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Current and Future Potential Distribution Areas of *Carphoborus minimus* (Fabricius, 1798) in Turkey

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Our study aims to model the current and future (2041-2060 and 2081-2100) distribution areas of *Carphoborus minimus* (Fabricius, 1798) according to SSP2 and SSP5 emission scenarios. Current and future potential distribution areas of the species were predicted using the maximum entropy (MaxEnt) method and the MIROC6 climate change model. Finally, change analysis was performed to reveal the distributional changes between the present and future distribution ranges of the species. Our study has made it clear that the most impactful bioclimatic factors on the distribution of the species are temperature seasonality, isothermality, and precipitation of the driest quarter. Model results showed that the suitable distribution range for *C. minimus* is western and southern Anatolia. Models presented that the species will expand its distribution area through northern Anatolia in the 2050s and 2090s due to the changing ecological environment. In addition to that, the results of the change analysis showed that suitable distribution areas for the species will increase between 7% and 13.5% with time. Therefore, the species can become a new threat to the forests of Northern Anatolia. As a result, state forestry authorities should take precautions against this bark beetle species in the pine stands of northern Turkey in the future. Moreover, land-use plans should be developed to prevent the degradation of forest areas and to plan suitable trees for afforestation.

Key words: Bark beetle, MaxEnt, distribution, climate change.

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The availability of both suitable climatic conditions and a wide variety of plant species in Turkey enables many insects to live in the forests. Some of these insects are one of the most important factors affecting forest health in Turkey (ÇANAKÇIOĞLU & MOL 1998; ERDEM 1982). Climate change not only leads to changes in the natural habitats of insects but also affects pests in agriculture and forest areas. For habitats, the increase in temperature poses a threat to forest trees in two ways. Firstly, insects can cause damage for a longer time with the prolongation of the summer seasons. Secondly, increasing temperatures will cause trees to experience water stress (ŞIMŞEK *et al*. 2010). This situation is an important factor restricting the growth of trees, and also decreases the production of resin, which is an important defense barrier (ŞIMŞEK *et al*. 2010; TESKEY & HINCKLEY 1986). Climate change can cause an increase in the reproductive and outbreak potential of insect species. It will be difficult to manage forests due to these cascade effects caused by climate change (CUDMORE *et al*. 2010; WEED *et al*. 2013).

It is a known fact that the global average temperature has increased by 0.85°C between 1880-2012 due to greenhouse gas emissions according to the Intergovernmental Panel on Climate Change (IPCC) (PACHAURI *et al*. 2014). Some insect species that are not harmful today will cause an epidemic over time because the population dynamics of insects dwelling in forest ecosystems will change due to climate change. Bark beetles, which are one of the most affected species by climate change, are serious disturbance agents in forest ecosystems. It is quite crucial to predict their potential distributions to understand the potential impacts they will have on the forests they live in (ŞIMŞEK *et al*. 2010; BENTZ & JÖNSSON 2015; PURESWARAN *et al*. 2018; JACTEL *et al*. 2019).

Among the bark beetle species, *Carphoborus minimus* (Fabricius, 1798) has increased in severity in Turkey in recent years. The species is distributed in Europe, Russia, Israel, Caucasus, Cyprus, and Palestine and feeds on *Pinus sylvestris*, *P. nigra*, *P. montana*, *P. leucodermis*, and *P. brutia* (KNÍŽEK 2011; PFEFFER 1995). In Turkey, the species feeds on *P. brutia*, *P. pinea*, *P. sylvestris*, and C*edrus libani* (SARIKAYA & AVCI 2009; SCHEDL 1961; SELMI 1998; TOSUN 1975). This species attracts attention because it causes damage and dryness in the branches in the crowns of black pines, Taurus cedars, and especially Brutian pines in recent years.

Today, current and future potential distributions according to different climate scenarios of the species can be revealed by machine learning methods. For this purpose, point records where the species are distributed, and also bioclimatic data of these areas are used (ELITH & FRANKLIN 2013; ELITH *et al*. 2006; ELITH *et al*. 2011; FUKUDA *et al*. 2013; PETERSON *et al*. 2002; PHILLIPS *et al*. 2006; PHILLIPS *et al*. 2004; THUILLER *et al*. 2009).

In this study, our goal was to determine the most important environmental factors affecting the spread of *C. minimus*, to predict the current and future potential distribution areas of the species based on different climate scenarios, and to demonstrate the potential threat situation to the forests of Turkey.

Material and Methods

Study area

Turkey is situated at the crossroads of Asia, Europe, and North Africa (CIPLAK 2003; 2004). The country is rich in coniferous tree species because of its geographical position at the crossing region of the temperate continental and Mediterranean climates. 42% of forests in Turkey are covered with coniferous forests (MUTHOO 1997; ATALAY *et al*. 2014). The hosts (*P. brutia*, *P. pinea*, *P. sylvestris* and *Cedrus libani*) of *C. minimus* are distributed across the northern, western, and southern parts of Turkey (AKYOL & ÖRÜCÜ 2019; ARSLAN & ÖRÜCÜ 2019; ÖRÜCÜ & ARSLAN 2020a,b; ÖRÜCÜ *et al*. 2020a,b; AKYOL *et al*. 2020) (Fig. 1).

Species distribution and environmental data

Occurrence data was acquired from the second author's personal museum samples which he has been collecting from different host tree species in Turkish forests since 2008. The determined points were marked in the WGS 84 coordinate system using Google Satellite Hybrid base maps in QGIS 3.8.1 (QGIS 2019) (Fig. 2). Elevation and 19 bioclimatic variables were downloaded from the WorldClim database. In addition, aspect was created with QGIS. These variables

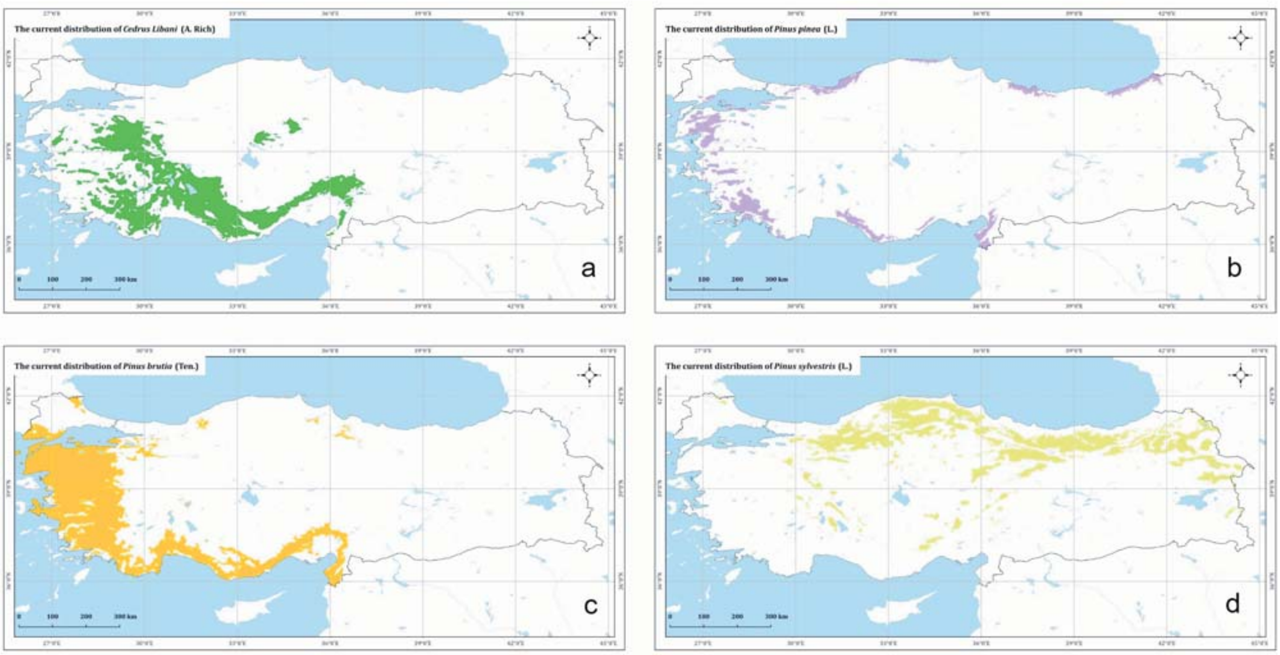

Fig. 1. The current distribution map of Pinaceae species used as a host by *Carphoborus minimus* in Turkey. a – *Cedrus libani; b – Pinus pinea; c – Pinus brutia; d – Pinus sylvestris.*

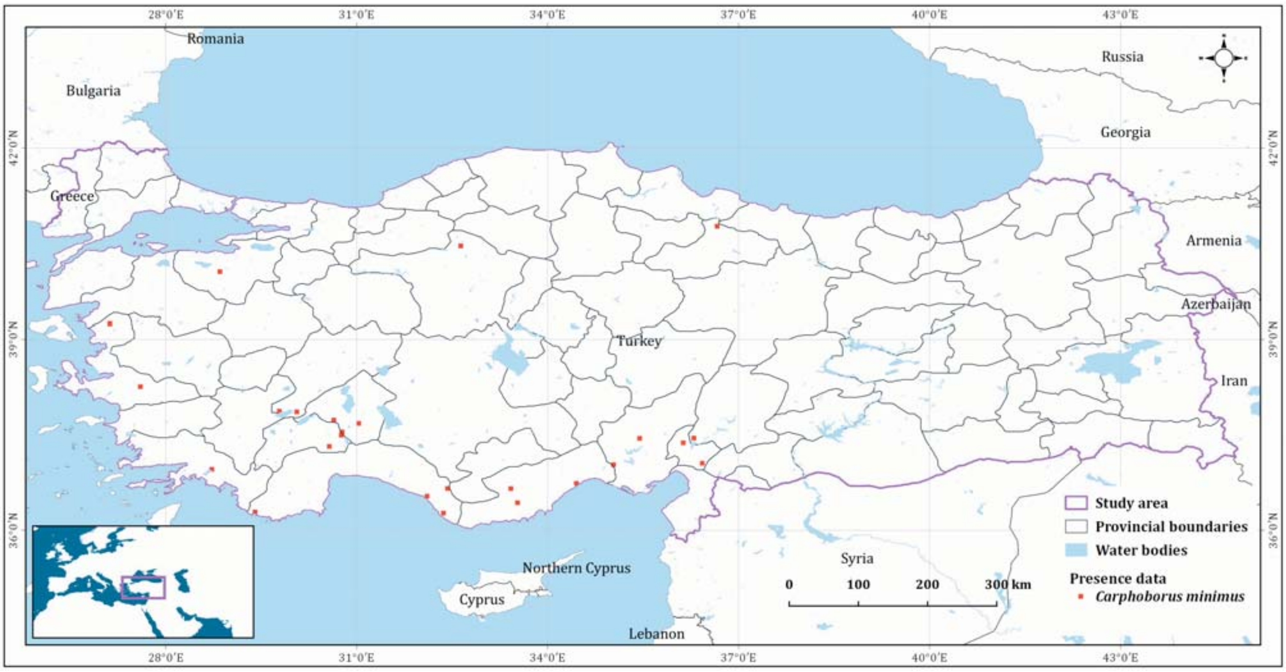

Fig. 2. The distribution areas of *Carphoborus minimus* in Turkey.

were used as the environmental variables (Eyring *et al*. 2016). Next, the Pearson correlation test was performed using SPSS (version 25). Highly correlated variables (r>0.80) were removed to improve the accuracy of the model by eliminating the collinearity among variables.

Two Shared Socioeconomic Pathways (SSPs) scenarios (SSP2-4.5 and SSP5-8.5) issued by the Coupled Model Intercomparison Projects (CMIP6) were used to determine potential distribution areas in the current and future (the 2050s [2041 to 2060] and the 2090s [2081 to 2100]) of *Carphoborus minimus* under climate change (Eyring *et al*. 2016; Gidden *et al*. 2019). Predictions were performed by using the MIROC6 climate model in MaxEnt 3.4.1 (Elith *et al*. 2011; Tatebe & Watanabe 2018; Shiogama *et al*. 2019a,b; Tatebe *et al*. 2019). Models were performed with linear and quadratic feature classes by separating as test data 25% of the presence data (Anderson & Gonzalez Jr. 2011). Areas under the curve (AUC) values were used to determine the performance of the model. The Jackknife test was also performed to determine the contribution of environmental variables (Phillips 2005). At the end, the predictions were divided into five suitability classes: class 0: no possibility of being (0), class 1: unsuitable areas (0-0.25 intervals), class 2: slightly suitable areas (0.25-0.50 intervals), class 3: suitable areas (0.5-0.75 intervals), class 4: highly suitable areas (0.75-1 intervals).

Maps created for future models are compared with the current potential distribution map. To determine changes that will occur, the data obtained from all maps were converted to polygon data with a raster/vector transformation function using QGIS 3.8.1 (QGIS 2019). Intersection analysis was performed to calculate the differences among the polygon data. Finally, the determined changes were digitized as area with QGIS 3.8.1 (QGIS 2019).

Results

Highly correlated variables were removed by using the Pearson correlation test and models were performed with eight variables (mean diurnal range (BIO2), isothermality (BIO3), temperature seasonality (BIO4), max temperature of warmest month (BIO5), annual precipitation (BIO12), and precipitation of the driest quarter (BIO17), aspect, and elevation). The train and test AUC values of the models were 0.919 and 0.823 respectively. These results show that the model has a high predictive power (Gassó *et al*. 2012). According to the Jackknife test, temperature seasonality, isothermality, precipitation of the driest quarter, and elevation were the most impactful variables that shaped the distribution area of the species (Fig. 3).

Current and future predictions of the model are presented in Figs 4-6. The current potential distribution model was highly compatible with the known distribution of the species. Future potential distribution models showed that the distribution area of the species will change with time (Figs 7-8). From the present to the 2050s and 2090s, the distribution range change maps show that suitable distribution areas for

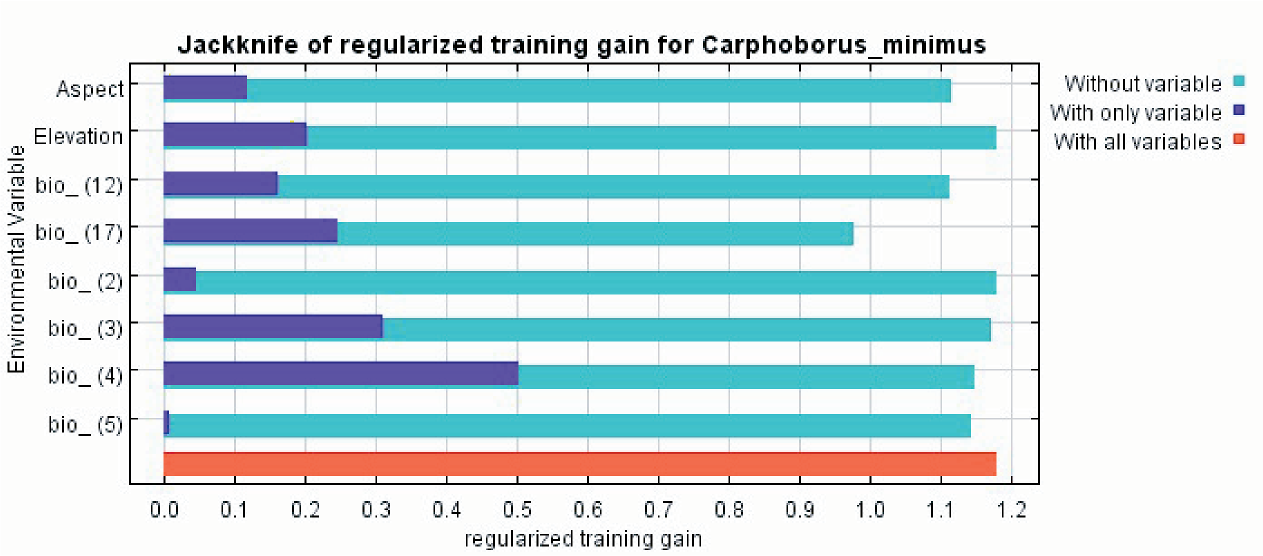

Fig. 3. Jackknife test results of the variables in the model.

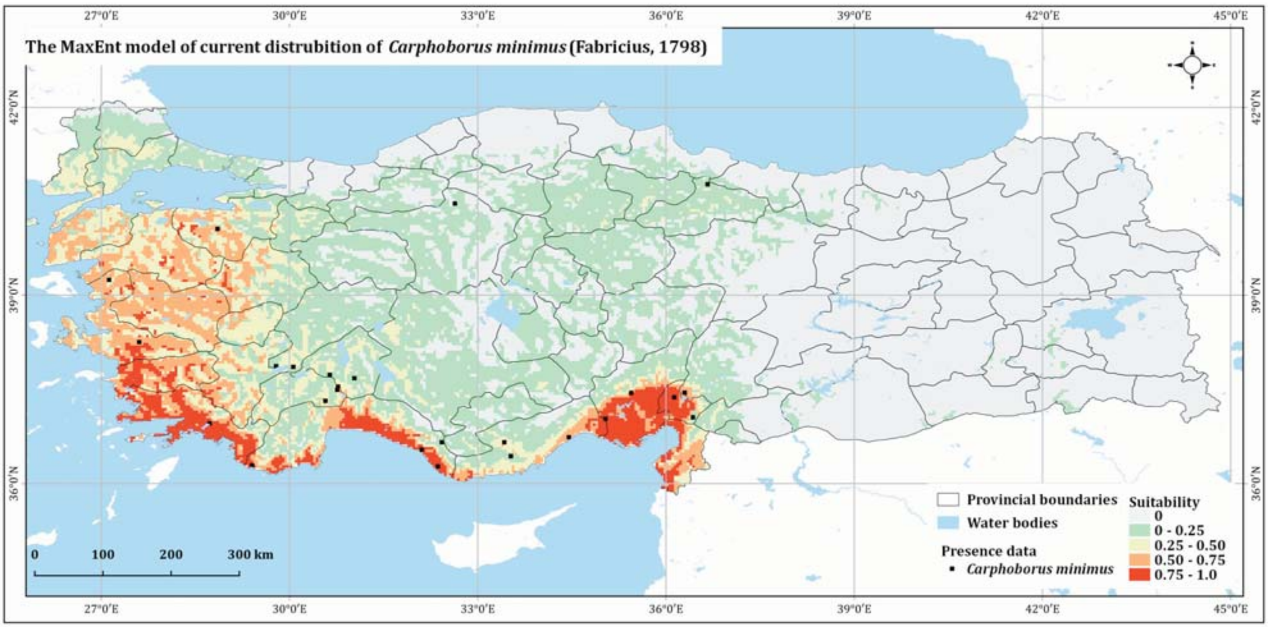

Fig. 4. Current potential distribution of *Carphoborus minimus*.

Carphoborus minimus will decrease in western and southern Turkey and, increase in northern Turkey. The changes between the current and future potential distribution areas were analyzed (Table 1). Highly suitable areas will decrease approximately 15-20% in the 2050s and 2090s according to the SSP2 4.5 climate model, respectively. Also, highly suitable areas will decrease 25% from the present to the 2050s and 40% from the present to the 2090s according to the SSP2 8.5 climate model. Change analysis showed that the suitable distribution area for the species will increase by 4% in the 2050s and 1% in the 2090s for the SSP2 4.5 model, and will rise by 4% in the 2090s for the SSP5 8.5 model (Table 2).

Discussion

According to the Jackknife test, it is understood that the most impactful bioclimatic factor on the distribution of the species are the variables related to both temperature (temperature seasonality and isothermal-

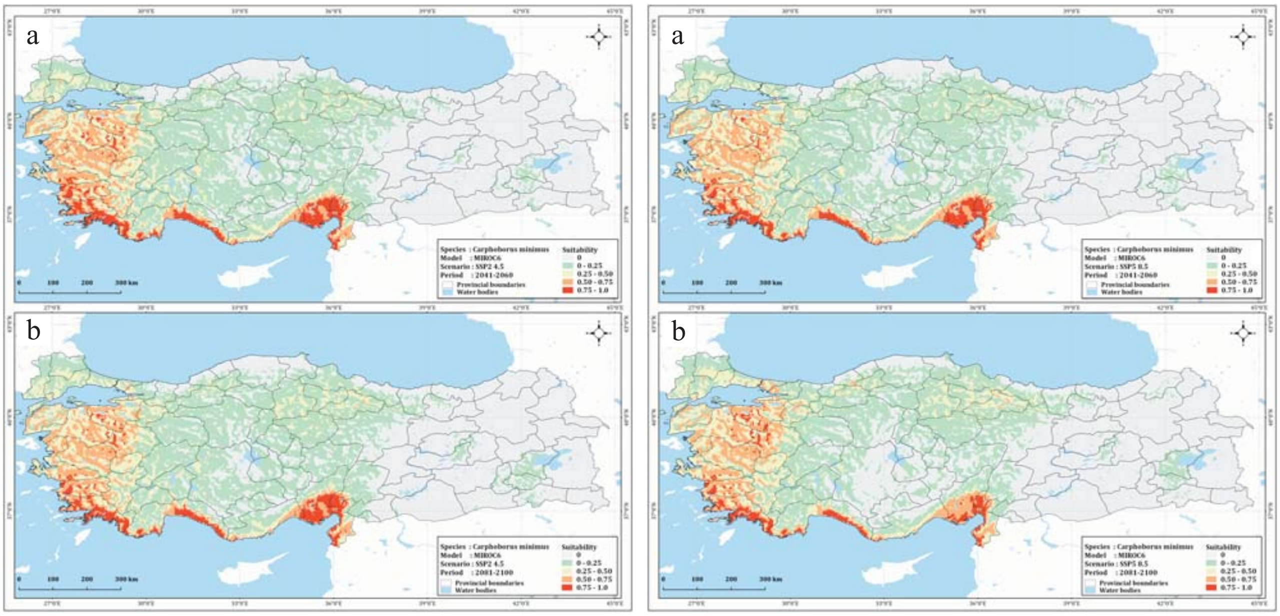

Fig. 5. Future potential distribution of *Carphoborus minimus* in (a) 2050s and (b) 2090s according to SSP2 4.5 (left) and SSP5 8.5 (right).

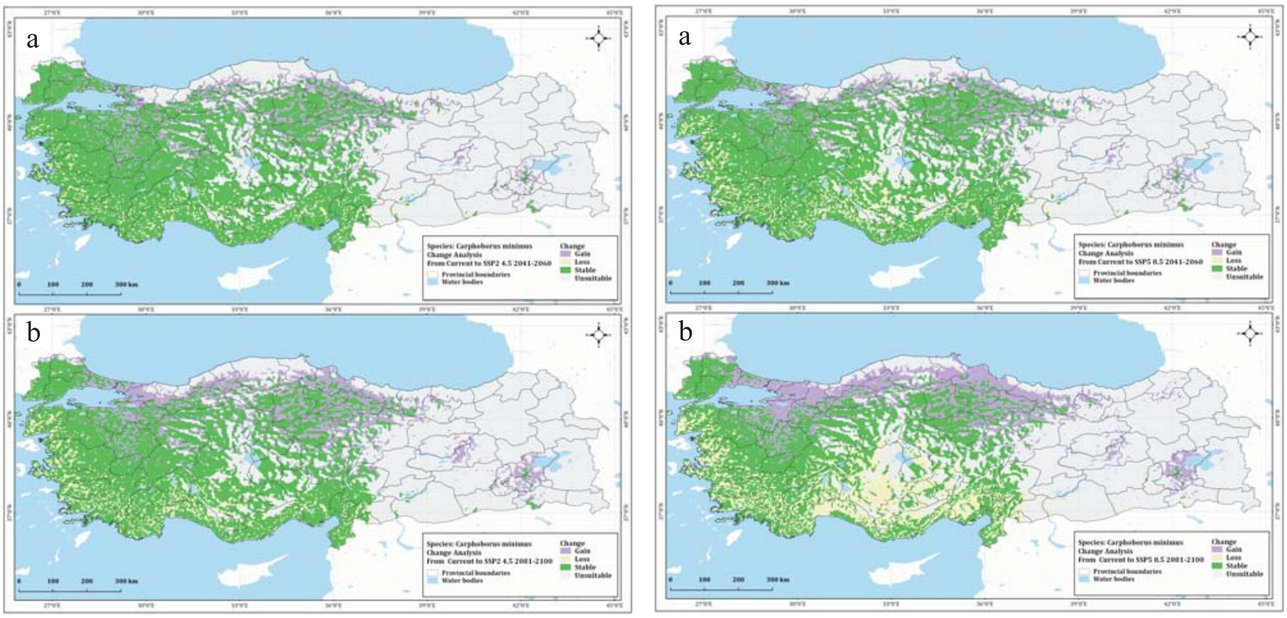

Fig. 6. Distribution range changes of *Carphoborus minimus* from current potential (a) 2050s to future potential (b) 2090s according to SSP2 4.5 (left) and SSP5 8.5 (right).

ity) and precipitation (precipitation of the driest quarter). Temperature affects almost all life history parameters, such as emergence, growth rate, and voltinism (BALE *et al*. 2002; CORNELISSEN 2011). Also, precipitation changes the humidity level of the ecological environment. Thus, precipitation affects not only flight activity but also the reproductive capacity of the insects (JAWORSKI & HILSZCZAŃSKI 2013). It is known that temperature and precipitation are important in the distribution of other Scolytinae species such as *Dendroctonus rhizophagus*, *Dendroctonus rufipennis*, and *Ips mannsfeldi* (BENTZ *et al*. 2010; MENDOZA

Table 1

Spatial analyses of the current geographical distribution of *Carphoborus minimus* and its future potential geographical distribution in the 2050s and 2090s according to SSP2 4.5 and SSP5 8.5 scenarios

Suitability Classes	Current	SSP2 4.5 2041-2061	%	SSP2 4.5 2081-2100	%	SSP5 8.5 2041-2061	%	SSP5 8.5 2081-2100	%
0	396030.15	359218.40	90.70	340862.63	86.07	369445.14	93.29	376984.26	95.19
0-0.25	224993.89	251189.77	111.64	266522.30	118.46	248191.71	110.31	233233.78	103.66
0.25-0.50	70545.46	83106.86	117.81	90011.47	127.59	81321.20	115.27	90253.90	127.94
0.50-0.75	53558.44	55617.94	103.85	53761.15	100.38	53186.27	99.31	56046.11	104.64
0.75-1	27768.83	23763.78	85.58	21739.21	78.29	20752.44	74.73	16378.71	58.98
Total	772896.76	772896.76	100.00	772896.76	100.00	772896.76	100.00	772896.76	100.00

Suitability Classes: 0 - no possibility of being; 0-0.25 unsuitable areas; 0.25-0.50 slightly suitable areas; 0.5-0.75 suitable areas; 0.75-1 highly suitable areas for the species.

Table 2

Changes from the current geographical distribution of *Carphoborus minimus* to the predicted distribution in 2050s and 2090s according to SSP2 4.5 and SSP5 8.5 scenarios

Change (km^2)	SSP2 4.5				SSP5 8.5			
	2050s	%	2090s	%	2050s	%	2090s	%
Unsuitable	354940.98	45.92	333154.98	43.10	358110.99	46.33	331682.15	42.91
Stable	336449.28	43.53	312785.91	40.47	320764.28	41.50	239647.38	31.01
Gain	61491.77	7.96	91855.57	11.88	54794.37	7.09	103920.37	13.45
Loss	20014.74	2.59	35100.30	4.54	39227.12	5.08	97646.86	12.63
Total	772896.76	100.00	772896.76	100.00	772896.76	100.00	772896.76	100.00

et al. 2011; SARIKAYA *et al*. 2018). Studies conducted on beetle species besides bark beetles have also presented that one or more variables of the following variables: temperature seasonality (BIO4), isothermality (BIO3), and precipitation of the driest quarter (BIO17), are among the most important bioclimatic variables for the beetle species (e.g. *Cactophagus spinolae* (BIO4, BIO17), *Liparus glabrirostris* (BIO3, BIO4), *Otiorhynchus sirentensis* (BIO3) (Curculionidae), *Aphthona alcina* (BIO4), *A. perrisi* (BIO4), *A. wagneri* (BIO4), *Neocrepidodera ligurica* (BIO4), *Cryptocephalus bari* (BIO3, BIO17), *C. bameuli* (BIO3, BIO17), *C. flavipes* (BIO3), *Longitarsus springeri* (BIO3), *Luperus fiorii* (BIO3), *Oreina sibylla* (BIO3), *Psylliodes biondii* (BIO3) (Chrysomelidae), *Batocera lineolata* (BIO4) (Cerambycidae)) (URBANI *et al*. 2015; LÓPEZ-MARTÍNEZ *et al*. 2016; URBANI *et al*. 2017; BRUNETTI *et al*. 2019; CERASOLI *et al*. 2020; LI *et al*. 2020; KUBISZ *et al*. 2020; LACHOWSKA-CIERLIK *et al*. 2020). In this study, it is understood that temperature seasonality and isothermality shapes the life history parameters of *C. minimus* while the precipitation of the driest quarter limits its flying capacity. As for elevation, results indicated that it is one of the factors which limits the upper distribution range of *C. minimus*.

Model results showed that a suitable distribution range for *C. minimus* is western and southern Anatolia. Models presented that the species will expand its distribution area through northern Anatolia in the 2050s and 2090s thanks to the changing ecological environment with the effect of both temperature and precipitation. Although the distribution area of a specialist bark beetle species is shaped by the distribution area of its host tree (NING *et al*. 2019), *C. minimus* is not limited by the distribution range of its hosts. In addition, it could feed on *Pinus sylvestris* once expanding its distribution area to northern Turkey (Fig. 1). Our change maps and data showed that the suitable distribution area for the species will increase between 7.09% and 13.45% with time. Similar studies conducted on pine tree species (such as *Pinus nigra*, *P. sylvestris*, and *P. pinea*) suggest that climate change will cause losses in the suitable areas of their current distribution range and fragment the habitats of these pine species (ARSLAN & ÖRÜCÜ 2019; AKYOL

& Örücü 2019). Climate change will cause water stress to the trees and stressed and weakened trees in these areas will potentially be suitable hosts for *C. minimus*. Therefore, the species can be a new threat to the forests of Northern Anatolia. The main conclusion is that state forestry authorities should take precautions against this bark beetle species in the pine stands of northern Turkey in the future. Moreover, land-use plans should be developed to prevent the degradation of forest areas and to plan suitable trees for afforestation. By doing this, even if the species increases its distribution area, the level of damage will be kept to a minimum as it will encounter tree species that are more resistant to climate change.

Author Contributions

Research concept and design: I.S., O.S., O.K.O.; Collection and/or assembly of data: I.S., O.S., O.K.O.; Data analysis and interpretation: O.S.; Writing the article: I.S., O.S.; Critical revision of the article: O.S.; Final approval of article: O.S.

Conflict of Interest

The authors declare no conflict of interest.

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