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Estimating potential future distribution of some selected Oak species in the Marmara Region

Marmara Bölgesinde seçilen bazı Meşe türlerinin gelecekteki potansiyel yayılış alanlarının tahmin edilmesi

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Abstract

In this study, climate simulations were obtained by reducing the global model results to 2.5 km resolution with the COSMO-CLM model with a dynamic downscaling approach. Bioclimatic variables corresponding to the reference years 2031-2040, 2051-2060, 2071-2080 and 2091-2100 were calculated by using high-resolution meteorological parameters produced from the current and future RCP8.5 emission scenario. With the help of the MaxEnt program run with these variables, habitat suitability analysis was carried out for *Quercus frainetto*, *Q. cerris*, *Q. petraea* and *Q. infectoria* species distributed in the Marmara Region. When examining the obtained results, it has been concluded that the areas of *Quercus frainetto*, *Q. cerris* and *Q. petrae*a increase while the area of *Quercus infectoria* decrease. It has been revealed that the suitable areas for *Quercus frainetto* increase from 2020 to 2050, but the highly suitable areas decrease from 2050 to 2070. Furthermore, it has been found that there will be an increase in the highly suitable areas from 2070 to 2100, while both less suitable and suitable areas will experience a decrease. It has been determined that future climatic conditions will increase the habitat suitability of *Quercus cerris* and *Q. petraea* and will create the most favourable conditions for their establishment. In contrast, it has been observed that the suitable areas for *Quercus infectoria* are projected to increase from 2020 to 2050 but decrease from 2050 to 2070 and subsequently from 2070 to 2100.

Keywords: Oak, climate change, habitat suitability modeling, Marmara Region, *Quercus*.

Öz

Bu çalışmada, iklim simülasyonları COSMO-CLM modeli ile küresel model sonuçlarının 2,5 km çözünürlüğe dinamik ölçek küçültme yaklaşımıyla indirgenmesi ile elde edilmiştir. Günümüz ve gelecek RCP8.5 emisyon senaryosundan hareketle üretilen yüksek çözünürlüklü meteorolojik parametreler kullanılarak 2031-2040, 2051-2060, 2071-2080 ve 2091-2100 referans yıllarına karşı gelen biyoiklimsel değişkenler hesaplanmıştır. Bu değişkenlerle çalıştırılan MaxEnt programı yardımıyla, Marmara Bölgesinde yayılış gösteren *Quercus frainetto*, *Q. cerris*, *Q. petraea* ve *Q. infectoria* türleri için habitat uygunluk analizi gerçekleştirilmiştir. Elde edilen sonuçlar irdelendiğinde, *Quercus frainetto*, *Q. cerris* ve *Q. petraea*'nın alanlarının artacağı ve *Quercus infectoria'*nın ise azalacağı sonucuna varılmıştır. *Quercus frainetto* için uygun alanların 2020 yılından 2050 yılına doğru arttığı, ancak yüksek uygun alanlarının ise 2050'den 2070'e azalacağı ortaya konmuştur. Ayrıca, 2070'den 2100'e kadar yüksek uygun alanlar artsa da, az uygun ve uygun alanların azalacağı tespit edilmiştir. Gelecek iklim koşullarının *Quercus cerris* ve *Q. petraea'*nın habitat uygunluğunu artacağı ve yüzyılın sonunda en elverişli koşulların oluştuğu tespit edilmiştir. Aksine, *Quercus infectoria* için uygun alanların 2020'den 2050'e artacağı, fakat 2050'den 2070'e ve sonrasında 2070'den 2100'e kadar azalacağı gözlemlenmiştir.

Anahtar Kelimeler: Meşe, iklim değişikliği, habitat uygunluğu modellemesi, Marmara Bölgesi, *Quercus*.

1. Introduction

1.1. Generalities

Global climate change is seen as one of the world's common problems, affecting almost all global or regional decisions (CBD, 2010). The impacts of climate change on forests vary from one region to another. The consequences for certain species will differ by geographic region and the extent of climatic change (Araujo and Guisan, 2006): while some species will respond positively with an increased development rate, increased survival and reproductive potentialities; some others however, will respond negatively with a decreased growth rate, decrease extension potentiality and reduced fecundity (Tüfekçioğlu et al., 2005). Furthermore, there will be an increasing rate of death wood due to drier climate conditions leading to drought and other factors like the venue of wood decomposers such as fungi (Zhang et al., 2017).

Türkiye's forest is one of the most vulnerable to the effects of climate change since the Mediterranean Basin is one of the hotspots for the climate change effects. For instance, the extinction of some species, a decrease in habitat quality, or drastic changes in some stand types serve as alarming signals for climate change (Koç et al., 2018). Although the Turkish forest area is increasing over the last decade, its structure and composition are susceptible to the effects of climate change. Accordingly, the vulnerability and adaptation capacities of Turkish forests are challenging issues due to the country's geo-climatic diversity (Karahalil and Köse, 2015).

Therefore, it is very crucial to find out which climate conditions will occur in forest areas in the future and which tree species will be more suitable to survive and continue to produce forest ecological services for future generations. Moreover, different existing and tolerant tree species should be tested, and their suitability maps should be produced showing where the suitability will increase, decrease or be stable for the selected tree species (Fosso and Karahalil, 2020; Fosso and Karahalil, 2021; Fosso, 2021). Within this context, Habitat Suitability Modeling (HSM) provides better advantages in finding the appropriate tree species for developing adaptation strategies (Araujo et al., 2005).

In total, there are around 400 to 500 Oak species worldwide, with nearly 78 species of Oak currently in an alarming state and about 100 species classified as rare or in danger of extinction (Faussett, 2021). Sadly, this number is rising with the misusing of biological diversity due to human activities in the forest and climate change. These Oak species are very important in the structure and composition of Türkiye's forests. In Türkiye, Oak species, which are widespread in almost every region cover a total area of 7,6 million hectares (Fosso and Karahalil, 2022). There are naturally 18 Oak species in Türkiye's forests (Yaltırık, 1998): *Quercus robur*, *Q. petraea*, *Q. pontica*, *Q. cerris*, *Q. hartwissiana*, *Q. macranthera*, *Q. frainetto*, *Q. vulcanica*, *Q. infectoria*, *Q. pubescens*, *Q. macrolepis*, *Q. brantii*, *Q. libani*, *Q. trojana*, *Q. ilex*, *Q. aucheri*, *Q. coccifera* and *Q. virgiliana*.

1.2. Problem statement and objectives

In Türkiye, most of the Oak species are found in the Marmara Region, which is one of the most sensitive regions to climate change (Özdemir et al., 2020; Fosso and Karahalil, 2022). Accordingly, native tree taxa such as Oak species should be modeled to find their habitat suitability distribution for the next decades until the end of this century using climate change scenarios. Furthermore, it is very important to reveal the potential future areas of Oak species, in order to identify adapted species and species at risk of extinction according to future projections and which cover large areas, mostly as trees and some as tall shrubs.

In this study, four main Oak species, namely *Quercus frainetto, Q. cerris, Q. petraea,* and *Q. infectoria* have been modelled using habitat suitability modelling with MaxEnt software to check their future potential distribution in the Marmara Region.

2. Material and Method

2.1. Material

2.1.1. Environmental data

In this study, global climate simulations have been used to downscale high resolution climatic data over the Marmara Region by COSMO-CLM regional climate model (Rockel and Geyer, 2008). Bioclimatic variables have been calculated from high resolution regional climate simulations for reference periods, 1986-2005, 2031-2040, 2051-2060, 2071-2080 and 2091-2100. Environmental data was prepared by the research team of the Department of Meteorology of İstanbul Technical University. A total of five sets of 19 bioclimatic variables data (Table 1) in the study have been produced under the NetCDF format and sent to the forest management team of Karadeniz Technical University, Trabzon.

These data have been clipped to the Marmara regional forest using ArcGIS 10.3TM (ESRI, 2018) software and saved under the ASCII format as required by MaxEnt (Philips, 2017). Then both presence and environmental data have been uploaded to MaxEnt Java application software and ran. All the environmental parameters had the same geographical extent, and projections were matched with presence data coordinates.

Global climate change has shown observable variability in the environment with increasing temperatures and changing precipitation patterns that might shift the existing tree species distribution in the future by creating new habitats and making regions unsuitable for some species (Zhang et al., 2022). In order to assess regional to local climate change, regional climate models (RCMs) are essential tools to extract more detailed features of the climate (Rockel and Geyer, 2008) compared to global climate circulation (GCCs) models, which have spatial resolutions on the order of 100 kilometers (IPCC, 2007). On the other hand, RCP8.5 corresponds to the worst-case scenario assuming that societies do not make concerted efforts to reduce greenhouse gas emissions (Hausfather, 2019). Using potential worst-case outcomes is important in order to analyze the impacts on a wider range of outcomes.

Table 1**.** Environmental variables used in study
Tablo1. Çalışmada kullanılan çevresel değişkenler

Bioclimatic Variables	Definitions	Unit
Bio_1	Annual Mean Temperature	°C
Bio_2	Mean Diurnal Range	°C
Bio_3	Isothermality (BIO2/BIO7) (* 100)	°C
Bio_4	Temperature Seasonality (standard deviation *100)	°C
Bio_5	Max Temperature of Warmest Month	°C
Bio_6	Min Temperature of Coldest Month	°C
Bio_7	Temperature Annual Range (BIO5-BIO6)	°C
Bio_8	Mean Temperature of Wettest Quarter	°C
Bio_9	Mean Temperature of Driest Quarter	°C
Bio_10	Mean Temperature of Warmest Quarter	°C
Bio_11	Mean Temperature of Coldest Quarter	°C
Bio_12	Annual Precipitation	mm
Bio_13	Precipitation of Wettest Month	mm
Bio_14	Precipitation of Driest Month	mm
Bio_15	Precipitation Seasonality (Coefficient of Variation)	mm
Bio_16	Precipitation of Wettest Quarter	mm
Bio_17	Precipitation of Driest Quarter	mm
Bio_18	Precipitation of Warmest Quarter	mm
Bio_19	Precipitation of Coldest Quarter	mm

2.1.2. Presence or occurrence data

The forest management plans of the Marmara Region's forests, provided by the Marmara Forestry Research Institute's team, have been used to generate presence or occurrence data from stand type maps for the four selected Oak species. The latitude and longitude giving the exact coordinates on the global positioning system of each presence points have been generated for each selected species from geo-processing, coordinate then features to points in ArcGIS 10.3™.

Attribute tables of feature points generated for each selected species have been exported as table data base, then cleansed in Microsoft Excel and saved as a "CSV" file as required by MaxEnt software. With the help of the MaxEnt program driven by these bioclimatic variables, habitat suitability analysis was carried out for four selected oak species namely; *Quercus frainetto*, *Q. cerris*, *Q. petraea* and *Q. infectoria* distributed in the Marmara Region, using high resolution meteorological parameters produced from current species distribution and the RCP8.5 emission scenario for 2020, 2030, 2050, 2070 and 2100 periods.

2.2. Method

To perform a run with MaxEnt, we need to supply a file containing presence data *Quercus* sp., and environmental data (i.e. bioclimatic parameters) (Figure 1).

There is only one species in the sample file, which

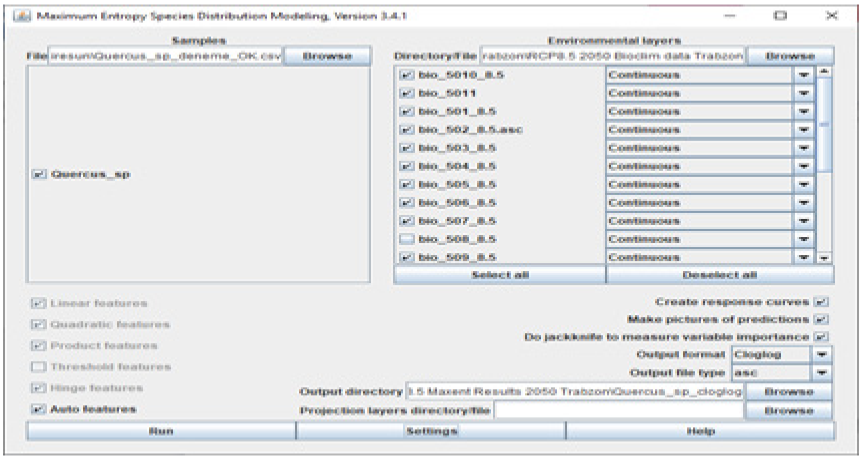

Figure 1. General outlook for the MaxEnt software
Şekil 1. MaxEnt yazılımının genel görünümü

is why one species appears in the panel. There can be multiple species in the same samples file, in which case more species would appear in the panel, along with one species. Coordinate systems other than latitude and longitude can be used provided that the samples file and environmental layers use the same coordinate system.

All these variables are continuous variables describing potential climatic classes. The categorical variables are not presented in Table 1. After the environmental layers are loaded and some initialization is done, progress towards training of the MaxEnt model is shown like in Figure 2. The software runs species and analyses environmental parameters one after one.

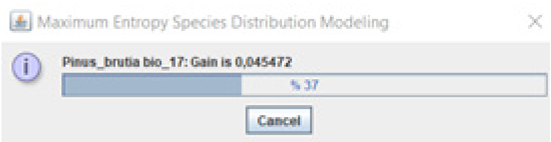

Figure 2. Progress over MaxEnt running
Şekil 2. MaxEnt yazılımının çalıştırılması

The run produces multiple output files. To see what other (more interesting) output there can be in an "html" file, we will turn on a couple of options and rerun the model (Elith et al., 2006). Prediction: The file pointed to is an image file (.png) that we can just click on or open in most image processing software. If you want to copy these images or open them with other software, you will find the .png files in the directory called "plots" that has been created as an output during the run.

MaxEnt supports four output formats for model values: raw, cumulative, logistic and cloglog. First, the raw output is just The MaxEnt exponential model itself. Second, the cumulative value corresponds to a raw value of r (coefficient of correlation) with the percentage of the MaxEnt distribution where raw value is at its maximum r value. Cumulative output is best interpreted in terms of predicted omission rate. Third, if c is the exponential of the entropy for MaxEnt distribution, then the logistic value corresponding to a raw value of r is c*r/ (1+c*r). This is a logistic function because the raw value is an exponential function of the environmental variables. The cloglog value corresponds to a raw value of r = 1-exp (-c*r).

The four output formats are all monotonically related, but they are scaled differently and have different interpretations. Then it is necessary to run a statistical analysis to find the predictions of each species' distribution or habitat suitability. We can keep track of which environmental variables are making the greatest contribution to the model (Figure 3).

MaxEnt also help in tracking which environmental variables are making the greatest contribution to the model. HSM aim at defining, for any chosen species, the 'envelope' that best describes its spatial range by identifying those environmental variables that limit its distribution. Predictive performance of the model is provided by species response curves produced from model output. Therefore model calibration was divided into a training set (90% of the total occurrence data) and test (10% of the total occurrence data) for design assessment.

The Area under the Curve of Receiver Operating Characteristic (AUC of ROC) is a measure of model performance that range between 0 to 1 (Phillips, 2006). The AUC is an autonomous threshold index capable of evaluating the ability of the model to discriminate presence from absence efficiently. AUC < 0.5 describes models that have less than chance

Variable	Percent contribution	Permutation importance
bio_16	34.6	0.4
bio_2	15.6	6
bio_19	14.6	34.2
bio_18	13.2	22.6
bio_4	6.6	8.9
bio_6	4.8	4.6
bio_8	4.7	1.8
bio_13	2	1.8
bio_5	1	6.5
bio_12	0.9	2.5
bio_7	0.9	2.9
bio_17	0.3	3.3
bio_15	0.2	1
bio_11	0.2	1
bio_9	0.2	1.2
bio_3	0.1	1.3
bio_14	0	0
bio_10	0	0.1

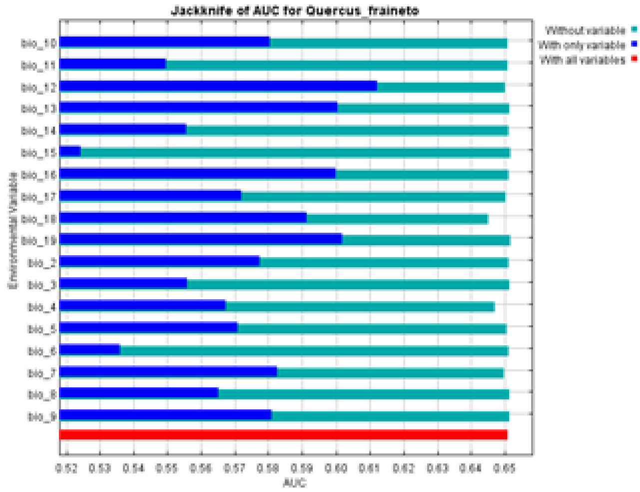

Figure 3. Analysis of variable contributions
Şekil 3. Katkılarının analizi

and rarely occur in reality. An AUC of 0.5 is a pure guess. Model performance is classified as failing (0.5 to 0.6), bad (0.6 to 0.7), reasonable (0.7 to 0.8), good (0.8 to 0.9), or great (0.9 to 1) (Swet, 1988).

The Jackknife test was used to assess the dominant environmental variables that determined the species' potential distribution (Yang et al., 2013). MaxEnt provides results in a folder containing a raster dataset JPEG image corresponding to the picture of prediction for each species, an ASCII file that has been converted into raster and used in ArcGIS for further analysis, response curves and Jackknife variable importance picture as well as HTML extension file presenting the summary of the analysis and providing more details on all results.

Suitability maps are used to show where the suitability will increase, decrease or be stable for the selected tree species using Habitat Suitability Model (HSM) with help of projected climatic data and other parameters such as topography or site conditions (Elith et al., 2006). The consequences for habitat suitability map will be a good reference for the adaptation strategies via forest management and silviculture plans.

3. Results

The potential future distributions of *Quercus frainetto* are presented in Figure 4. It can be mentioned that from 2020 to 2030, moderately suitable area is expanding in the Marmara Region, while the suitable area is reducing and moving to the south-west of the region. From 2030 to 2050, there is a slight increase in suitable area, and then this area is retracting from the southwest in 2070. Finally from 2070 to 2100, there is an expansion of suitable area all over the south and the north of the region, with highly suitable area spots that will appear in 2100. The model is calibrated with an AUC = 0.66, and the factor affecting the most distribution of this Oak species is Bio 12 that is the annual precipitation.

The potential future distributions of *Quercus cerris* are presented in Figure 5. It can be mentioned that this species is merely found in the west side of the Marmara Region with moderately suitable and suitable areas that will stay nearly constant from 2020 to 2030, then 2050 and 2070. Then this suitable and highly suitable area will increase from 2070 to 2100, occupying more area in the west side of the Marmara Region. The model is well calibrated with an AUC = 0.84, and the factor affecting the most the distribution of this Oak species is Bio 18 that is the precipitation of the warmest quarter.

The potential future distributions of *Quercus petraea* are presented in Figure 6. For this specie, it can be mentioned that the highly suitable area that is present in 2020 in a spot of the north-west of this region will disappear from 2030 to 2050 and from 2050 to 2070, then reappear with more highly suitable area in 2100. Suitable area will also increase from 2070 to 2100. The model is well calibrated with an AUC = 0.77, and the factor affecting the most the distribution of this Oak species is Bio 6 that is the minimum temperature of the coldest month.

The potential future distributions of *Quercus infectoria* are presented in Figure 7. It can be mentioned a progressive maintenance of moderately suitable area from 2020 to 2030, 2030 to 2050 and from 2050 to 2070, then a reduction of moderately suitable area from 2070 to 2100. It is also the case for suitable area that reduces from 2070 to 2100 with an increase of not suitable area of *Quercus infectoria* in that period. The model is well calibrated with an AUC = 0.80, and the factor affecting the most the distribution of this species is Bio 3 that is isothermality and Bio 12 that is the annual precipitation.

Finally, when the results obtained are examined, it is found that habitat suitability of *Quercus frainetto*, *Q. cerris* and *Q. petraea* will increase in their potential future distribution, while *Q. infectoria* habitat suitability will decrease.

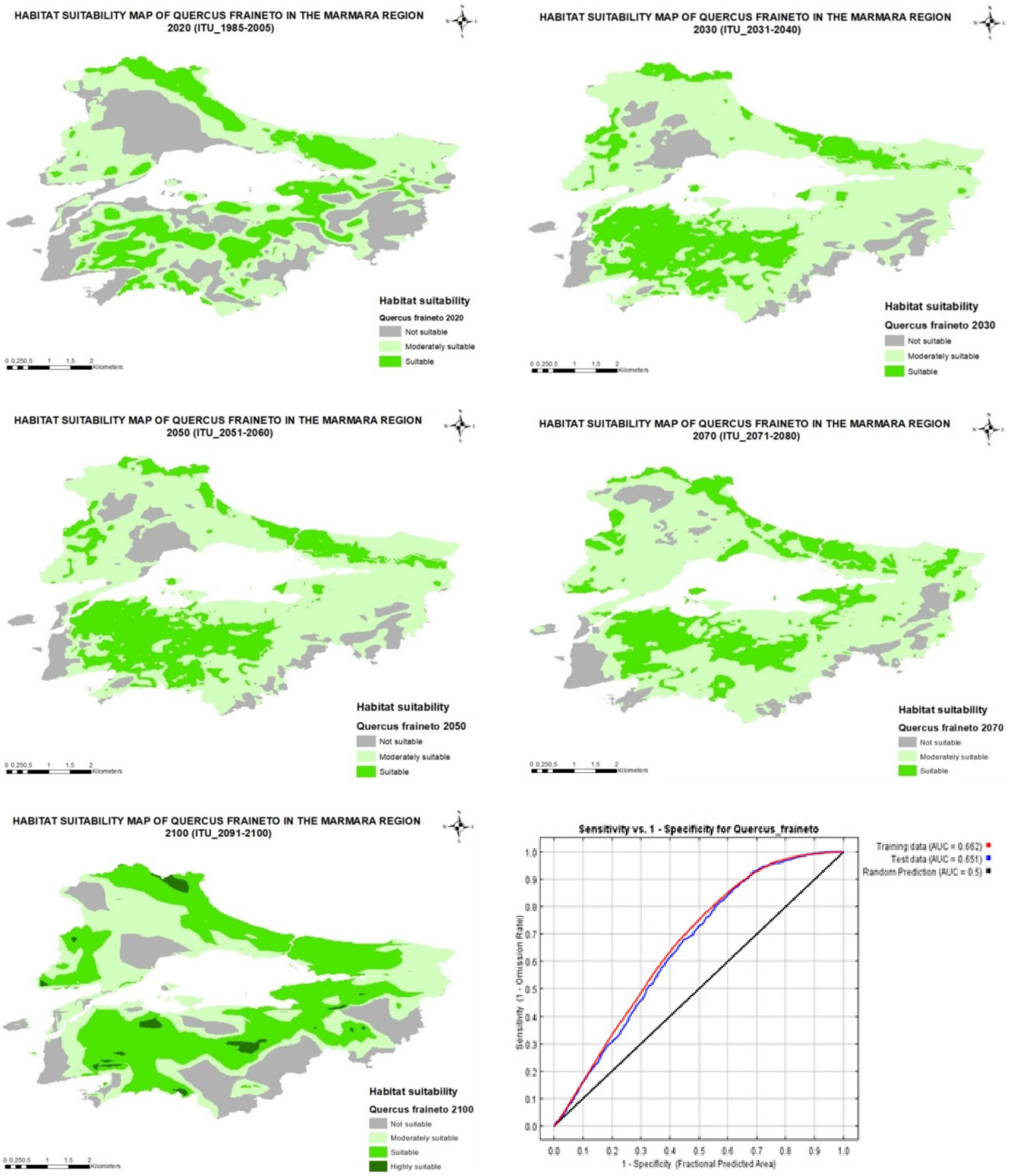

Figure 4. Potential future distributions of *Quercus frainetto* in 2020, 2030, 2050, 2070 and 2100 under RCP8.5 scenario

Şekil 4. *Quercus frainetto*'nun RCP8.5 senaryosuna göre 2020, 2030, 2050, 2070 ve 2100 yıllarına ilişkin gelecekteki potansiyel dağılımı

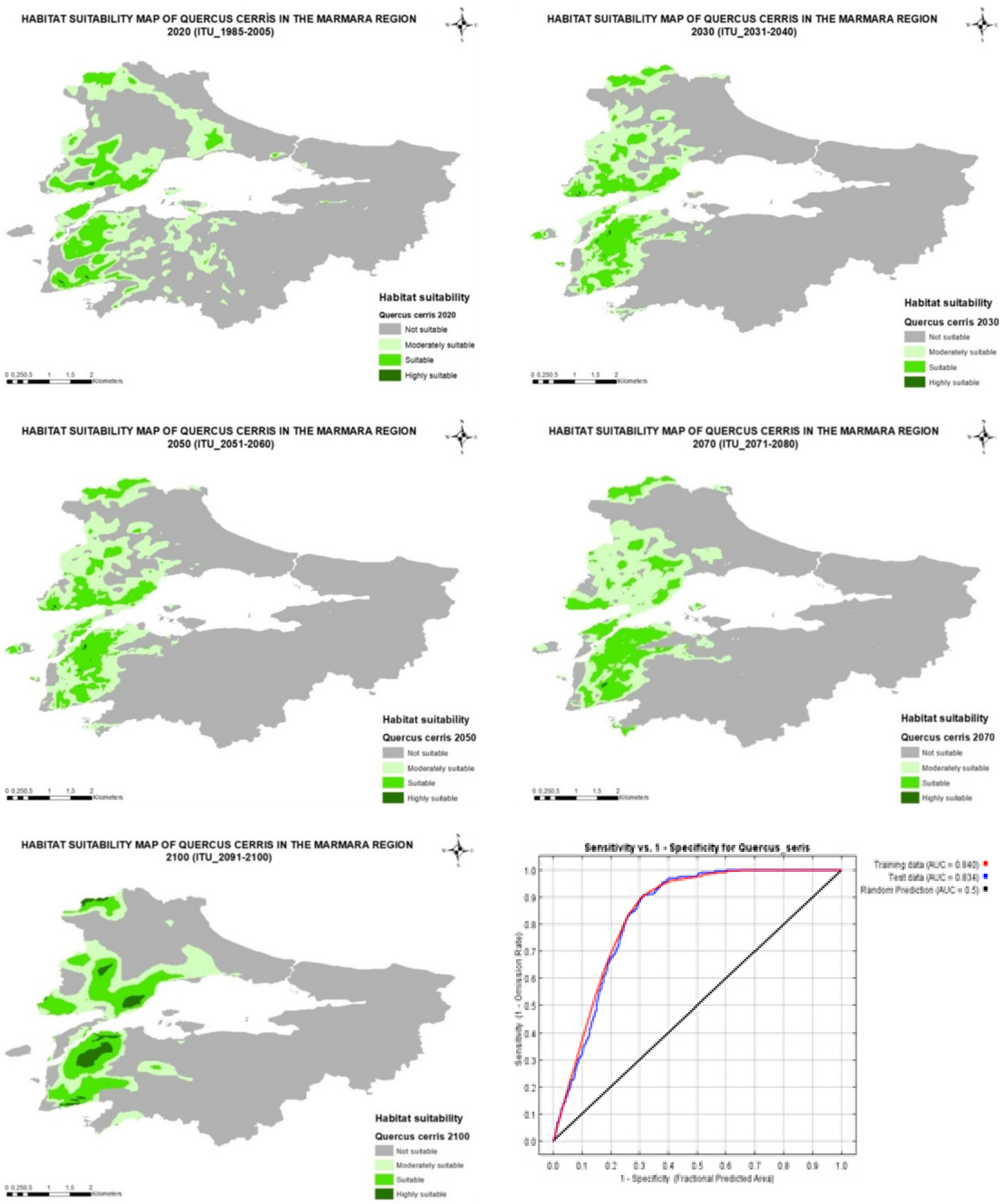

Figure 5. Potential future distributions of *Quercus cerris* in 2020, 2030, 2050, 2070 and 2100 under RCP8.5 scenario

Şekil 5. *Quercus cerris*'in RCP8.5 senaryosuna göre 2020, 2030, 2050, 2070 ve 2100 yıllarına ilişkin gelecekteki potansiyel dağılımı

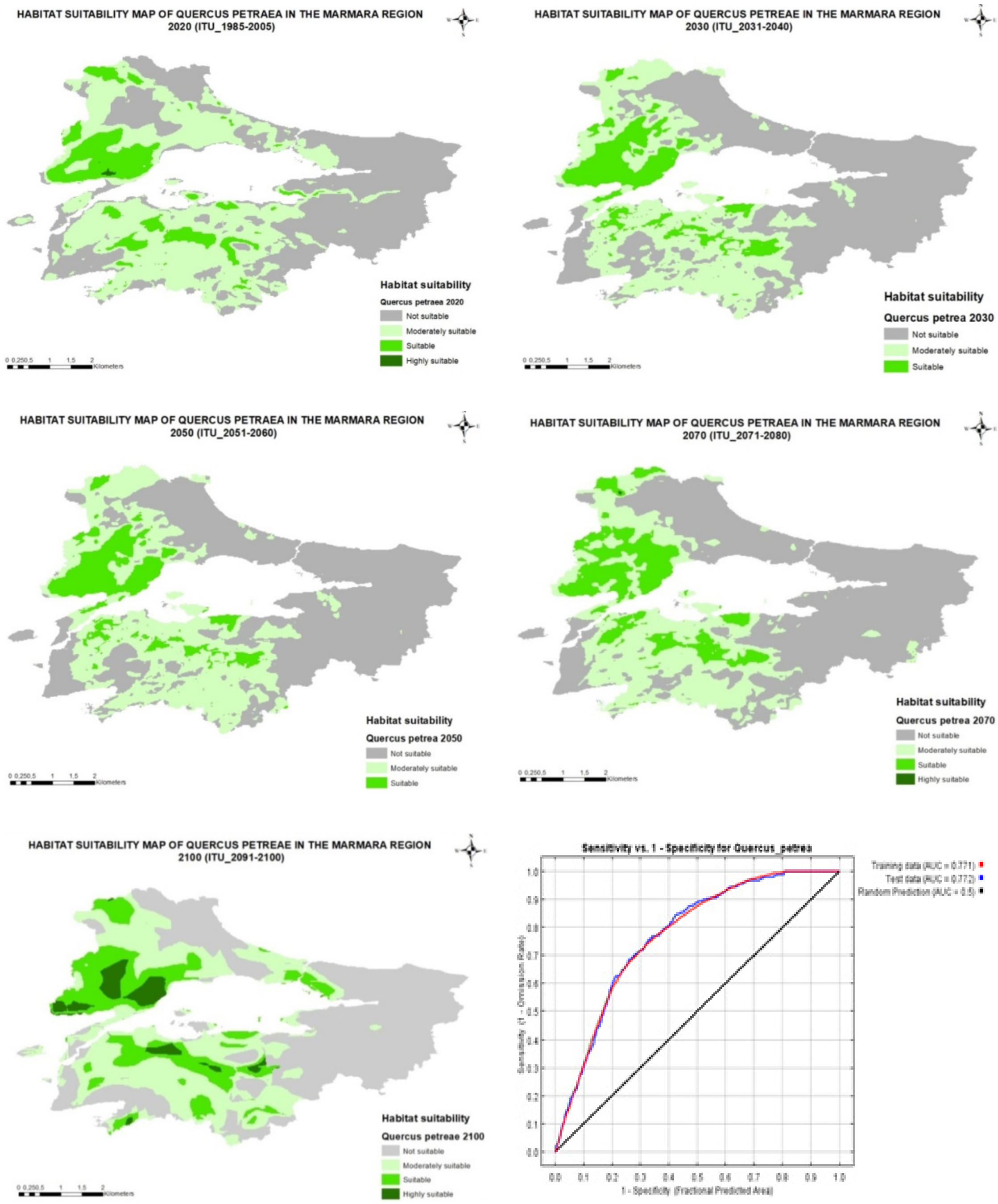

Figure 6. Potential future distributions of *Quercus petraea* in 2020, 2030, 2050, 2070 and 2100 under RCP8.5 scenario

Şekil 6. *Quercus petraea*'nın RCP8.5 senaryosuna göre 2020, 2030, 2050, 2070 ve 2100 yıllarına ilişkin gelecekteki potansiyel dağılımı

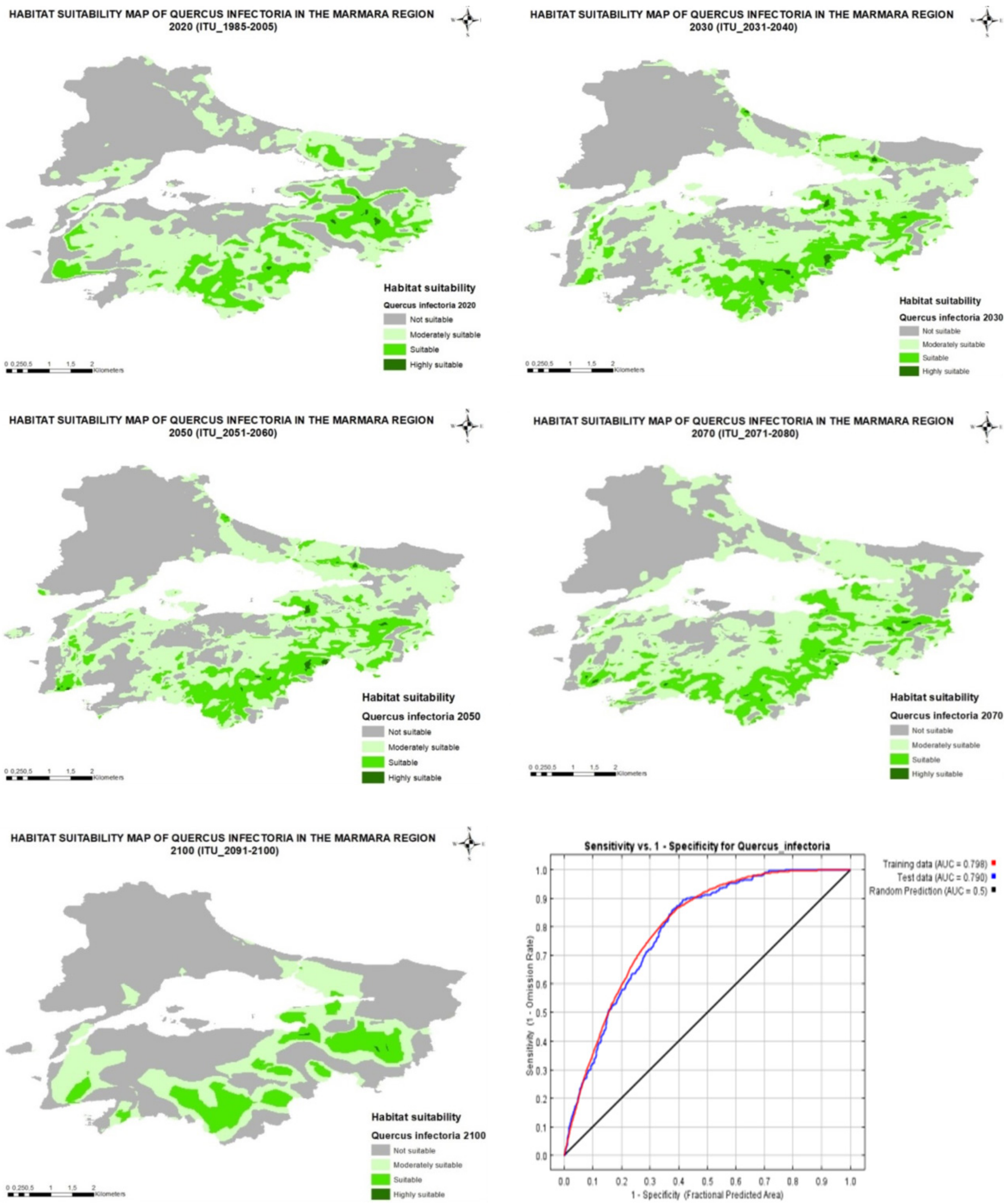

Figure 7. Potential future distributions of *Quercus infectoria* in 2020, 2030, 2050, 2070 and 2100 under RCP8.5 scenario

Şekil 7. *Quercus infectoria*'nın RCP8.5 senaryosuna göre 2020, 2030, 2050, 2070 ve 2100 yıllarına ilişkin gelecekteki potansiyel dağılımı

4. Discussions and Conclusions

Habitat Suitability Analysis results have shown that the suitable areas for *Quercus frainetto* will increase from 2020 to 2050, but its highly suitable areas will decrease in that same period. But from 2050 to 2070, its suitable areas will decrease. In addition, although highly suitable areas will increase from 2070 to 2100, it has been found that less suitable and suitable areas will decrease in that same period. It was determined that the habitat suitability of *Quercus cerris* and *Quercus petraea* will increase progressively from one period to another. Their highly suitable areas showed the highest in 2100.

In contrast, areas of suitability for *Quercus infectoria* have been observed to increase from 2020 to 2050, but decrease from 2050 to 2070 and thereafter from 2070 to 2100. This means that *Quercus infectoria* will be more vulnerable to climate change that will affect its future habitat suitability and reduce its future distribution over the Marmara Region. Furthermore, a conservation strategy should be designed to protect and conserve *Quercus infectoria* which can be at higher risk of extinction if wrong planning decisions are taken now in the design of forest management plans without taking into account this alarming signal. This species as well as other Oak taxa are very important for traditional medicine and pharmacopeia in Türkiye where all native trees are beneficial to biodiversity (Jansson et al., 2017).

Oak species diversity remains the king of biodiversity. Up to 2300 species are known to be associated with Oaks (Faussett, 2021), and this does not include all of the fungi, or any of the bacteria and other microorganisms which create a symbiotic home with the Oaks. The 2300 species consist of some 38 birds, 229 bryophytes, 108 fungi, 1178 invertebrates, 716 lichens, and 31 mammals (Faussett, 2021). Of these species, 320 are found only on Oak trees, and a further 229 species are rarely found on species other than Oaks. For these reasons, Oak species are very important keystone species and the reduction of their habitat suitability will lead also to a mass reduction of other species, while their extinction will lead to mass extinction in the Türkiye's forests (Avcı, 2010).

Oak trees are also a favorite species for wild bees and pollinators. Uniquely, they do not offer the traditional nectar from flowers but provide a similar substance that is secreted through gals growing on the tree. The Oak's main reason for secreting this secret substance is to attract insects that can help to protect the tree from other harmful insect's attacks. This means that Oak species can protect themselves naturally and help to protect other surrounding tree species against harmful insects. Oaks are also perfect nesting spots for many species of birds such as the pied flycatcher or woodpecker. In turn, holes made by woodpeckers are ideal for bats to roost in. Finally and to finish, the Oak species diversity should be conserved to avoid their reduction or disappearance according to their future potential distribution (Faussett, 2021).

In conclusion, it is important to consider different climate change scenarios, related to tree species habitat suitability and adaptation strategies in the planning and silvicultural interventions in Türkiye's forests, especially for different Oak species, in other to determine their conservation status. It can be suggested to conduct similar studies for other Oak species in Türkiye in order to determine their future habitat suitability change. The adaptation potential should be analyzed for Oak species in other to be integrated into future silvicultural planning in forest management. Future ecosystem services should be projected and displayed in other to see if the change in the habitat suitability of some Oak species will increase or reduce the provision of some selected ecosystem services such as wood quantity or quality, carbon storage, soil protection and water provision.

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