J. Entomol. Res. Soc., 26(3): 337-346, 2024 *Research Article*
Doi: 10.51963/jers.v26i3.2604 *Online ISSN:2651-3579*

Predictive Determination of *Cydalima perspectalis* Spread Areas by Using Maxent Model

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ABSTRACT

Boxwood, which is used as a source of raw material in various areas and contributes greatly to nature with its ecological properties, is in danger of extinction due to pests, primarily the boxwood moth (*Cydalima perspectalis*), uncontrolled cutting, fungal drying and diseases. In addition to these, climate change also plays a negative role on biodiversity and the distribution of many species. Therefore, necessary measures need to be taken to minimize the effects of climate change on species. In this study, coordinate information of 45 boxwood locations obtained with the help of field studies and literature was used. The presence of *Cydalima perspectalis* in these locations was observed with field studies. After data acquisition, the current potential distribution area of boxwood (*Buxus spp.*) and its pest, the boxwood moth (*Cydalima perspectalis*), which naturally spread in Türkiye, was modeled using the Maxent 3.4.4 program and the WorldClim V1 database obtained from the Google Earth Engine (GEE) platform. According to the modeling results, the pest is expected to spread mainly in the Black Sea Region and the West Marmara Region, and boxwood (*Buxus spp.*) is expected to spread in the Aegean and Mediterranean Regions in addition to these regions. It was also observed that the current locations overlap with the potential distribution areas to a great extent.

Keywords: Boxwood, *Cydalima perspectalis*, GIS, Climate Change, Distribution

Yaman, Ş. & Yaman, M. (2024). Predictive determination of *Cydalima perspectalis* spread areas by using maxent model. *Journal of the Entomological Research Society*, 26(3), 337-346.

Received: February 07, 2024 *Accepted: October 23, 2024*

INTRODUCTION

Boxwood (*Buxus spp.*), of which there are 105 species in the world and of which two species, the Anatolian boxwood (*Buxus sempervirens*) and Spanish boxwood *(Buxus balearica*), are naturally distributed in our country, have features such as high density and durability (Ak et al., 2021). Due to these characteristics, it is used in many areas, such as furniture, carving, music, art, and landscaping and contributes significantly to the national economy. The contribution of boxwood is not only limited to the material economy but also to nature, with its ecological characteristics, which cannot be underestimated.

When the distribution of boxwood species in Türkiye was examined, although the *B. sempervirens* is mainly distributed in the Black Sea Region, it also has distribution areas in the Mediterranean Region, while the *B. balerica* is distributed only in the Mediterranean Region (Sarı, Çelikel, & Yaşar, 2021). Although boxwood has a wide geographical distribution and contributes to the country and the environment, it is in danger of extinction due to factors such as pests, uncontrolled felling, fungal drying and diseases (Çoban, Aksoy, & Tunçkol, 2021). Harmful insects are the leading cause of the extinction of forests and plant species because they have fast reproduction, high flight capacity and easy adaptation to the environment. For this reason, the damage caused by pests spreading to a whole forest in a short time is much more than the damage caused by fires (Eroğlu, 2017; Yaman &Tunç Görmüş, 2022).

The *Cydalima perspectalis* Walker (Lepidoptera: Crambidae) (box tree moth) is a pest species that causes damage to the boxwood (Öztürk, Akbulut, & Yüksel, 2016). In the study of Toper Kaygın and Taşdeler (2019), it was stated that boxwood is the main host of the pest. It is stated that the pest can fly up to five kilometers per year and therefore its potential for causing damage is quite high, which puts boxwood species at serious risk of extinction (Matosevic, 2013).

It is one of the newest invasive species originating from East Asia, is widespread in Europe, and is especially dangerous for *B. sempervirens* shrubs (Gugea &Vîrteiu, 2017). In Türkiye, *C. perspectalis* was encountered for the first time in Istanbul Sarıyer Park and garden areas in 2011 (Hızal, 2012). In the following years, it was also observed in Düzce, Artvin and Bartın (Öztürk et al., 2016; Göktürk, 2017; Toper Kaygın & Taşdeler, 2018). The pest has a high flight capability of traveling an average of 5 km per year. It can feed on different hosts (Matosevic, 2013) and can give more than one generation in a year depending on climatic conditions (Van der Straten & Muus, 2010), and these are the reasons for its rapid spread every year.

Climate is the most important ecological factor affecting the diversity of plant species in the world and their geographical distribution (Günal, 2013). Our country has a wide variety of plant species due to its climate conditions. However, the climate system has been changing since the earth existed (Türkeş, 2008). With the changing climate system, the habitat systems of plants are also changing and are under threat (Zhang Yao, Meng, & Tao, 2018). Changing factors such as temperature, precipitation, humidity, wind, etc., stress plants and reduce their resistance or cause an increase in pest populations, leading to the extinction of the species (Sarıkaya, Örücü, Şen, & Açıcı, 2019). Therefore, early measures should be taken to protect biodiversity before the distribution areas of species change.

Recently, the use of Geographic Information Systems (GIS) in pest control, early detection, monitoring, mapping, analysis and interpretation of pest damage has increased (Rano, Afroz, & Rahman, 2022). Technologies such as GIS are used to analyze the geography of disease, especially the relationships between pathological and ecological factors (hosts, climate, humans) and their geographical environments, natural resource management, wildlife movement analysis, ecological niche modeling and land records applications (Cromley, 2003; Hochmair, Tonini, & Scheffrahn, 2013). However, there are many modeling tools used to examine the relationship between climate change and species distribution and predict the potential distribution areas of a species under different climate change scenarios. The Maxent (Maximum Entropy) model is one of these modeling tools, and it uses the current known distribution of species and various environmental variables to predict their potential future range (Jarnevich & Young, 2015).

This study aimed to determine the distribution and current estimated distribution areas of boxwood (*Buxus spp.*) and *C. perspectalis* in Türkiye to compare and analyze the local data obtained from field studies with the maps produced by using GIS technologies and Maxent model.

MATERIALS AND METHODS

Türkiye's borders between 36°- 42° north latitude and 26°- 45° east longitude were determined as the study area. Before starting the study, the necessary bioclimatic variables data were obtained from the WorldClim Version 1 (V1) database in the Google Earth Engine (GEE) data catalog, and the data on the administrative boundaries of Türkiye were obtained from the General Command of Mapping (Table 1.). All analyses and operations were performed using ArcGIS 10.7.1 and Maxent 3.4.4 programs.

Table 1. Data and data sources used in the study.

Data Name	Data Source
Country and Provincial Borders	General Command of Mapping
Bioclimatic variables	Google Earth Engine&WorldClim
Current Boxwood Locations	Literature and field study

For the distribution and observation map of boxwood and its pest, *C.perspectalis*, in Türkiye, the coordinates of 45 sample points were determined based on field studies and existing literature information (Toper Kaygın, & Taşdeler, 2019; Sarı et al., 2021) (Table 2) and the sample points were marked on the map of the administrative boundaries of Türkiye using the WGS 84 coordinate system in ArcGIS 10.7.1 program (Fig. 1).

The WorldClim Version 1 ("WORLDCLIM/V1/BIO") database in the GEE data catalog ("WORLDCLIM/V1/BIO") was used to model the current distribution of boxwood and *C. perspectalis*. The WorldClim V1 database contains monthly minimum, average and maximum temperature values and monthly average precipitation data for the period 1960-1990. The bioclimatic variables used to determine the current distribution area were generated from the information in WorldClim V1 (Table 3) (Hijmans, 2005; Sarıkaya et al., 2019; WorldClim, 2019; Uzun, Aksu, & Uzun, 2020).

Table 2. Attribute information of sample points.

Province	District	Latitude	Longitude	Altitude	*C. perspectalis*
Adana	Aladağ	37,472725	35,415433	841	No
Adana	Feke	37,875833	35,846389	760	No
Adana	Kozan	37,523192	35,887592	418	Yes
Ankara	Bilkent	39,878894	32,763065	987	Yes
Antalya	Kumluca	36,674724	30,56324	11	No
Antalya	Adrasan	36,3181	30,468091	172	No
Artvin	Hatila Vadisi	41,1917595	41,7465325	487	Yes
Bartın	Ulus	41,700119	32,787793	842	No
Bilecik	Abadiye	40,162467	29,736998	611	Yes
Bolu	Merkez	40,730776	31,600048	728	No
Bolu	Merkez	40,727694	31,589538	727	Yes
Bolu	Göynük	40,453774	30,782739	920	No
Bursa	Çiviliçam	39,913512	28,695068	760	No
Düzce	Merkez	40,839721	31,15567	149	Yes
Giresun	Merkez sahil yolu	40,908196	38,358613	11	Yes
Giresun	Dereli	40,634912	38,384502	847	No
Giresun	Dereli	40,695057	38,439748	516	No
İstanbul	Subaşı	41,227502	28,44964	75	No
İstanbul	Şile	41,070757	29,796066	32	Yes
İzmir	Aliağa	38,802361	26,97705	16	No
Karabük	Keltepe	41,096242	32,526848	803	Yes
Kastamonu	Azdavay	41,596535	33,200209	1238	Yes
Kastamonu	Pınarbaşı	41,6005434	33,1303023	797	Yes
Kastamonu	Pınarbaşı	41,603045	33,111549	666	Yes
Kastamonu	Kurtgirmez	41,590214	33,2077	1171	Yes
Manisa	Şehzadeler	38,638218	27,441271	25	No
Muğla	Marmaris	36,827249	28,243102	6	No
Ordu	Altınordu	40,974944	37,96825	7	Yes
Rize	Zilkale	40,907621	40,948851	996	Yes
Rize	Zilkale/Meydanköyü	40,902112	40,946254	1020	Yes
Rize	Çamlıhemşin	40,897286	40,942511	1056	No
Sakarya	Taraklı	40,489545	30,555345	1087	No
Sakarya	Taraklı/Uğurlu köyü	40,491776	30,559678	1124	No
Sakarya	Taraklı/Kemaller köyü	40,501315	30,586408	1162	No
Samsun	Terme	41,170052	37,056641	5	Yes
Samsun	Fatsa-Kumru	40,863116	37,278007	708	No
Sinop	Durağan	41,36246	34,996704	538	Yes
Trabzon	Merkez	41,005602	39,73099	32	No
Trabzon	Pelitli	40,990173	39,788589	66	Yes
Trabzon	Sürmene-Yeniköy	40,775848	40,052544	605	No
Trabzon	Hayrat	40,791757	40,381897	992	No
Trabzon	Araklı	40,724553	40,015572	1251	No
Trabzon	Maçka	40,7994756	39,7087916	807	No
Trabzon	Arsin	40,709464	39,825475	1063	No
Zonguldak	Yenice	41,1981116	32,3667461	170	No

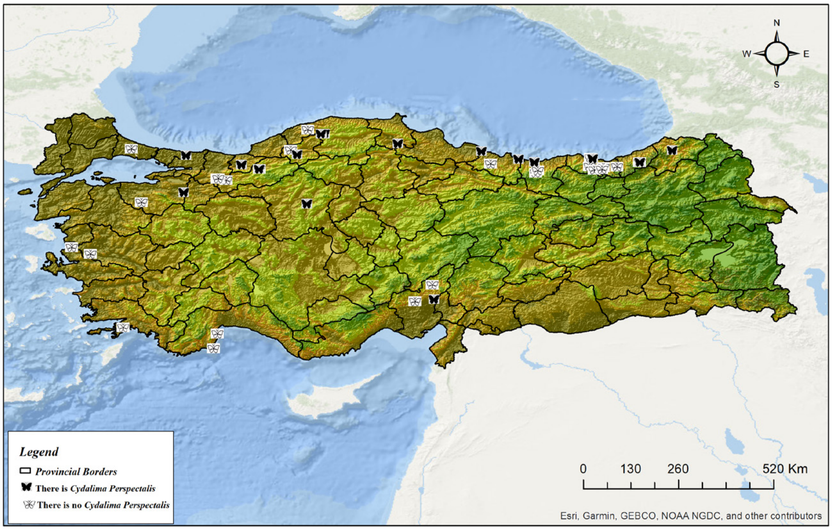

Figure 1. Location and observation map of the study area for boxwood and *Cydalima perspectalis*

Each bioclimatic variable was exported in the GEE interface in ".TIFF" format, restricted to Türkiye's borders. The maximum entropy approach, a correlative model, was used to model the potential distribution of the species (Phillips, Anderson, & Schapire, 2006; Elith & Leathwick, 2009; Uzun et al., 2020). For this reason, the transferred data were processed in the ArcGIS 10.7.1 program and converted into a format suitable for the Maxent 3.4.4 program. In the program, sample data created with geographical coordinates were entered in the "Samples" section, and bioclimatic variables data were entered in the "Environmental Layers" section. To evaluate the performance of the model, the AUC (Area Under the ROC Curve) value obtained as a result of ROC (Receiver Operating Characteristic) analysis was taken as a basis. The jackknife test was used to evaluate bioclimatic variables (Uzun et al., 2020). The graphs obtained with these process steps were interpreted, and the results were visualized in ArcGIS 10.7.1 program.

RESULTS

According to the results of modeling the current distribution of boxwood and *C. perspectalis*, the models performed better than a random prediction because the AUC values were higher than 0.5 (AUC>0.5). The closer the AUC test value is to 1, the better the discrimination is considered, and this indicates how sensitive and descriptive the model is (Hosmer, Lemeshow, & Sturdivant, 2013; Örücü, 2019; Akyol & Örücü, 2020; Uzun et al., 2020). The AUC value of 0.933 in the ROC curve obtained for the boxwood (Fig. 2a) and the AUC value of 0.945 for *C. perspectalis* (Fig. 2b) revealed the sensitivity of the models. These results show that the models have a high predictive power, and the performance is quite successful. (Gassó, Thuiller, Pino, & Vilà, 2012).

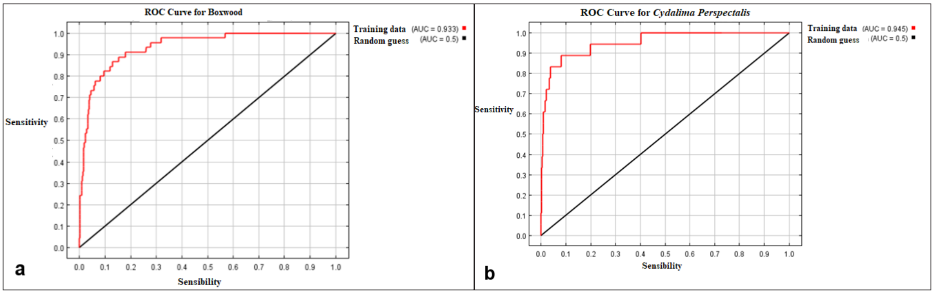

Figure 2. ROC curve. a) boxwood (*Buxus* spp.); b) boxwood moth (*Cydalima perspectalis*)

The jackknife test is an option in the Maxent 3.4.4 modeling program to measure the effects of environmental variables, such as bioclimatic variables. It is used to measure how much each variable contributes to the model (Uzun et al., 2020). Accordingly, the jackknife test gain table for the boxwood is shown in Fig. 3a, and the jackknife test gain table for *C. perspectalis is shown* in Fig. 3b.

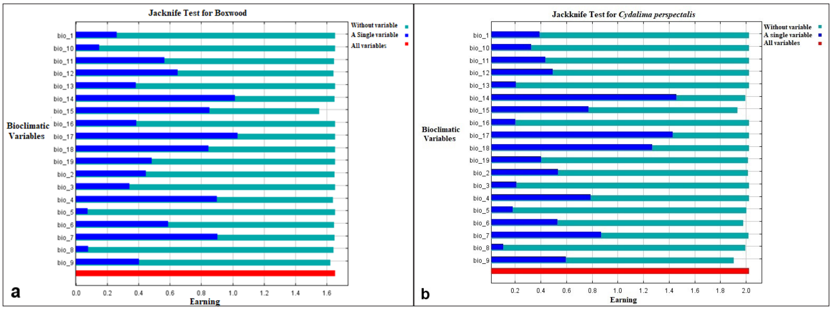

Figure 3. Jackknife test. a) boxwood (*Buxus* spp.); b) boxwood moth (*Cydalima perspectalis*)

When the jackknife test for boxwood was analyzed, the bioclimatic variable with the highest gain was Bio 17, which shows the precipitation amount of the driest quarter, followed by Bio 14, which shows the precipitation amount of the driest month, Bio 7, which shows the annual temperature ratio, and Bio 4, which shows the seasonal temperature. These findings show that the most important bioclimatic variables affecting the distribution of the species are drought and temperature-related variables.

When the jackknife test for *C. perspectalis* was analyzed, the bioclimatic variable with the highest gain was Bio 14, which shows the rainfall of the driest month, followed by Bio 17, which shows the rainfall of the driest quarter, and Bio 18, which shows the rainfall of the hottest first three months. These findings show that the most important bioclimatic variables affecting the distribution of the species are the variables related to drought and temperature.

Using ArcGIS 10.7.1, the present-day estimated distribution maps for the boxwood and *C. perspectalis* created by the Maxent 3.4.4 modeling program were visualized. Fig. 4 shows the estimated distribution map for the boxwood, while Fig. 5 shows the estimated distribution map for *C. perspectalis*.

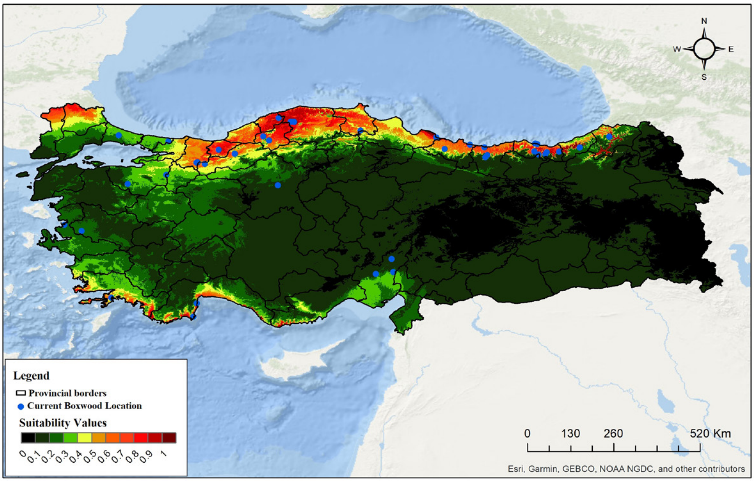

Figure 4. Current distribution area estimate for boxwood (*Buxus* spp.)

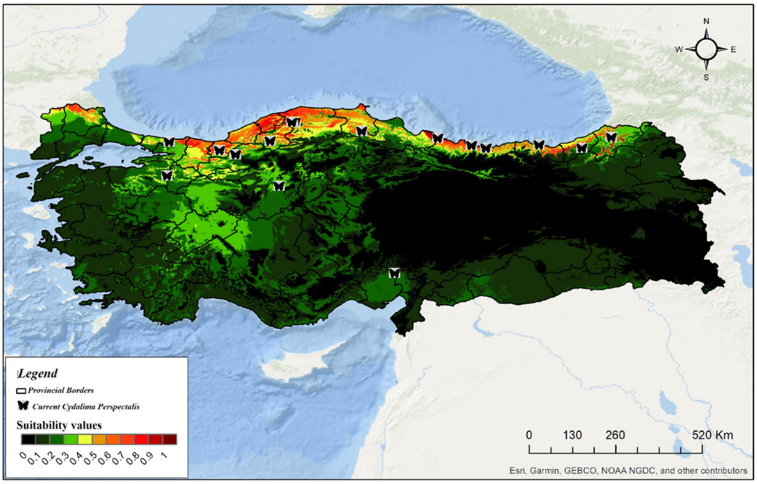

Figure 5. Current distribution area estimate for boxwood moth (*Cydalima perspectalis*)

In Maxent modeling, the probability of a species being present in an area is defined by a value between 0 and 1. As the values approach 1, the probability that the species is potentially present in that area increases and as the values approach 0, the probability that the species is not present in that area increases. For this reason, habitat suitability values for the region were categorized as between 0-1. In the study, in order to show the current and potential distribution of boxwood and *C. perspectalis*, suitability values were determined as 0 not suitable (black), 1.0 very suitable (red), and intermediate values were determined as areas that are progressively suitable from 0 to 1. Accordingly, when the current distribution area prediction maps are examined, the species is distributed in the Black Sea Region and the West Marmara Region.

However, unlike *C. perspectalis*, the boxwood is expected to be distributed in the Aegean and Mediterranean Regions. In addition, it was observed that the current locations overlap with the potential distribution prediction maps to a great extent.

DISCUSSION

This study presented important findings using the MaxEnt modeling program to determine the potential distribution areas of boxwood and *C. perspectalis* species in Türkiye. There are studies conducted to determine the current and future potential distribution areas of pests in our country (Örücü, 2019; Akyol & Örücü, 2019; Uzun, 2020). According to the results obtained from the study conducted by taking these studies as reference, it was revealed that climate variables are one of the most important factors affecting the distribution of species. The Jackknife test results for boxwood showed that the bioclimatic variable with the highest gain was Bio 17, which indicates the amount of rainfall in the driest quarter. This shows that drought conditions have a decisive effect on the existence of boxwood. Drought increases stress levels by reducing water intake of plants, which negatively affects the distribution of species. Similarly, in the analyses conducted for *C. perspectalis*, it was determined that the bioclimatic variable with the highest gain was Bio 14, which indicates the rainfall amount of the driest month. These findings show that the increase in pest populations is also related to drought conditions.

Increasing temperatures and changing precipitation patterns with climate change can expand the distribution areas of these species and disrupt the ecosystem balance. In line with the results obtained, it is estimated that the current and future potential distribution areas of boxwood and *C. perspectalis* within the borders of Türkiye may gradually increase, and this situation will cause both ecological and economic losses.

Further examining the effects of climate variables on the formation and distribution of species is a critical necessity in terms of ecosystem management and biodiversity protection. Such studies will form an important basis for understanding the effects of climate change scenarios on the future distribution areas of species and developing conservation strategies.

For boxwood locations in Türkiye, it is important to take precautions against the insect's epidemiology, starting from the current distribution areas, increase biological control, and diversify the control methods with fast, economical and functional methods such as GIS and remote sensing.

Some limitations were encountered within the scope of this study, for example, it was not possible to reach all boxwood locations and biodiversity maps in Türkiye. Increasing the number of locations determined will increase the efficiency obtained from the study. Therefore, it is aimed for this study to be an example for future studies and to increase this number. Future studies are expected to better understand the ecological needs and potential threats of the species by examining climate variables in more detail.

ACKNOWLEDGMENT

The study was financially supported as a research project by the Scientific and Technological Research Council of Türkiye (221O401).

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