J. Insect Biodivers. Syst. 09 (4), 711–725

https://jibs.modares.ac.ir

OPEN ACCESS

Tarbiat Modares University Press | Research Article | https://doi.org/10.61186/jibs.9.4.711 | **ISSN**: 2423-8112

Entomological Society of Iran | Biodiversity | *https://zoobank.org/urn:lsid:zoobank.org:48BDDC81-40AA-44B4-8B30-12F9B33B0381*

Maximum entropy modelling to predict the impact of abiotic variables on the potential distribution of *Orthotomicus erosus* (Wollaston) (Coleoptera, Curculionidae, Scolytinae) in Iran

Mona Ghorbanian
Department of Plant Protection, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran.
monaghorbanian@yahoo.com *https://orcid.org/0009-0009-6916-6432*

Azadeh Karimi-Malati
Department of Plant Protection, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran.
a_karimi@guilan.ac.ir *https://orcid.org/0000-0002-0290-3946*

Mahdi Jalaeian
Department of Plant Protection, Rice Research Institute of Iran, (AREEO), Rasht, Iran.
mahdi_jalaeian@yahoo.com *https://orcid.org/0000-0002-1965-9695*

Mahmood Fazeli Sangani
Department of Soil Science, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran.
mfazeli@guilan.ac.ir *https://orcid.org/0000-0001-7259-6593*

ABSTRACT. Risk assessment is utilized to prioritize preventive measures based on the probability of dispersal success of pests. A main part of the risk assessment procedure is to determine the effects of environmental variables on the current and potential geographical distributions. In the present study, the spatial distribution of the Mediterranean pine engraver, *Orthotomicus erosus* (Wollaston), was mapped and predicted using *MaxEnt*. Presence records of *O. erosus* (north, northeast, west and centre of Iran), environmental and topographic variables, with the lowest correlations among themselves and the highest effects on the pest distribution were used. A total of 76 presence records of *O. erosus* were collected. The results of the distribution prediction modelling revealed that the northern part of Iran and the areas along the Zagros are the most suitable habitats for this species. Examining environmental variable importance on the distribution of *O. erosus* showed that the variables related to temperature and precipitation had more contribution in the *MaxEnt* model, respectively than the altitude. Furthermore, the high accuracy of the model (0.928) indicated that the *MaxEnt* had an acceptable performance for the prediction of *O. erosus* distribution. These findings would provide primary and critical information about the potential distribution of *O. erosus* in Iran, which could be effective for the stable population regulation of this destructive pest.

Received:
23 June, 2023

Accepted:
13 August, 2023

Published:
20 August, 2023

Subject Editor:
Abbas Ali Zamani

Key words: Climatic variables, ecological niche, jackknife, *MaxEnt*, pine forests

Citation: Ghorbanian, M., Karimi-Malati, A., Jalaeian, M. & Fazeli Sangani, M. (2023) Maximum entropy modelling to predict the impact of abiotic variables on the potential distribution of *Orthotomicus erosus* (Wollaston) (Coleoptera, Curculionidae, Scolytinae) in Iran. *Journal of Insect Biodiversity and Systematics*, 9 (4), 711–725.

INTRODUCTION

In recent decades, billions of coniferous trees have been killed by bark beetles worldwide (Mendel & Halperin, 1982; Bentz et al., 2010; Pernek et al., 2019). More attacks of secondary bark beetles to healthy pines have been reported in response to climate change and long drought periods in Europe, Asia and

Corresponding author: Karimi-Malati, A., *a_karimi@guilan.ac.ir*

America (Kuhnholz et al., 2001). The Mediterranean pine engraver, *Orthotomicus erosus* (Wollaston, 1857) (Coleoptera, Curculionidae, Scolytinae), is an economically important bark beetle and has been found to colonize weakened and even healthy living trees (Jiang et al., 1992; Arkani et al., 2018; Farsani et al., 2018). These beetles cause economic damage to pine trees by feeding on the phloem, disrupting the sap flow as well as transferring phytopathogens and nematodes (Haack, 2004; Akbulut & Stamps, 2012). The Mediterranean pine engraver, as one of the principal bark beetles, was recorded from Tehran, Isfahan, Guilan, Kerman and Kermanshah provinces in Iran (Ahadiyat & Akrami, 2015; Salehi-Jouzani et al., 2016; Arkani et al., 2018; Farsani et al., 2018). Moreover, the pest was responsible for more than 80% of pine destructions in Isfahan (Salehi-Jouzani et al., 2016).

The phenological research of *O. erosus* showed that the number of generations varied from four generations in Turkey to seven generations in Israel (Mendel, 1983; Sarikaya et al., 2013). In Africa, 3–4 generations were reported on pine trees (Lee et al., 2005). In addition, the pheromone traps recorded six generations of *O. erosus* in Tehran, Iran (Arkani et al., 2018). Despite using chemical and biological control (Henin & Paiva, 2004; Cebeci & Baydemir, 2018), the pest damage is still considerable, which could partly be related to the lack of ecological information and the climate impacts on *O. erosus* performance and host preference. Survival, development and distribution of bark beetles are highly correlated with climate conditions (Witkowski et al., 2022), and their outbreaks have been dependent on temperature (Logan & Powell, 2001; Taylor et al., 2006), humidity and precipitation (Berg et al., 2006; Bassett et al., 2011) as well as photoperiod (Mendel et al., 1991). According to research, the high potential for *O. erosus* expansion would be related to climate rather than host availability (Lantschner et al., 2017). Climate change, especially the annual temperature range, can immediately affect the distribution of invasive pests such as bark beetles, altering irreversible forest structure (Lee et al., 2008; Brockerhoff et al., 2013; Hulme, 2017; Pernek et al., 2019).

Ecological niche modelling is an effective method for the distribution prediction of species. The accurate models combine insect presence records and climatic data to generate maps for potential habitat identification and assess the effects of future climate changes on insect distributions (Allouche et al., 2006; Hijmans & Graham, 2006; Zabihi et al., 2021). Suitable habitat predictions have been applied for Hemiptera, Lepidoptera, Diptera, Coleoptera as well as Hymenoptera based on climate changes (Evangelista et al., 2011; Andrew et al., 2013; Kumar et al., 2015; Zabihi et al., 2021; Mao et al., 2022). Furthermore, the *MaxEnt* model was used for bark beetle species (other than *O. erosus*) to predict their potential geographical distribution under current and future climate conditions (Evangelista et al., 2011; Sanchez-Garcia et al., 2015; Sarikaya et al., 2018; Okland et al., 2019; Yu et al., 2019; Li et al., 2021; Ning et al., 2021; Urvois et al., 2021). *MaxEnt*, as a common species distribution model (SDM), uses occurrence records (i.e., presence-only and pseudo-absence) or abundance and climatic variables (i.e., predictors) from the widely used Worldclim database (Tognelli et al., 2009; Elith et al., 2011; Lissovsky & Dudov, 2021). The basic idea of *MaxEnt* is to estimate the unknown distribution probability of a specific species (Phillips et al., 2006).

Due to information deficiency and differences in the biology and ecology of *O. erosus*, the need to develop distribution models seems to be necessary in Iran. In the current study, *MaxEnt* modelling was used to assess the potential establishment risk and present habitat suitability of *O. erosus*. The *MaxEnt* predicted the impacts of climate conditions on *O. erosus* distribution to prepare the forests for future possible outbreaks of the bark beetle in Iran. Despite some studies existing on population density and seasonal fluctuations, there is no information on distribution models and climatic variables affecting the habitat selection of *O. erosus*. Due to the recent population outbreak and worrying dispersal ability of *O. erosus*, the resulting map of this serious pest occurrence will provide useful information to prioritize forest management measures cost-effectively, especially in semi-arid and arid regions. Therefore, comprehensive researches on geographical distribution are necessary to determine the suitable areas for *O. erosus* spread.

MATERIAL AND METHODS

Species records. To determine the current occurrence of *O. erosus,* detailed fieldwork was conducted in the pine forests of Iran during 2019–2020. The bark beetles were collected using an aggregation pheromone trap of *O. erosus* (Econex *O. erosus* from the Spanish company Econex). The specimens were randomly sampled over the geographical extent of the studied area based on the host plant presence, initial observation of bark beetle damage and pheromone availability. We considered at least a 10 km distance between the sampling locations to avoid a geographical bias (Kramer-Schadt et al., 2013; Jalaeian et al., 2018). The records of species occurrence were registered by the pheromone trap catches (68 records), published scientific documents (five records) (Farsani et al., 2018; Amini et al., 2013) and available samples in local collections (three records) (in municipal research centres of 22 districts of Iran) into the dataset. In total, 76 occurrence records were obtained from different areas. The longitude and latitude of the trap locations were recorded by a GPS device (Garmin®) with an accuracy of at least one-hundredth of a decimal degree (DD). Furthermore, the geographical coordinates of the previously studied locations (Farsani et al., 2018; Amini et al., 2013) were georeferenced using Google Earth Pro (Google Inc., 2022).

Predictor variable selection. First, all 20 predictors included 19 climatic variables (bioclim dataset) and one topographic variable (altitude) that were downloaded from the WorldClim database with a spatial resolution of 30 arc-seconds (~1 km²) (Fick & Hijmans, 2017). Country coordinate systems for environmental variables were defined by ArcGIS version 10.2 software (ESRI, 2013) and finally converted to the acceptable form of the *MaxEnt* algorithm. Inappropriate environmental variables which had collinearity (negative effect on each other) or had no effect on the model construction, were removed and not included in the modelling process (Jalaeian et al., 2018). For this purpose, the variance inflation factor (VIF) was applied to find variable collinearity (Marquardt, 1970) and a VIF greater than 10 (signal of the collinearity) was excluded in the R package usdm (Naimi, 2014; Naimi & Araujo, 2016). In the second step, to quantify the variable importance in the distribution prediction model, the Jackknife test in the *MaxEnt* model was considered. In this way, the most important abiotic variables were determined, wherein, the variables that had no contribution to the models were also removed (Jalaeian et al., 2018). Finally, nine variables were selected according to the information related to the pest ecology and its host trees (Taylor et al., 2006; Bassett et al., 2011; Lantschner et al., 2017) (Table 1). Moreover, the response diagrams (the impact of each variable on the predicted probability of species presence) were prepared in a graph.

Species distribution modelling. The *MaxEnt* modelling procedure, version 3.4.4 (Phillips et al., 2023) was used to assess the ecological niche of *O. erosus* based on the presence and background data (Elith et al., 2006; Phillips & Dudik, 2008). In this model, possible distributions of the bark beetle would be evaluated based on the general principle of maximum entropy in each pixel of the studied space (Elith et al., 2006; Hijmans & Graham, 2006; Phillips et al., 2006). The automatic feature selection was applied for running the model, wherein, a randomly selected 75% of the available records were used for model training. For model testing, the remaining data (25%) were selected. Moreover, the maximum number of background points = 10,000; convergence threshold = 0.00001; the maximum number of iterations = 500; and the regularization multiplier = 1. The range between 0 (unsuitable habitat) and 1 (suitable habitat) was considered for probability values of *O. erosus* occurrence. The mean confidence limits over the 10 predicted variables were used for the probability of occurrence maps. The outputs were processed and visualized using ArcGIS 10.2 (ESRI, 2013).

AUC (area under the curve) value analysis was used to evaluate the model performance and measure its accuracy. By calculating the AUC of a receiver operating characteristic (ROC) plot, predicted distributions can be obtained (Elith et al., 2006; Phillips et al., 2006). The AUC values ranged between 0 and 1, representing the worst and the best predictions. A low accuracy model was related to AUC values less than 0.7 (poor performance). The AUC values between 0.7 and 0.8 were acceptable, higher than 0.9 indicated high accuracy or excellent predictive models (Pearce & Ferrie, 2000).

Table 1. Selected predictor variables for distribution of *Orthotomicus erosus* (Wollaston, 1857) in Iran

Variables	Description
bio-01	Annual mean temperature (°C)
bio-05	Maximum temperature of the warmest month (°C)
bio-06	Minimum temperature of the coldest month (°C)
bio-07	Temperature annual range (°C)
bio-10	The mean temperature of the warmest quarter (°C)
bio-12	Annual precipitation (mm)
bio-14	Precipitation of driest month (mm)
bio-18	Precipitation of warmest quarter (mm)
alt	Altitude (m)

RESULTS

Potential geographical distribution. According to Fig 1, the distribution of *O. erosus* was observed in the provinces of Tehran (Chigar Forest Park, Sorkhe hesar national Park, Zaferanieh Park, Abuzar Park, Modares Park and Kaj Park), Guilan (Rasht and Saravan Forest), Fars (Jahrom), Isfahan (Isfahan and Shahin Shahr), Kerman (Kerman and Zarand), Kermanshah (Kermanshah), Khorasan Razavi (Bardaskan and Kashmar) and South Khorasan (Birjand). Potentially suitable distribution areas for *O. erosus* were shown in Fig. 2. The predicted maps (Fig. 2) demonstrated the mean confidence limits of habitat suitability for *O. erosus*. High-suitable and unsuitable areas have been shown with red and blue colours on the map, respectively. The results of the prediction model demonstrated that the northern part of Iran (north and south parts of the Alborz Mountain) and the areas along both sides of the Zagros were the most suitable habitats for this destructive pest (Fig. 2). Oppositely, the central desert areas, the southeast, the border of the Oman Sea and the Persian Gulf, and the southwest areas in Iran had the least probability of *O. erosus* presence.

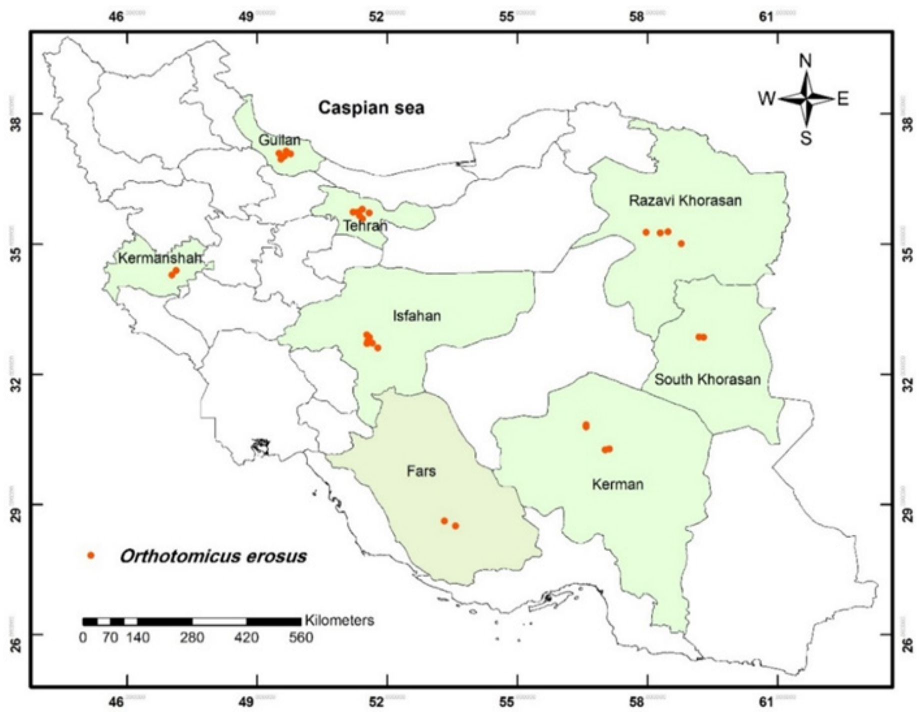

Figure 1. Current distribution map of *Orthotomicus erosus* (Wollaston, 1857) in Iran.

Important variable selection. According to the current results, nine variables were selected among the 20 predictor factors in the initial analysis of the distribution modelling for *O. erosus*, (Table 1). The excluded predictors belonged to the collinear variables or unimportant variables (biologically or statistically) for explaining the species distribution. The importance of the environmental variables that contributed to the distribution model of *O. erosus* was assessed by the Jackknife test and shown in Fig. 3. The red column in each graph shows the total profit for the created model, taking into the effects of all variables, and the green columns show the effect of each removed variable on the total profit of the model. According to Fig. 3, we ranked the variable importance in three groups. The top four contributors of the model including the annual mean temperature (*bio-1*), the average temperature in the warmest quarter (*bio-10*), annual precipitation (*bio-12*) and precipitation of the warmest quarter (*bio-18*) were ranked in the first group. The next group, with a moderate effect on pest distribution, included precipitation of the driest month (*bio-14*), maximum temperature of the warmest month (*bio-5*) and minimum temperature of the coldest month (*bio-6*). The last group that had the least impact on the *O. erosus* distribution consisted of altitude (*alt*) and temperature annual range (*bio-7*).

Response curves of important variables and model accuracy. The response curves (Fig. 4) show the effect of each variable in predicting potential geographical distribution for pest if other factors were constant. Based on Fig. 4a, when the annual mean temperature (*bio-1*) reached 16 °C, the probability of *O. erosus* occurrence was evaluated to be more than 65%. Furthermore, with an increase in the maximum temperature of the warmest month (*bio-5*) from 20 to 37 °C, the occurrence probability of *O. erosus* gradually increased from 20 to >55% (Fig. 4b). The current results revealed that *O. erosus* had a limited tolerance to the minimum temperature of the coldest month (*bio-6*, Fig. 4c). For the variable *bio-7* (temperature annual range), the presence probability increased from 10% at 20 °C to 70% at 27 °C, where the highest presence probability of the pest occurred (Fig. 4d). In addition, the variable *bio-10* (average temperature in the warmest quarter) showed the highest distribution probability in the range of 24–27 °C (Fig. 4e).

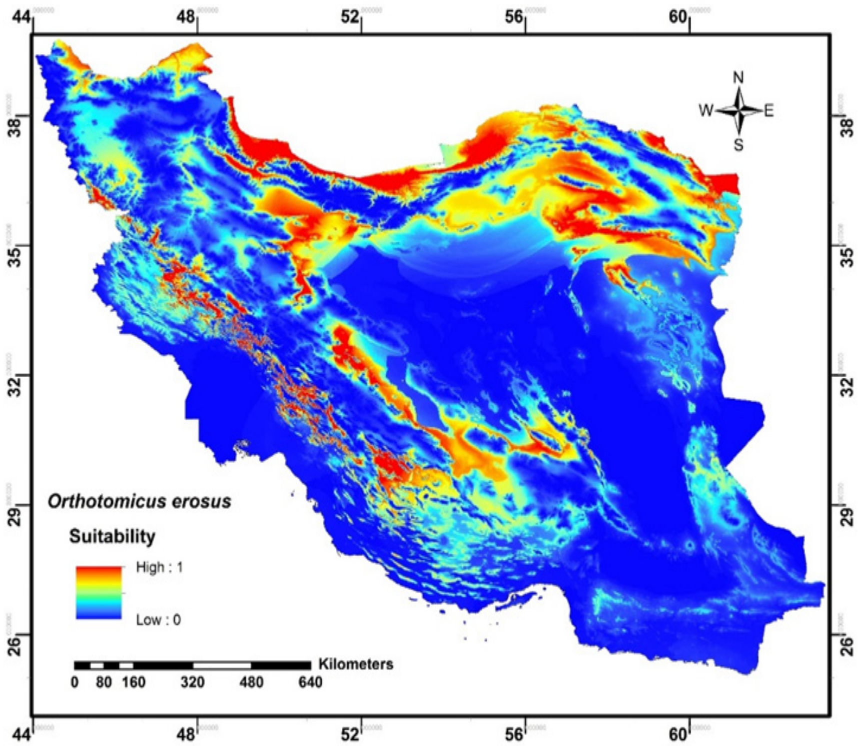

Figure 2. Predicted distribution map of *Orthotomicus erosus* (Wollaston, 1857) in Iran using *MaxEnt*. The red color indicates high suitable habitat and the blue color indicates unsuitable habitat

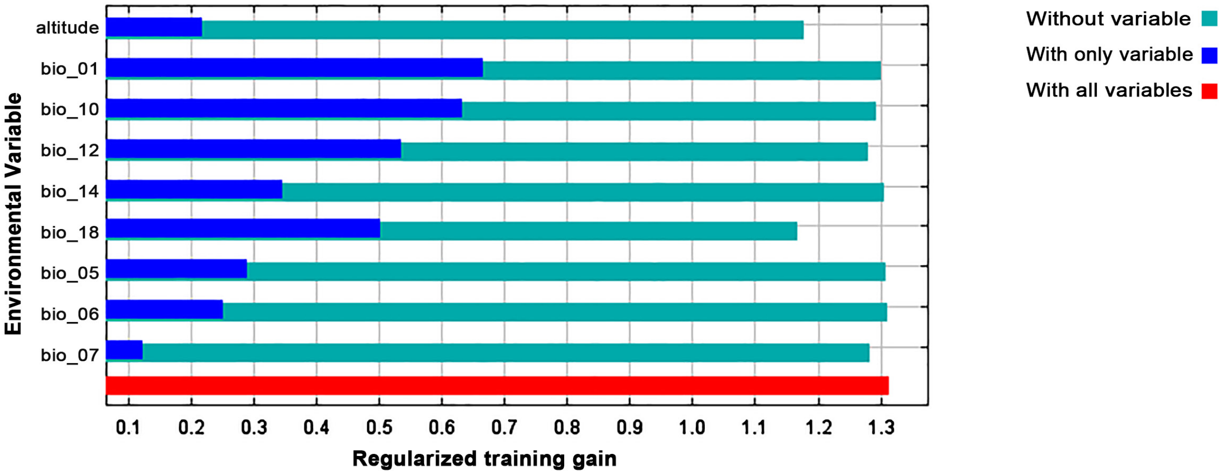

Figure 3. Jackknife test of variable importance for distribution prediction of *Orthotomicus erosus* (Wollaston, 1857) in Iran.

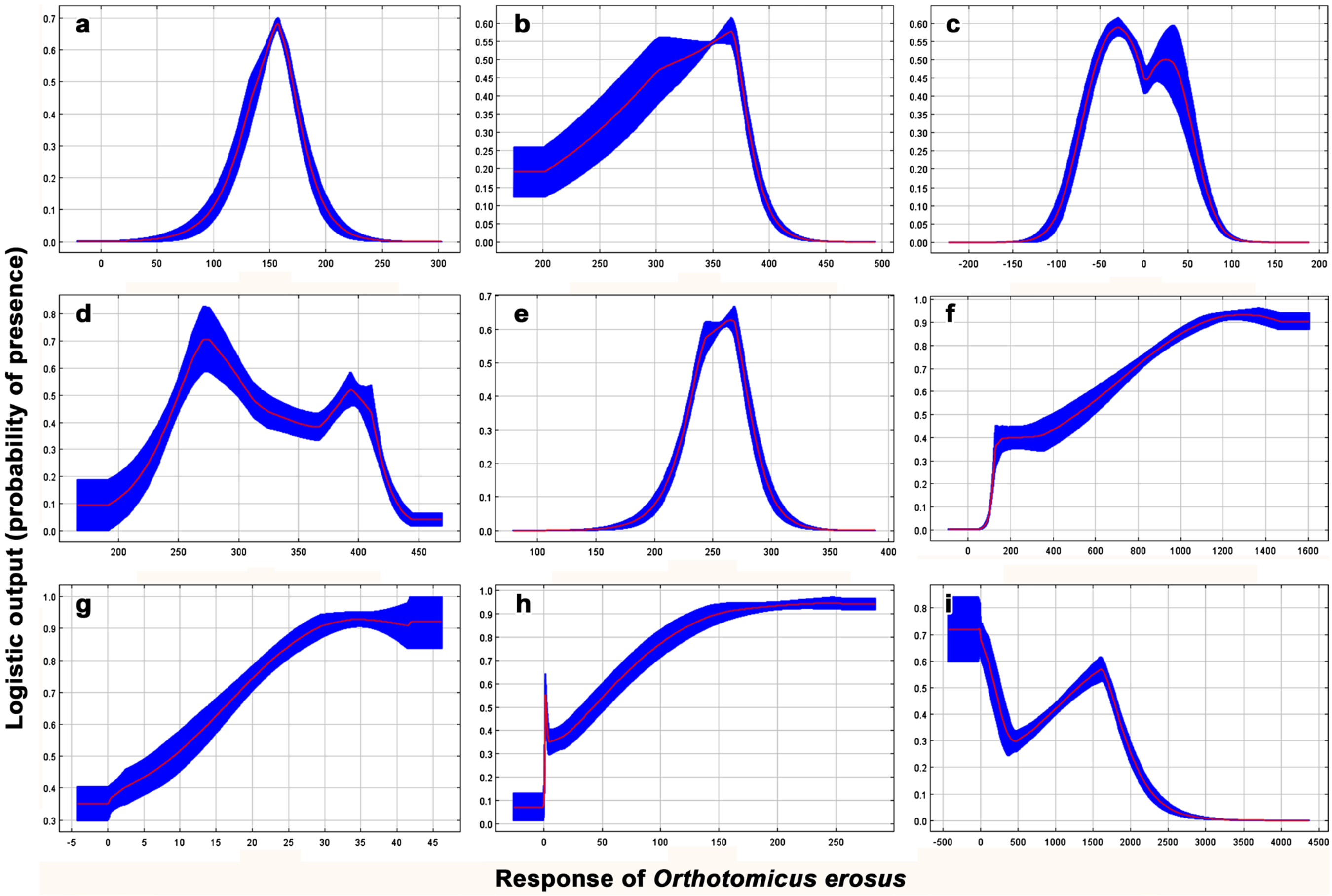

Figure 4. Response curves of important variables for distribution prediction of *Orthotomicus erosus* (Wollaston, 1857) in Iran. The temperature data are in °C × 10. **a.** the marginal response curve of the annual mean temperature (°C × 10) (*bio-1*); **b.** the marginal response curve of the maximum temperature of the warmest month (°C × 10) (*bio-5*); **c.** the marginal response curve of the minimum temperature of the coldest month (°C × 10) (*bio-6*); **d.** the marginal response curve of the temperature annual range (°C × 10) (*bio-7*); **e.** the marginal response curve of the mean temperature of warmest quarter (°C × 10) (*bio-10*); **f.** the marginal response curve of the annual precipitation (mm) (*bio-12*); **g.** the marginal response curve of the precipitation of driest month (mm) (*bio-14*); **h.** the marginal response curve of the precipitation of warmest quarter (mm) (*bio-18*); **i.** the marginal response curve of the elevation (altitude).

According to the Figs 4f–4h, the presence probability of *O. erosus* had a positive relationship with the annual precipitation (*bio-12*), the precipitation of the driest month (*bio-14*) and the precipitation of the warmest quarter (*bio-18*). On the other hand, the altitude increase had negative effects on the distribution of *O. erosus*, except at altitudes of 500–1600 m (Fig. 4i). Based on the accuracy evaluation results of the AUC test, the model had an acceptable performance in predicting the distribution of *O. erosus*. The training and test data revealed that the mean AUC values over the 10 replications were 0.928 for *O. erosus* distribution.

DISCUSSION

The occurrence, survivorship, reproduction and dispersal of bark beetles are closely related to climatic conditions and host species (Avci & Sarikaya, 2009; Qin et al., 2019; Zabihi et al., 2021). The Mediterranean pine engraver, as most abundant bark beetle in Iran, was found to reduce the resistance of pine trees to other xylophagous beetle attacks (Arkani et al., 2018; Farsani et al., 2018). The bark beetle has been recorded from Tehran (Chitgar forest), Fars, Isfahan, Guilan (the forests of Saravan and Rasht), Khorasan Razavi, South Khorasan, Kerman and Kermanshah provinces (Amini et al., 2013; Salehi-Jouzani et al., 2016; Arkani et al., 2018). It should be considered that because of the suitable climatic conditions and the host plant availability, *O. erosus* might be present in other regions where the sampling has not been done (Faccoli et al., 2020). Although the Mediterranean pine bark beetle is native to the central and southern regions of Europe and around the Mediterranean Sea (Mendel & Halperin, 1982), it has a wide distribution in America, Asia, Africa and other parts of Europe (Ozcan et al., 2014; Rassati et al., 2015; Faccoli et al., 2020). The successful dispersal of *O. erosus* to countries outside its native range has led to considerable concern for coniferous species.

The potential distribution prediction would be critical for risk assessment and reducing the negative impacts of pest unexpected attacks (Jimenez-Valverde et al., 2008; Liebhold & Tobin, 2008; Tsoar et al., 2007). Therefore, the *MaxEnt* model was used to illustrate the relationship between the presence probability of *O. erosus* and abiotic variables in Iran at present research. The current results of the distribution model demonstrated that the suitable habitats for *O. erosus* presence included the northern part of Iran and some provinces along the Zagros Mountains as well as parts of the provinces of Kerman, Isfahan and Fars. Although there was a wide distribution of coniferous trees in the central plateau of Iran (deserts with salt marshes, sandy areas, very dry moisture regimes and limited plant cover), the presence probability of *O. erosus* was low based on the distribution prediction map. On the other hand, Avci and Sarikaya (2009) found that the occurrence of other bark beetle species, *O. tridentatus* Eggers, 1921 was dependent on the host plant availability. However, despite the coniferous presence in the southeast, southwest and coast of the Oman Sea and the Persian Gulf, the distribution model predicted the least possibility of *O. erosus* presence. It seems that unfavourable climatic conditions, especially the temperature higher than the pest tolerance might lead to the lack of *O. erosus*.

A comparison between current and predicted distributions of the scolytine species revealed that *O. erosus* was present in the suitable habitats predicted by the model. In other words, large parts of the suitable ecological niches recognized by the model were occupied by *O. erosus* in Iran. In addition, the comparison showed that some other provinces of Iran, including the Golestan, West and East Azerbaijan provinces, were susceptible to the pest presence, although no reports have been recorded so far. In fact, the pest absence in some predicted areas might be due to the lack of ability or opportunity to spread. Therefore, it would be necessary to take more precautions (quarantine) in these predicted suitable areas. In general, the current and predicted geographical distribution showed that the *O. erosus* had no specific ecological habitat and adapted to various climatic conditions as mentioned by Skendzic et al. (2021). It should be considered that despite the strong relationship between the specialist herbivores and host plant distributions, climatic factors are also critical for limiting their geographical distributions (Newbold et al., 2009). According to the present results, predictor variables had different effects on the *O. erosus* distribution in Iran. Temperature-related variables, such as annual mean temperature (*bio-1*), were the strongest predictors according to the jackknife test (66% contribution in the *MaxEnt* model). Ungerer et al. (1999) confirmed the importance of annual temperature on the distribution of *Dendroctonus* bark beetles, wherein, an increase of 3 °C in minimum annual temperature could extend the distribution of *Dendroctonus frontalis* Zimmermann, 1868. Based on Pernek et al. (2019), an increase in temperature led to an increase in the survival, reproductive and developmental rates of *O. erosus* in Croatia.

Based on the model, at 37 °C (the maximum temperature of the warmest month, *bio-5*), there was the highest probability of pest presence and occurrence probability decreased at higher temperatures. Previously, Mendel and Halperin (1982) demonstrated that *O. erosus* had good adaptation to the high temperature, where the daily maximum temperature reached 36 °C in August and the females were capable to oviposit even at 42 °C. However, *O. erosus* completed their development at 40–42 °C only in the moist barks. Fettig et al. (2007) stated that high temperatures negatively affected the distribution of *O. erosus*. Similarly, the flight of *D. ponderosae* Hopkins, 1902 (other bark beetle species) was observed to be restricted at temperatures above 38 °C (McCambridge, 1971). Mendoza et al. (2011) also found that the geographical distribution of *D. rhizophagus* Thomas & Bright, 1970 was limited by the high temperature. Therefore, it seems that the most important climatic factor limiting *O. erosus* distribution in the provinces of Khuzestan, Sistan and Baluchistan and the central desert regions, might be the higher temperature than the pest tolerance.

The present results showed that other than the high temperatures, the minimum temperature of the coldest month (variable *bio-6*), affected the bark beetle distribution and the pest presence was impossible in the regions with a minimum temperature of <-15 °C. So, it seems that colder winter might be the limiting factor in the pest spread to provinces such as the major part of West Azarbaijan, East Azarbaijan, Zanjan and Qazvin. According to other researchers, the survival of overwintering bark beetles was closely related to winter temperature, and mortality increased at temperatures below critical thresholds (Bentz et al., 1991; Bentz & Mullins, 1999; Gan, 2004). However, Gan (2004) demonstrated that only the previous year's winter temperature affected *D. frontalis* outbreak and a warmer winter (1% increase in the previous winter temperature) might lead to a little higher outbreak risk (0.53%) of the southern pine beetle. Findings by Gan (2004) showed that the impact of minimum temperature in the coldest month was relatively insignificant on *D. frontalis* outbreak compared to other season temperatures. It should be noted that the importance of temperature variables was generally higher than other information layers and contained the most important ecological information for *O. erosus* distribution model in Iran.

Humidity variables such as annual precipitation *(bio-12*), precipitation of driest month (*bio-14*) and precipitation of warmest quarter (*bio-18*) were also positively effective on *O. erosus* distribution. On the other hand, Haack (2004) demonstrated that California with a dry climate was a suitable habitat for this pest, but *O. erosus* was not observed in the state of Georgia with a tropical and humid climate. But according to Gomez et al. (2020), *O. erosus* emergence showed no significant relationship with temperature or precipitation in subtropical South America. However, Faccoli et al. (2020) confirmed *O. erosus* presence in the humid Mediterranean conditions of European countries (France, Greece, Hungary, Italy, Portugal and Spain) as well as two non-European countries (Uruguay and South Africa). Similar to our results, Gan (2004) stated that the increases in the winter, spring, and fall precipitation of the previous year resulted in the current outbreak of the southern pine beetle (*D. frontalis*). However, a wetter summer would reduce infestations of the bark beetle three years later. It should be considered that *O. erosus* was present in both dry and humid climatic conditions (provinces near the Caspian Sea) in the current research. Therefore, it seems that despite the precipitation importance, temperature would be a more important limiting factor in *O. erosus* distribution. The topographic variable, altitude (alt) showed a low contribution in the *MaxEnt* model based on the jackknife test. According to the current results, the presence probability of *O. erosus* increased at altitudes 500 m to 1600 m. Taylor et al. (2006) confirmed that outbreaks of bark beetle occurred at altitudes 800–1400 m in British Columbia. Similarly, Avci and Sarikaya (2009) observed the highest presence probability of *O. tridentatus* at altitudes of 1300 to 1785 m. In addition, Sarikaya et al. (2013) observed the highest number of *O. erosus* beetles per trap in the Menderes-Catalca site located at a higher elevation (850 m) compared to five other sampling sites in Turkey (elevation 120–650 m). Despite the direct effect of altitude, it should be noted that the elevation variable can indirectly affect pest dispersal through temperature change or drought, especially in summer (Marini et al., 2012; Cerrato et al., 2016). Therefore, the negative correlation of *O. erosus* distribution with higher altitudes (> 1600 m) might be related to the lower temperature than the pest tolerance.

To evaluate the prediction accuracy of models, various tests have been considered (Guisan & Thuiller, 2005; Allouche et al., 2006; Barry & Elith, 2006). In the current research, the accuracy of the model (AUC) was evaluated to be 0.928, indicating that the distribution model was accurate and displayed reliable performance for predicting *O. erosus* distribution. When the current distribution of species and its potential distribution prediction are limited to the points with special ecological characteristics, AUC shows higher values than species with a wide distribution range (Elith et al., 2006; Hernandez et al., 2006; Jimenez-Valverde et al., 2008). Despite the acceptable performance of the *MaxEnt* model, predictions of pest distributions should be made with caution. One of the most important data on the presence of bark beetles is sampling by traps (Rabaglia et al., 2008). However, trapping alone would not necessarily mean that a species has colonized those particular locations. The geographical distribution of Scolytinae species might be limited by non-climatic factors, preventing a potential niche was occupied by bark beetles. Other possible factors, including the presence of competitors, parasites and pathogenic agents as well as the host plant availability could affect pest distribution (Beaumont et al., 2009). Moreover, prediction models investigate the direct effects of climate on pests, while the indirect effects of climatic factors (for example on host plant distribution) should be also considered. In addition, information about flexibility and adaptation in Scolytinae species would be necessary because the species with higher phenotypic flexibility might have a higher risk of establishment and dispersal (Bentz et al., 2010).

This is the first study to predict the distribution of *O. erosus* based on climate and topographic variables using *MaxEnt* model. The present research provides supplementary insights into existing knowledge of the relationship between abiotic factors and *O. erosus* infestations. Considering that Middle Eastern countries such as Iran are predicted to become warmer and drier under global warming, these findings will be useful in developing effective management strategies for this bark beetle in the current and predicted habitats. However, additional research are strongly recommended to clarify the performance of *O. erosus* under future climate-change scenarios.

AUTHOR'S CONTRIBUTION

The authors confirm their contribution to the paper as follows: M. Ghorbanian: Conceptualization, investigation, data curation, writing – original draft; A. Karimi-Malati: Conceptualization, methodology, formal analysis, supervision, project administration, writing – review & editing; M. Jalaeian: Methodology, formal analysis, writing – review & editing; M. Fazeli Sangani: Writing – review & editing. All authors read and approved the final version of the manuscript.

FUNDING

This work was funded by the University of Guilan, Iran.

AVAILABILITY OF DATA AND MATERIAL

Not applicable.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENTS

This work is a part of the Ph.D. dissertation of the first author that was supported by the University of Guilan (Iran), which is greatly appreciated.

REFERENCES

Ahadiyat, A. & Akrami, M.A. (2015) Oribatid mite (Acari: Oribatida) associated with bark beetles (Coleoptera: Curculionidae: Scolytinae) in Iran, with a review on *Paraleius leontonychus* (Berlese) and a list of bark beetles in association with this species. *Persian Journal of Acarology*, 4, 355–371. https://doi.org/10.22073/pja.v4i4.14730

Akbulut, S. & Stamps, W.T. (2012) Insect vectors of the pinewood nematode: A review of the biology and ecology of *Monochamus* species. *Forest Pathology*, 42, 89–99. https://doi.org/10.1111/j.1439-0329.2011.00733.x

Allouche, O., Tsoar, A. & Kadmon, R. (2006) Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology*, 43, 1223–1232. https://doi.org/10.1111/j.1365-2664.2006.01214.x

Amini, S., Hosseini, R. & Sohani, M.M. (2013) A faunal study of bark beetles (Coleoptera: Curculionidae: Scolytinae) in Guilan province in North of Iran. *Entomofauna*, 34, 169–176.

Andrew, N.R., Hill, S.J., Binns, M., Bahar, M.H., Ridley, E.V., Jung, M.P. & Khusro, M. (2013) Assessing insect responses to climate change: What are we testing for? Where should we be heading? *Peer Journal*, 1, e11. https://doi.org/10.7717/peerj.11

Arkani, T., Ostovan, H., Farazmand, H. & Gheybi, M. (2018) Seasonal population fluctuations of Mediterranean pine bark beetle, *Orthotomicus erosus* (Wollaston) (Coleoptera: Curculionidae: Scolytinae), in the Tehran Chitgar forest park. *IAU Entomological Research Journal*, 9, 309–319.

Avci, M. & Sarikaya, O. (2009) *Orthotomicus tridentatus* Eggers: distribution and biology in cedar forests of Turkey. *Turkish Journal of Agriculture and Forestry*, 33, 277–283. https://doi.org/10.3906/tar-0901-6

Bassett, M.A., Baumgartner, J.B., Hallett, M.L., Hassan, Y. & Symonds, M.R. (2011) Effects of humidity on the response of the bark beetle *Ips grandicollis* (Eichhoff) (Coleoptera: Curculionidae: Scolytinae) to synthetic aggregation pheromone. *Australian Journal of Entomology*, 50, 48–51. https://doi.org/10.1111/j.1440-6055.2010.00780.x

Barry, S. & Elith, J. (2006) Error and uncertainty in habitat models. *Journal of Applied Ecology*, 43, 413–423. https://doi.org/10.1111/j.1365-2664.2006.01136.x.

Beaumont, L.J., Gallagher, R.V., Thuiller, W., Downey, P.O., Leishman, M.R. & Hughes, L. (2009) Different climatic envelopes among invasive populations may lead to underestimations of current and future biological invasions. *Diversity and Distributions*, 15, 409–420. https://doi.org/10.1111/j.1472-4642.2008.00547.x

Bentz, B.J. & Mullins, D.E. (1999). Ecology of mountain pine beetle cold hardening in the Intermountain West. *Environmental Entomology*, 28, 577–587. https://doi.org/10.1093/ee/28.4.577

Bentz, B.J., Logan, J.A. & Amman, G.D. (1991) Temperature-dependent development of the mountain pine beetle (Coleoptera: Scolytidae) and simulation of its phenology. *Canadian Entomologist*, 123, 1083–1094. https://doi.org/10.4039/Ent1231083-5

Bentz, B.J., Regniere, J., Fettig, C.J., Hansen, E.M., Hayes, J.L., Hicke, J.A., Kelsey, R.G. Negron, J.F. & Seybold, S.J. (2010) Climate change and bark beetles of the Western United States and Canada: direct and indirect effects. *BioScience*, 60, 602–613. https://doi.org/10.1525/bio.2010.60.8.6

Berg, E.E., Henry, J.D., Fastie, C.L., De Volder, A.D. & Matsuoka, S.M. (2006) Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes. *Forest Ecology and Management*, 227, 219–232. https://doi.org/10.1016/j.foreco.2006.02.038

Brockerhoff, E.G., Kimberley, M., Liebhold, A.M., Haack, R.A. & Cavey, J.F. (2013) Predicting how altering propagule pressure changes establishment rates of biological invaders across species pools. *Ecology*, 95, 594–601. https://doi.org/10.1890/13-0465.1

Cebeci, H.H. & Baydemir, M. (2018) Predators of bark beetles (Coleoptera) in the Balikesir region of Turkey. *Revista Colombiana de Entomologia*, 44, 283–287. https://doi.org/10.25100/socolen.v44i2.73

Cerrato, C., Lai, V., Balletto, E. & Bonellil, S. (2016) Direct and indirect effects of weather variability in a specialist butterfly. *Ecological Entomology*, 41, 263–275. https://doi.org/10.1111/een.12296

Elith, J., Graham, C.H., Anderson, R.P., Dudik, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M.M., Peterson, A.T., Phillips, S.J., Richardson, K., Scachetti-Pereira, R., Schapire, R.E., Soberon, J., Williams, S., Wisz, M.S. & Zimmermann, N.E. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29, 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x

Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, Y.E. & Yates, C.J. (2011) A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*, 17, 43–57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

ESRI (2013) ARCMAP. *ArcGIS. 10.2.* Environmental Systems Research Institute, Redlands, California.

Evangelista, P.H., Kumar, S., Stohlgren, T.J. & Young, N.E. (2011) Assessing forest vulnerability and the potential distribution of pine beetles under current and future climate scenarios in the Interior West of the US. *Forest Ecology and Management*, 262, 307–316. https://doi.org/10.1016/j.foreco.2011.03.036

Faccoli, M., Gallego, D., Branco, M., Brockerhoff, E.G., Corley, J., Coyle, D.R., Hurley, B.P., Jactel, H., Lakatos, F., Lantschner, V., Lawson, S., Martinez, G., Gomez, D.F. & Avtzis, D. (2020) A first worldwide multispecies survey of invasive Mediterranean pine bark beetles (Coleoptera: Curculionidae, Scolytinae). *Biological Invasions*, 22, 1785–1799. https://doi.org/10.1007/s10530-020-02219-3

Farsani, N.S., Zamani, A.A. & Jamali, S. (2018) Predicting distribution pattern of the Mediterranean pine engraver, *Orthotomicus erosus* (Coleoptera: Curculionidae: Scolytinae), by geostatistics and artificial neural network. *Journal of Entomological Society of Iran*, 38, 331–343. https://doi.org/10.22117/jesi. 2018.120190.1177

Fettig, C.J., Klepzig, K.D., Billings, R.F., Munson, A.S., Nebeker, T.E., Negron, J.F. & Nowak, J.T. (2007) The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. *Forest Ecology and Management*, 238, 24–53. https://doi.org/10.1016/j.foreco.2006.10.011

Fick, S.E. & Hijmans, R.J. (2017) WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37, 4302–4315. https://doi.org/10.1002/joc.5086

Gan, J.B. (2004) Risk and damage of southern pine beetle outbreaks under global climate change. *Forest Ecology and Management*, 191, 61–71. https://doi.org/10.1016/j.foreco.2003.11.001

Gomez, D.F., Skelton, J., Maria, M.D. & Hulcr, J. (2020) Influence of temperature and precipitation anomaly on the seasonal emergence of invasive bark beetles in subtropical South America. *Neotropical Entomology*, 49, 347–352. https://doi.org/10.1007/s13744-019-00760-y

Google Inc. (2022) Google Earth (Version 7.1.1.1871). Retrieved from http://www.google.com/earth/index.html [Accessed at 15th April 2023].

Guisan, A. & Thuiller, W. (2005) Predicting species distribution: offering more than simple habitat models. *Ecology Letters*, 8, 993–1009. http://dx.doi.org/10.1111/j.1461-0248.2005.00792.x

Haack, R.A. (2004) *Orthotomicus erosus*: A new pine-infesting bark beetle in the United States. *Newsletter of the Michigan Entomological Society*, 49, 3.

Henin, J.M. & Paiva, M.R. (2004) Interactions between *Orthotomicus erosus* (Woll.) (Col., Scolytidae) and the Argentine ant *Linepithema humile* (Mayr) (Hym., Formicidae). *Journal of Pest Science*, 77, 113–117. https://doi.org/10.1007/s10340-003-0045-y

Hernandez, P.A., Graham, C.H., Master, L.L. & Albert, D.L. (2006) The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography*, 29, 773–785. https://doi.org/10.1111/j.0906-7590.2006.04700.x

Hijmans, R.J. & Graham, C.H. (2006) The ability of climate envelope models to predict the effect of climate change on species distributions. *Global Change Biology*, 12, 1–10. https://doi.org/10.1111/j.1365-2486.2006.01256.x

Hulme, P. (2017) Climate change and biological invasions: evidence, expectations, and response options. *Biological Reviews*, 92, 1297–1313. https://doi.org/10.1111/brv.12282

Jalaeian, M., Golizadeh, A., Sarafrazi, A. & Naimi, B. (2018) Inferring climatic controls of rice stem borers' spatial distributions using maximum entropy modelling. *Journal of Applied Entomology,* 142, 388–396. https://doi.org/10.1111/jen.12493

Jiang, Y.P., Huang, Z. Y. & Huang, X.C. (1992) Studies on *Orthotomicus erosus*. *Journal of Zhejiang Normal University* (*Natural Sciences*), 15, 79–81.

Jimenez-Valverde, A., Lobo, J.M. & Hortal, J. (2008) Not as good as they seem: The importance of concepts in species distribution modelling. *Diversity and Distributions*, 14, 885–890. https://doi.org/10.1111/j.1472-4642.2008.00496.x

Kramer-Schadt, S., Niedballa, J., Pilgrim, J.D., Schroder, B., Lindenborn, J., Reinfelder, V., Stillfried, M., Heckmann, I., Scharf, A.K., Augeri, D.M., Cheyne, S.M., Hearn, A.J., Ross, J., Macdonald, D.W., Mathai, J., Eaton, J., Marshall, A.J., Semiadi, G., Rustam, R., Bernard, H., Alfred, R., Samejima, H., Duckworth, J.W., Breitenmoser-Wuersten, C., Belant, J.L., Hofer, H. & Wilting, A. (2013) The importance of correcting for sampling bias in MaxEnt species distribution models. *Diversity and Distributions*, 19, 1366–1379. https://doi.org/10.1111/ddi.12096

Kuhnholz, S., Borden, J.H. & Uzunovic, A. (2001) Secondary ambrosia beetles in apparently healthy trees: Adaptations, potential causes and suggested research. *Integrated Pest Management Reviews*, 6, 209–219. https://doi.org/10.1023/A:1025702930580

Kumar, S., Neven, L.G., Zhu, H. & Zhang, R. (2015) Assessing the global risk of establishment of *Cydia pomonella* (Lepidoptera: Tortricidae) using CLIMEX and MaxEnt niche models. *Journal of Economic Entomology*, 108, 1708–1719. https://doi.org/10.1093/jee/tov166

Lantschner, M.V., Atkinson, T.H., Corley, J. C. & Liebhold, A.M. (2017) Predicting North American Scolytinae invasions in the Southern Hemisphere. *Ecological Applications*, 27, 66–77. https://doi.org/10.1002/eap.1451

Lee, J.C., Smith, S.L. & Seybold, S.J. (2005) The Mediterranean pine engraver, *Orthotomicus erosus*. *Pest Alert R5-PR-016*. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 4 p.

Lee, J.C., Flint, M.L. & Seybold, S.J. (2008) Suitability of pines and other conifers as hosts for the invasive Mediterranean pine engraver (Coleoptera: Scolytidae) in North America. *Journal of Economic Entomology*, 101, 829–837. https://doi.org/10.1093/jee/101.3.829

Li, Y., Johnson, A.J., Gao, L., Wu, C. & Hulcr, J. (2021) Two new invasive *Ips* bark beetles (Coleoptera: Curculionidae) in mainland China and their potential distribution in Asia. *Pest Management Science*, 77, 4000–4008. https://doi.org/10.1002/ps.6423

Liebhold, A.M. & Tobin, P.C. (2008) Population ecology of insect invasions and their management. *Annual Review of Entomology*, 53, 387–408. https://doi.org/10.1146/annurev.ento.52.110405.091401

Lissovsky, A.A. & Dudov, S.V. (2021) Species-distribution modeling: advantages and limitations of its application. 2. MaxEnt. *Biology Bulletin Reviews*, 11, 265–275. https://doi.org/10.1134/S2079086421030087

Logan, J.A. & Powell, J.A. (2001) Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). *American Entomologist*, 47, 160–173. https://doi.org/10.1093/ae/47.3.160

Mao, M., Chen, S., Ke, Z., Qian, Z. & Xu, Y. (2022) Using MaxEnt to predict the potential distribution of the little fire ant (*Wasmannia auropunctata*) in China. *Insects*, 13, 1008. https://doi.org/10.3390/insects13111008

Marini, L., Ayres, M.P., Battisti, A. & Faccoli, M. (2012) Climate affects severity and altitudinal distribution of outbreaks in an eruptive bark beetle. *Climatic Change*, 115, 327–341. https://doi.org/10.1007/s10584-012-0463-z

Marquardt, D.W. (1970) Generalized inverses, ridge regression, biased linear estimation, and nonlinear estimation. *Technometrics*, 12, 591–612. https://doi.org/10.2307/1267205

McCambridge, W.F. (1971) Temperature limits of flight of the mountain pine beetle, *Dendroctonus ponderosae*. *Annals of the Entomological Society of America*, 64, 534–535. https://doi.org/10.1093/aesa/64.2.534

Mendel, Z. (1983) Seasonal history of *Orthotomicus erosus* (Coleoptera: Scolytidae) in Israel. *Phytoparasitica*, 11, 13–24. https://doi.org/10.1007/BF02980707

Mendel, Z. & Halperin, J. (1982) The biology and behavior of *Orthotomivus erusus* in Israel. *Phytoparasitica*, 10, 169–181. https://doi.org/10.1007/BF02994526

Mendel, Z., Boneh, O., Shenhar, Y. & Riov, J. (1991) Diurnal flight patterns of *Orthotomicus erosus* and *Pityogenes calcaratus* in Israel. *Phytoparasitica*, 19, 23–31.

Mendoza, M.G., Salinas-Moreno, Y., Olivo-Martinez, A. & Zuniga, G. (2011) Factors influencing the geographical distribution of *Dendroctonus rhizophagus* (Coleoptera: Curculionidae: Scolytinae) in the Sierra Madre Occidental, Mexico. *Environmental Entomology*, 40, 549–559. https://doi.org/10.1603/en10059

Naimi, B. (2014) *usdm: Uncertainty analysis for species distribution models*, R Software Package.

Naimi, B. & Araujo, M.B. (2016) A reproducible and extensible R platform for species distribution modelling. *Ecography*, 39, 368–375. https://doi.org/10.1111/ecog.01881

Newbold, T., Reader, T., Zalat, S. & El-Gabbas, A. (2009) Effect of characteristics of butterfly species on the accuracy of distribution models in an arid environment. *Biodiversity and Conservation*, 18, 3629–3641. https://doi.org/10.1007/s10531-009-9668-5

Ning, H., Tang, M. & Chen, H. (2021) Mapping invasion potential of the pest from Central Asia, *Trypophloeus klimeschi* (Coleoptera: Curculionidae: Scolytinae), in the shelter forests of Northwest China. *Insects*, 12, 242. https://doi.org/10.3390/insects12030242

Okland, B., Flo, D., Schroeder, M., Zach, P., Cocos, D., Martikainen, P., Siitonen, J., Mandelshtam, M.Y., Musolin, D.L., Neuvonen, S., Vakula, J., Nikolov, C., Lindelow, A. & Voolma, K. (2019) Range expansion of the small spruce bark beetle *Ips amitinus*: a newcomer in northern Europe. *Agricultural and Forest Entomology*, 21, 286–298. https://doi.org/10.1111/afe.12331

Ozcan, G.E., Cicek, O., Enez, K. & Yildiz, M. (2014) A new approach to determine the capture conditions of bark beetles in pheromone-baited traps. *Biotechnology and Biotechnological Equipment*, 2, 1057–1064. https://doi.org/10.1080/13102818.2014.974015

Pearce, J. & Ferrie, S. (2000) Evaluating the predictive performance of habitat models developed using logistic regression. *Ecological Modelling*, 133, 225–245. https://doi.org/10.1016/S0304-3800(00)00322-7

Pernek, M., Lackovic, N., Lukic, I., Zoric, N. & Matosevic, D. (2019) Outbreak of *Orthotomicus erosus* (Coleoptera, Curculionidae) on Aleppo pine in the Mediterranean region in Croatia. *South-East European forestry* (SEEFOR), 10, 19–27. https://doi.org/10.15177/seefor.19-05

Phillips, S.J. & Dudik, M. (2008) Modelling of species distributions with MaxEnt: New extensions and a comprehensive evaluation. *Ecography*, 31, 161–175. https://doi.org/10.1111/j.0906-7590.2008.5203.x

Phillips, S.J., Anderson, R.P. & Schapire, R.E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 190, 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips, S.J., Dudik, M. & Schapire, R.E. (2023) MaxEnt software for modeling species niches and distributions (Version 3.4.1). Available from http://biodiversityinformatics.amnh.org/open_source/maxent [Accessed at 15th May, 2023]

Qin, Y.J., Wang, C., Zhao, Z.H., Pan, X.B. & Li, Z.H. (2019) Climate change impacts on the global potential geographical distribution of the agricultural invasive pest, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae). *Climatic Change*, 155, 145–156. https://doi.org/10.1007/s10584-019-02460-3

Rabaglia, R.J., Duerr, D., Acciavatti, R. & Ragenovich, I. (2008) *Early detection and rapid response for non-native bark and Ambrosia beetles*. USDA Forest Service, Forest Health Protection, Washington DC, USA. 12 p.

Rassati, D., Faccoli, M., Toffolo, E.R., Battisti, A. & Marini, L. (2015) Improving the early detection of alien wood-boring beetles in ports and surrounding forests. *Journal of Applied Ecology*, 52, 50–58. https://doi.org/10.1111/1365-2664.12347

Salehi-Jouzani, G., Farazmand, H., Saadat, D., Golmohamadi, G. & Amirian, R. (2016) Study on distribution, biology, prevention strategies and control of Mediterranean pine bark beetle, *Orthotomicus erosus* (Wollaston), in Isfahan. In: Talaei-Hassanloui, R. (ed) *Proceedings of the 22nd Iranian Plant Protection Congress*, 27–30 August 2016, University of Tehran, Karaj, p. 648.

Sanchez-Garcia, F.J., Galian, J. & Gallego, D. (2015) Distribution of *Tomicus destruens* (Coleoptera: Scolytinae) mitochondrial lineages: phylogeographic insights and niche modelling. *Organisms Diversity and Evolution*, 15, 101–113. https://doi.org/10.1007/s13127-014-0186-2

Sarikaya, O., Ibis, H.M. & Toprak, O. (2013) The flight activity and population density of *Orthotomicus erosus* (Wollaston, 1857) in the Brutian pine (*Pinus brutia* Ten.) forests of Izmir Province, Turkey. *International Journal of Sciences*: *Basic and Applied Research*, 12, 208–219.

Sarikaya, O., Karaceylan, I.B. & Sen, I. (2018) Maximum entropy modeling (MaxEnt) of current and future distributions of *Ips mannsfeldi* (Wachtl, 1879) (Curculionidae: Scolytinae) in Turkey. *Applied Ecology and Environmental Research*, 16, 2527–2535. https://doi.org/10.15666/aeer/1603_25272535

Skendzic, S., Zovko, M., Zivkovic, I.P., Lesic, V. & Lemic, D. (2021) The impact of climate change on agricultural insect pests. *Insects*, 12, 440. https://doi.org/10.3390/insects12050440

Taylor, S.W., Carroll, A.L., Alfaro, R.I. & Safranyik, L. (2006) Forest, climate and mountain pine beetle outbreak dynamics in western Canada. In: Safranyik, L. & Wilson, B. (eds) *The Mountain Pine Beetle: A Synthesis of*

Biology, Management and Impacts in Lodgepole Pine. Natural Resources Canada, Canadian Forest Service, Victoria, British Columbia, pp. 67–94.

Tognelli, M.F., Roig-Junent, S.A., Marvaldi, A.E., Flores, G.E. & Lobo, J.M. (2009) An evaluation of methods for modelling distribution of Patagonian insects. *Revista Chilena de Historia Natural*, 82, 347–360. https://doi.org/10.4067/S0716-078X2009000300003

Tsoar, A., Allouche, O., Steinitz, O., Rotem, D. & Kadmon, R. (2007) A comparative evaluation of presence-only methods for modelling species distribution. *Diversity and Distributions*, 13, 397–405. https://doi.org/10.1111/j.1472-4642.2007.00346.x

Ungerer, M., Ayres, M. & Lombardero, M. (1999) Climate and the northern distribution limits of *Dendroctonus frontalis* Zimmerman (Coleoptera: Scolytidae). *Journal of Biogeography*, 26, 1133–1145. https://doi.org/10.1046/j.1365-2699.1999.00363.x

Urvois, T., Auger-Rozenberg, M.A., Roques, A., Rossi, J.P. & Kerdelhue, C. (2021) Climate change impact on the potential geographical distribution of two invading *Xylosandrus ambrosia* beetles. *Scientific Reports*, 11, 1339. https://doi.org/10.1038/s41598-020-80157-9

Witkowski, R., Dyderski, M.K., Belka, M. & Mazur, A. (2022) Potential European geographical distribution of *Gnathotrichus materiarius* (Fitch, 1858) (Coleoptera: Scolytinae) under current and future climate conditions. *Forests*, 13, 1097. https://doi.org/10.3390/f13071097

Yu, Y., Chi, Z., Zhang, J., Sun, P., Wang, C. & Pan, X. (2019) Assessing the invasive risk of bark beetles (Curculionidae: Scolytinae and Platypodinae). *Annals of the Entomological Society of America*, 112, 451–457. https://doi.org/10.1093/aesa/saz030

Zabihi, K., Huettmann, F. & Young, B.D. (2021) Predicting multi-species bark beetle (Coleoptera: Curculionidae: Scolytinae) occurrence in Alaska: open-access big GIS-data mining to provide robust inference. *Biodiversity Informatics*, 16, 1–19. https://doi.org/10.17161/bi.v16i1.14758

مدل‌سازی بیشینه آنتروپی برای پیش‌بینی تأثیر متغیرهای غیرزنده بر پراکنش احتمالی *Orthotomicus erosus* (Wollaston) (Coleoptera, Curculionidae, Scolytinae) در ایران

منا قربانیان[1]، آزاده کریمی ملاطی[1،*]، مهدی جلائیان[2]، محمود فاضلی سنگانی[3]

۱ گروه گیاه‌پزشکی، دانشکده علوم کشاورزی، دانشگاه گیلان، رشت، ایران
۲ بخش تحقیقات گیاه‌پزشکی، موسسه تحقیقات برنج کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی، رشت، ایران
۳ گروه علوم خاک، دانشکده علوم کشاورزی، دانشگاه گیلان، رشت، ایران

* پست الکترونیک نویسنده مسئول مکاتبه: a_karimi@guilan.ac.ir

| **تاریخ دریافت:** ۰۲ تیر ۱۴۰۲ | **تاریخ پذیرش:** ۲۲ مرداد ۱۴۰۲ | **تاریخ انتشار:** ۲۹ مرداد ۱۴۰۲ |

چکیده: ارزیابی ریسک وقوع آفت در یک منطقه، بر اساس احتمال موفقیت پراکنش آن آفت، به منظور برنامه‌ریزی در انجام اقدامات پیشگیرانه مورد استفاده قرار می‌گیرد. پایه و اساس ارزیابی ریسک وقوع آفت، تعیین اثر متغیرهای محیطی بر مناطق پراکنش کنونی و نیز بالقوه آن است. در پژوهش حاضر، نقشه پراکنش سوسک پوستخوار مدیترانه‌ای کاج، *Orthotomicus erosus* (Wollaston, 1857) با استفاده از مدل *MaxEnt* پیش‌بینی و تهیه شد. از گزارش‌های حضور *O. erosus* (شمال، شمال شرقی، غرب و مرکز ایران)، متغیرهای محیطی و نیز متغیر توپوگرافی به نحوی استفاده شد که کمترین همبستگی بین خود و بیشترین تأثیر را بر پراکنش آفت داشتند. در مجموع ۷۶ گزارش حضور آفت *O. erosus* جمع‌آوری شد. نتایج مدل‌سازی پیش‌بینی پراکنش نشان داد که بخش شمالی ایران و نواحی حاشیه زاگرس مناسب‌ترین زیستگاه برای پراکنش این گونه آفت است. بررسی میزان اهمیت متغیرهای محیطی بر پراکنش *O. erosus* نشان داد که به ترتیب متغیرهای مربوط به دما و بارندگی نسبت به ارتفاع مشارکت بیشتری در مدل پراکنش *MaxEnt* داشتند. علاوه بر این، دقت بالای مدل (۰/۹۲۸) نشان داد که مدل *MaxEnt* عملکرد قابل قبولی برای پیش‌بینی پراکنش آفت *O. erosus* داشته است. این یافته‌ها، اطلاعات اولیه و مهمی را در مورد مناطق پراکنش احتمالی سوسک پوستخوار *O. erosus* در ایران ارایه می‌دهد که می‌تواند برای کنترل پایدار جمعیت این آفت مخرب، موثر باشد.

واژگان کلیدی: متغیرهای اقلیمی، زیستخوان اکولوژیک، جک‌نایف، مکسنت، جنگل‌های کاج