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Modelling the potential distribution of the endemic oak *Quercus vulcanica* Boiss. & Heldr. ex Kotschy in Turkey from the last interglacial to the future: From near threatened to endangered

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Abstract: The aims of this study are to model past (LIG, LGM and Mid-Holocene), present and future (2050 and 2070) distributions of the *Quercus vulcanica* Boiss. & Heldr. ex Kotschy by using Maximum Entropy, and to predict suitable areas for the conservation of the species for future planning. MaxEnt distribution modeling was used to model distributions. Results for past bioclimatic conditions show that the distribution area of the species expanded and then contracted (LIG to LGM and LGM to HOL). The modelling shows that the distribution range of the species will be narrower in the future. The species will be facing extinction towards 2070. Therefore, the conservation status of the species should be evaluated according to the present findings. Although the largest population of the *Q. vulcanica* is found in Isparta and Afyonkarahisar Provinces located in Southwestern Turkey, this area will not be suitable for the growth and survival of the species in the future. For this reason, a new nature reserve area should be established in a more suitable climate.

Keywords: oak, biogeography, species distribution modelling, MaxEnt, biodiversity conservation

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Introduction

The genus *Quercus* L. is one of the biggest genera in the Fagaceae with 400–500 described species (Govaerts & Frodin, 1998; Nixon, 1993; Valencia et al., 2016). Besides being rich in species, oaks constitute one of the most common types of forest in the Northern Hemisphere (Cavender-Bares, 2016; Kubitzki, 1993; Nixon, 2002; Standiford et al., 2003). The forest ecosystems formed by these trees are important not only ecologically, but also economically (Bugalho et al., 2011; Hubert et al., 2014; Standiford et al., 2003). However, oak forests, especially in the Mediterranean Basin, have been exposed to strong human pressures and to land use/land cover changes since ancient times (Kaplan et al., 2009; Scarascia-Mugnozza et al., 2000; López-Sánchez et al., 2014; Marquer et al., 2017). In addition, there is a lot of evidence for the adverse effects of climate change on forest landscapes around the world (Azevedo et al., 2014; Kirilenko & Sedjo, 2007; Whipple et al., 2019). It is known that the Mediterranean Basin, which is the third richest hotspot in terms of plant biodiversity, has two main centers of biodiversity. These are the Iberian Peninsula (notably with Andalusia) and Morocco (with the Atlas and Rif Mountains) in the west, and some parts of Turkey and Greece in the east. In addition, the Mediterranean Region is one of the most vulnerable areas to global climate change, along with typical forest ecosystems, including native oak woodlands (Médail & Quézel, 1999; Giorgi &Lionello, 2008; Kovats et al., 2014; Lindner et al., 2014; Lindner et al., 2010; Mittermeier et al., 2004; Schröter et al., 2005). 24 oak taxa occur in Turkey which is located in the Eastern Mediterranean Basin. Four of them are also endemic: *Quercus aucheri* Jaub. & Spach., *Quercus macranthera* subsp. *syspirensis* (K.Koch), *Quercus trojana* subsp. *yaltirikii* Ziel. and *Quercus vulcanica* Boiss. & Heldr. ex Kotschy (Öztürk, 2013). Among these endemic oaks, the *Quercus vulcanica* Boiss. & Heldr. Ex Kotschy. is in the Near Threatened (NT) group according to the IUCN's risk categories (Ekim et al., 2000). Besides being NT, *Q. vulcanica* is ecologically important because it is a significant component of certain forest ecosystems containing endemic butterflies and wild mountain flowers in Turkey (Sarıkaya & Sayın, 2016; EUFORGEN, 2019). There are three main reasons why the species is under threat. Firstly, the species has been extensively used for timber and ornamental purposes over the last millennia. Thus, it can grow only in some isolated and small locations included in the scattered areas in Turkey (Akman, 1995; Avcı, 1996; EUFORGEN, 2019; Ozturk et al., 2010). Secondly, although a recent local study suggests otherwise, this species is at risk of reduced genetic diversity due to sensitivity to genetic drift, inbreeding, and hybridization (Rushton, 1993; Rhymer & Simberloff, 1996; Ellstrand et al., 1996; Curtu et al., 2007; Yücedağ et al., 2021). The third threat is that this species will be affected by climate change, such as *Quercus libani* Oliv. and *Quercus ilex* L. Because of these threats and the ecological importance of the species, approximately 1300.5 ha forest area near the Yukari Gokdere village in Eğirdir district, Isparta province was declared as a Nature Reserve Area to protect this endemic species in 1987 (Karatepe, 2005; Bayindir et al., 2013). However, there are not enough precautions to conserve this species except this Nature Reserve Area established in Isparta Province. In this context, the aims of the study are (1) to predict the past, present and future distributions of the *Q. vulcanica* by using Maximum Entropy Modeling and (2) to predict suitable areas for planning the conservation of the species in Turkey.

Materials and Methods

Thirty nine records of the occurrence of the *Q. vulcanica* in Turkey were obtained from the literature (Altınözü, 2004; Avcı, 1996; Çetik, 1982; Çırpıcı, 1985; Dinc et al., 2014; Hedge & Yaltırık, 1982; Kargıoğlu, 2009, 2018; Katılmış et al., 2011; Yaltirik, 1984; IUCN, 2021) (Fig. 1).

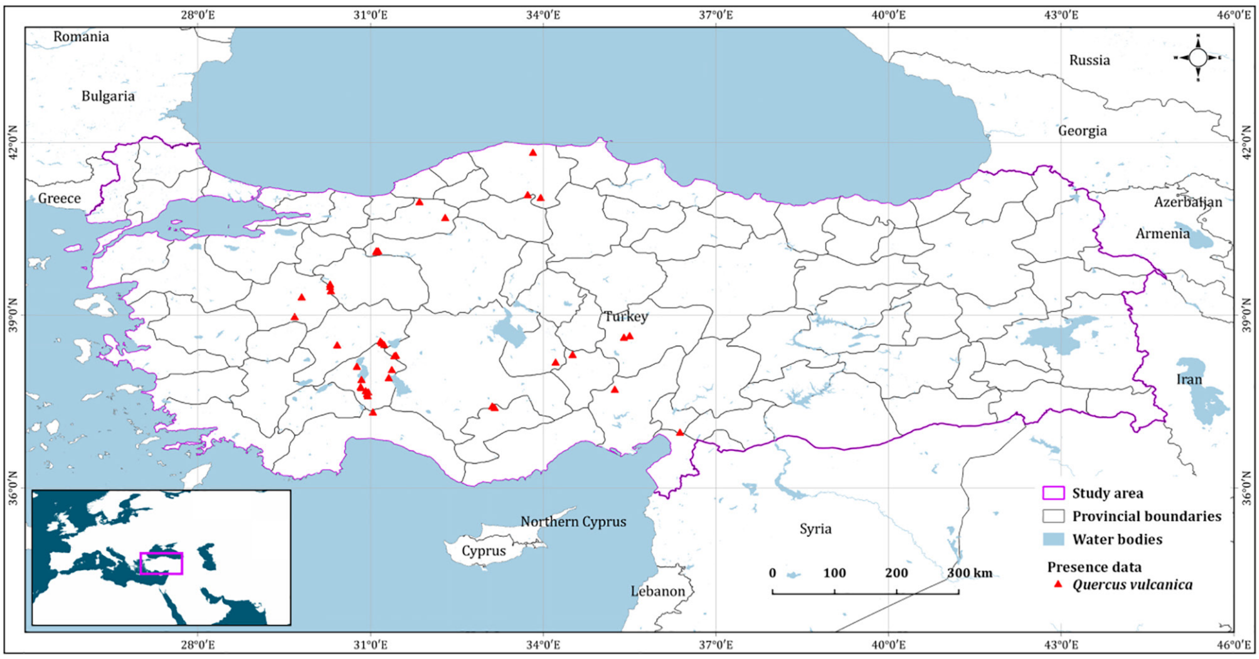

Fig. 1. The geographic position of Turkey and the occurrence sites of *Quercus vulcanica*

MaxEnt 3.4.1 was performed with the occurrence data of *Quercus vulcanica*. Random test percentage was defined 25% and replicated run type was chosen as subsample. The number of replicates was set as 10. 'Linear', 'quadratic' and 'hinge' modelling procedure was applied to create for the best performance of modeling current and future distribution. Because the training data represented by 75% of the occurrence data. To identify the model performance Area under the Receiver Operating Characteristic (ROC) Curve (AUC) was analyzed (Phillips et al., 2017).

Nineteen Bioclim variables of the WorldClim database were used as present environmental variables (Hijmans et al., 2005). Past (Mid-Holocene [MIH; c. 6000 years ago], Last Glacial Maximum [LGM; c. 21 kyr bp], Last Interglacial [LIG; c. 120–140 kyr bp] and future climate (2050 and 2070) projections were carried out to explain distributional changes over time. For past and future projections, climate data were obtained from the WorldClim database (www.worldclim.org). The LIG climate data were based on the Community Climate System Model, version 3 (Community Climate System Model: CCSM; Otto-Bliesner et al., 2006). Bioclim variables for the past, present and future (CCSM4) and for four greenhouse gas emission scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) were used to project the model. All variable rasters were at 30 arc-seconds resolution, except the LIG climate data, with a spatial resolution of 2.5'. MaxEnt version 3.4.1 was used to model the distribution of the species (Phillips et al., 2017; Phillips et al., 2006). The jackknife method described by Pearson et al. (2007) was used to validate the model. According to the results of the Pearson correlation test performed to solve the multicollinearity problem among the statistical analyzes specified in the method, the variables with an r-value of ±0.8 in the correlation matrix were extracted according to their importance. After then, the variables that increase the predictive ability of the model were bio 1, bio 3, bio 7, bio 8, bio 9, bio 11, bio 12, bio 18 and bio 19 (Fig. 2).

Results

Figure 2 shows the test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.

Figure 3 is the receiver operating characteristic (ROC) curve for the same data, again averaged over the replicate runs. Note that the specificity is defined using predicted area, rather than true commission (Phillips et al., 2017). The average test AUC for the replicate runs is 0.892, and the standard deviation is 0.082. Figure 3 shows the performance of the model is sensitive.

Figure 4 shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is bio 8, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is bio 8, which therefore appears to have the most information that isn't present in the other variables. Values shown are averages over replicate runs.

Figure 5 shows how each environmental variable affects the MaxEnt prediction. The curves show how the predicted probability of presence changes as each environmental variable is varied, keeping

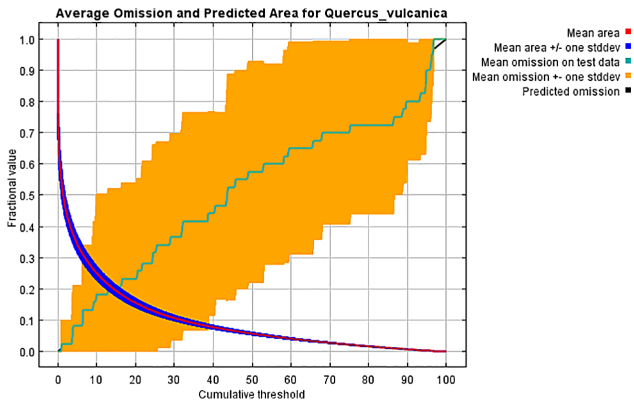

Fig. 2. Average Omission and Predicted Area

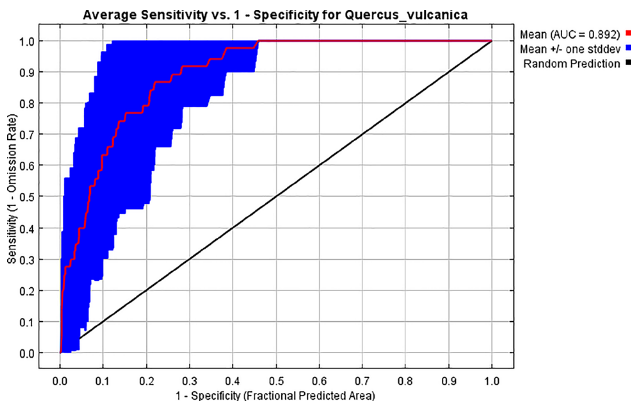

Fig. 3. Reliability of the prediction

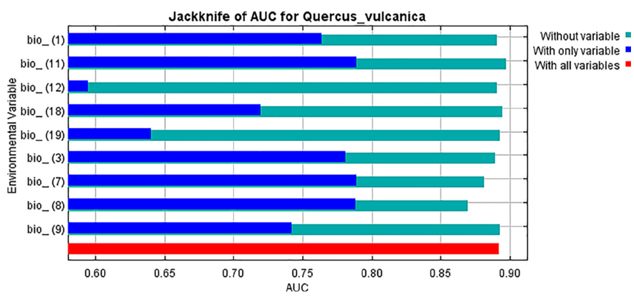

Fig. 4. Jackknife test of variable importance (Green: without variable, Blue: with only variable, Red: with all variables)

all other environmental variables at their average sample value. The curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together. The curves show the mean response of the 10 replicate Maxent runs (red) and the mean +/− one standard deviation (blue, two shades for categorical variables).

In contrast to the above marginal response curves, each of the following curves represents a different model, namely, a Maxent model created using only the corresponding variable in Figure 6. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables.

The prediction of the model conducted using present climate data matches up to the present distribution range of the *Q. vulcanica* very closely. According to the prediction of the model conducted using past climate data, the area of distribution of the species has expanded and contracted over time (LIG to LGM and LGM to HOL) (Fig. 7). The model predicted that the species had narrower distribution ranges during

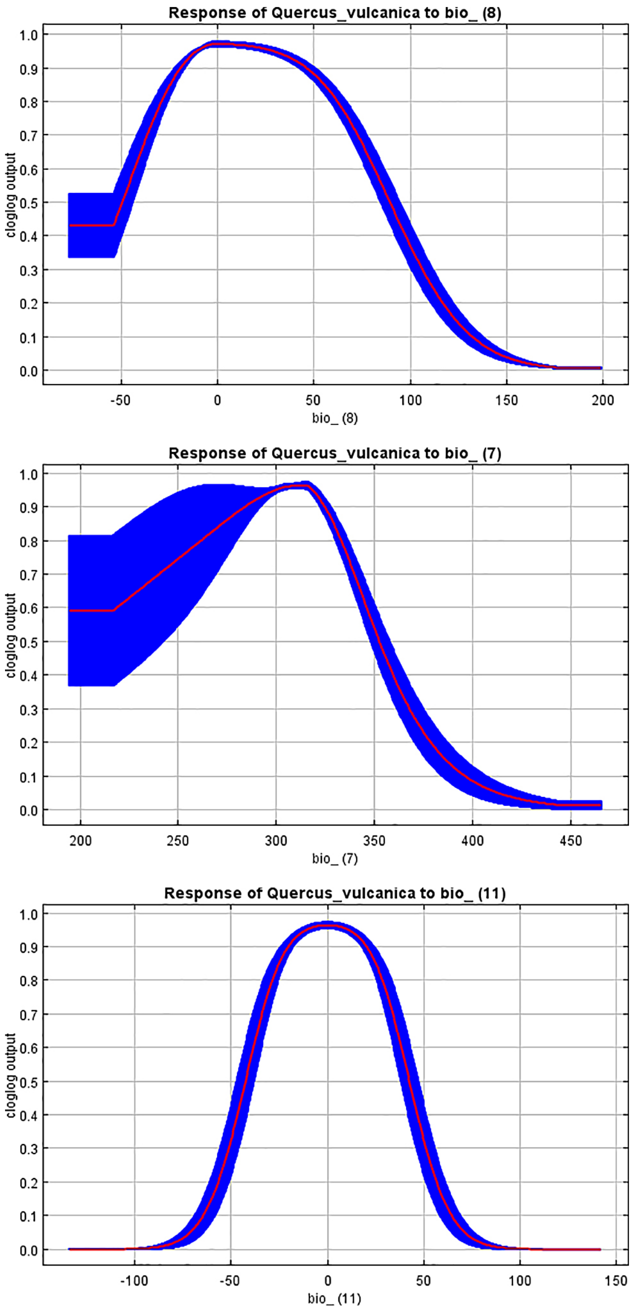

Fig. 5. Response curves of biolimatic variables that affected of *Quercus vulcanica* (A: bio 8, B: bio 7, C: bio 11)

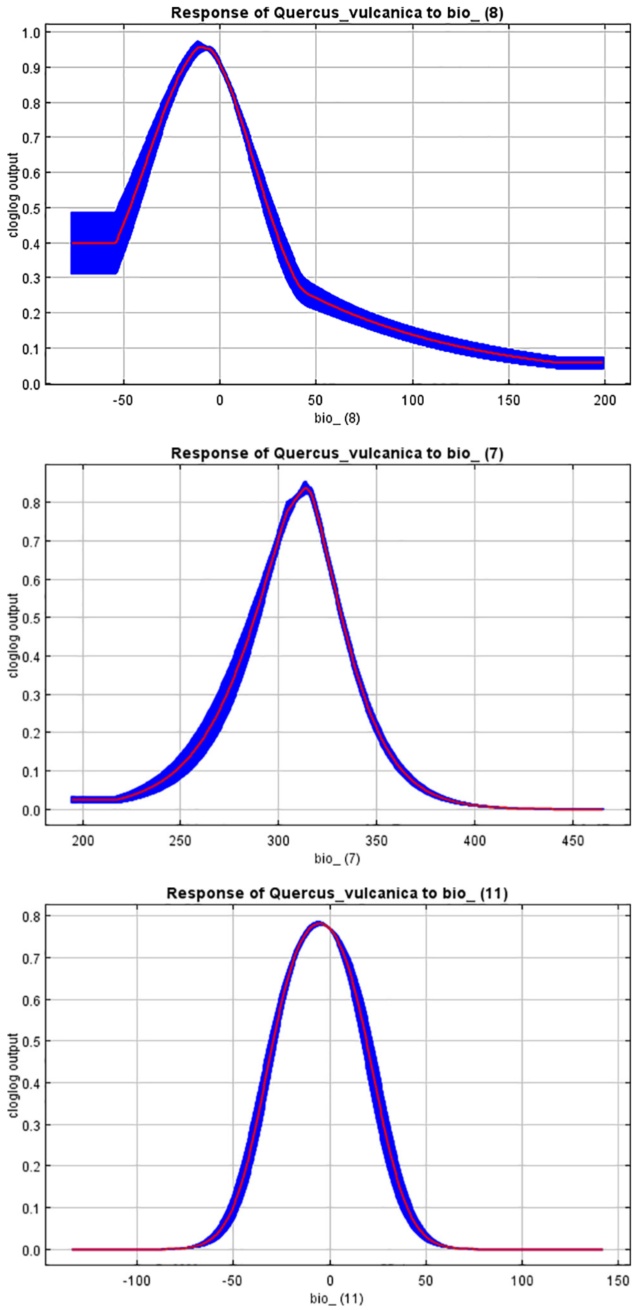

Fig. 6. Response curves of by correlations between the selected variable and other variables.(A: bio 8, B: bio 7, C: bio 11)

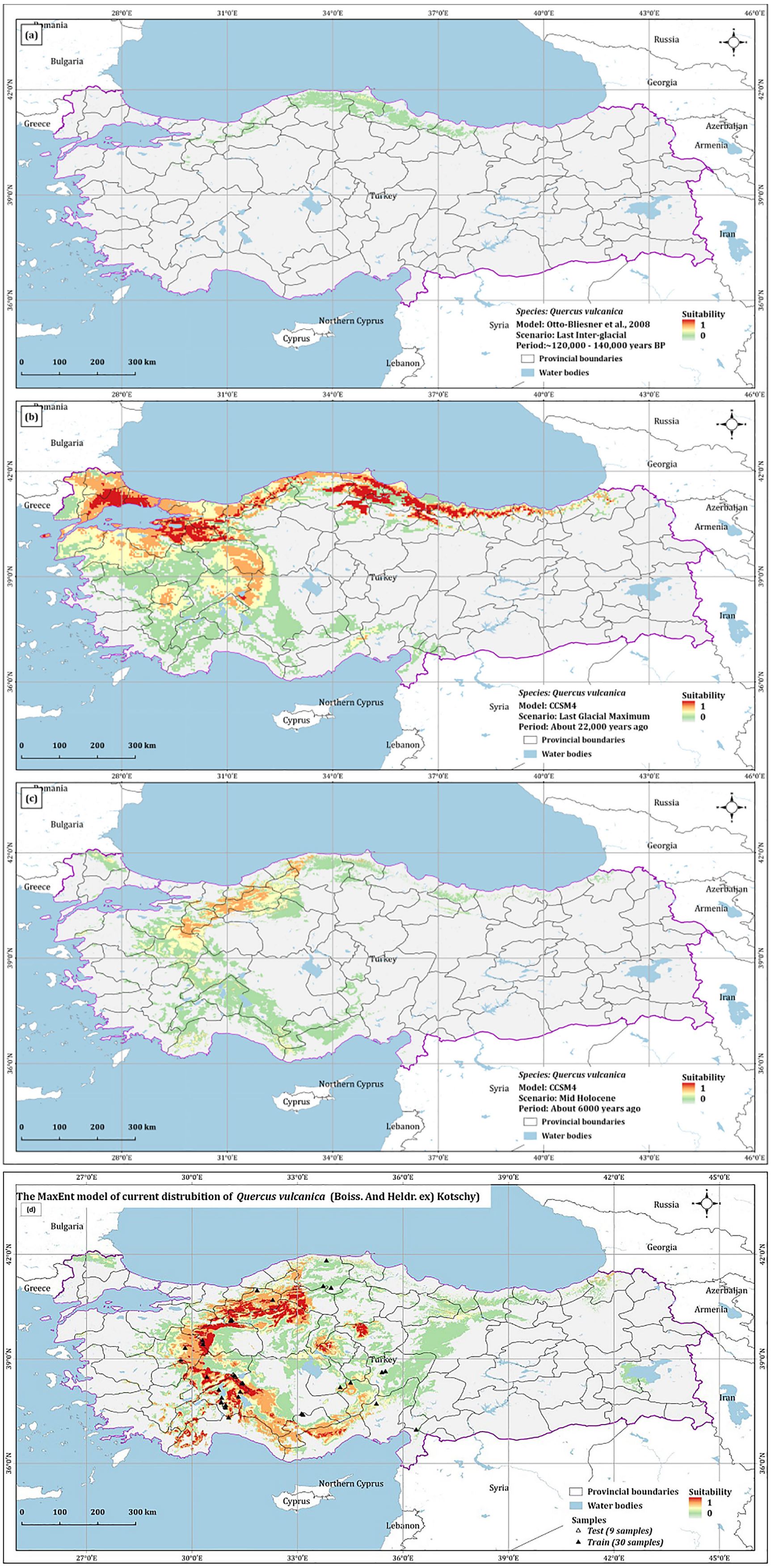

Fig. 7. Distribution maps of *Quercus vulcanica* according to the study model ((a)Last Interglacial, (b) Last Glacial Maximum, (c) Mid-Holocene and (d)current, respectively)

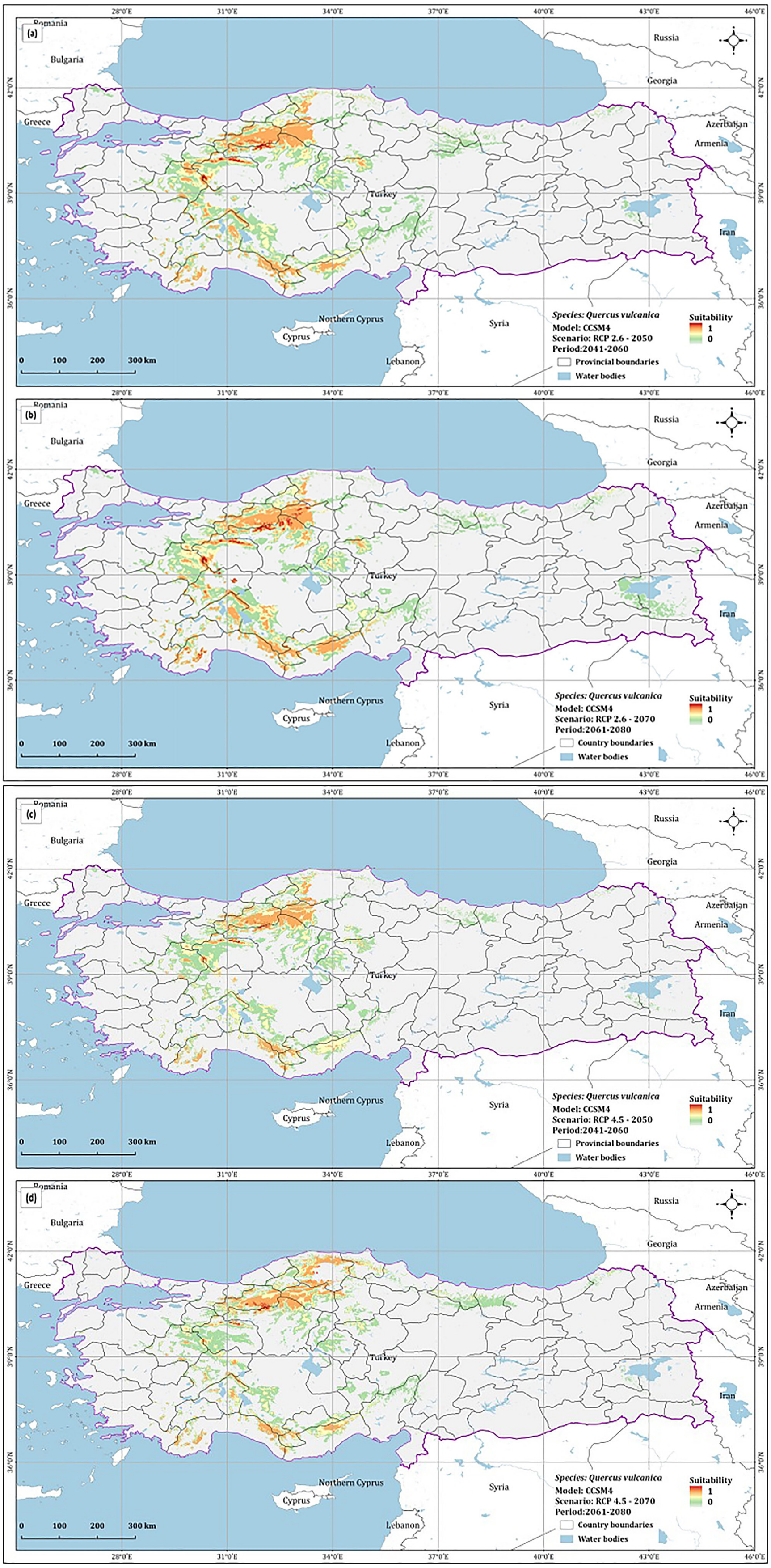

Fig. 8. Distribution maps of *Quercus vulcanica* according to the study model [distribution in 2050 and 2070 according to RCP2.6 (a,b) climate change scenario, distribution in 2050 and 2070 according to RCP4.5 (c,d) climate change scenario

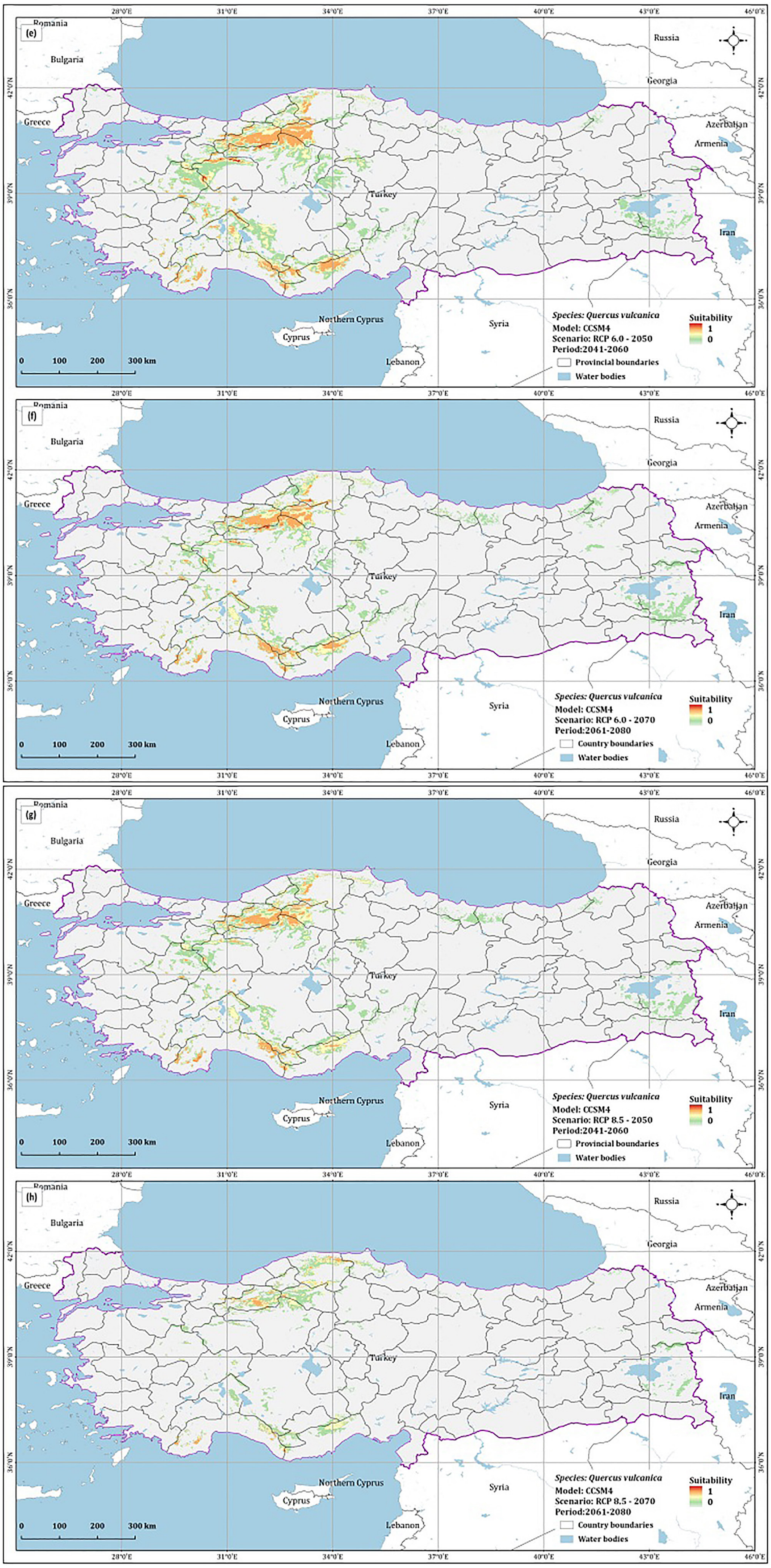

Fig. 8. Distribution maps of *Quercus vulcanica* according to the study model [distribution in 2050 and 2070 according to RCP6.0 (e,f) scenario, and distribution in 2050 and 2070 according to RCP8.5 (g,h) scenario

the LIG and the HOL, while its distribution expanded towards climatically favourable areas in the LGM.

Future potentially suitable distribution areas were modelled under bioclimatic conditions for 2050 and 2070 according to different climate change scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5). All future distribution models show that the potential distribution areas of the species will shrink over time (Fig. 8). In particular, the RCP8.5 scenario predicts that the species will be on the brink of extinction in 2070 because there will be very limited suitable habitats for its survival in the Northwestern and Southwestern parts of Turkey.

Discussion

From the ecological perspective, the model produced for the current study shows that the species is a cold tolerant species. Additionally, it is known that, during the Glacial Periods, some tree species (such as *Fagus*, *Carpinus*, some *Quercus* species and *Tilia*) which need relatively higher temperatures were negatively affected by changes in the climate, but survived in small patches in the mountainous areas of the Pyrenees, the Alps, the Iberian Peninsula, the Caucasus, Turkey, and Italy. The results for *Q. vulcanica* obtained in this study are to the contrary. In this respect, the study findings are consistent with the literature (Arslan et al., 2013; Hewitt, 1999; Kargıoğlu, 2018; Svenning et al., 2008).

For the LIG distribution model, it can be concluded that the species had a more suitable distribution area in northern Anatolia (especially around Mount Uludağ) than Southern Anatolia during LIG. Although Aydınözü (2004) has claimed that the species probably proliferated from the Southwestern Turkey (Isparta, Afyon and Kütahya) to the Northwestern Turkey (the Köroğlu, Ilgaz and Küre mountains), it is more probable that the route of distribution of the species was from north to the south. It is known that the climatic conditions during LIG and the Present were very similar. However, during LIG, the “mean temperature of coldest quarter” and “annual mean temperature” were higher than in the Present (Cowie, 2007). For the LGM distribution model, it can be concluded that the species had a very wide suitable distribution area in the Western and the Northern parts of Anatolia during LGM. The dominant climate throughout Anatolia, except for East Anatolia, is known from pollen records to have been cold and humid (between 23 and 19 cal ka BP) during the LGM (Şenkul & Doğan, 2013). In addition, climatic conditions during that period are known to have been suitable for glacier development at higher levels on some mountain ranges in Anatolia (e.g. Uludağ, Ilgaz, Erciyes Dedegöl, Geyikdağı, Bolkar and Aladağ) (Akçar et al., 2017; Gür, 2017; Hughes et al., 2013; Hughes & Woodward, 2008; Sarıkaya et al., 2011). Therefore, the species would not have been able to survive in several mountainous regions– something which the model predicted accurately. For the Mid-Holocene distribution model, it can be concluded that the species had a much narrower distribution than in LGM. Past distribution models show the species to be cold tolerant and demonstrate that mean annual temperature, which is one of the most important factors in the model, was crucial for the distribution of the species. The study model also showed that the distribution area of the species contracted when the mean annual temperature increased.

The results of the Present distribution model are substantially consistent with the disjunct distribution, which proves expansion and contraction from LGM to the Present. Although the species has a scattered and localized distribution, the model results show that the species may have been distributed more widely than its present distribution area. This may be due to three main reasons. Firstly, the distribution area of the species has not expanded at all from the Mid-Holocene to the Present. Secondly, considering that the areas densely populated by the species are to be found in high-altitude mountain ecosystems far removed from human factors (Altınözü, 2004), it can be concluded that the species was probably completely exhausted in some regions by human pressure during the 18^{th} and 19^{th} centuries. Thirdly, the oak may have lost out in competition with other tree species.

Conclusion

A recent genetic study showed that the species has high levels of genetic variation and has low genetic differentiation among the studied four populations (Isparta, Afyonkarahisar, Karaman, and Kütahya Provinces). Although this knowledge is limited, it highlights the importance of isolated populations for the conservation of genetic variation (Yücedağ et al., 2021). Future distribution models show that the *Q. vulcanica* will respond negatively to climate change and that its area of distribution will have shrunk further by 2050 and 2070. If these future models are realized, it is evident that the species will be facing extinction towards 2070. Therefore, the conservation status of the species will likely change from Near Threatened to Endangered in the near future. Although the largest population of *Q. vulcanica* is found in Isparta and Afyonkarahisar Provinces situated in Southwestern Turkey, which includes the Kasnak Oak Forest Nature Reserve, this area will not be suitable for the growth and survival of the species in the future. For this reason, a new nature reserve area should be established in a more suitable climate – perhaps in the Northwestern Black Sea part of Turkey and also Kütahya and Eskişehir provinces where the species is currently growing. Thus, detailed molecular studies would be helpful for a more complete understanding of both historical biogeography, and intraspecific diversity which may be helpful for the conservation.

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