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Predicting Present and Future Distribution Ranges of an Endemic Flea Beetle, *Psylliodes anatolicus* Gök and Çilbiroğlu 2004 (Coleoptera: Chrysomelidae) in Türkiye

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Extinction

Abstract: This study aimed to construct species distribution models (SDMs) to predict present and future (2050 and 2070) potential distribution ranges of the endemic leaf beetle *Psylliodes anatolicus* Gök and Çilbiroğlu, 2004 under different climate change scenarios (Representative Concentration Pathway (RCP) 4.5 and 8.5). The distribution records were gathered from the related literature and unpublished data of the authors. SDMs were constructed by the maximum entropy (MaxEnt) method using the bioclimatic variables of Community Climate System Model 4 (CCSM4). As a result of this study, the most effective bioclimatic factors determining the distribution of species were isothermality, temperature seasonality, and mean temperature of the wettest quarter. The SDM conducted for the present distribution showed that the species may occur in large parts of the Aegean and Mediterranean Regions of Türkiye, beyond the known records. The SDMs for 2050 and 2070 suggest that the range of the species will shrink considerably or go extinct totally in the next 50 years, probably due to the changing climate. In conclusion, this study revealed that changing climate threatens the endemic members of Anatolian biodiversity, especially the endemic species living in mountain ecosystems.

Endemik Yaprak Böceği, *Psylliodes anatolicus* Gök ve Çilbiroğlu 2004'un (Coleoptera: Chrysomelidae) Türkiye'deki Şimdiki ve Gelecekteki Dağılış Alanının Tahmin Edilmesi

Anahtar Kelimeler
Tür dağılım modellemesi,
Maxent,
Biyoiklimsel değişkenler,
Niş,
Nesli tükenme

Öz: Çalışmada, endemik yaprak böceği *Psylliodes anatolicus* Gök ve Çilbiroğlu, 2004'nın günümüz ve farklı iklim değişikliği senaryolarına (Representative Concentration Pathway (RCP) 4.5 ve 8.5) göre gelecekteki (2050 ve 2070) potansiyel yayılış alanlarının tahmin edilmesi için tür dağılım modellerinin yapılması amaçlanmıştır. Türün dağılış kayıtları ilgili literatür ve yazarların yayınlanmamış kayıtlarından derlenmiştir. Türün günümüz ve gelecekteki dağılışları Community Climate System Model 4 (CCSM4) iklim değişikliği senaryolarına göre maksimum entropi (MaxEnt) metodu kullanılarak tahmin edilmiştir. Çalışmanın sonucunda, izotermallik, en nemli çeyreğin ortalama sıcaklığı ve mevsimsel sıcaklık türün dağılışını belirleyen en etkili biyoiklimsel faktörler olarak bulunmuştur. Günümüz dağılış modeli, bilinen yayılış alanının aksine, türün Ege ve Akdeniz bölgelerinin büyük bir bölümünde bulunabileceğini ortaya koymuştur. Gelecek dağılış modelleri ise, türün dağılış alanının iklim değişikliği nedeniyle 2050 ve 2070 dönemlerinde oldukça daralacağını veya hatta gelecek 50 yıl içinde neslinin tükenebileceğine işaret etmiştir. Bu çalışma değişen iklime bağlı olarak, dağ ekosistemlerinde yaşayan endemik türlerin başta olmak üzere, tüm Anadolu endemik biyoçeşitliliğinin tehdit altında olduğuna işaret etmektedir.

1. Introduction

The genus *Psylliodes* Latreille, 1829 includes about 250 species worldwide and 48 in Türkiye. Among these species, *P. anatolicus* Gök and Çilbiroğlu, *P. cerenae* Gök, Doguet and Çilbiroğlu, *P. diversicolor* Nadein, *P. dogueti* Warchałowski, *P. ridenda* Nadein, *P. taurica* Leonardi, and *P. yalvacensis* Gök are endemic

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to Türkiye [1, 2]. It is known that *P. anatolicus*, *P. cerenae*, and *P. yalvacensis* are belonging to the *picinus* species group. Of these species, *P. cerenae* feeds on Poaceae, while *P. anatolicus* and *P. yalvacensis* on Fagaceae (*Quercus*).

All of these three species were distributed sympatrically in Southwestern Türkiye [1, 3-5]. *P. cerenae* is known from Antalya and Isparta Provinces and *P. yalvacensis* was reported only from Isparta Province. Also, *P. anatolicus* is known from a wider range than the other two species and recorded from Antalya, Aydın, Isparta, Konya and Diyarbakır Provinces [4, 6-11] (Figure 1, Table 1). Although the taxonomy of endemic *Psylliodes* species mentioned here is well known, information on their ecology is limited to the host plant records only. Also, information on range limits is restricted to the faunistic records [4, 6-9, 11].

Table 1. Species distribution data.

Province	District	Coordinates
Isparta	Gelendost	31.17500,38.15000
Burdur	Gölhisar	37.13333,29.50000
Isparta	Center	30.48016,37.86314
Isparta	Center	30.76690,37.53815
Antalya	Kumluca	30.26783,36.63700
Isparta	Eğirdir	30.87418,37.62858
Isparta	Şarkikaraağaç	31.37218,38.04001
Aydın	Didim	27.41076,37.55501
Diyarbakır	Çermik	39.46400,38.17300
Konya	Akşehir	31.40089,38.35431
Isparta	Eğirdir	30.83033,37.73911
Antalya	Korkuteli	30.38470,36.88058

For more than two centuries, the distribution area of a species is one of the most fundamental subject matter which has been studied by biogeographers. Also, how the distribution area of the species changes through time is another fundamental subject of biogeography [12, 13]. Species distribution models (SDMs) predict possible distribution areas by combining statistical modeling methods, which predicts a model that might mathematically explain the dataset, with georeferenced records of the species and the environmental variables [14-17]. SDMs have been more frequently used during the last two-three decades [18, 19]. Thus, SDMs are of great use to evaluate the potential range of species whose distribution areas are not exactly known [20].

Among the endemic *Psylliodes* species mentioned here, *P. anatolicus* establishes populations consisting of a large number of individuals on oak trees within its range [8]. Therefore, this species is likely to cause increment losses in oak trees. From this perspective, it is important to know the exact distribution range of *P. anatolicus*. In this study, the aim was to predict present and future (2050 and 2070) potential distribution ranges of the endemic leaf beetle *P. anatolicus*, which is discontinuously distributed in Southwestern Türkiye, under different climate change scenarios (RCP 4.5 and RCP 8.5) according to Community Climate System Model 4 (CCSM4) model.

2. Material and Method

2.1. Species occurrence and environmental data

Species distribution data were acquired from the related literature and unpublished data of the authors [4,6-11] (Figure 1, Table 1). All of the nineteen bioclimatic variables were downloaded from WorldClim [21]. Before the modeling, highly correlated (r > 0.75) variables were removed to build a more robust model. To do that, correlations among the variables were determined by using ENMTools v1.0 and raster v3.5-11 packages in RStudio [22-24] and excluded from the analysis [25, 26].

2.2. Species distribution modeling (SDM)

SDMs had been carried out using the present and future (2050 and 2070) bioclimatic variables and one optimistic (RCP4.5) and one pessimistic (RCP8.5)

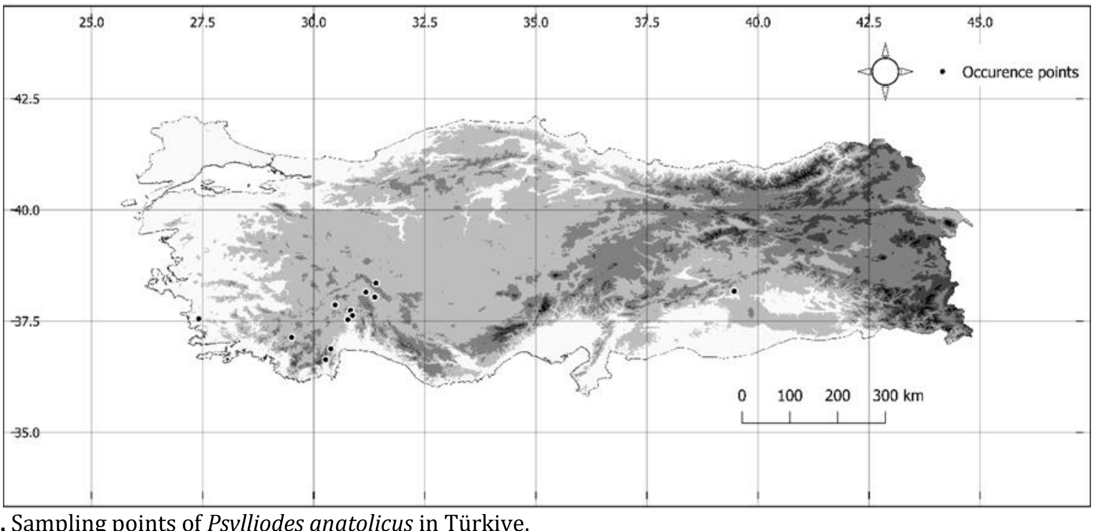

Figure 1. Sampling points of *Psylliodes anatolicus* in Türkiye.

climate change scenarios of the CCSM4 global climate model [27]. The resolutions of rasters of the bioclimatic variables were at 30 arc-seconds. During modeling, feature types had been selected linear and quadratic according to used occurrence number (>10) and jackknife test had been used to define the importance of bioclimatic variables [28-30]. The model had been conducted with 10.000 background samples to train the model. Model success was evaluated by using the area under the curve (AUC) score, which calculates the area under Receiver Operating Characteristic Curve (ROC). MaxEnt version 3.4.1 was used to model the distribution of the species [31,32]. In the end, four threshold values had selected when potential distribution maps have created. These thresholds were unsuitable (0-0.25), moderately suitable (0.25-0.50), suitable (0.50-0.75) and very suitable (0.75-1.0).

3. Results

The bioclimatic variables strongly correlated with each other were determined and removed from the data set. Models were performed with the remaining variables: BIO1, BIO2, BIO3, BIO4, BIO8, BIO12, BIO14 and BIO15 (Table 2). Results showed that the models had a strong predictive ability with the AUC values in the range of 0.881-0.894. According to the jackknife test, variables, which make the biggest contribution to the presence of the species, are isothermality (BIO3), mean temperature of the wettest quarter (BIO8) and precipitation of driest month (BIO14), while the variables that cause the biggest loss with its absence are temperature seasonality (BIO4) and mean temperature of the wettest quarter (BIO8) (Figure 2). According to the relative contributions of the bioclimatic variables to the model, mean temperature of the wettest quarter and temperature seasonality were the most crucial bioclimatic variables that determine species distribution.

The model showed that the current potential distribution range of the species is much wider than its presently known distribution area (Figure 3). SDM suggests that species could be distributed in a large part of the Aegean and Mediterranean Regions, plus

Table 2. Bioclimatic variables used and their correlated variables (r > 0.75). Code of the bioclimatic variables used in the study are shown with asterisk.

Code	Bioclimatic variables	Correlated variables (r > 0.75)
BIO1*	Annual Mean Temperature	BIO5, BIO6, BIO9, BIO10, BIO11
BIO2*	Mean Diurnal Range	
BIO3*	Isothermality	
BIO4*	Temperature Seasonality	BIO7
BIO5	Max Temperature of Warmest Month	BIO1, BIO9, BIO10
BIO6	Min Temperature of Coldest Month	BIO 1, BIO 10, BIO 11
BIO7	Temperature Annual Range	BIO4
BIO8*	Mean Temperature of Wettest Quarter	
BIO9	Mean Temperature of Driest Quarter	BIO1, BIO5, BIO10
BIO10	Mean Temperature of Warmest Quarter	BIO1, BIO5, BIO6, BIO9, BIO11
BIO11	Mean Temperature of Coldest Quarter	BIO1, BIO6, BIO10
BIO12*	Annual Precipitation	BIO13, BIO16, BIO19
BIO13	Precipitation of Wettest Month	BIO12, BIO16, BIO19
BIO14*	Precipitation of Driest Month	BIO17, BIO18
BIO15*	Precipitation Seasonality	BIO18
BIO16	Precipitation of Wettest Quarter	BIO12, BIO13, BIO19
BIO17	Precipitation of Driest Quarter	BIO14, BIO18
BIO18	Precipitation of Warmest Quarter	BIO14, BIO15, BIO17
BIO19	Precipitation of Coldest Quarter	BIO12, BIO13, BIO16

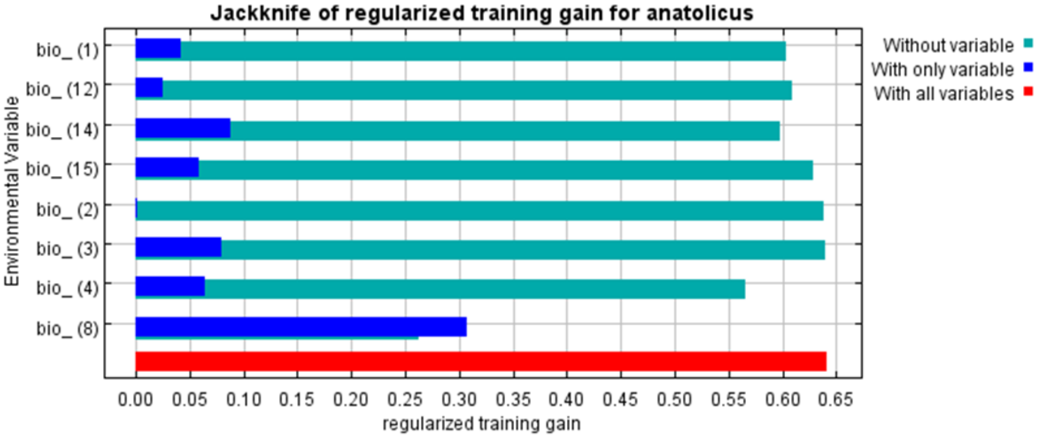

Figure 2. The relative importance of bioclimatic variables according to the Jackknife test.

the Southeastern and Central Anatolian Regions of Türkiye. The most suitable distribution areas includes Afyonkarahisar, Aksaray, Ankara, Antalya, Burdur, Çanakkale, Denizli, Eskişehir, Isparta, İzmir, Karaman, Kırıkkale, Kırşehir, Konya, Kütahya, Manisa, Mersin, Uşak and Yozgat Provinces. According to SDMs of 2050 and 2070, the present possible distribution area will extremely shrink. The models based on the RCP4.5

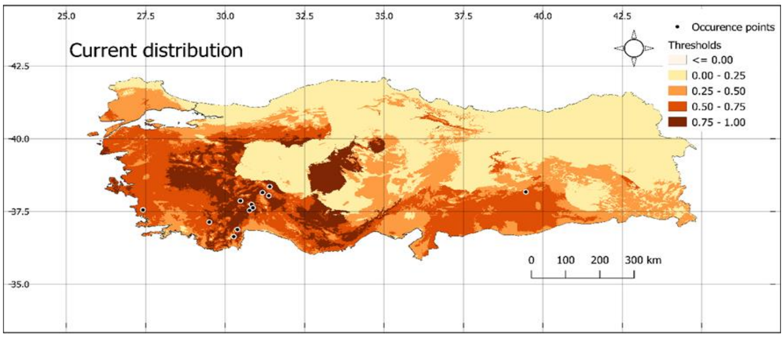

Figure 3. The current potential distribution range of *Psylliodes anatolicus*

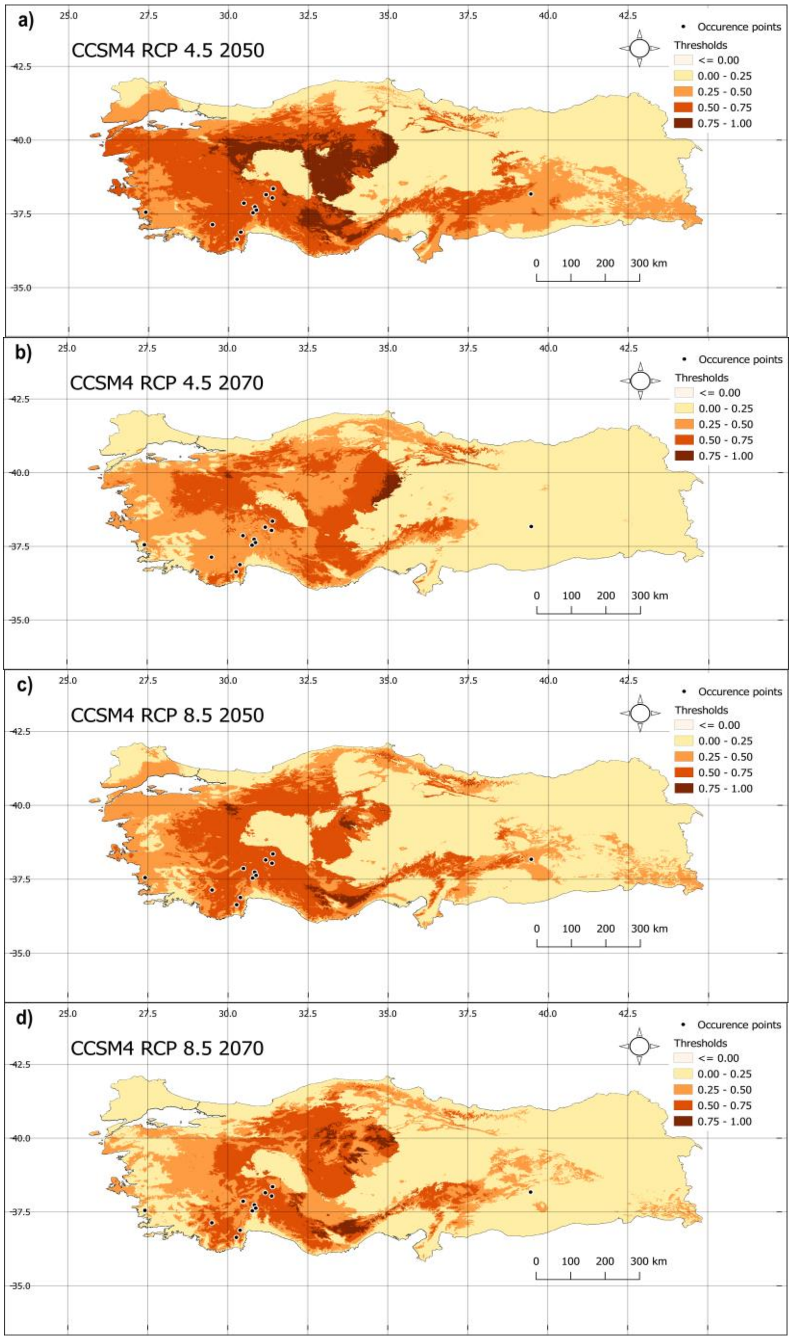

Figure 4. The potential distribution ranges of *Psylliodes anatolicus* in a) 2050 and b) 2070 for RCP 4.5 climate scenario and in c) 2050 and d) 2070 for RCP 8.5 climate scenario.

scenario show that the suitable niches for the species will substantially disappear throughout Anatolia, except Central Anatolia Region (Figure 4a-b) while the models based on the RCP8.5 scenario put forward that there will be suitable habitats at both Central Anatolia Region and Mediterranean Region for *P. anatolicus* (Figure 4c-d).

4. Discussion and Conclusion

Correlation analysis presented that there are eleven strongly correlated bioclimatic variables. The remaining eight bioclimatic variables are related to both temperature and precipitation. This shows that the range of the species is limited not only by temperature but also by humidity. It is known that temperature has a significant impact on insects from growth rates, metabolism, and body size to life history, geographic ranges, and species diversity [33]. Also, temperature seasonality defines the thermal tolerance limits of a species [34,35]. Most probably, temperature seasonality determines the elevation-dependent distributions of this species. Thus, the species seems to be a thermal specialist has narrower elevation ranges. On the other hand, increased precipitation is known to have a substantial impact on insects by limit insect flight ability [36]. Thus, the species most probably prefers areas with relatively dry summer seasons because precipitation limits its flying capacity.

Studies conducted on other leaf beetle species have also presented that isothermality (BIO3), temperature seasonality (BIO4) and mean temperature of the wettest quarter (BIO8) are determinants of the distribution of some Galerucinae and Cryptocephalinae species such as *Aphthona alcina*, *A. perrisi*, *A. wagneri* (BIO4, BIO9, BIO15), *Neocrepidodera ligurica* and *N. melanostoma* (BIO3, BIO4, BIO6, BIO8, BIO18, BIO19), *N. cyanescens concolor* and *N. cyanescens cyanescens* (BIO3, BIO4, BIO6, BIO8, BIO18), *N. corpulenta* and *N. rhaetica* (BIO3, BIO4, BIO6, BIO8, BIO18, BIO19), *Cryptocephalus bari* (BIO2, BIO3, BIO17), and *C. bameuli* (BIO3, BIO14) [20,37,38,39]. According to our model, the suitable current distribution range of *P. anatolicus* is very large covering from Aegean, Mediterranean, and also Southeastern Anatolian Regions, plus some parts of the Central Anatolia. Future SDMs suggested that the suitable range of the species would have been extremely shrunk up, to 2070, possibly because of climate change as the isothermality (BIO3), temperature seasonality (BIO4) and mean temperature of the wettest quarter (BIO8) are the main determinants of the species range. In general, the survival chance of a species under climate change is dependent on the ability to shift its range towards suitable habitats. [40-42]. However, the SDM for 2050 and 2070 showed that the species would not find suitable and very suitable habitats fitting to its ecological requirements. As a result, it can be concluded that the species will have to distribute in harsh conditions (unsuitable and moderately suitable habitats) in terms of its ecological requirements. On the other hand, it was proved that some *Quercus* species may also have to change their distribution range in Türkiye because of changing climate [43,44]. It is a known fact that the species with smaller distribution ranges and with narrow habitat breadths are more at risk than others [45]. In conclusion, similarly, the present study showed that this phytophagous and endemic leaf beetle species with a small distribution range would survive as small isolated populations because both itself and its host plants (*Quercus* spp.) are adversely affected by the changing climate.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

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