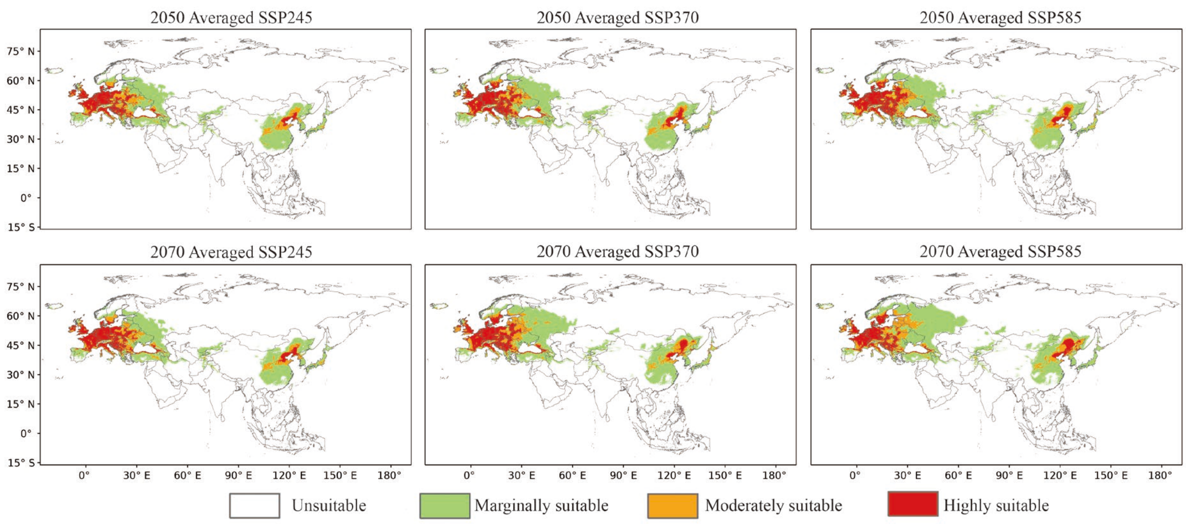


Figure 2. Averaged projected ranges of *O. robiniae* invasion for three climate change scenarios: SSP245, SSP370, SSP585 for 2050 and 2070, SSPs= shared socio-economic pathways

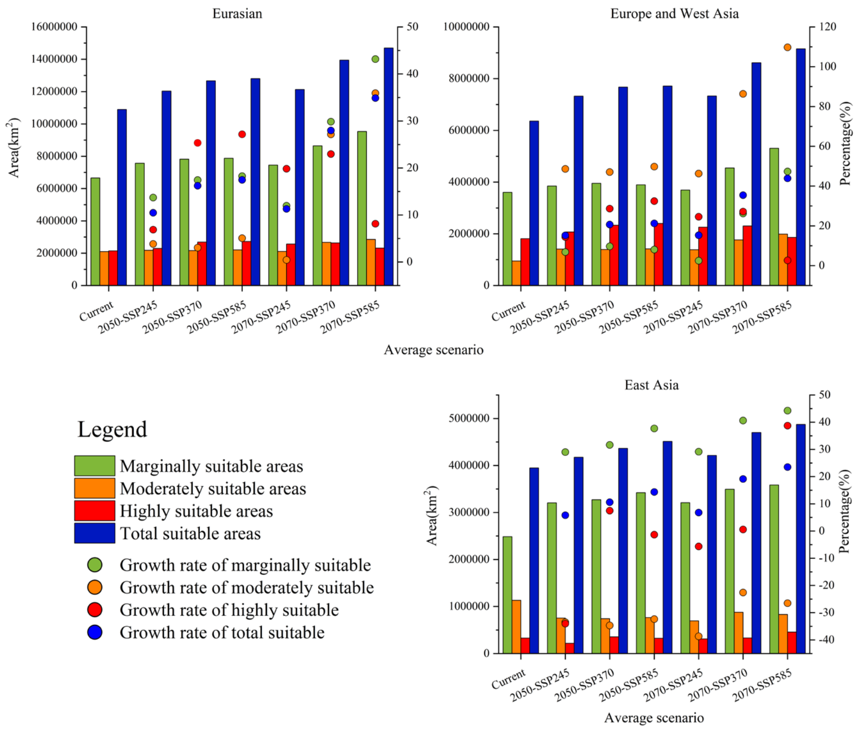


Figure 3. Predicted suitable areas for *O. robiniae* under current and future climatic conditions (km2) and Percentage (%) of increase/decrease (compared to the current suitable areas)

Figure 4 illustrates the trends of the expansion and contraction of CFD of *O. robiniae*, mainly showing large-scale expansion in the north (red) but small-scale reduction in the south (blue). The central and southern parts of Spain and most of the southern parts of China would gradually become non-suitable areas. However, the European Alps, the Taurus Mountains in West Asia, and the Hexi Corridor in China, which are currently unsuitable areas, would gradually increase the suitable areas of *O. robiniae*. Combined with the trend of centroid change (Figure 5), it can be seen that the centroid of FPD in East Asia and EWA shifted to the northeast, whereas the centroid of East Asia was altered to the northeast of China (azimuth angle 20.03 ± 7.6°), and the centroid in Europe changed at a larger angle, mainly towards central Russia (azimuth angle 40.10 ± 4.74°). With the enhancement of the SSPs emission scenarios, the FPD centroid offset distance was also increasing. The farthest EWA SSP585 scenario in 2070 was 773.81 km from the current centroid. At that time, the *O. robiniae* suitable area would cross the Ural Mountains, reaching the West Siberian Plain.

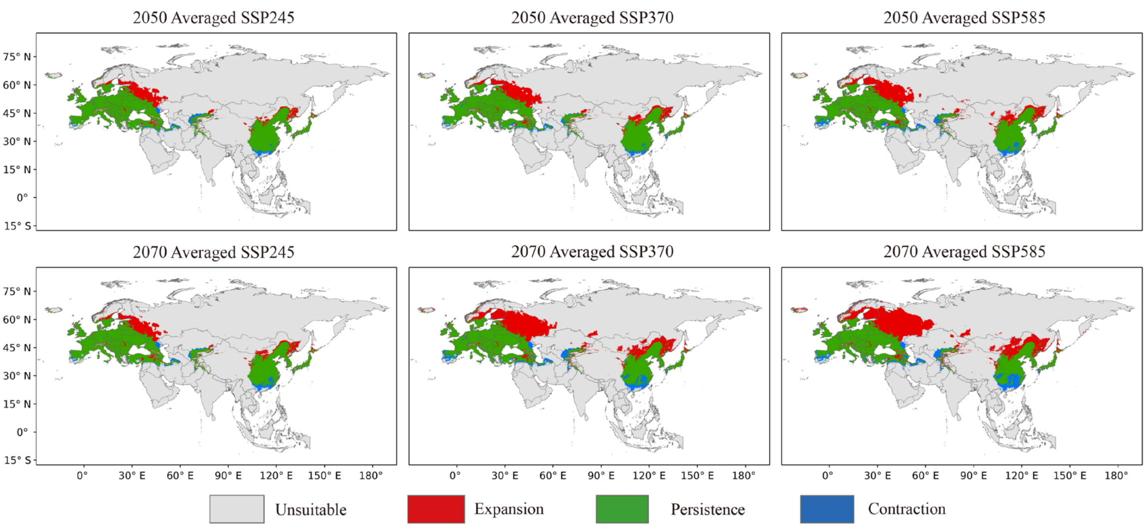


Figure 4. Shift in the *O. robiniae* average potential distribution range under the

three climate change scenarios for 2050( 2041-2060)and 2070 ( 2061-2080), compared with the current potential distribution.(green correspond to areas of persistence, blue of the contraction zone, and the red is the expansion zone).Spatial resolution: 2.50 minutes

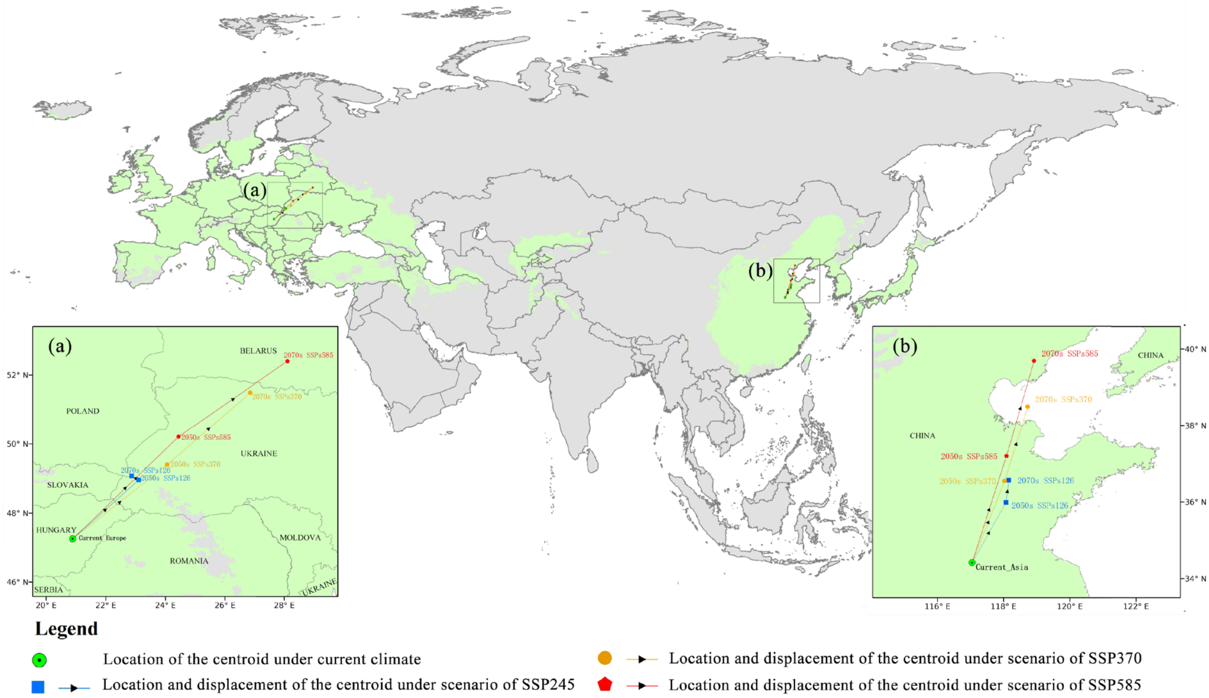


Figure 5. Map of centroids range shifts depicts the predicted future distribution changes under each scenario. Each line depicts predicted distributional shifts of *O. robiniae* range centroid from current (start of arrow) to 2070 (end of arrow) scenarios. Green represents the current potential distribution of *O.robiniae*, while a green circle represents the current centroid

## 4. Discussion

The assessment and prediction of impact of invasive alien species on a global scale have attracted considerable research attention (Tingley et al., 2014; Zhu et al., 2020). *O. robiniae*, originating from the Nearctic region, has invaded almost simultaneously from the eastern and western parts of Eurasia at the beginning of the 21st century and then spread explosively mainly due to the perception that it did not pose a major risk to forest stands, frequent trade activities, and the widespread presence of its host *R. pseudoacacia* (Tóth et al., 2009; Tóth et al., 2011). However, our research discovered that human negligence was the major cause for its spread in almost every corner of the distribution of *R. pseudoacacia* in China. It is distributed not only in the coastal protective and timber forests, as well as other forest lands, but is also widely distributed in urban corners such as university campuses, wetland parks, and residential neighborhoods. *O. robiniae* is reproduced illegally in China. A compound leaf can contain a maximum of 54 galls, and a maximum of 18 larvae can feed gregariously within each gall, leading to damage rates reaching 90%–100% in July and August (Bakay and J., 2010; Han et al., 2010; Wang et al., 2006). The infestation of *O. robiniae*, which perms the crown of black locusts into "curls", has a serious ecological and socio-economic impact. Furthermore, its distribution range continues to expand outwards, reaching the city of Lanzhou in 2017 (It had previously spread only to Tianshui in western China). Although *O. robiniae* is a newly introduced species, it is already a common insect, because of its unique galls and exclusive host features, which make its identification easy and accurate; it can be easily found by careful observation of black locust leaves (Петров, 2019). To prevent the further spread of *O. robiniae*, it is essential to identify the main climatic factors influencing the distribution of *O. robiniae* and to predict the potential distribution area. MaxEnt software has high reliability as a model for predicting the potential distribution area of species (Peterson et al., 2007).

### 4.1. Analysis of model results and CPD

We have completed the first study of the potential range of *O. robiniae* distribution in Eurasia using MaxEnt software, based on literature evidence and data obtained from GBIF and a comprehensive field survey conducted in China. Through relevant screening of the available occurrence records, optimization of bioclimatic variables, and adjustment of model parameters, the performance of the present MaxEnt model was confirmed to be good; the ROC curve and omission rates (Figure S6) objectively validated these results.

In this study, the suitable and non-suitable areas were defined by the LPT, indicating that the CPD of *O. robiniae* was distributed between 21.58–48.05°N in East Asia and between 34.96–65.66°N in Europe. The results showed that the distribution of *O. robiniae* was strongly driven by three factors: Annual Mean Temperature (Bio1), Annual Precipitation (Bio12), and Precipitation of the Driest Month (Bio14). The most suitable climate for *O. robiniae* breeding is under the following values of the main factors: Bio1 = 9.42 °C, Bio12 = 798.15 mm, and Bio14 = 46.94 mm (Figure S7b-d). These results were in line the data obtained from our survey in China where *O. robiniae* was heavily infested, and in which we found that not only the degree of harm caused by *O. robiniae* in semi-humid, semi-arid, and warm areas was serious, but also the number of the larvae in a single gall was significantly larger. These areas were also areas with strong germination and tillering abilities of the host black locust, highly overlapping with the moderately and highly suitable areas of the CPD of *O. robiniae*. Because adults only lay eggs on newly sprouted leaves, these areas also provided facilities and chances for the prolific expansion of *O. robiniae*.

We used climate data collected from the latest WorldClim Version 2.1, but, compared with the current period (2021) released at the time of manuscript preparation, there was still a lack of 20-year data, and a remarkable trend in the climate warming is observed for the period from 2000 to present time(Fan et al., 2021; Wu et al., 2019), so the predictive result of the CPD of *O. robiniae* is rather conservative. In addition, the host black locust is widely planted in parks, roadsides, and other areas in many countries: sites that are significantly influenced by human management. For example, we found planted black locusts in residential quarters and parks in Turpan, Xinjiang, China. By human management, a microclimate suitable for its growth was created, which promoted the growth of these black locust trees. This unique artificial microclimate (Bakay and Kollár, 2014), combined with the biological characteristics of *O. robiniae* larvae, whose supercooling point is -12.19 °C (data not published) and that overwinter as cocoons in the soil, would certainly facilitate their successful future establishment and spread in Turpan. The aforementioned two points inferred that the suitable area of *O. robiniae* in Eurasia was wider than the CPD range predicted.

### 4.2. Analysis of the trends of the FPD of *O. robiniae*

In 2050s and 2070s, along with global climate warming, the FPD of *O. robiniae* would continue to expand in the Eurasian continent, mainly to the north. The average suitable area in 2050 would increase by 14.72 ± 4.26% compared to the CPD area, and the area in 2070 would be expanded by 8.56 ± 7.81% compared with the area in 2050, dominated by an increase in the marginally and moderately suitable areas. These results show that *O. robiniae* is a beneficiary of climate warming. Although the southern regions of China and Spain would no longer be suitable for *O. robiniae* due to high temperature and humidity changes in the future, the reduced area is far less than the increased area to the north (Figure 4), with the largest expansion in EWA, averaging 1,607,771.89 $km^2$, 3.23 times larger than the area of growth in East Asia. Similar results were obtained in the shifts movement of the centroids. The average moving distance of centroids in EWA in 2070 was predicted to be 554.98 km, which is 23.77% more than the offset distance of centroids in East Asia. Currently, *O. robiniae* has covered the black locust planting area on a large scale in the Eurasian continent, and its FPD expansion trend is highly coincident with the FPD expansion trend of black locust in Europe (Puchałka *et* *al.*, 2021), which provides an opportunity for the explosive spread of *O. robiniae* into a large area in the future.

The impact of climate change on the distribution of species is becoming increasingly more significant. IPCC AR6 has performed a large number of scientific assessments and concluded that the recent global warming has been more widespread, faster, and more intense than that observed for thousands of years (CLIMATE（IPCC）, 2020). Studies have shown that changes in the trend of FPD may appear earlier than previously expected. For example, black locust seems to have a high potential to adapt to changes in climatic conditions, and its potential distribution in Eastern Europe may increase 20 years earlier than previously predicted (Klisz *et al.*, 2021). Although we have not yet found any infestation of *O. robiniae* in Heilongjiang Province, China (Changchun, Jilin Province, has the northernmost occurrence records in China.), during our surveys we established that the local semi-humid environment may be suitable for *O. robiniae* colonization, which also requires regular observations of the margins where *O. robiniae* has been recorded to occur. It is likely that in this year it has already spread 200 km outwards.

### 4.3. Final considerations and quarantine management measures

*O. robiniae* is a monophagous pest that solely attacks the black locust, which is also native to North America. Black locust is considered a problematic woody plant. It has long been controversy whether the black locust is a beneficial plant. As a result, whether *O. robiniae* is an invasive species is likewise debatable. *Robinia pseudoacacia* is regarded a contributor to forest stand and biodiversity degradation in several European countries, and it has a vast and aggressive root system (Rumlerová et al., 2016), and has even been blacklisted in some European countries, including Switzerland, Norway, the Czech Republic, Italy and Germany (Vítková *et al.*, 2020). However, black locust is also useful for social development, as a supplementary fodder source for the animal industry, as a quality timber plant, and as a rehabilitation plant for reclaimed mining areas, *etc.* (Filcheva et al., 2000; Vítková et al., 2017). In Hungary, *R. pseudoacacia* occupies 24% of the country's forest area and provides 25% of the annual wood production (Honfy et al., 2021; Tobisch and Kottek, 2013). In South Korea, *R. pseudoacacia* provides more than 70% of the honey production, accounting for a large proportion of farmers' income (Kim et al., 2021). In China, *R. pseudoacacia* is a pioneer tree species used for afforestation in the arid areas of North China and Northwest China, which is of great significance for ensuring ecological security (Yin et al., 2014). There are also industrial and medical studies on green corrosion inhibitor and antioxidant, cytotoxic and antitumor activities of black locust fruit and flower extracts (Bratu et al., 2021; Pourzarghan and Fazeli-Nasab, 2021). Furthermore, society accepts black locust as an internal part of the landscape (Fischer *et al.*, 2011). Therefore, black locust can more likely be considered to be a deliberately introduced alien species, which is now naturalized. However, *O. robiniae* is more like a "stowaway," the high-level infestation of black locust by *O. robiniae* has directly or indirectly caused serious ecological and economic impacts. It can be classified as an alien invasive species; China has listed it as a quarantine object (Mihajlović et al., 2008).

Although many species can spread on their own, biological invasion also has an anthropogenic factor, and long-distance dispersal is often caused by or related to human activities (Gilbert *et al.*, 2005). For example, motorway networks are involved in the distribution of *O. robiniae*. The transportation of black locust with larvae is an important source of the long-distance transmission of *O. robiniae*, and the adults or the infected leaves may be disseminated by the wheels and other parts of motor vehicles (Pernek and Matošević, 2009). In our investigation, we found that the numbers of *O. robiniae* individuals in cities and villages were not significantly different (Bakay and Kollár, 2014), abundant pest occurrence was observed on isolated hills or small islands in the middle of lakes, for which the wind might have played a leading role due to the weak body of adults (Duso et al., 2011). This spread was also closely related to the exponential growth of the population during the growing season and the large-scale cultivation of black locust.

Currently, the natural enemies of *O. robiniae* include predatory insects such as lacewing, ladybeetle, and crickets(Tóth *et al.*, 2011; Yu *et al.*, 2009), as well as parasitic insects- *Platygaster robiniae* Buhl and Duso, *Systasis obolodiplosis* Eulophidae, Genus Systasis Walker species, *etc.* (Tóth et al., 2011;

Yao et al., 2009), among which *Platygaster robiniae* occupies a dominant position in parasitic wasps. It has been detected in European and East Asian countries, where it is considered to be among the key factors that reduce the population density of *O. robiniae* (Bella, 2007; Buhl and Duso, 2008; Lu et al., 2010). However, the outbreak period of *Platygaster robiniae* lags behind that of *O. robiniae*, and its role in population reduction is exerted mainly from the 3rd *O. robiniae* generation and thereafter. Even when *O. robiniae* is parasitized, parasitic wasps would delay the development stage, staying in a prolonged egg stage or embryonic period until the host larva has almost fully grown, and would not prevent the leaves from curling and forming galls; thus, an ideal control effect cannot be achieved (Kim et al., 2011). We believe that, in addition to biological control, human intervention is necessary to prevent the spread of *O. robiniae.* Due to the protection to *O. robiniae* provided by the gall during the vegetation period and the high reproductive power of females, early prevention and control can be more effective as management strategies. Therefore, winter and spring are the key periods when prevention and control should be realized. After the leaf fall of black locust at the end of October, the fallen leaves should be timely cleaned, burned, and buried to prevent larvae overwintering. In spring, the leaf-expansion period of black locust is also a peak period of overwintering adult emergence. Sprays with systemic insecticides are also an effective approach against the spread of the pest. The main strategies for pest management are the control of the total occurrence of larvae, achieving a reduction in the population density and the occurrence base of pests, and obtaining one-time protection ensuring no harm throughout the year (Mu et al., 2010; Park et al., 2009).

Climate warming causes the spring phenology of plants in most parts of the world to be ahead of schedule, such as leaf bud opening, leaf spreading, and flowering, which further affects predator activities (Fitter and Fitter, 2002; Ma et al., 2021). *O. robiniae* is a beneficiary in this respect. It is an adaptive multivoltine insect whose numbers of generations change with the alterations in the temperature and host. In Europe, a number of 2-4 generations a year is common, whereas seven generations a year were observed in Lunan area of China. With climate warming, the abundance and destructive activities of *O. robiniae* will increase, which will reduce the growth rate of black locust in large areas (Bella, 2014; Zhao et al., 2011). Although it seems that *O. robiniae* has not reached the status of pests until now, this status may change over time. Hence, its future occurrence and possible economic importance should be carefully monitored. The rapid spread of *O. robiniae* is due to its fast reproduction and wide spread of its host. Similarly to the current coronavirus disease 2019 (COVID-19) pandemics, it has a greater potential impact on human life and natural environment. Its control or eradication after its invasion and spread have started are extremely difficult and costly(Vaes-Petignat and Nentwig, 2014). Therefore, it is strongly recommended that corresponding control measures have been promptly undertaken, based on the predicted FPD trend of *O.*

*robiniae* distribution, to prevent its further spread.

## 5. Conclusions

This study was based on a field survey of *O. robiniae* in China, a thorough understanding of the biological characteristics of *O. robiniae*, and the development of various models through appropriate parameter screening, breaking the limitations of previous modeling based solely on literature or database occurrences. The results of the existing and projected future appropriate regions show that *O. robiniae* will benefit from global warming. Temperature is the primary predictor of *O. robiniae* distribution. A large-scale northward expansion tendency with temperature elevation characterizes the region suited for *O. robiniae* habitat. Our investigation found that human neglect was the primary source for *O. robiniae* spread in almost every corner of the distribution of *R. pseudoacacia* in China. It has a bigger potential impact on human life and the natural environment, similar to the current COVID-19 pandemics. Controlling or eradicating it after its invasion and spread has begun is exceedingly tough and costly. The existing and future possible distribution and change patterns of *O. robiniae* are more intuitively described by ecological niche models. This information would help the forestry quarantine departments of Asian and European nations provide early warnings about the probable distribution regions of *O. robiniae*, as well as offer a scientific basis for the prevention and control of *O. robiniae* spread and outbreaks.

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## Data Availability Statement

The Global Climate Data Version 2.1 dataset was acquired from https://www.worldclim.org/data/index.html.The data used in this study are available at https://zenodo.org/record/6326587#.YiGCwMiKvZs.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Supplementary Data

Supplementary data to this article can be found online at version of this article.

## References

Ashoori A, Kafash A, Varasteh Moradi H, Yousefi M, Kamyab H, Behdarvand N, et al. Habitat modeling of the common pheasant Phasianus colchicus (Galliformes: Phasianidae) in a highly modified landscape: application of species distribution models in the study of a poorly documented bird in Iran. The European Zoological

Journal 2018; 85: 372-380.https://doi.org/10.1080/24750263.2018.1510994

Bakay L, J. K. Insect pests on the black locust (Robinia pseudoacacia L.) in the locality Čebovce. Acta horticulturae et regiotecturae (online), 2010; 13: 55-57.

Bakay L, Kollár J. Influence of urban environment on the population biology of alien insect species: *Obolodiplosis robiniae* (Haldeman, 1847), Parectopa robiniella Clemens, 1863 and Phyllonorycter robiniella Clemens, 1859 in conditions of Slovakia. Pensee 2014; 76: 88-94.

Bálint J, Neacşu P, Balog A, Fail J, Vétek G. First record of the black locust gall midge *Obolodiplosis robiniae* (Haldeman)(Diptera: Cecidomyiidae) in Romania. North-Western Journal of Zoology 2010; 6: 319-322.https://doi.org/10.1515/MAMM.2010.044

Bella S. Presenza di *Obolodiplosis robiniae* (Haldeman, 1847) in Italia centro-meridionale e in Sicilia (Diptera Cecidomyiidae). Bollettino di Zoologia agraria e di Bachicoltura 2007: 239-242.

Bella S. Invasive insect pests and their associated parasitoids on ornamental urban plants on Corfu island - Steyskal and Spencer 1978 (Diptera, Agromyzidae) a new record in Greece. Hellenic Plant Protection Journal 2014; 7: 53-59.https://doi.org/10.1002/er.1211

Berest Z, Titar V. Robinieva krajova galicja (Obolodiplosis robiniae)(Diptera: Cecidomyiidae), mozlivist podalsogo rozsirennja arealu v Ukraini. Karantin i Zachist rostlin 2007; 7: 24-26.

Boria RA, Olson LE, Goodman SM, Anderson RP. Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. Ecological modelling 2014; 275: 73-77.https://doi.org/10.1016/j.ecolmodel.2013.12.012

Bratu MM, Birghila S, Stancu LM, Mfflai CC, Emoke P, Popescu A, et al. Evaluation of the antioxidant, cytotoxic and antitumoral activities of a polyphenolic extract of Robinia Pseudoacacia L. flowers. Journal of Science and Arts 2021; 21: 547-556.https://doi.org/10.46939/J.Sci.Arts-21.2-b04

Brown JL, Bennett JR, French CM. SDMtoolbox 2.0: the next generation Python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. PeerJ 2017; 5: e4095.https://doi.org/10.7717/peerj.4095

Buhl PN, Duso C. Platygaster robiniae n. sp.(Hymenoptera: Platygastridae) parasitoid of *Obolodiplosis robiniae* (Diptera: Cecidomyiidae) in Europe. Annals of the Entomological Society of America 2008; 101: 297-300.https://doi.org/10.1037/a0017578

CLIMATE（IPCC） IPO. The IPCC and the Sixth Assessment cycle. IPCC, 2020.

Descombes P, Pitteloud C, Glauser G, Defossez E, Kergunteuil A, Allard P-M, et al. Novel trophic interactions under climate change promote alpine plant coexistence. Science 2020; 370: 1469-1473.https://doi.org/10.1126/science.abd7015

Diagne C, Leroy B, Vaissière A-C, Gozlan RE, Roiz D, Jarić I, et al. High and rising economic costs of biological invasions worldwide. Nature 2021; 592: 571-576.https://doi.org/10.1038/s41586-021-03405-6

Duso C, Boaria A, Surian L, Buhl P. Seasonal abundance of the nearctic gall midge

*Obolodiplosis robiniae* in Italy and the impact of its antagonist Platygaster robiniae on pest populations. Annals of the Entomological Society of America 2011; 104: 180-191.https://doi.org/10.1603/an10030

Duso C, Fontana P, Tirello P. Spread of the gall midge *Obolodiplosis robiniae* (Haldeman) injurious to black locust in Italy and Europe. Informatore Fitopatologico 2005; 55: 30-33.

Essl F, Lenzner B, Bacher S, Bailey S, Capinha C, Daehler C, et al. Drivers of future alien species impacts: An expert-based assessment. Global Change Biology 2020; 26: 4880-4893.https://doi.org/10.1111/gcb.15199

Fan X, Miao C, Duan Q, Shen C, Wu Y. The performance of CMIP6 versus CMIP5 in simulating temperature extremes over the global land surface. Journal of Geophysical Research: Atmospheres 2020; 125: e2020JD033031.https://doi.org/10.1029/2020JD033031

Fan X, Miao C, Duan Q, Shen C, Wu Y. Future Climate Change Hotspots Under Different 21st Century Warming Scenarios. Earth's Future 2021; 9: e2021EF002027.https://doi.org/10.1029/2021EF002027

Fick SE, Hijmans RJ. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International journal of climatology 2017; 37: 4302-4315.https://doi.org/10.1002/joc.5086

Filcheva E, Noustorova M, Gentcheva-Kostadinova S, Haigh M. Organic accumulation and microbial action in surface coal-mine spoils, Pernik, Bulgaria. Ecological Engineering 2000; 15: 1-15.https://doi.org/10.1016/S0925-8574(99)00008-7

Fischer A, Bednar-Friedl B, Langers F, Dobrovodská M, Geamana N, Skogen K, et al. Universal criteria for species conservation priorities? Findings from a survey of public views across Europe. Biological conservation 2011; 144: 998-1007.https://doi.org/10.1016/j.biocon.2010.12.004

Fitter A, Fitter R. Rapid changes in flowering time in British plants. Science 2002; 296: 1689-1691.https://doi.org/10.1126/science.1071617

Fois M, Bacchetta G, Cuena-Lombraña A, Cogoni D, Pinna MS, Sulis E, et al. Using extinctions in species distribution models to evaluate and predict threats: a contribution to plant conservation planning on the island of Sardinia. Environmental Conservation 2018; 45: 11-19.https://doi.org/10.1017/S0376892917000108

Fricko O, Havlik P, Rogelj J, Klimont Z, Gusti M, Johnson N, et al. The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century. Global Environmental Change 2017; 42: 251-267.https://doi.org/10.1016/j.gloenvcha.2016.06.004

Fujimori S, Hasegawa T, Masui T, Takahashi K, Herran DS, Dai H, et al. SSP3: AIM implementation of shared socioeconomic pathways. Global Environmental Change 2017; 42: 268-283.https://doi.org/10.1016/j.gloenvcha.2016.06.009

Gilbert M, Guichard S, Freise J, Grégoire JC, Heitland W, Straw N, et al. Forecasting Cameraria ohridella invasion dynamics in recently invaded countries: from validation to prediction. Journal of Applied Ecology 2005; 42: 805-813.https://doi.org/10.1111/j.1365-2664.2005.01074.x

Glavendekić M, Roques A, Mihajlović L. An ALARM case study: the rapid colonization of an introduced tree, black locust by an invasive North-American midge and its parasitoids. Atlas of Biodiversity Risk, Eds. Josef Settle et al. Pensoft, Sofia and Moscow 2009: 24-25.

Haldeman SS. Description of several new and interesting animals. American Journal of Agriculture and Science 1847; 6: 191-194.

Han L, Wu J, Wang D. Occurrence of *Obolodiplosis robiniae* Haldemann and Corresponding Measures to control. Shaanxi Forest Science and Technology 2010: 41-43.https://doi.org/10.3969/j.issn.1001-2117.2010.03.013

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology: A Journal of the Royal Meteorological Society 2005; 25: 1965-1978.https://doi.org/10.1002/joc.1276

Honfy V, Ábri T, Juhász L, Rásó J, Keserű Z, Rédei K. A simplified method for application of natural regeneration in black locust (Robinia pseudoacacia L.) stands in Hungary. Journal of Forest Science 2021; 67: 66-70.https://doi.org/10.17221/147/2020-JFS

Jiang L, O'Neill BC. Global urbanization projections for the Shared Socioeconomic Pathways. Global Environmental Change 2017; 42: 193-199.https://doi.org/10.1016/j.gloenvcha.2015.03.008

Kenis M, Branco M. Impact of alien terrestrial arthropods in Europe. Chapter 5. BioRisk 2010; 4: 51-71.https://doi.org/10.3897/biorisk.4.42

Kim I-K, Park J-D, Shin S-C, Park I-K. Prolonged embryonic stage and synchronized life-history of Platygaster robiniae (Hymenoptera: Platygastridae), a parasitoid of *Obolodiplosis robiniae* (Diptera: Cecidomyiidae). Biological Control 2011; 57: 24-30.https://doi.org/10.1016/j.biocontrol.2010.12.007

Kim K, Lee M-y, Choi Y-S, Kang E-J, Park H-G, Park B-s, et al. Status and Environmental Factors of the Annual Production of Acacia Honey from the False Acacia ( *Robinia pseudoacacia*)in South Korea. Journal of Apiculture 2021; 36(1): 11-16.https://doi.org/10.17519/apiculture.2021.04.36.1.11

Klisz M, Puchałka R, Netsvetov M, Prokopuk Y, Vítková M, Sádlo J, et al. Variability in climate-growth reaction of Robinia pseudoacacia in Eastern Europe indicates potential for acclimatisation to future climate. Forest Ecology and Management 2021; 492: 119194.https://doi.org/10.1016/j.foreco.2021.119194

Kodoi F, Lee H-S, Uechi N, Yukawa J. Occurrence of *Obolodiplosis robiniae* (Diptera: Cecidomyiidae) in Japan and South Korea. Esakia 2003; 43: 35-41.https://doi.org/10.5109/2671

Kriegler E, Bauer N, Popp A, Humpenöder F, Leimbach M, Strefler J, et al. Fossil-fueled development (SSP5): an energy and resource intensive scenario for the 21st century. Global environmental change 2017; 42: 297-315.https://doi.org/10.1016/j.gloenvcha.2016.05.015

Kriegler E, O'Neill BC, Hallegatte S, Kram T, Lempert RJ, Moss RH, et al. The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. Global Environmental Change 2012; 22: 807-822.https://doi.org/10.1016/j.gloenvcha.2012.05.005

Lu C, BUHL PN, DUSO C, Zhao C, Zhang J, Ji Z, et al. First discovery of Platygaster robiniae(Hymenoptera: Platygastridae) parasitizing the invasive *Obolodiplosis robiniae* Diptera:Cecidomyiidae), a gallmaker in China. Acta Entomologica Sinica 2010; 53: 233-237.https://doi.org/10.16380/j.kcxb.2010.02.011

Ma Q, Huang JG, Hänninen H, Li X, Berninger F. Climate warming prolongs the time interval between leaf-out and flowering in temperate trees: Effects of chilling, forcing and photoperiod. Journal of Ecology 2021; 109: 1319-1330.https://doi.org/10.1111/1365-2745.13558

Mack R, Smith M. Invasive plants as catalysts for the spread of human parasites. NeoBiota 2011; 9: 13-29.https://doi.org/10.3897/neobiota.9.1156

Martínez-López O, Koch JB, Martínez-Morales MA, Navarrete-Gutiérrez D, Enríquez E, Vandame R. Reduction in the potential distribution of bumble bees (Apidae: Bombus) in Mesoamerica under different climate change scenarios: Conservation implications. Global Change Biology 2021; 27: 1772-1787.https://doi.org/10.1111/gcb.15559

McCain CM, Garfinkel CF. Climate change and elevational range shifts in insects. Current Opinion in Insect Science 2021; 47: 111-118.https://doi.org/10.1016/j.cois.2021.06.003

Merow C, Smith MJ, Silander Jr JA. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 2013; 36: 1058-1069.https://doi.org/10.1111/j.1600-0587.2013.07872.x

Mihajlović L, Glavendekić MM, Jakovljević I, Marjanović S. *Obolodiplosis robiniae* (Haldeman)(Diptera: Cecidomyiidae): A new invasive insect pest on black locust in Serbia. Glasnik Sumarskog fakulteta 2008: 197-207.https://doi.org/10.2298/GSF0897197M

Molnar B, BodduM T, Szőcs G, HillBur Y. Occurrence of two pest gall midges, *Obolodiplosis robiniae* (Haldeman) and Dasineura gleditchiae (Osten Sacken)(Diptera: Cecidomyiidae) on ornamental trees in Sweden. Entomologisk tidskrift 2009; 130: 113-120.

Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, Van Vuuren DP, et al. The next generation of scenarios for climate change research and assessment. Nature 2010; 463: 747-756.https://doi.org/10.1038/nature08823

Mu X, Sun J, Lu W, Li M, Qu H, Gao Z. Bionomics and control of *Obolodiplosis robiniae* in Beijing. Forest Pest and Disease 2010; 29: 15-18.https://doi.org/10.3969/j.issn.1671-0886.2010.05.005

Negrete L, Lenguas Francavilla M, Damborenea C, Brusa F. Trying to take over the world: Potential distribution of Obama nungara (Platyhelminthes: Geoplanidae), the Neotropical land planarian that has reached Europe. Global Change Biology 2020; 26: 4907-4918.https://doi.org/10.1111/gcb.15208

Nie S, Fu S, Cao W, Jia X. Comparison of monthly air and land surface temperature extremes simulated using CMIP5 and CMIP6 versions of the Beijing Climate Center climate model. Theoretical and Applied Climatology 2020; 140: 487-502.https://doi.org/10.1007/s00704-020-03090-x

Park J-D, Shin S-C, Kim C-S, Jeon M-J, Park I-K. Biological characteristic of *Obolodiplosis robiniae* and control effects of some insecticides. Korean journal of applied entomology 2009; 48: 327-333.https://doi.org/10.5656/KSAE.2009.48.3.327

Pearson RG, Raxworthy CJ, Nakamura M, Townsend Peterson A. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of biogeography 2007; 34: 102-117.https://doi.org/10.1111/j.1365-2699.2006.01594.x

Pernek M, Matošević D. Black Locust Gall Midge (Obolodiplosis robiniae), New Pest on Black Locust Trees and first Record of ParasitoidPlatygaster robinaein Croatia. Šumarski list 2009; 133: 157-163.

Peterson A, Papeş M, Eaton M. Transferability and model evaluation in ecological niche modeling: a comparison of GARP and Maxent. Ecography 2007; 30: 550-560.https://doi.org/10.1111/j.0906-7590.2007.05102.x

Phillips SJ, Anderson RP, Schapire RE. Maximum entropy modeling of species geographic distributions. Ecological modelling 2006; 190: 231-259.https://doi.org/10.1016/j.ecolmodel.2005.03.026

Pourzarghan V, Fazeli-Nasab B. The use of *Robinia pseudoacacia* L fruit extract as a green corrosion inhibitor in the protection of copper-based objects. Heritage Science 2021; 9: 1-14.https://doi.org/10.1186/s40494-021-00545-w

Puchałka R, Dyderski MK, Vítková M, Sádlo J, Klisz M, Netsvetov M, et al. Black locust (*Robinia pseudoacacia* L.) range contraction and expansion in Europe under changing climate. Global change biology 2021; 27: 1587-1600.https://doi.org/10.1111/gcb.15486

Radosavljevic A, Anderson RP. Making better Maxent models of species distributions: complexity, overfitting and evaluation. Journal of biogeography 2014; 41: 629-643.https://doi.org/10.1111/jbi.12227

Raza MM, Khan MA, Arshad M, Sagheer M, Sattar Z, Shafi J, et al. Impact of global warming on insects. Archives of Phytopathology and Plant Protection 2015; 48: 84-94.https://doi.org/10.1080/03235408.2014.882132

Rumlerová Z, Vilà M, Pergl J, Nentwig W, Pyšek P. Scoring environmental and socioeconomic impacts of alien plants invasive in Europe. Biological invasions 2016; 18: 3697-3711.https://doi.org/10.1007/s10530-016-1259-2

Saha A, Rahman S, Alam S. Modeling current and future potential distributions of desert locust Schistocerca gregaria (Forskål) under climate change scenarios using Maxent. Journal of Asia-Pacific Biodiversity 2021; 14: 399-409.https://doi.org/10.1016/j.japb.2021.05.001

Seebens H, Bacher S, Blackburn TM, Capinha C, Dawson W, Dullinger S, et al. Projecting the continental accumulation of alien species through to 2050. Global Change Biology 2021; 27: 968-969.https://doi.org/10.1111/gcb.15333

Shao X, Ma X, Shao K, Lu J, Kao G. Occurrence,endangered grade and prevention and control experiments of *Oblodiplosis robiniae*. Liaoning forestry science and technology 2010: 31-32+45+49.https://doi.org/10.3969/j.issn.1001-1714.2010.04.010

Sillero N. What does ecological modelling model? A proposed classification of ecological niche models based on their underlying methods. Ecological Modelling 2011; 222: 1343-1346.https://doi.org/10.1016/j.ecolmodel.2011.01.018

Skuhravá M, Skuhravý V, Csóka G. The invasive spread of the gall midge *Obolodiplosis robiniae* in Europe. Cecidology 2007; 22: 84-90.

Tang B, Hu W, Duan A, Gao K, Peng Y. Reduced Risks of Temperature Extremes From 0.5°C less Global Warming in the Earth's Three Poles. Earth's Future 2022; 10: e2021EF002525.https://doi.org/10.1029/2021EF002027

Tingley R, Vallinoto M, Sequeira F, Kearney MR. Realized niche shift during a global biological invasion. Proceedings of the National Academy of Sciences 2014; 111: 10233-10238.https://doi.org/10.1073/pnas.1405766111

Tobisch T, Kottek P. Forestry-related databases of the Hungarian forestry directorate. National Food Chain Safety Office (NFCSO) 2013: <http://www.nebih.gov.hu/> (accessed 25.05.16).

Tóth P, Váňová M, Lukáš J. The distribution of *Obolodiplosis robiniae* on black locust in Slovakia. Journal of pest science 2009; 82: 61-66.https://doi.org/10.1007/s10340-008-0220-2

Tóth P, Váňová M, Lukáš J. Impact of natural enemies on *Obolodiplosis robiniae* invasion. Biologia 2011; 66: 870-876.https://doi.org/10.2478/s11756-011-0089-z

Uechi N, Yukawa J, Usuba S. Recent distributional records of an alien gall midge, *Obolodiplosis robiniae* (Diptera: Cecidomyiidae) in Japan, and a brief description of its pupal morphology. Kyushu Plant Protection Research 2005; 51: 89-93.https://doi.org/10.4241/kyubyochu.51.89

Vaes-Petignat S, Nentwig W. Environmental and economic impact of alien terrestrial arthropods in Europe. NeoBiota 2014; 22: 23.https://doi.org/10.3897/neobiota.22.6620

Vanbergen AJ, Espíndola A, Aizen MA. Risks to pollinators and pollination from invasive alien species. Nature ecology & evolution 2018; 2: 16-25.https://doi.org/10.1038/s41559-017-0412-3

Verbruggen H, Tyberghein L, Belton GS, Mineur F, Jueterbock A, Hoarau G, et al. Improving transferability of introduced species’ distribution models: new tools to forecast the spread of a highly invasive seaweed. PLoS One 2013; 8: e68337.https://doi.org/10.1371/journal.pone.0068337

Vilà M, Corbin JD, Dukes JS, Pino J, Smith SD. Linking plant invasions to global environmental change. Terrestrial ecosystems in a changing world. Springer, 2007, pp. 93-102.https://doi.org/10.1007/978-3-540-32730-1_8

Vítková M, Müllerová J, Sádlo J, Pergl J, Pyšek P. Black locust (Robinia pseudoacacia) beloved and despised: A story of an invasive tree in Central Europe. Forest ecology and management 2017; 384: 287-302.https://doi.org/10.1016/j.foreco.2016.10.057.

Vítková M, Sádlo J, Roleček J, Petřík P, Sitzia T, Müllerová J, et al. Robinia pseudoacacia-dominated vegetation types of Southern Europe: Species composition, history, distribution and management. Science of the Total Environment 2020; 707: 134857.https://doi.org/10.1016/j.scitotenv.2019.134857

Wang R, Wang L, Wang S, Li B, Wang Z. A New Pest of Robinia -Preliminary observations on Obolodiplosis robiniae. Journal of Liaoning Agricultural College 2006; 8: 24-25.

Warren DL, Seifert SN. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. Ecological applications 2011; 21: 335-342.https://doi.org/10.1890/10-1171.1

Wermelinger B, Skuhrava M. First records of the gall midge *Obolodiplosis robiniae*

(Haldeman)(Diptera: Cecidomyiidae) and its associated parasitoid Platygaster robiniae Buhl & Duso (Hymenoptera: Platygastridae) in Switzerland. Bull Soc Entomol Suisse 2007; 80: 217-221.

Woo K, Choe H, Kim H. A report on the occurrence of yellow locust midge *Obolodiplosis robiniae* (Haldeman, 1987) from Korea. Korean Journal of Applied Entomology 2003; 42: 77-79.https://doi.org/10.1021/ma9000429

Wu S, Liu L, Gao J, Wang W. Integrate Risk From Climate Change in China Under Global Warming of 1.5 and 2.0 °C. Earth's Future 2019; 7: 1307-1322.https://doi.org/10.1029/2019EF001194

Yan J, Wang S, Li D. A new foreign forest pest found in Shandong-Obolodiplosis robiniae. Shandong Forestry Science and Technology 2007: 60.https://doi.org/

Yang Z, Qiao X, Bu W, Yao Y, Xiao Y, Han Y. First discovery of an important invasive insect pest, *Obolodiplosis robiniae* (Diptera: Cecidomyiidae) in China. Acta Entomologica Sinica 2006; 49: 1050-1053.https://doi.org/10.1016/S1872-2067(06)60034-X

Yao Y, Yang Z, Yan J. A new species of the genus Systasis Walker, 1834 (Hymenoptera: Pteromalidae) parasitizing an important invasive alien insect pest *Obolodiplosis robiniae* (Diptera: Cecidomyiidae) from China. Scientia Silvae Sinicae 2009; 45: 88-90.https://doi.org/10.11707/j.1001-7488.20090815

Yao Y, Zhao W, Shang X. Development of polymorphic microsatellite markers of *Obolodiplosis robiniae* (Haldeman)(Diptera: Cecidomyiidae), a North American pest invading Asia. Journal of insect science 2015; 15: 127-132.https://doi.org/10.1093/jisesa/iev104

Yin D, Du N, Fei X, Wang R. Research Progress of Alien Species of *Robinia pseudoacacia* L. in China. Shandong Forestry Science and Technology 2014; 44: 92-99.https://doi.org/10.3969/j.issn.1002-2724.2014.06.026

Yu J, Lu C, Wen X, Wang J, Zhang L, Song G, et al. The Functional Response of Chrysopa sinica Tjeder to *Obolodiplosis robiniae* (Haldemann) Larvae. Journal of Hebei Norml University of Science ＆ Technology 2009; 23: 21-24.https://doi.org/10.3969/j.issn.1672-7983.2009.04.005

Zang Z. Technical points for the control of *Obolodiplosis robiniae*. China Agricultural Information 2015: 69-70.

Zhang D, Lu C, Wang X, Gao B. Potential Risk Assessment of Obolodiplosis Robininae (Haldemann) in China. Acta Ecologica Sinica 2009; 29: 2155-2161.https://doi.org/10.1007/978-1-4020-9623-5_5

Zhang W, Fu J, Wei G, Sun Y. *Obolodiplosis robiniae* was found in Jilin City. Northern Horticulture 2008: 207.

Zhao C, Gao S, Xue H, Song G, Zhao Z. Biological Features of *Obolodiplosis robiniae* (Haldemann) Adults. Journal of Hebei Norml University of Science＆Technology 2011; 25: 61-65.https://doi.org/10.3969/j.issn.1672-7983.2011.02.014.

Zhao J, Shi J. Prediction of the potential geographical distribution of *Obolodiplosis robiniae* (Diptera: Cecidomyiidae) in China based on a novel maximum entropy model. Scientia Silvae Sinicae 2019; 55: 118-127.https://doi.org/10.11707/j.1001-

7488.20190212

Zhou Y, Zhang Z, Zhu B, Cheng X, Yang L, Gao M, et al. MaxEnt Modeling Based on CMIP6 Models to Project Potential Suitable Zones for Cunninghamia lanceolata in China. Forests 2021; 12: 752.https://doi.org/10.1111/gcb.15333

Zhu G, Illan JG, Looney C, Crowder DW. Assessing the ecological niche and invasion potential of the Asian giant hornet. Proceedings of the National Academy of Sciences 2020; 117: 24646-24648.https://doi.org/10.1073/pnas.2011441117

Петров ДЛ. Повреждающие декоративные древесные растения тератформирующие фитофаги, осуществившие инвазию на территорию Беларуси в текущем столетии. Журнал Белорусского государственного университета. Экология 2019: 24-31.