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Creation of Turkiye risk map for *Cydalima perspectalis* (box tree moth) by weighted overlay analysis

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Abstract
Boxwood (Buxus spp.), which is widespread all over the world except Antarctica and widely used in many areas, is threatened by *Cydalima perspectalis* (box tree moth). *Cydalima perspectalis*, which has become widespread in Europe, is a new invasive species originating from East Asia and has become widespread in Turkiye in the last ten years. This species was first observed in parks and gardens in Sarıyer, Istanbul, in 2011. Since then, it has continued to spread rapidly in Turkiye. The pest causes intense damage by causing drying on boxwood areas, which causes economic and ecological losses. The rich ecological and topographical conditions of Turkiye are also favorable for the spread of this species. Therefore, it is important to develop pest control methods and take early measures. Within the scope of this study, the aim was to realize early detection of *Cydalima perspectalis* in Turkiye and make a risk map in this context. For this purpose, a risk map was created by determining the risky areas where *Cydalima perspectalis* can spread in Turkiye using weighted overlay analysis from geographic information system (GIS) technologies. Existing boxwood locations obtained from field studies were compared with the risk map and analyzed. As a result of the analysis, the presence of *Cydalima perspectalis* was found in the boxwood in the identified risk areas, and it is expected to be transmitted in boxwood that is in the risk area but not observed to have *Cydalima perspectalis*. With this research, a risk map for *Cydalima perspectalis* was made for the first time.

1. Introduction

Boxwood, which has a natural population in forested areas in Turkiye, is also used as a landscape plant in parks and gardens [1-2]. The use of boxwood in Turkiye is not limited to this; it is also used to make toys, spoons, furniture, musical instruments and art tools [3-4]. Boxwood has a strong and durable structure that can further expand its usage areas. Two species of boxwood, Anatolian boxwood (*Buxus sempervirens*) and Spanish boxwood *(Buxus balearica*), are naturally distributed in Turkiye. *B. sempervirens* is found in Osmaniye, Bolu, Karabük, Kastamonu, Artvin, Denizli, Hatay, Kocaeli, Kahramanmaraş, Rize and Trabzon, and *B. balearica* is found in Adana, Antalya and Hatay [4]. It is also cultivated in many other provinces. However, despite its widespread use and distribution, boxwood is in danger of extinction in Turkiye, as in the world, due to pests, diseases, climate change, etc. It is primarily threatened by the *Cydalima perspectalis*, an invasive species that was first encountered in Europe in 2007 in Germany and the Netherlands [5-6]. In Turkiye, it was first encountered in 2011 in parks and gardens in Sarıyer, Istanbul, and it has continued to spread until today.

The primary host of the *C. perspectalis*, which can feed on different hosts, is boxwood [7-8]. The pest feeds on shoots and leaves during the larval period, causing the plant to dry out and damage [4].

It is revealed that the pest causes damage by giving two generations in May and July [9]. Found that the pest gives three generations per year [8, 10]. It has also been reported that it gives five generations per year in China [11]. The number of generations of *C. perspectalis*, which is generally associated with climate and geography, increases depending on the conditions [12]. In addition, the pest has a high flight capacity, covering an average distance of 5 km per year [7].

C. perspectalis can produce more than one generation per year, feed on different hosts, and have a high flight ability, which are the reasons for its rapid spread. Early measures should be taken to prevent rapid spread, control pests, and protect biodiversity.

According to the literature and research were examined, it was seen that the pest was handled only biologically, and the pest control methods were biological in this context [8-9, 13-15]. Moreover, Geographic Information Systems (GIS), which have recently been widely used in pest control, early detection, monitoring, mapping, analysis and interpretation of the damage caused by pests, have not been used in this field neither in the world nor in Turkiye.

GIS is an integrated system used in the processes of collection, storage, analysis, visualization, and interpretation of geographical data in many fields, such as biology, military, engineering, and medicine [16]. 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 geographic environments, natural resource management, wildlife movement analysis, ecological niche modeling and land records applications [17-18]. When we look at the usage areas of GIS, it is seen that it is used in integration with many fields, however, there are also academic studies in all fields of science, health and social sciences [19].

The coordinates of the pheromone traps set for the pest *Orthotomicus erosus (Woll.)* (Mediterranean Pine Bark Beetle) were obtained using GPS and the samples taken from the traps were analyzed using geostatistical methods in the GIS environment [20]. As a result of the analysis, seasonal damage intensity and diversity were revealed. Similarly, [21] analyzed the results and analysis of satellite images used in monitoring the damage caused by insect pests in Artvin spruce forests in a GIS environment. In this study, the damage caused by pests was determined spatially, and the 203 ha area was damaged. Again, [22] used remote sensing and GIS methods to monitor the damage caused by the red-tailed beech caterpillar (*Calliteara pudibunda*), which is a threat to beech forests. [23] used GIS-based methods to identify the most common insect pests affecting citrus production and the areas where pests are most common by using GIS-based methods to identify Calamansi diseases and pests.

In light of these studies, a risk map will be created by determining the risky areas where *C. perspectalis* can spread in Turkiye by using weighted overlay analysis from GIS technologies and analysis methods in ArcGIS 10.7.1 program. In addition, local data obtained from field studies will be compared and analyzed with the result maps produced.

2. Method

2.1. Study area and data collection

Turkiye, located between 36°- 42° north latitude and 26°- 45° east longitude, was chosen as the study area. Before starting the study, the required soil type data were obtained from the Food and Agriculture Organization (FAO) map catalog, the data on the administrative boundaries of Turkiye were obtained from the General Command of Mapping, and the monthly average temperature and precipitation data were obtained from the General Directorate of Meteorology (Table 1). All analyses and operations were performed using ArcGIS 10.7.1 software.

Table 1. Data and data sources used in the study

Data Name	Data Source
Country and Provincial Borders	General Command of Mapping
Temperature	General Directorate of Meteorology (Monthly Average)
Precipitation	General Directorate of Meteorology (
Digital Elevation Model	USGS Earth Explorer-SRTM 1 Arc-Second Global
Soil Type	Food and Agriculture Organization (FAO)

For the distribution and observation map of boxwood and its pest, *C. perspectalis* in Turkiye, the coordinates of 45 sample points were determined based on field studies and existing literature information [8, 24] (Table 2) and the sample points were marked on the map of the administrative boundaries of Turkiye using the WGS 84 coordinate system in ArcGIS 10.7.1 program (Figure 1).

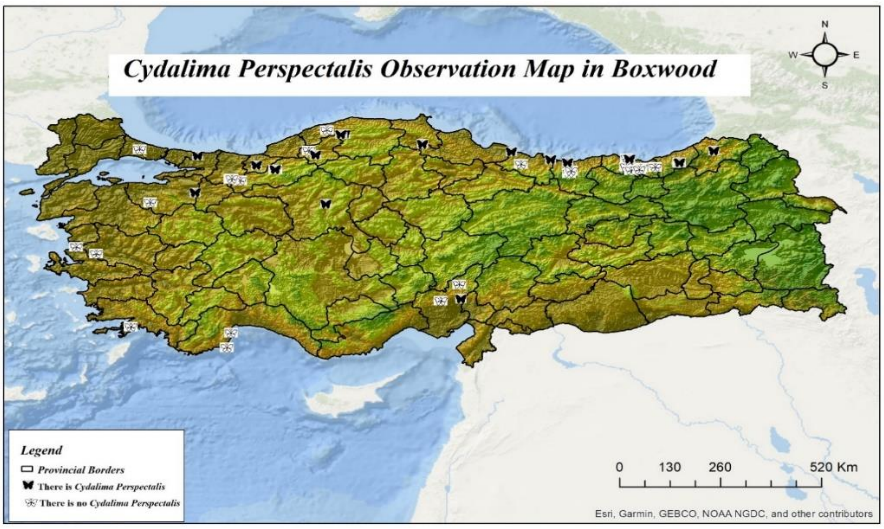

Figure 1. Location and observation map of the study area for boxwood and *Cydalima perspectalis*

Table 2. Attribute information of sample points

Province	District	Latitude	Longitude	Altitude	*Cydalima 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

2.2. Weighted overlay analysis

ArcGIS 10.7.1 program and "Weighted Overlay Analysis", one of the GIS analysis methods, were used for the Turkiye *C. perspectalis* risk map. Weighted overlay analysis is a multi-criteria analysis that provides a result map by evaluating, weighting and overlapping multiple thematic maps according to each other [25-26]. Multi-Criteria Decision Making techniques (MCDM) were developed to address problems arising from competing preferences between different criteria [27]. This method not only creates a solid and quantitative basis, but also significantly increases transparency and rationality in the decision-making process by combining subjective assessments and objective data [28].

2.3. Criteria selection

Since criteria are decision components used in the evaluation of alternatives, they must be chosen meticulously and carefully because they play a critical role in achieving the goals [29]. Each criterion produces its thematic map, and these maps are aggregated in proportion to the weights determined by expert opinions [30]. An example of a mathematical representation of this process is given in Formula 1.

Suitability Value= (Temperature*0.20) + (Precipitation*0.20) + (Soil Moisture*0.15) + (Elevation*0.10) + (Aspect*0.15) + (Flight Distance*0.20) (Formula 1)

Ecological and morphological criteria (temperature, precipitation, elevation, aspect, soil moisture, and flight distance) that prevent the development of boxwood and are suitable for the spread of *C. perspectalis* were selected from the literature and expert opinions, and the risky areas were determined.

2.3.1. Temperature

Although parameters such as geographical location and ecological factors vary, it has been observed that the minimum threshold temperature for the development of eggs, larvae and pupae of *C. perspectalis* is in the range of 8-12 °C [31-32] and in studies on larval development, it has been observed that development lasts at least 17 days at 30 °C and 84 days at 15 °C [8]. In addition, based on field observations and literature, it was determined that the pest causes damage by giving two generations in May and July [9]. Temperature is directly related to the development of the pest, and high temperature is a risky criterion.

2.3.2. Precipitation

After 2016, due to the driest years in the region, chinchillas were under water stress, and this caused an increase in the population of *C. perspectalis*, an invasive species [33]. [34] observed that individuals damaged in the research area were mostly found in habitats with low rainfall. This shows that low rainfall is a risky criterion.

2.3.3. Elevation

It is known that boxwood has a vertical distribution from sea level to 1500 m [35]. However, it has been observed that the pest causes damage in low-elevation habitats such as valley floors [35-36]. Considering the elevation criterion, it was determined that low elevation is associated with high risk.

2.3.4. Aspect

Criteria such as high temperature, low rainfall and drought are risky for shade-tolerant boxwood. When these criteria are taken into consideration, facing the sunlit south direction is also a risky criterion.

2.3.5. Soil moisture

It has been shown that the decrease in the amount of water that boxwood roots can take from the soil negatively affects the development, and the plant is stressed due to drought [37-44]. Similarly, moisture-free soil is a risky criterion.

2.3.6. Flight distance

C. perspectalis is known to fly approximately 7-10 km per year [8-9]. In this case, a boxwood affected by *C. perspectalis* will likely infect all boxwood within a maximum distance of 10 km.

2.4. Determination of class ranges and criterion weights

After the criteria were determined, they were converted into data suitable for weighted overlay analysis. Firstly, Digital Elevation Model (DEM) data was downloaded from the USGS Earth Explorer page and cropped according to the study area. Then, aspect and elevation data were created from the DEM data. Monthly average precipitation and temperature data obtained from the General Directorate of Meteorology on a point basis for each province were converted into areal precipitation and temperature data using the "IDW" interpolation method. For another criterion, soil moisture, the worldwide soil type data was downloaded from the map catalog of the Food and Agriculture Organization (FAO) and adapted to Turkiye's borders. Finally, for the flight distance criterion, buffer zones of 10 kilometers each were created by applying the "Multiple Buffer" process to the coordinates obtained from field studies. The prepared data were reclassified with the "Reclassify" process and divided into appropriate criteria ranges. While determining the criteria ranges, i.e., class values, the maximum and minimum values in the data and expert opinions were taken into consideration. After the class values were determined, each criterion was rated from 1 to 5 in terms of importance. While 5 represents the most risky class range, 1 represents the risk-free class range. Considering that the 1st generation of the pest occurred in May and the 2nd generation in July, all operations were carried out separately for these two months. Table 3 shows the class ranges and importance levels determined for May, and Table 4 shows for July.

Table 3. Criterion class ranges and assignment of importance levels in May

May	No Risk	Low Risk	Medium Risk	Risk	High Risk
Temperature	10>	10-15	15-17	17-20	20<
Precipitation	100<	75-100	60-75	30-60	30>
Soil Moisture	High	Moisture	Medium	Low	No Moisture
Elevation	4000<	2000-4000	1000-2000	100-500	500>
Aspect	North	NE,NW	East,West	SE,SW	South
Flight Distance	50	40	30	20	10

Table 4. Criterion class ranges and assignment of importance levels in July

July	No Risk	Low Risk	Medium	Risk	High Risk
Temperature	19>	19-21	21-25	25-28	28<
Precipitation	150<	80-150	45-80	25-45	25>
Soil Moisture	High	Moisture	Medium	Low	No Moisture
Elevation	4000<	2000-4000	1000-2000	100-500	500>
Aspect	North	NE,NW	East,West	SE,SW	South
Flight Distance	50	40	30	20	10

Weight values were determined with expert opinions for the criteria whose class intervals and importance levels were prepared. The weight values of the criteria to be analyzed at the determined weight ratio are given in Table 5.

Table 5. Criteria and weight values

Criteria	Weight Value (%)
Temperature	0.20
Precipitation	0.20
Soil Moisture	0.15
Elevation	0.10
Aspect	0.15
Flight Distance	0.20

With all the data required for the weighted overlay analysis, a model was built in ArcGIS 10.7.1 program through "ModelBuilder", and the risk map was created by multiplying the thematic maps of each criterion by their weights. The model and weighted overlay analysis are shown in Figure 2.

At the end of the study, the existing boxwood and *C. perspectalis* coordinates were marked on the risk map and compared and analyzed.

3. Results

Elevation, aspect, temperature in May, precipitation in May, temperature in July, precipitation in July, soil moisture and flight distance maps of the criteria determined to create a risk map with weighted overlay analysis are shown in Figure 3.

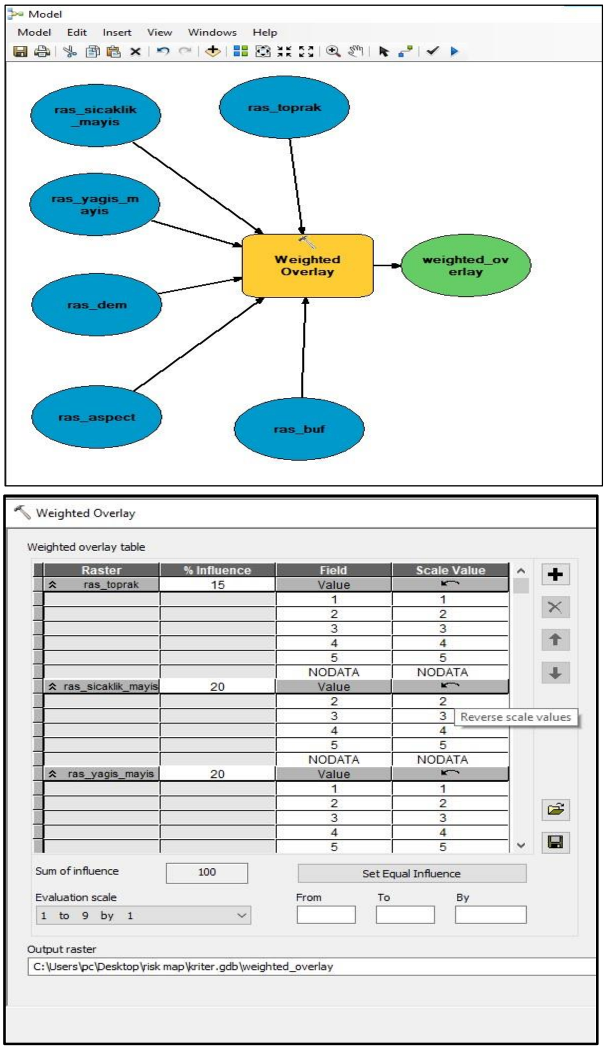

Figure 2. Weighted overlay analysis and model

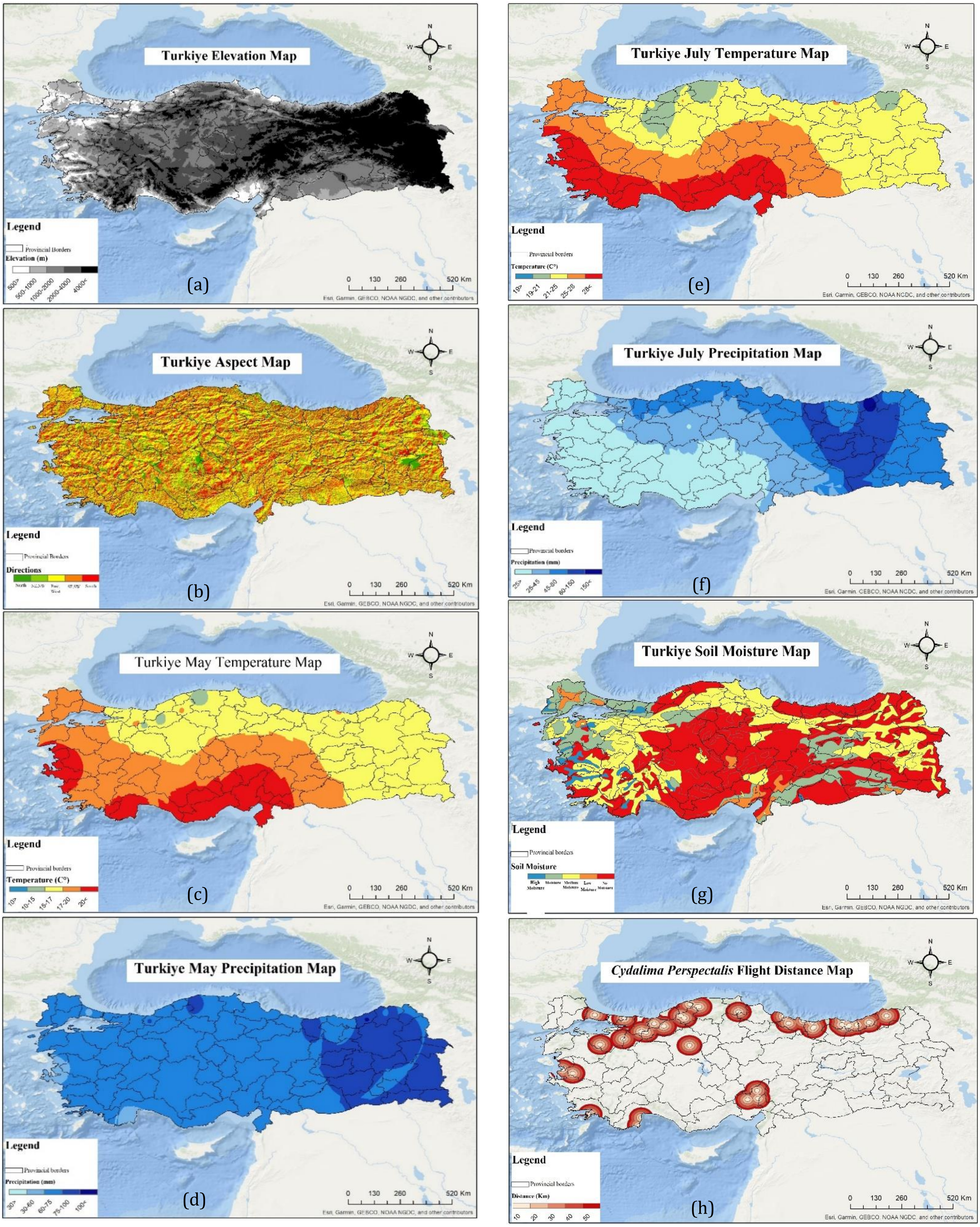

Figure 3. Class ranges and suitability map of the criteria (a: elevation map, b: aspect map, c: May temperature map, d: May precipitation map, e: July temperature map, f: July precipitation map, g : soil moisture map, h: flight distance map)

When the risk maps of each criterion produced are examined, it is seen that the Eastern Anatolia Region, Eastern Black Sea Region and some parts of the Central Anatolia Region are not risky for *C. perspectalis* due to the elevation in the elevation map of Turkiye, and when looking at the aspect map, the red regions represent the south, that is, they are risky locations for *C. perspectalis*, when the temperature maps are examined, the yellow colored areas represent the average risky areas and the red colored areas represent the very hot and risky areas, the Mediterranean and Marmara regions are risky regions for *C. perspectalis*, similarly, when looking at the precipitation maps, the same regions are drier in July compared to May and the dark blue regions receive a lot of precipitation and are not risky regions, when the soil moisture map is examined for drought, which is one of the criteria that affects *C. perspectalis* the most, it is seen that most of the region has moisture-free and low-moisture soil types, and finally, when the flight distance map is examined, the 5-year flight zones of *C. perspectalis* are seen at intervals of 10 kilometers each. All these criteria were overlaid with weighted overlay analysis to create risk maps for May and then July. Figure 4 shows the risk map for May, and Figure 5 shows the risk map for July.

The risk maps produced by weighted overlay analysis were categorized into five classes: "No Risk, Low Risk, Medium Risk, Risk, and High Risk". The red areas on the maps indicate that the current boxwood locations are high-risk areas for a possible *C. perspectalis* transmission, while the green areas do not contain any risk. However, it was observed that the risk areas increased even more in July compared to May due to the increase in temperature and decrease in rainfall.

Finally, the risk maps produced in the study were overlaid with the current boxwood locations and the *C. perspectalis* observations found in this boxwood. Accordingly, the comparison map for May is given in Figure 6, and the comparison map for July is given in Figure 7.

When the existing locations obtained by field studies and observations on the risk maps and the presence of *C. perspectalis* in these locations were examined, it was determined that *C. perspectalis* was present in the risky locations. However, transmission is expected to occur in boxwood where *C. perspectalis* is not observed despite being in the risk zone.

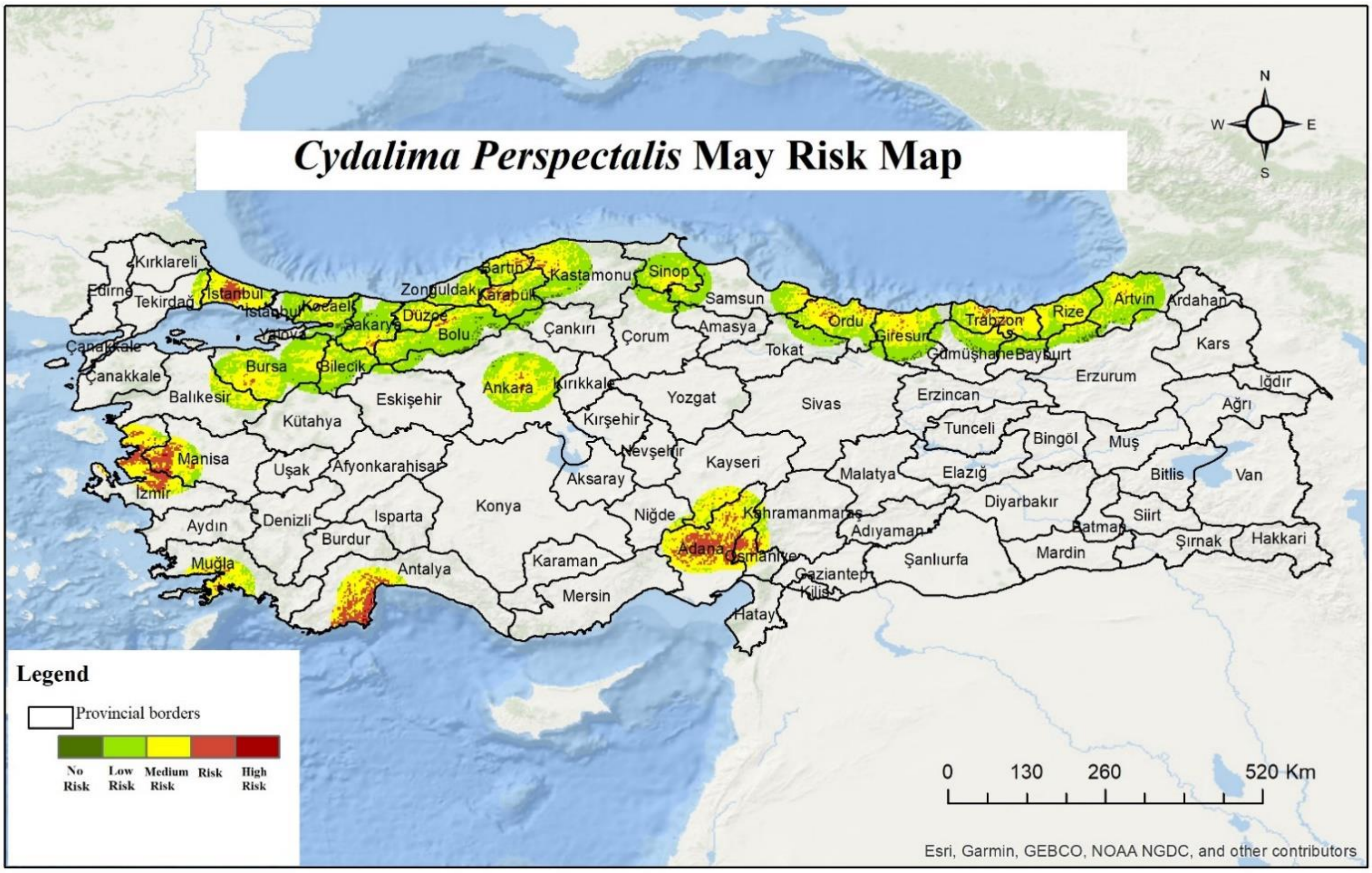

Figure 4. Risk map for *Cydalima perspectalis* in May

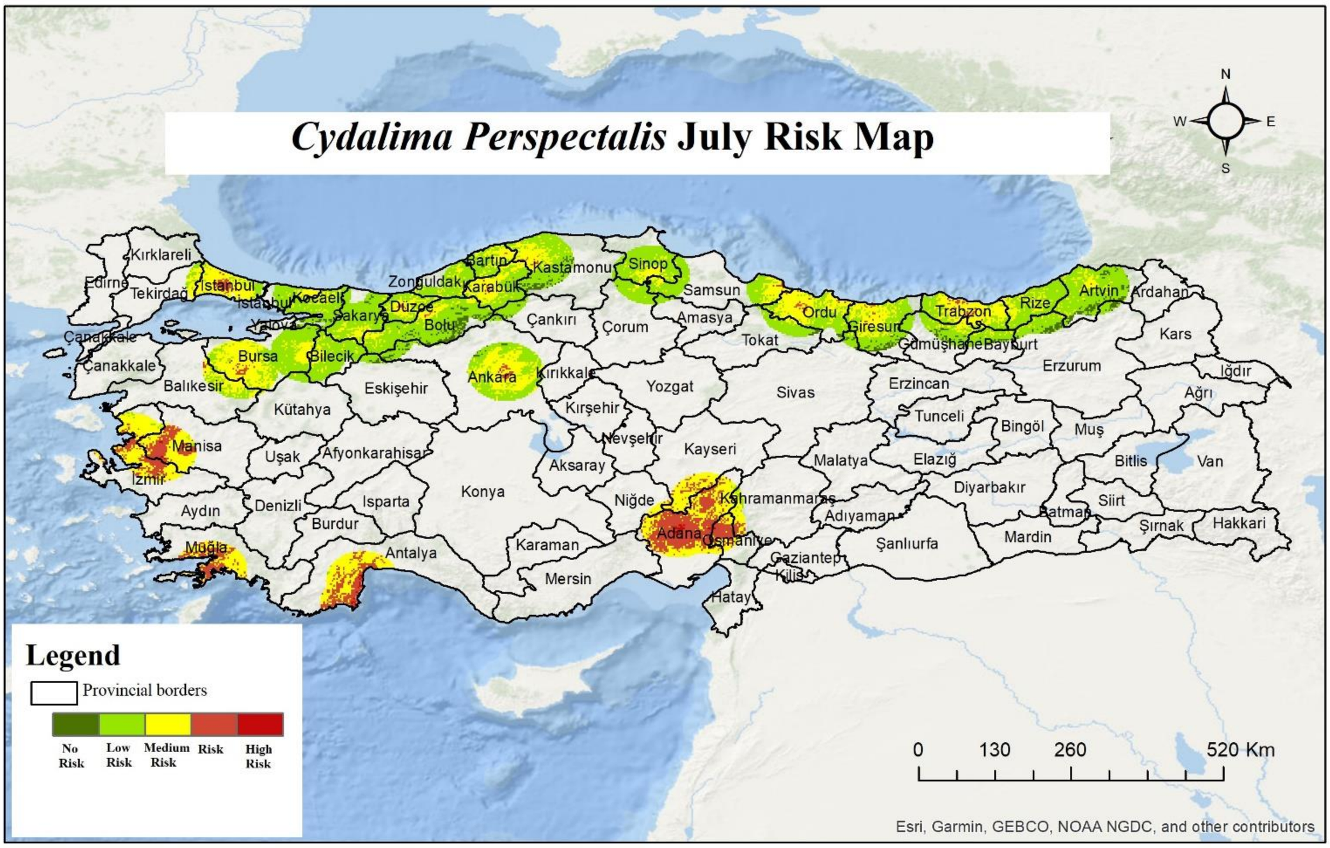

Figure 5. Risk map for *Cydalima perspectalis* in July

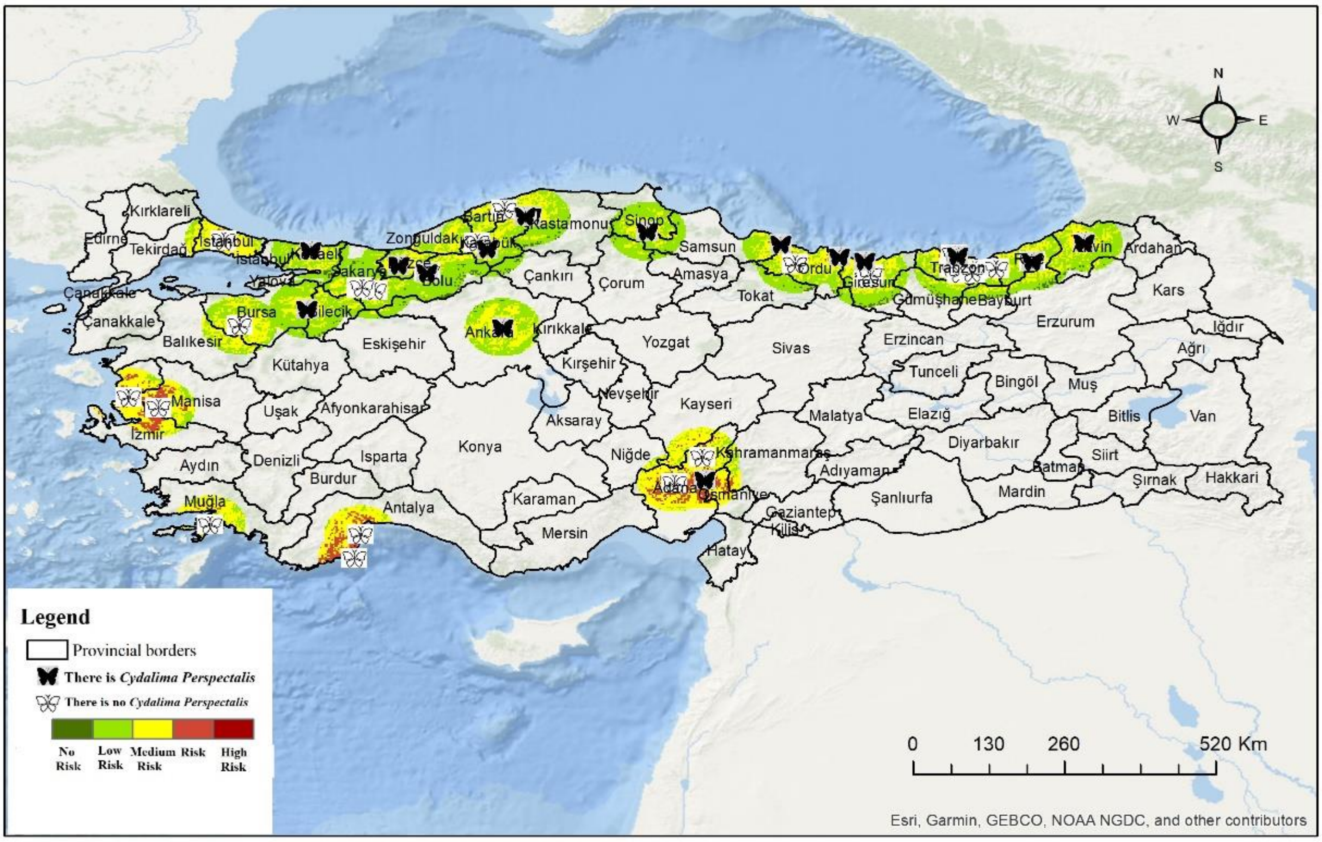

Figure 6. Comparison of boxwood and *Cydalima perspectalis* with the risk map for May

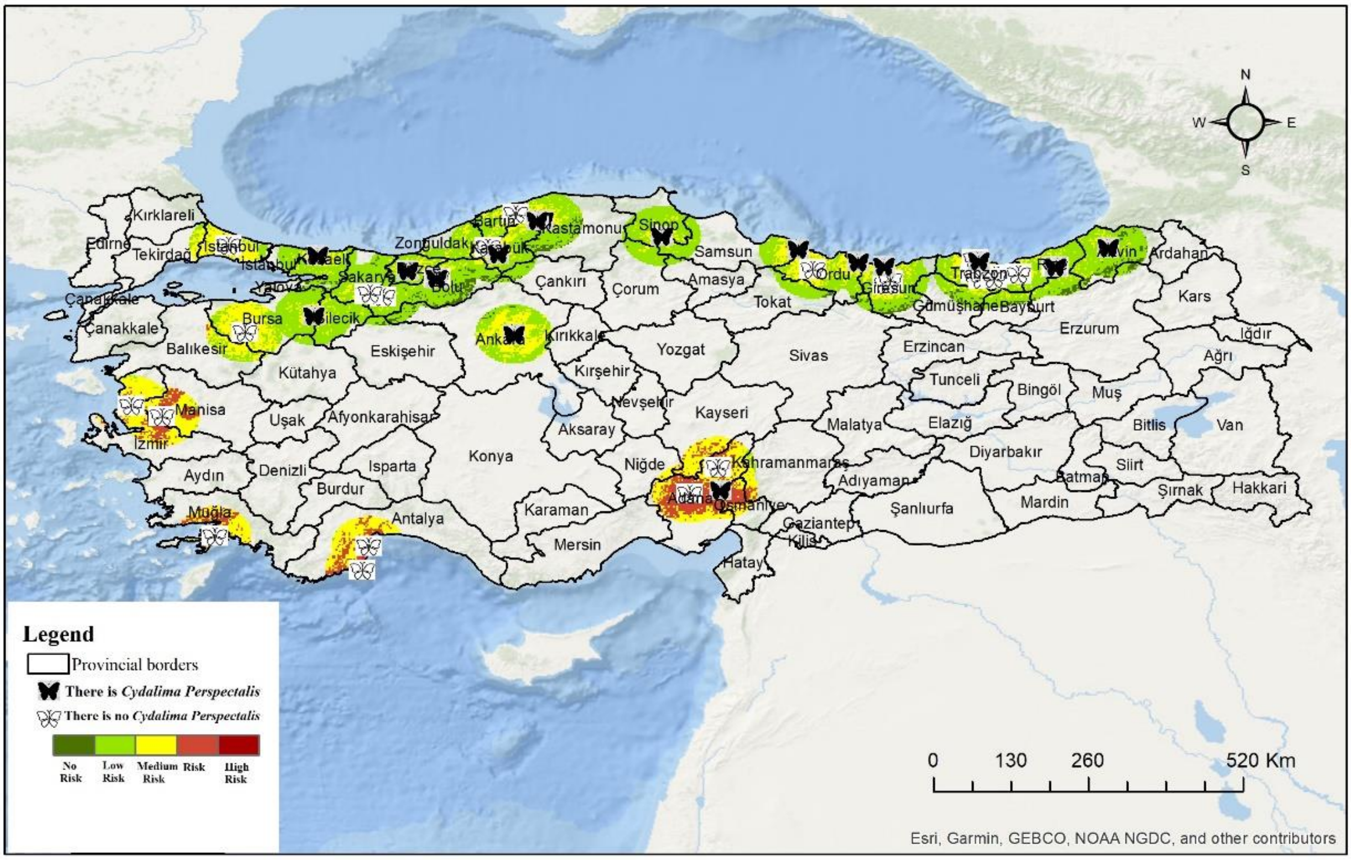

Figure 7. Comparison of boxwood and *Cydalima perspectalis* with the risk map for July

4. Discussion

Although it is difficult to determine risk criteria for C. perspectalis, it is possible to determine criteria that will represent the region or even the country with local applications. The basis of creating healthy and sustainable risk maps is based on criteria. Correctly determined criteria will make the risk map more precise. Although there are no risk maps for boxwood and C. Perspectalis in Turkiye, the International Boxwood Workshop held in 2021 made a significant contribution to the progress and development of this study. For this reason, it is of great importance to increase such studies in Turkiye, and the evaluations of experts who know the region and the localities well are of great importance in determining the criteria. Increasing the criteria will contribute to making the risk map more detailed and sensitive.

Some limitations were encountered within the scope of this study. For example, all boxwood locations and biodiversity maps in Turkiye could not be accessed. In addition, since no studies or research on this subject could be found in the literature, comparisons with other studies could not be made.

5. Conclusion

In this study, for the first time, a risk map was created for a pest using Weighted overlay analysis, one of the GIS-based AHP methods. Since there is no such study in this field, and since it is the first study conducted for C. perspectalis, this study will contribute significantly to other studies to be carried out. By overcoming the limitations encountered within the scope of the study, early detection in the fight against pests will accelerate. It should be taken into consideration that the study was carried out in the context of Turkiye and that each country has a different ecological and topographic structure. For this reason, increasing the number of criteria used in the studies to be carried out, keeping more detailed records and opening the source data will increase the efficiency of the study.

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Author contributions

Şule Yaman: Conceptualization, Methodology, Software, Writing-Original draft preparation; **Mustafa Yaman**: Field study, Data collection, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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