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PREDICTING THE POTENTIAL GEOGRAPHIC DISTRIBUTION AND SEASONALITY OF *CERATITIS CAPITATA* WIEDEMANN (DIPTERA, TEPHRITIDAE) IN THE MEDITERRANEAN REGION OF TURKEY

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ABSTRACT

Ceratitis capitata Wiedemann (Diptera: Tephritidae) is a very destructive pest which feeds on many fruit and vegetable species. To effectively manage this pest, it is necessary to predict its potential geographical distribution and biology. In this study, the population of the pest was monitored in 59 citrus orchards in the Mediterranean region of Turkey (Hatay, Adana, Mersin and Antalya provinces) in 2014 and 2015. A weighted scoring method, which was used to create a risk model, was adopted to predict the distributions of the fly within different seasons. The relationship between the presence of *C. capitata* and 11 environmental factors, including the four seasons, were studied using PASW software. Thus, the risk areas for the pest based on environmental factors and geographical characteristics were mapped. The results show that the more suitable areas for *C. capitata* infestations were mainly located in the coastal areas of the region. The pest population differed significantly according to season. The distribution of the pest was associated with night-time land surface temperature (LSTNIGHT). The southern part of Adana (Yüreğir district), the Syrian border of Hatay, the Mut district of Mersin and Antalya were determined to have a dense population of the Mediterranean fruit fly compared to other areas. The summer season had the highest-level risk group in the study areas, according to the validation map (83.10%). The climatic differences between seasons and locations, as well as host availability and suitability, have been shown to influence the abundance and distribution of *C. capitata* populations.

KEYWORDS:
Ceratitis capitata, citrus, population dynamics, distribution, geographic information system

INTRODUCTION

The Mediterranean fruit fly is a serious economic pest, attacking more than 579 species of fruits and vegetables throughout the world, most of which are of high commercial value [1]. It is a quarantine pest with an extensive dispersive ability and tolerance to live in a warm, Mediterranean, tropical, and subtropical climate [2]. This species changes its hosts during its life throughout the year. It is known that host preferences of *C. capitata* vary across the world. In Turkey, economically, citrus is the main host. The adults puncture the tissue of the host during oviposition and the larvae feed on the fruit pulp. The larvae develop only in mature fruit and when they mature, they leave the fruit, throw themselves onto the ground and pupate in the soil at a depth of 2 to 10 cm. The adults are very active, and when no mature fruits are available in a certain area, they disperse rapidly [3]. This may be related to their ability to adapt and settle into new areas easily. When host fruit is present continuously and weather conditions are favorable for many months, successive generations turn out to be large and continuous. When the average temperature falls below 16°C, *C. capitata* populations also decrease and survive as eggs or larvae inside fruits, as pupae in the soil, or as adults in small numbers [4].

The potential distribution of *C. capitata* was studied by many researchers worldwide [5-9]. In Turkey, the population dynamics of the pest have been studied with adult trapping in different host fruits [10-15]. Comprehensive global information on *C. capitata* occurrence, both in spatial and temporal terms, is very important for understanding the current and historical extent of its occurrence and also the conditions in which it is able to survive and areas suitable for potential invasion and establishment [16]. Occurrence records with temporal reference are important for understanding the factors that drive the pest seasonal population dynamics, which can be used for managing the pest more precisely in large geographic regions [17].

There is no study in Turkey about the seasonal modeling of *C. capitata* performed on global and

regional scales. In this study, the *C. capitata* population was monitored at a total of 59 citrus orchards in the Mediterranean region of Turkey during 2014-2015. The results of pest trapping data from different citrus host plants in various locations and the timing of these records are presented. Seasonally-varying environmental variables were added to these records to offer predictions of the seasonal distributions of suitability for medfly presence on a global scale, with an aim to identify the locations that can be potential risk areas for medfly invasions depending on the season. The results were used to investigate the ecological relationship between the presence of *C. capitata* populations and the phenology of citrus plants and their environment.

MATERIALS AND METHODS

Sampling Areas. The study area was located in the southern part of Turkey, with a particular focus on the southern mountain range of Taurus. *C. capitata* samples were collected from citrus orchards located in 4 different provinces in this region (Hatay, Adana, Mersin, and Antalya). A little over 75% of citrus production is produced in the eastern part of the region, including the cities of Adana, Mersin, and Hatay. Another 15% or takes place around the town of Antalya [18]. All these provinces have a Mediterranean climate along with a hot and dry summer, and a wet and mild winter, especially in the south due to the mountains running parallel to the coast. The areas near the mountains are slightly cooler than the sea region. The elevations of the study areas were between 1 and 341 m. Furthermore, the Mediterranean region of Turkey has a heterogeneous fruit growing area, including a wide range of citrus varieties, mainly cultivated along the coast of the region. Additionally, the other potential hosts of *C. capitata* include peaches, apricots, persimmons, nectarines, pears, figs, pomegranates, quinces, avocados, apples, loquats, etc. [11].

Medfly Collection. The study was conducted at a total of 59 citrus orchards, with 22 orchards in Hatay, 12 in Adana, 10 in Mersin, and 15 in Antalya during 2014-2015 (Figure 1). The *C. capitata* population was monitored across different citrus varieties; Orange (Washington navel, Navelina, Velencia), Mandarin (Okitsu, Satsuma, Nova), and Grapefruit (Starruby). For the monitoring of the adults, Jackson traps were used alongside the attractant Trimedlure (AgriSence, Fresno, CA), which is male-specific. The traps were set up 1,5-2 m above the ground on the south-east side inside the canopy so that the trap was not in direct sunlight. The Trimedlure dispensers were replaced every 6 weeks. The traps were employed weekly throughout the entire year. In case of low capture numbers, the counting and identification were done on site, either by removing the flies (if they were few in number) or by removing the insert and bringing it to the laboratory for examination; they were properly identified with a trap number. When the sticky surface was covered with insects, debris or exposed to heavy rainfall, it was replaced with a new one. The orchards were treated against the pest during the fruit maturation periods with one of the registered insecticides.

Environmental Data Collection. In the study, obtained datasets were separated into five main categories (MODIS, Copernicus, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global DEM v.2, CCI soil moisture and vector data, such as distance to settlements). The environmental data corresponding to the coordinates of each location where *C. capitata* samples consisted of topographical and remotely sensed images. Data on elevation and aspect of the study area were derived from ASTER Global DEM v.2. The ASTER GDEM V2 maintains the GeoTIFF format and the same gridding and tile structure as V1, with 30-meter postings and 1 x 1 degree tiles (Table 1) [19].

The normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), and land surface temperature (LST) were obtained from a moderate resolution imaging spectroradiometer sensor (MODIS) data set. The land surface temperature data set was taken from the MODIS Land Surface Temperature and Emissivity (MOD11) mission. The Land Surface Temperature (LST) and Emissivity daily data were retrieved at 1 km pixels by the generalized split-window algorithm [20]. For the study, the Land Surface Temperature/Emissivity 8-Day L3 Global 1km. (MOD11A2 v. 6) for day and night data were used. The 17-24 May, 18-25 February, 16-23 October and 13-20 August 2014 and 2015 values were obtained from the NASA database.

The normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI) were obtained from the (MODIS) data set. The reflectance layers were extracted from MOD13Q1 files. The MOD13Q1 version for six products provides a vegetation index (VI) value on a pixel basis. There are two primary vegetation layers in MOD13Q1. The first one is the NDVI, which is referred to as the continuity index to the existing National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR). The second vegetation layer was the EVI, which improved sensitivity over high biomass regions [21]. In the study, 250 meters (m) spatial resolution NDVI-EVI values were obtained from the NASA database for the 09-24 May, 02-17 February, 16-31 October and 13-28 August 2014 and 2015 time periods.

The land cover/land use data were obtained from the CORINE (coordination of information on the environment) Land Cover (CLC) inventory. The satellite imagery provides the geometrical and thematic basis for mapping with in-situ data. The basic technical parameters of CLC (44 classes in nomenclature, 25 hectares minimum mapping unit (MMU), and 100 meters minimum mapping width) have not changed since the beginning [22].

The soil moisture data were obtained from the European Space Agency (ESA) Climate Change Initiative (CCI) Soil Moisture team inventory. ESA CCI SM v04.4 comprises active, passive, and combined satellite soil moisture datasets [23]. In the study soil, the moisture values for the 20 May, 20 February, 20 October and 20 August 2014 and 2015 time periods were obtained from the ESA database.

Vector data, such as distance to the settlements, were digitized in a GIS environment as a polygon first within the limits of the study area. The fruit varieties of the study area were digitized as points. ArcMAP 10.3 software and the WGS 84 coordinate reference system were used for this purpose [24].

Choice of Seasons. By considering the biology of the pest, climatic conditions, and host plant phenology, a group of seasonally varying environmental variables were used for the modeling of the dispersion pattern of *C. capitata* on a global scale. Four seasonal maps were created: December-February, March-May, June-August, and September-November. The seasons were chosen according to the studies in the region at different host plants of *C. capitata*. According to the literature, the pest population declines starting from December, and is low or inactive between December-February. The pest activity gains acceleration in March-May. This time, the hosts of the pest are stone fruits like loquats, peaches, and nectarines. The first peak is during June. In August, the pest infects early mandarins (okitsu variety). The fall peak is between September-November when citrus (orange, grapefruit) mature [10-12, 25]. These months are important for the phenology of the host plants, the biology of the pest and for some environmental characteristics of the seasons.

TABLE 1
Data set used for the modelling

Parameters	Description	Source
Digital elevation Model (DEM)	Altitude from the sea level (m)	[19]
Aspect	Aspect in degrees obtained from altitude (Direction)	[19]
NDVI	The normalized difference vegetation index (-)	[21]
EVI	Enhanced vegetation index (-)	[21]
LST	Land surface temperature (°C)	[20]
LSTN	Land surface temperature night (°C)	[20]
SM (Soil moisture)	Soil moisture	[23]
LANDCOV (Land cover / Land use)	Land cover (-)	[22]
Distance	Distance to settlements (km)	[24]
Fruit	Fruit varieties	[24]
Altitude	Altitude of locations (m.)	[24]



FIGURE 1
Study area and locations of traps in the Mediterranean region.

The Risk Model Formulation. The relationship between the presence of *C. capitata* and 11 environmental factors (Fruit, Altitude, EVI, NDVI, CA_LANDCOV, CA_ASTERDEM, Distance, LST, LSTN, SM_LAYER, CA_ASPECT) were analyzed.

The risk model for the *C. capitata* probable distribution was formulated using a weighted scoring method. It was calculated for every significant (P<0.005) environmental variable (Ev) of the four seasons and derived from a logistic regression analysis.

$W_i = (1-p_i)$

Weighted scores (w_i) were needed to determine the risk values (Rv). The risk value for *C. capitata* was independently modeled as follows: $Rv = 1/\log(w_1Ev_1 + w_2Ev_2 + W_nEv_n)$ [26]. Also, the risk maps, including the four-season data, generated for *C. capitata* in the study area were categorized as 4-high to 1-low.

Statistical Analysis. The statistical relationships between the environmental variables and *C. capitata,* fauna data were analyzed using PASW 18.0 software with a univariate regression analysis. In addition, a multivariate regression analysis was conducted to estimate the descriptive variables of the areas that could be damaged by *C. capitata.*

RESULTS AND DISCUSSION

In field studies, 252,182 *C. capitata* individuals were caught in traps in 59 sample points (Figure 1). *C. capitata* trap catches varied between seasons. The pest population was found to be high especially in the summer season in all study sites. Its population was less dense in the winter season. Weekly trapping activity was low, even negligible, in January and February in many districts. Among all the districts, Yüreğir (Adana) had the highest probable damage in the study areas with 8,252 caught Mediterranean fruit flies in the summer season. Figure 1 shows the locations of *C. capitata* occurrence in the Mediterranean region obtained from the data.

Recommended Risk Model. We analyzed the relationship between the presence of *C. capitata* and 11 environmental factors, including four-season data, using the univariate binary regression analysis shown in Table 2. The presence of detected probable *C. capitata* in each station remarkably correlated with NDVI, LST, LSTN, and SM LAYER values.

In the present study, we determined different significant (P<0.005) values related to *C. capitata* probable distribution (NDVI, LST, LSTN, and SM_LAYER) in the univariate analysis, which were also used in multivariate logistic regression analysis (Table 2). Multivariate analysis results showed the relationship between the presence of *C. capitata* and only LSTNIGHT data. The risk model was calculated based on multivariate logistic regression and spatial weighted overlay analysis, which calculated for highly significant (P<0.001) environmental variables (Table 3).

TABLE 2
Univariate regression analysis of between environmental variables and presence of *Ceratitis capitata*

Variables	(P-values) *Ceratitis capitata*
FRUIT	0.815
ALTITUDE	0.352
EVI	0.421
NDVI	0.003*
CA_LANDCOV	0.636
CA_ASTERDEM	0.286
DISTANCE	0.650
LST	0.000***
LSTN	0.000***
SM_LAYER	0.001**
CA_ASPECT	0.374

***Highly significant (<0.001); **Very significant (<0.002); *Significant (<0.05).
FRUIT: Species of citrus, ALTITUDE: Altitude, EVI: Enhanced Vegetation Index, NDVI: Normalized Difference Vegetation Index, CA_LANDCOV: Landcover, CA_ASTERDEM: Digital Elevation Model, DISTANCE: Distance to Settlements, LST: Land Surface Temperature, LSTN: Land Surface Temperature Night, SM_LAYER: Soil Moisture, CA_ASPECT: Aspect.

TABLE 3
Multivariate regression analysis of between meaningful environmental variables in univariate analyze and presence of *Ceratitis capitata*

Variables	(P-values) *Ceratitis capitata*
LSTN	0.000***

***Highly significant (<0.001); **Very significant (<0.002); *Significant (<0.05)

Four risk value maps, associated with the presence of *C. capitata,* were created considering the data sets of MODIS, COPERNICUS, ASTER-GLOBAL, ESA, and the results of the fieldwork data. The medfly niche suitability model, produced using all geolocated occurrence records according to season is presented in Figure 2. Although *C. capitata* was not seen in the inner parts of the region; in other words, the foothills of the Taurus Mountains included 25 sample points, and in the eastern part of the region, the *C. capitata* probable population was more intense than other parts in winter months (Figure 2a).

C. capitata was trapped in all sample points in the spring season, and its probable distribution showed a more homogenous tendency. Especially the southern part of Adana (Yüreğir) and Hatay (border of Syria) were determined to have a high population of *C. capitata* (Figure 2b). The pest was

caught in the summer season in many areas where it was not trapped in other seasons. In this period, during which the risk for potential presence stretched all the way up to the Taurus Mountains, samples were collected at all stations. In many parts of the central, western and eastern parts of the Mediterranean region, a potential distribution was determined, especially in the Taurus Mountains Range, which separates the region from the Central Anatolian region. The pest was caught at elevations up to 1,500 m (Figure 2c). In the autumn season, unlike in spring months, the western part of the Mediterranean region was marked as probable intense distribution of *C. capitata* on the risk map. Especially in the province of Antalya, a high-density of flies were caught compared to other areas (Figure 2d).

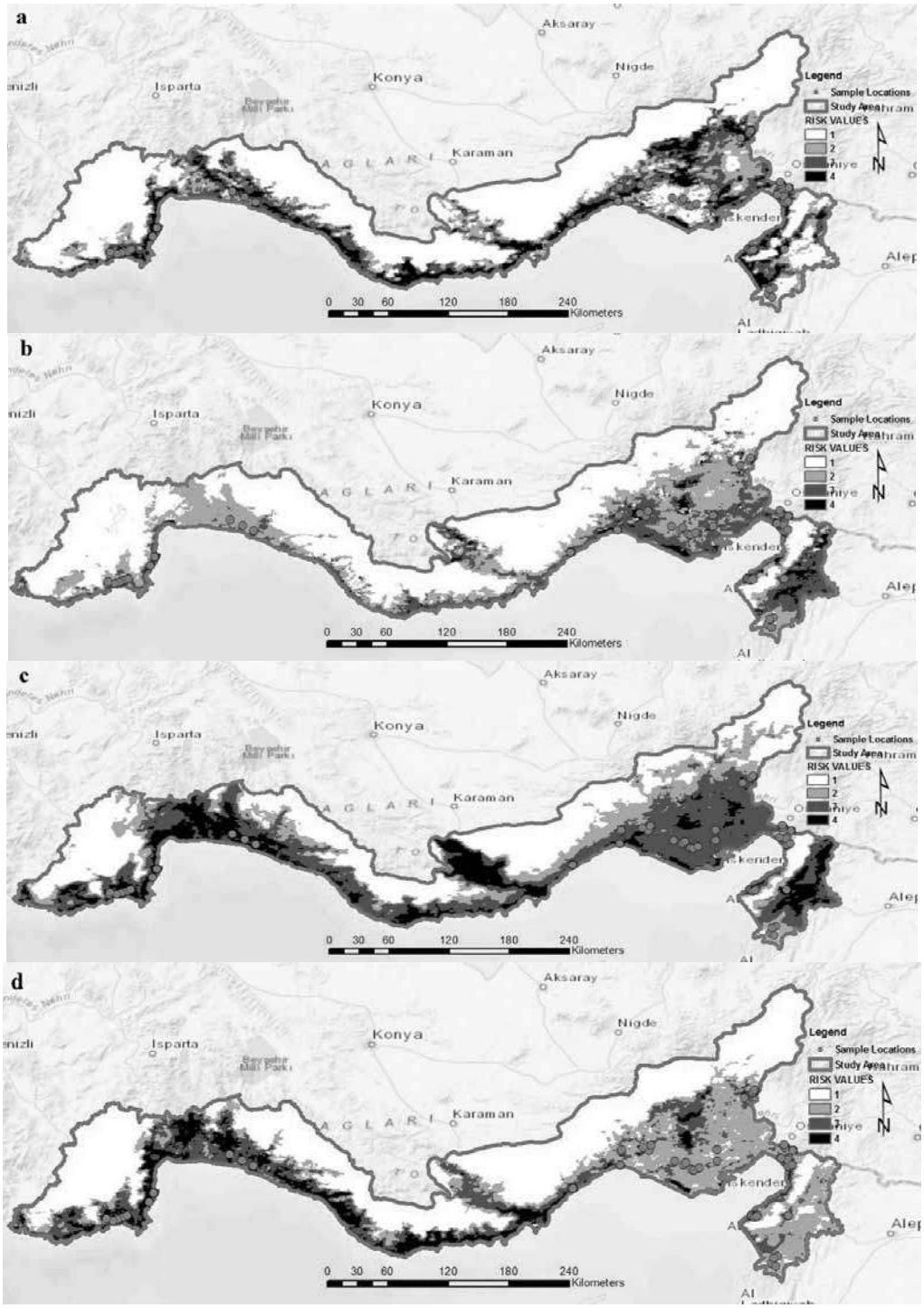


FIGURE 2
Risk level map of *Ceratitis capitata* in winter (a), spring (b), summer (c) and autumn (d) months in Mediterranean region of Turkey.

The distribution model data represent the first global assessment of the seasonally changing potential distribution of *C. capitata* in Turkey, illustrating the significant shifts in environmental suitability that occur throughout a typical year. The seasonal prediction maps reflect changes in the environmental suitability for the pest. Some areas identified in this study were found to be highly suitable for the pest population. Some areas were suitable for 3 or 4 of the seasons mapped (Figure 2c-d). This may not be clearly established due to the unsuitable conditions for the rest of the year. In the locations close to the north of the region, the flies were able to survive for several seasons and did not constitute a long-term stable population.

In the univariate analysis, the 'Normalized difference vegetation index' is statistically significant for the *C. capitata* population. As NDVI data are one of the most important data that show the effect of climatic conditions on vegetation, the dynamics of vegetation are mostly related to rain. The presence of host plants could be considered a vegetation characteristic and may influence the activity, development, and distribution of *C. capitata* [27]. In our study, citrus fruits were limited during the January-March period in the Mediterranean region. It has been reported that the pest overwinters at larval stage in grapefruits which have not been gathered and have been left on the tree in the Cukurova plain [25]. At higher altitudes, apples are a suitable fruit that the larvae can survive on during the winter months [28].

'Soil moisture' has been determined to be very significant for the presence of *C. Capitata* and its distribution. Third-instar *C. capitata* drop in relation with the fruits to the ground, burrow in the soil, and form a puparium within the first 2-4 cm [29, 30]. It is known that the stage that continues in the soil is the most indefensible stage of the life cycle of soil-dwelling pests, especially tephritids [31]. The *C. capitata* activity, development and distribution were influenced by air and soil temperature and soil moisture [27]. In Turkey, nearly 100% of pest control targets the capturing of adults. *C. capitata* control strategies may be applied to adults as is currently done or more attention must be given to prepupating larvae and puparia in the soil.

'Land surface temperature' is of great importance for the *C capitata* population. Surface temperature is an important parameter for environmental as well as climatic studies. The multivariate analysis of environmental variables revealed that only 'Night land surface temperature' values were statistically significant for *C. capitata* (Table 2). Temperature and moisture are major determinants of the developmental rates and natural mortality of soil-dwelling insect stages, and they are particularly important for the preimaginal stages of tephritids [32, 33]. Thus, monitoring soil moisture and temperature would allow for the prediction of the onset of adult emergence and, ultimately, the optimization of the timing of preimaginal and adult control operations, such as mass trapping, the sterile insect technique or biological control with parasitoids and entomopathogens [34].

In the winter season, a limited area in the region is suitable for the pest. The area near the sea coast is predicted to be more suitable. From December onwards, the pest population starts to decrease in citrus orchards. This is because of the maturation and the harvesting of the citrus comes to an end, and the temperature decreases [25]. There is no or very limited adult activity in the January-March period. *C. capitata* overwinters mostly in citrus groves, where damage is initially produced during spring. Between May and July, all citrus fruits are small, thus there are no hosts to puncture in citrus groves. However, in this three-month period, other hosts, such as stone or pome fruits, appear. The pest enlarges its population on these hosts and moves to citrus in late summer and in autumn. *C. capitata* populations usually increase in the growing season, from May to July, and then fluctuate until the end of autumn, when decreasing temperatures reduce the population of flying adults [35]. Our observations demonstrate that low winter temperatures and the absence of host fruits for a long period of time are the two main factors limiting the pest population in southern Turkey. During this unsuitable period, the pest tends to overwinter as larvae in host fruits or in a pupa in the ground. A small number of adults might also be active during the winter at locations where mild winter temperatures are present. In the March-May season, the least amount of the land is suitable for *C. capitata* in our study. During this period, there aren't any matured hosts of the pest. In May, some early varieties of loquat, apricot, nectarine, and peach matures and these varieties of the hosts are usually harvested free from the pest. However, in warmer years, these varieties also could be infected. For this reason, the seasonal suitability maps presented in this paper show considerably lower suitability for medfly activity in the spring months. The presence of *C. capitata* is influenced by the availability of hosts [36]. In northern parts of Greece, apricots maturing early in the season are very important for population development because they constitute the host on which adults of the overwintering generation oviposit first. Among the districts, Adana is more suitable for the pest during this period. During the spring period, stone fruits like peaches, plums, and nectarines are in the maturation stage. Also, the land near the Syrian border is more suitable for the pest population and it is thought that Syria is creating a threat for the pest that is passing over to Turkey. As shown in Figure 2d, the western part of the region (Antalya province) has more highly suitable areas than the eastern part, for which the results are in conformity with other authors [8]. In the western

part of the region, 15% of citrus production is around Antalya, in which bananas and avocados are also cultivated. Most of the Valencia orange in Turkey is produced in this province and starts to be harvested from March onwards. In the summer months, the high amount of land area in the Mediterranean region is shown as suitable for *C. capitata* and it was determined as the most suitable time for the pest population. The most suitable locations for the pest occurrence are mainly located in coastal areas which have a warmer temperature. This season is the period of maturation for many stone fruits and pome fruits. During this period, the suitability of the pest well extended beyond its northern distribution limit and higher suitability was observed in the region. The Antalya province, the Mut district of Mersin and the Syrian border area of Hatay are more suitable than other land areas during this season. The Mut district is far from the coastal areas and the elevation reaches up to 1,300 m. This area is one of the apricot producing areas. Adults that appeared in the summer are thought to probably have originated from larvae that bred on apricots in late spring. In the Adana province, the Saimbeyli district is also suitable for the medfly population. The average altitude of this area is 1,000 m and different species of hosts of the pest, such as apples, peaches, apricots, plums, pears, quinces, etc., are grown here. During this season, the Antalya province has been determined as more suitable than the Adana province. This could be due to more insecticide treatments against the pest in the Adana province than the Antalya province. Farmers mainly prefer chemical control as cover or bait sprays against *C. capitata*. The use of pesticides is important for the activity, development, and distribution of *C. capitata* [27]. The highest suitability for the pest population in the Mediterranean region was the summer season (May-August), which corresponds with other studies [17]. *C. capitata* adults and other tephritids have a notable ability to move long distances in search of food or available oviposition sites [37, 38]. However, when resources in an area are sufficient, flies may settle [39].

Validation. Using environmental data obtained from our field work and different sources, we created four risk maps, including four-season data, related to the presence of *C. capitata*. The risk map was generated based on the three groups of risk levels (high, moderate, and low), and it was tested according to the captured *C. capitata* specimens. The highest-level risk group in the study area was determined according to the validation map (83.10%) in the summer season (Table 4). We presumed that the maps enabled us to estimate the future status of the probable distribution of the related pest in the study areas. According to the maps, in the summer season, the spatial probability of the presence of *C. capitata* was higher than the other seasons.

Medfly Collection. New technological tools in ecology and geographical information systems (GIS) allow for the prediction of the presence of species studied in agriculture. The GIS is a computer-based tool which is efficient in establishing the geographical distributions of insects based on environmental factors. The spatio-temporal distribution patterns of communities, species, and populations in nature are created by environmental factors, such as climate, biotic interactions, topography or human management activity by anthropogenic factors [40]. There is no comprehensive study in Turkey about the seasonal modeling of *C. capitata* performed on global and regional scales. *C. capitata*, like many other insects, is sensitive to climatic conditions. In this study, climatic differences between locations, as well as host availability and suitability, have been shown to influence the abundance and distribution of *C. capitata* populations. It was determined that *C. capitata* adults were captured in all traps where its hosts were present and caused damage to the fruits. Since *C. capitata* was considered to be the main pest in all sample points in the study areas, the created risk maps have been validation maps at the same time.

TABLE 4
The rates of citrus damage by *Ceratitis capitata* at different risk levels in four seasons

Season	Risk levels	Sample points	%
Winter (December-February)	High	33	55.90
	Moderate	18	30.50
	Low	8	13.60
	Total	59	100
Spring (March-May)	High	25	42.40
	Moderate	28	47.46
	Low	6	10.14
	Total	59	100
Summer (June-August)	High	49	83.10
	Moderate	5	8.50
	Low	5	8.40
	Total	59	100
Autumn (September-November)	High	31	52.55
	Moderate	22	37.30
	Low	6	10.15
	Total	59	100

The differences in the fly population between the seasons within each province, as well as the decreasing/increasing trend in trap catches over time, are besides food source, primarily due to climatic variations. *C. capitata* prefers hot and dry areas over wet and cold areas [41, 42]. The warmer and drier climate might have favoured the development and survival of *C. capitata* populations and could have contributed to the relatively higher mean trap catches in these areas. The optimum temperature for the development of this pest is

between 21-26.7°C. Below 10°C, the development stops and in cool climates the larval development can take well over 200 days [43]. Low temperatures have been shown to limit the survival and development of *C. capitata* populations [44]. Moreover, low temperature may hinder its ability to overwinter [5, 6], and high precipitation may have an adverse impact on the pupae development in the soil. Since warmer climates extend the season, the flies are active and able to reproduce [7]. The ability to overwinter at high altitudes on the fringes of suitable areas is very limited and depends on the availability of hosts favoring slow growth, inside which pests can survive [45, 44]. Rainfall and temperature, as well as the interaction between the two, have been found to affect the abundance of *C. capitata* populations [41]. Higher rainfall and lower temperatures during the winter/spring period negatively influence fruit fly development and survival, leading to lower seasonal populations [46, 47].

CONCLUSIONS

Geographic variability in distribution and densities of pests are required for any IPM program. Climatic and faunistic data and suitability can affect the variation in a pest's potential geographic distribution. Using these data, mapping technology is of great importance in analyzing and controlling insects, including the medfly. Produced risk maps allow researchers to control and observe the medfly at a lower cost in all infected regions in Turkey.

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