European Journal of Forest Research (2023) 142:579–591
https://doi.org/10.1007/s10342-023-01543-2

ORIGINAL PAPER

Predicting the distribution of European Hop Hornbeam: application of MaxEnt algorithm and climatic suitability models

Ömer K. Örücü[1] · Hossein Azadi[2,3,4] · E. Seda Arslan[1] · Özgür Kamer Aksoy[5] · Shahla Choobchian[6] · Saeedeh Nazari Nooghabi[7] · Horatiu Ioan Stefanie[8]

Received: 5 April 2022 / Revised: 16 January 2023 / Accepted: 6 February 2023 / Published online: 25 March 2023

Abstract

Ostrya carpinifolia Scop. (European Hop Hornbeam) is a native tree in Europe as a species of the Betulaceae family. European Hop Hornbeam has a significant value for the European flora, and assessing the effects of climate change on habitats of species is essential for its sustainability. With this point of view, the main aim of the research was to predict the present and future potential distribution of European Hop Hornbeam across Europe. ''IPSL-CM6A-LR'' climate change model, ninety-six occurrence data, and seven bioclimatic variables were used to predict potential distribution areas with MaxEnt 3.4.1 program. This study applied a change analysis by comparing the present predicted potential distribution of European Hop Hornbeam with the future predicted potential distribution under the 2041–2060 and 2081–2100 SSP2 4.5 and SSP5 8.5 climate change scenarios. Study results indicated that the sum of suitable and highly suitable areas of European Hop Hornbeam is calculated to be 1,136,706 km^2 for the current potential distribution. On the contrary, 2,107,187 km^2 of highly suitable and suitable areas will be diminished in the worst case by 2100. The most affected bioclimatic variable is BIO 19 (Precipitation of Coldest Quarter), considering the prediction of the species distribution. These findings indicated that the natural ecosystems of the Mediterranean region will shift to northern areas. This study represented a reference for creating a strategy for the protection and conservation of the species in the future.

Keywords Climate change · Species distribution model · CMIP6 · Change analysis · European Hop Hornbeam

Introduction

The Earth's temperature has increased and precipitation patterns of climate have changed (Rosencranz et al. 2009; Vallese et al. 2021). As a consequence of global warming, ecological environments and ecosystems are under significant pressure (Li et al. 2020a; Arzac et al. 2021). A changing climate means changing biodiversity and habitats because the climate is a key driver for shaping biodiversity patterns (Thuiller 2007; Nunez et al. 2019; Warren et al. 2018). The unpredictable results of climate change have threatened the habitats of the species and caused the species to shift to different latitudes or altitudes (Sun et al. 2020).

Communicated by Christian Ammer.

✉ Hossein Azadi
hossein.azadi@ugent.be

✉ E. Seda Arslan
sedaarslan@sdu.edu.tr

Shahla Choobchian
shchoobchian@modares.ac.ir

[1] Faculty of Architecture, Department of Landscape Architecture, Süleyman Demirel University, Isparta, Turkey

[2] Department of Geography, Ghent University, Ghent, Belgium

[3] Research Group Climate Change and Security, Institute of Geography, University of Hamburg, Hamburg, Germany

[4] Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic

[5] Aydın Adnan Menderes University, Aydın, Turkey

[6] Department of Agricultural Extension and Education, Tarbiat Modares University, Tehran, Iran

[7] Agricultural Research, Education and Extension Organization (AREEO), Ministry of Agricultural-Jahad, Tehran, Iran

[8] Faculty of Environmental Science and Engineering, Babeş-Bolyai University, 400084 Cluj-Napoca, Romania

For example, Thuiller (2007) indicated that small changes in temperature shift ecological zones, and if it continues dramatically, species might have to shift northward to find suitable climatic conditions. According to recent research predicting the threat of species extinction owing to climate change, the distribution of species during the previous three decades has likely been altered by climate change on a worldwide scale (Sayyadi et al. 2019; Bellard et al. 2012; Thrippleton et al. 2020; Pearson et al. 2014). These impacts can vary when it comes to different regions of the world (Garzón et al. 2008). Climate change is expected to enlarge regional changes in Europe's natural resources (IPCC 2007). In this situation, assessing changes in organism spatial distribution may be a tool to understand the impacts of climate change.

In Turkey, endangered plant species are protected at various levels by national parks. One of these species is *Ostrya carpinifolia Scop*. which is protected in the "least concern" (LC) category according to IUCN criteria in Uludağ National Park located in the province of Bursa and forms mixed forests with some other species (Kulac et al. 2016). *The European Hop* Hornbeam, *Ostrya carpinifolia Scop*., is indigenous to mild West Eurasia; furthermore, its natural range includes Middle and Southern Europe, the Balkan region, European Turkey, Western Asia, and Caucasian nations (Pasta et al. 2016; Marsberg et al. 2017; Kiliç et al. 2018; Shaw et al. 2014). The mature forest ecosystems of the Near East have benefited greatly from the contributions of European Hop-Hornbeam. Most of the time, the communities it governs are in an early and shaky stage of continuous succession processes. They quickly transition to mixed broadleaved forests under low disturbance conditions, with deciduous oaks predominating (primarily *Quercus pubescens*, but also *Quercus cerris*, *Quercus congesta*, *Quercus petraea*, and *Quercus frainetto*), conifers like *Pinus nigra subsp*. *dalmatica* and *subsp. nigra* in the *Balkan peninsula*, Cedrus *Syria and Lebanon*, *Pinus brutia and Pinus nigra* up to 1700 m in Anatolia, *Quercus coccifera/calliprinos* more infrequently in Eastern Mediterranean nations, or *Fagus sylvatica* at the northern boundary of its range, for example in central and northern Italy and Bulgaria (Kiliç et al. 2018). Hop-hornbeam wood has been utilized for a variety of tasks in the past, particularly in rural regions, such as creating small objects and making charcoal (Ilari et al. 2022). Although it still makes for great firewood, it is not preferred for industrial uses since it tends to fracture when dry. For this reason, the majority of Hop-Hornbeam forests in central Italy are still used as coppices. The tendency of these species to grow in dry places and shallow soils rich in lime and magnesium helps to repair damaged soil tissues (Marsberg et al. 2017). It is planted as a decorative tree and used to make hedges along the sides of roads. The white truffle (Tuber magnatum), which has several medicinal benefits, is essential for preventing diseases like cancer and is used in the refereeing industry, names the hop tree one of its homes. -hornbeam (Kulac et al. 2016; Pasta et al. 2016). Due to its unique and indigenous characteristics, its distribution modeling is essential to prevent the extinction of this important species.

Modeling the shifting of the species is not only crucial for the knowledge about biodiversity and species distribution, but also for creating new sustainability approaches (Austin 2007; Sinclair et al. 2010). A great variety of modeling algorithms are practiced in different kinds of expertise areas in science such as ecological planning and conservation, and using modeling algorithms is a way of predicting species ranges from spatial data for scientists (Rather et al. 2020). Species distribution modeling (SDM) is becoming more common for analyzing the effects of global warming caused the changes in suitable habitats for species (Booth 2018). SDM is a quick way to model current and future potential distribution via analyzing bioclimatic variables and occurrence data of the species (Ward 2007; Yuan et al. 2015). The MaxEnt approach is effective for discretization and species distribution model prediction based on the greatest entropy, and it has recently been used to anticipate appropriate habitats for species (Akhter et al. 2017; Maharaj et al. 2019; Sun et al. 2020). Phillips et al. (2006a) said: ''The MaxEnt method represents an idea of the probability of distribution and incomplete information about the target distribution.''

In the last several decades, scientists have done an increasing number of studies (e.g., Li et al. 2020a; Sun et al. 2020; Wang 2012; Yang et al. 2013; Yuan et al. 2015) to forecast the spread of species. These scientists have studied a variety of topics, including species distribution, habitat fragmentation detection, prospective new ecological modeling methods, projections of enhanced biodiversity, modeling of the implications of climate change on terrestrial biodiversity, etc. (Urban et al. 2016; McMahon et al. 2011).

When temperatures rise and glaciers melt, species shift their geographic ranges in search of their primary habitats and climate optimums. However, individual species' capacity to adapt to changing circumstances differs. Climate change has caused alterations in many plant species, demonstrating that the species has climatic thresholds that it cannot cross (Tytar 2019). If European Hop Hornbeam species are unable to travel to higher elevations on mountain ranges with restricted habitat availability above the tree line, they may suffer considerable habitat loss, fragmentation, and perhaps extinction. According to Harrison's (2020) research, the danger of extinction for this species because of limited geographic or climatic ranges and disturbance of existing communities' increases with the departure of some current climates. As a result, it is crucial to determine how sensitive the European Hop Hornbeam species is to climate change and to take appropriate action to preserve its biodiversity.

In order to anticipate the probable distribution of European Hop Hornbeam around Europe under the SSP2 4.5 and SSP5 8.5 scenarios across two time periods (2041–2060 and 2081–2100), the MaxEnt method was utilized in this work. Conservation and management of biodiversity would be based on estimating the extent of the probable geographic distribution range and determining the major variables. The conservation of rare species has made extensive use of species distribution models, which are useful for predicting the probable geographic distribution under various climatic situations. One of the most popular prediction techniques in SDMs is MaxEnt algorithm modeling, which outperforms other techniques using presence-only and biased sample data in terms of predicted accuracy. The MaxEnt methodology, which takes advantage of statistical mechanics, is an effective modeling method for regional distributions of European Hop Hornbeam species with limited scopes and existence information. The algorithm of MaxEnt also worked well in predicting the range of this species, which is widespread. This is the most significant innovation of the work, as relatively few studies (e.g., Ilari et al. 2022; Kulac et al. 2016) have examined the effect of climate change on the dispersion and biodiversity of European Hop Hornbeam using these statistical approaches. Correlation analysis was used to define more associated bioclimatic variables, while change analyses were used to identify changes in distribution regions. This research will be the very first instance in terms of representing the new climate model on a global scale. A native species' predicted range will be shown along with the climatic variability and response to anthropogenic and natural influences across Europe. MaxEnt and the IPSL-CM6A-LR climate change model are used to (1) predict potential habitat suitability areas for European Hop Hornbeam and (2) eliminate more associated bioclimatic factors using correlation analysis. (3) For planning and management purposes, change analysis was used to identify changes in distribution regions. In light of our objectives, this study is searching for the answers to the following questions:

(1) What are suitable current and future habitat areas of European Hop Hornbeam using the IPSL-CM6A-LR climate change model?
(2) What are the most correlated bioclimatic variables directly affecting the distribution of European Hop Hornbeam?
(3) What is the total area of the changes compared to the current and future distribution of European Hop Hornbeam?

Materials and methods

Study area

European Hop Hornbeam as the main topic of the research is a native species in Europe and belongs to the Betulaceae family. This species is generally found on slopes (Shaw et al. 2014). *Ostrya carpinifolia* Scop. is the only native species among *ostrya* species, and its dark wood is very precious for commercial purposes (Korkut 2009) (Fig. 1).

The presence-only data consist of 96 points in the research area borders represented from Middle and East Mediterranean part of Europe; North Anatolia and a small part of Caucasian neighboring Georgia and Armenia in the east; Syria and Lebanon in the south; Macedonia, Greece, Bulgaria, Albania, Italy, Malta, and Slovenia in the west; and

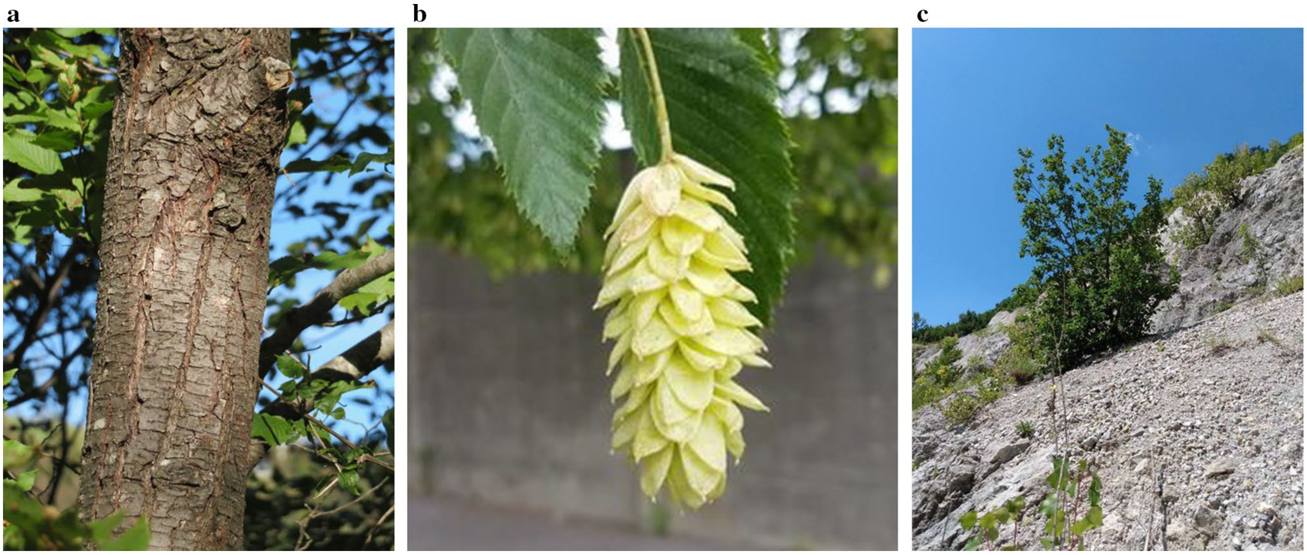

Fig. 1 General overview of European Hop Hornbeam. **a** Trunk;); **b** Leafs/fruit; and **c** Appearance Source: Ueda (2020)

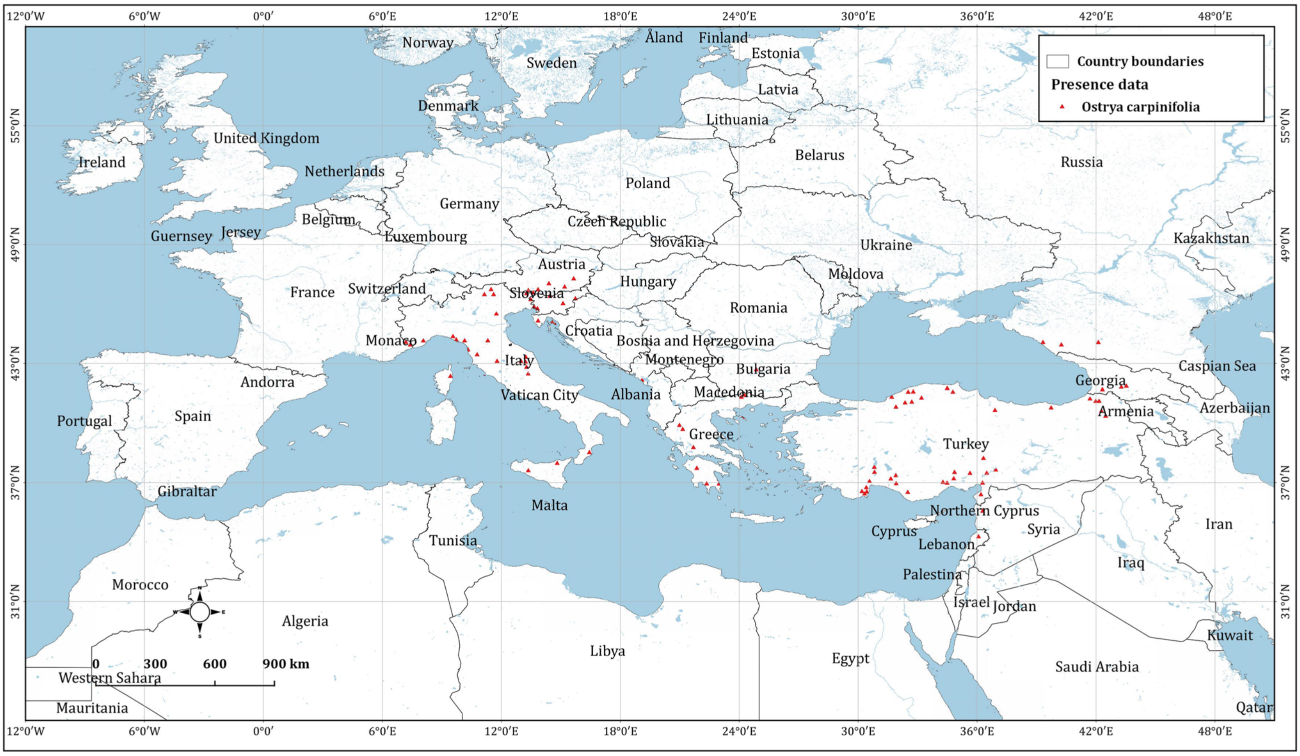

Fig. 2 Distribution of European Hop Hornbeam

Russia in the north. The species' presence positions were identified using the latest literature, the GPS database, and the Global Biodiversity Information Facility (GBIF 2022) (Fig. 2) (Akkemik 2014; Davis 1984). In the WGS84 coordinate scheme, the coordinates of these positions were named using QGIS 3.22.13 (QGIS 2022) and satellite data from Google Earth. Species responses are modeled in a boundary box as the geographical location. Boundary box coordinates are as follows: lower left corner: – 17.33333, 24.83333; upper right corner: 53.04166, 61.37500. According to this, Fig. 2 shows the boundaries of the box.

Bioclimatic variables and human footprint

Bioclimatic variables that have 2.5 m spatial resolution are obtained from the WorldClim future climate database (World Clim 2020). Pearson correlation analysis of 19 bioclimatic variables was conducted using SPSS version 26 to remove the effect of multicollinearity on the modeling process and for the selection of the most fitting variables that show a high contribution to the model, and to further increase the accuracy of the model simulation, the highly correlated variables with Pearson's correlation coefficients higher than 0.7 were eliminated.

Human footprint maps were used as a layer for creating the prediction model. Human footprint maps create an opportunity for interpreting human pressures for tracking environmental change and as a reason for altering ecological systems (Venter 2016). Human footprint data were downloaded from the NASA Socioeconomic Data and Applications Center (SEDAC) in GeoTIFF (.tif) format with the resolution of 1 km^2 (Venter 2018).

Climate change model and MaxEnt procedure

Climate models are effective and advantageous tools to identify the features of the climate system (Boucher et al. 2020). IPSL-CM6A-LR is a French atmospheric climate model developed by The Institute Pierre-Simon Laplace Climate Modelling Centre (IPSL 2020). Compared to other international climate models, the IPCC report is based on a report submitted to the CMIP6 project (Madeleine et al. 2020). The distribution of European Hop Hornbeam across Europe was predicted in this study using the IPSL-CM6A-LR climate change model with the SSP2 4.5 and SSP5 8.5 scenarios for the time periods 2041–2060 and 2081–2100, respectively.

Climate data (resolution of 2.5 arcminutes) and Coordinate Bias File (CBF) file were downloaded from www.sdmtoolbox.org, and "Ostrya_carpinifolia_Coord_Bias_file_for MaxEnt" output was obtained using SDM toolbox tool in Arcmap 10.6.1 program, (You can see the screenshot of output as FigX). Afterward, this file was used in the model as Settings- > Advanced Bias File in the MaxEnt program.

Utilizing European Hop Hornbeam occurrence data, MaxEnt 3.4.1 was run. Replicated run type was selected as the Crossvalidate, and the random test percentage was set at 25%. The number of replicates was set at 10. Because the training data represented 75% of the occurrence data, the 'linear,' 'quadratic,' 'hinge,' and 'threshold' modeling procedures produced the best performance for the purpose of modeling current and future distribution. In a MaxEnt model, it is important to determine the impacts of each environmental bioclimatic variable. Output format was selected as 'Logistic,' and the Jackknife test option was selected to identify the effects of each bioclimatic variable on the model (Pearson et al. 2007).

The model results were transformed into distribution maps using QGIS 3.22.13's raster to vector conversion tool. The extinction of a species in an area or region is calculated by the MaxEnt model as a value between 0 (absence) and 1 (presence). Three factors are often followed when choosing thresholds: objective, comparability, and discriminative capacity (Liu 2019, Bai et al. 2022). The omission error or the specificity and sensitivity of the forecast findings, in general, establish the threshold. The latter contains both omission and commission errors, whereas the former excludes commission mistakes. The latter is represented by the model maximum training sensitivity plus specificity (MTSS), which complies with the three threshold selection criteria (Bai et al. 2022). As classification thresholds for suitable and moderately suitable habitats, respectively, MTSS, balance training omission, projected area, and threshold value (TPT) were utilized to reclassify the MaxEnt model outputs into not suitable, marginally suitable, acceptable, and extremely appropriate habitats. The Reclassify tool of QGIS software, version 3.22.13, was then used to count and determine the area of the suitable distribution region for each class. Under various climate change scenarios, the current and future km2 of appropriate habitats were determined.

This study, therefore, applied a change analysis by comparing the present predicted potential distribution of European Hop Hornbeam with the future predicted potential distribution under the 2041–2060 and 2081–2100 SSP2 4.5 and SSP5 8.5 scenarios. To determine the changes in distribution areas, suitability values were classified as 0 = Not suitable, 1 = marginally suitable, 2 = suitable, and 3 = highly suitable, and potential distribution was compared to the current potential distribution. Output maps were classified based on suitable values for habitat gains and losses, stable and not suitable habitats, and km^2.

Results

Statistical analyses

As a result of Pearson correlation analysis, twelve bioclimatic variables were excluded and only seven variables were kept creating the potential distribution model of European Hop Hornbeam.

The selected variables include isothermality (BIO3), mean temperature of the wettest quarter (BIO08), temperature seasonality (BIO4), precipitation seasonality (coefficient of variation) (BIO15), max temperature of the warmest month (BIO5), annual precipitation (BIO12), and Precipitation of Coldest Quarter (BIO19). The variables Bio 19 (Precipitation of Coldest Quarter), Bio 12 (annual precipitation), and Bio 3 (isothermality) were found to have the greatest influence on the model, respectively.

The receiver operating characteristic (ROC) curve averaged over the replication was studied again. In this regard, the precision is specified using the predicted region instead of the true commission (Phillips et al. 2017). For replication runs, the average test area under the ROC curve (AUC) is 0.953, and the standard deviation is 0.008 (Fig. 3).

The findings of the jackknife test of variables' significance are shown in Fig. 4. BIO 19, the environmental component with the greatest advantage when used alone, frequently provides the most important information by itself. Human footprint layer is the environmental variable that greatly reduces the gain when it is eliminated, and as a result, it tends to provide the most data that is not present in the other variables.

Distribution of European Hop Hornbeam

MTSS = 0.2021 and TPT = 0.0432 in the MaxEnt model results indicate that the thresholds for identifying suitable and marginally appropriate habitats for European Hop Hornbeam are 0.2021 and 0.0432, respectively. The extremely suitable habitat is 1–0.5, the suitable habitat is 0.5–0.2021, the slightly suitable habitat is 0.2021–0.0432, and the not suitable habitat is 0.0432–0.

Figures 5 and 6 and Table 1 demonstrate the species' current and potential geographic distribution based on the degree of suitability classes, as well as prediction models for its potential future distribution. According to Fig. 5, the current possible range of the European Hop Hornbeam includes the coasts of Georgia, Russia, Turkey, Albania, Greece, Macedonia, Bosnia and Herzegovina, Montenegro, Croatia, Slovenia, Austria, Italy, Sicily, and southern France. Furthermore, the predicted model presented that European Hop Hornbeam has suitable habitats around the borders of Spain and Portugal,

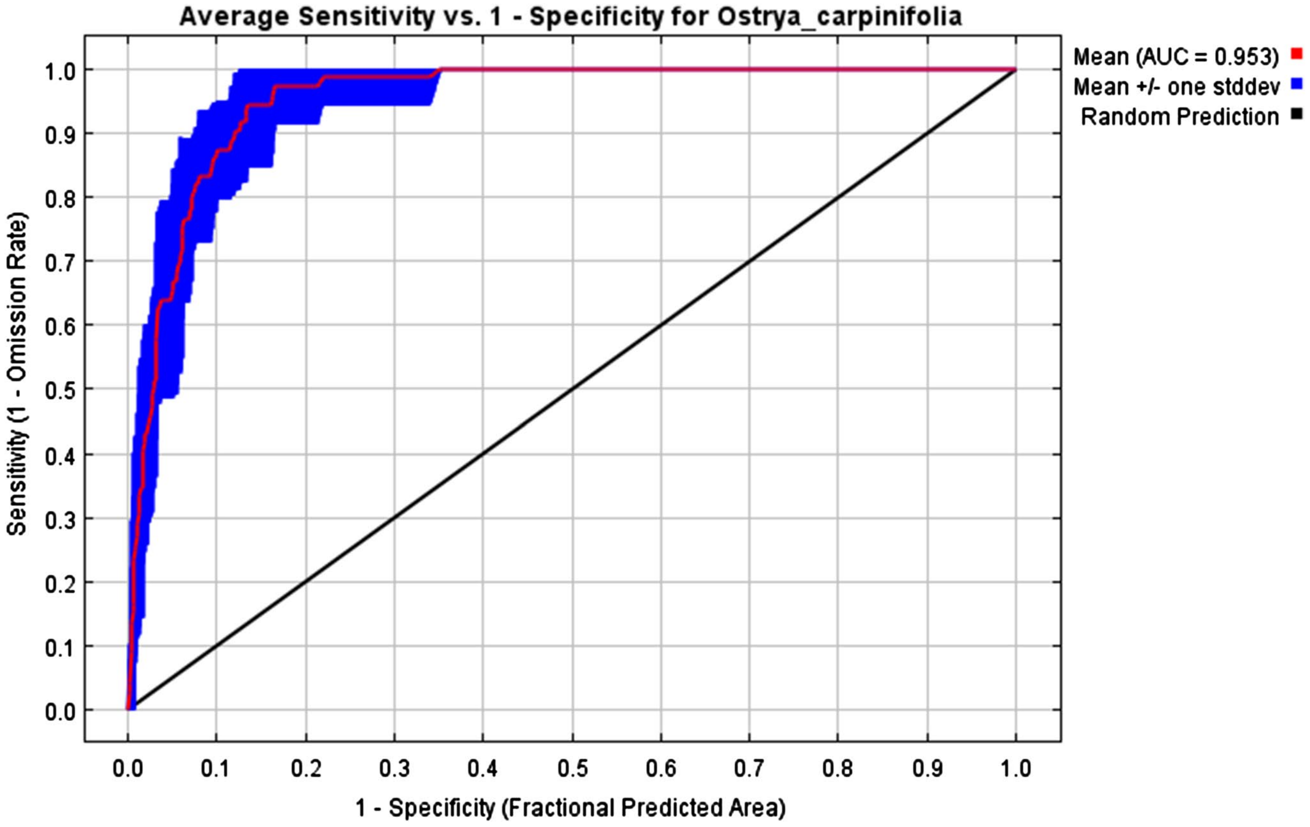

Fig. 3 Reliability of the prediction

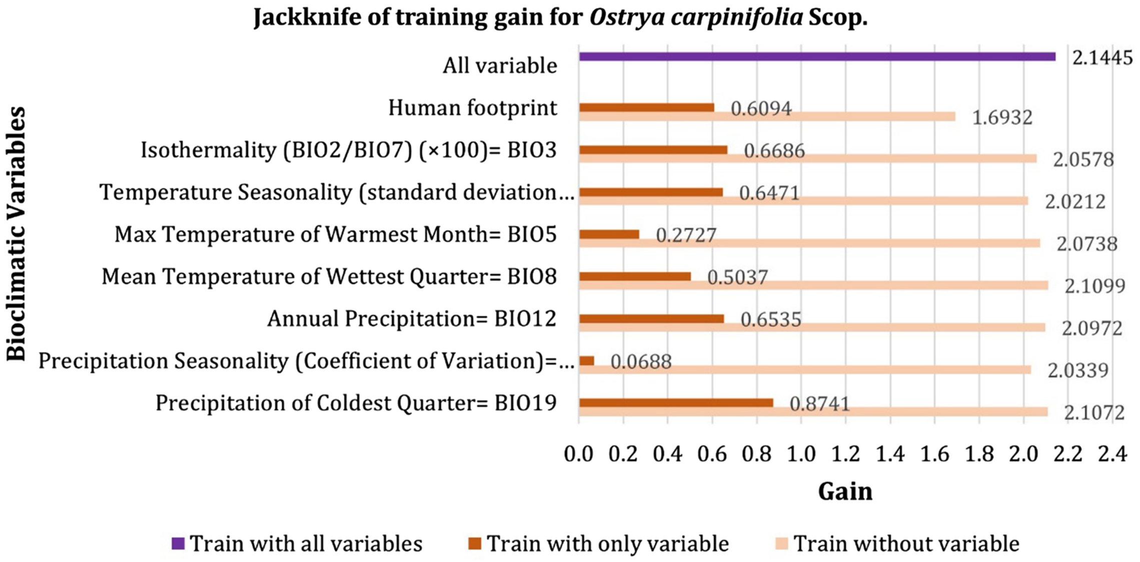

Fig. 4 Jackknife test of bioclimatic variable importance

the Mediterranean coastline of Algeria, and the coastline of the Caspian Sea of Iran, even though there is no occurrence data from those locations. It is calculated that, in total, ‘highly suitable’ areas cover 327,044 km^2 and ‘suitable’ areas cover 809,662 km^2. It is clearly seen that the predicted model is matched up with the EUFORGEN (Caudullo et al. 2017).

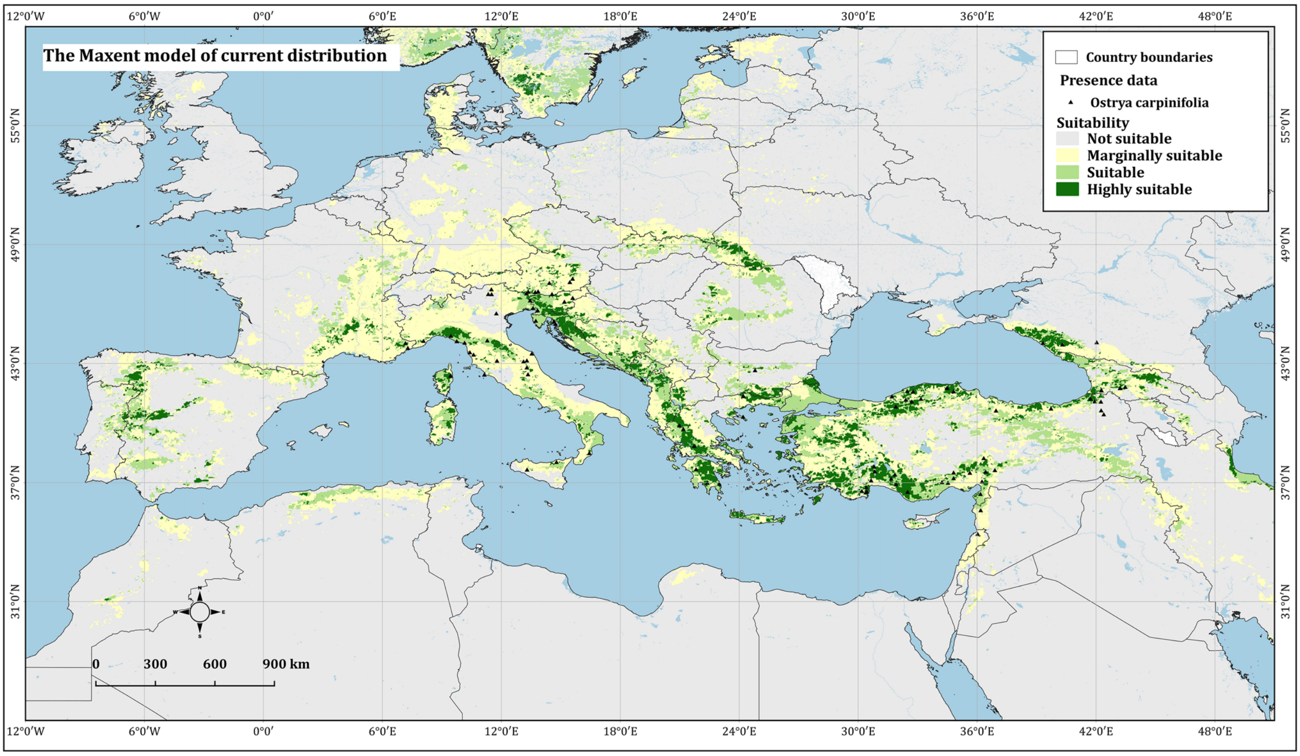

Fig. 5 Current distribution of European Hop Hornbeam

Aone and Attwo indicated that 'highly suitable' areas will increase to 361,584 km^2, and 'suitable' areas will decrease to 692,253 km^2 under the SSP2 4.5 2041–2060 climate change scenarios. It is also predicted that 'highly suitable' and 'suitable' areas will decrease to 324,014 and 683,581 km^2, respectively, under the SSP2 4.5 2081–2100 scenarios.

Athree and Afour show that 'highly suitable' areas will increase to 369,337 km^2, and 'suitable' areas will decrease to 695,784 km^2 under the SSP5 8.5 2041–2060 climate change scenarios. It is also predicted that 'highly suitable' and 'suitable' areas will decrease to 203,010 and 493,064 km^2, respectively, under the SSP5 8.5 2081–2100 scenarios.

Based on the scenarios of SSP2 4.5 and SSP5 8.5, the distribution of European Hop Hornbeam might shift in the future across the time periods 2041–2060 and 2081–2100, as shown in Fig. 6 B 1 through B4. Table 2 shows the modifications to the distribution areas in km^2. The findings of the analysis changes showed a comparison of the European Hop Hornbeam's current and future suitable habitats as km^2. Suitability classes were classified as habitat gains, losses, and stable habitats. For example, in Fig. 6 B 1, the current potential distribution was compared to the SPP2 4.5 climate change scenarios for the 2041–2060 and Figure B 2 for the 2081–2100 periods. Following the same logic, in Fig. 6 B 3, the current potential distribution was compared to the SPP5 8.5 scenarios for the 2041–2060 and 6B4 2081–2100 periods.

Discussion

Global warming as a threat to biodiversity and ecosystems is one of the most fundamental environmental problems of today's world. Nordhaus (2013) stressed that global warming effects are known "as a force that will shape human and natural landscapes for the indefinite future" along with violent conflicts and economic depressions. Several studies indicated that climate change as an environmental problem affects different aspects of human life (Azadi et al. 2020; Jamshidi et al. 2019; Manisalidis et al. 2020). Climate change also plays a key role in shaping the habitats of the species. Because the climate is deteriorating day by day (Zhao et al. 2020), determining the effects on species is crucial for their sustainability. According to studies on the consequences of climate change, animals will move to habitats that are more suitable for them under various climate change scenarios (Akyol et al. 2020; Arslan et al. 2020; Li et al. 2020b; Liu et al. 2019; Sun et al. 2020).

Compared to other regions, climate change projections showed a particular increase in the Mediterranean region during the twenty-first century (Giorgi and Lionello 2008;

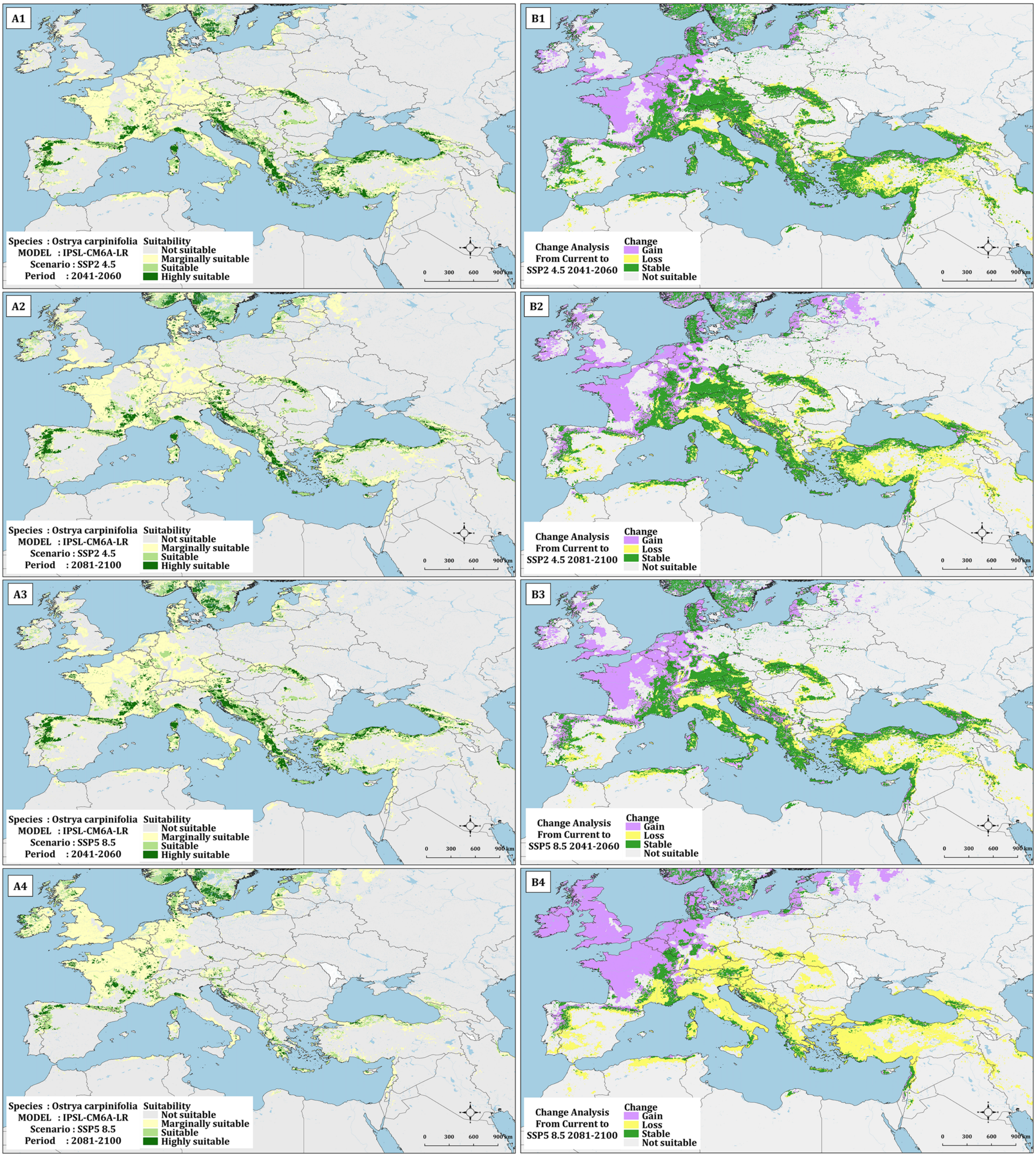

Fig. 6 Future potential distribution of European Hop Hornbeam (SSP2 4.5 **A1** 2041–2061 and **A2** 2081–2100) (SSP5 8.5 **A3** 2041–2061 and **A4** 2081–2100) and Distribution Changes of European Hop Hornbeam for the SSP2 4.5 scenario **B1** 2041–2060 **B2** 2081–2100 SSP5 8.5 scenario **B3** 2041–2060 **B4** 2081–2100

Thiébault and Moatti 2016). The Mediterranean region has the most intense human occupation in the world (Thiébault and Moatti 2016). On the one hand, human interactions surely affect the ecological environment and shape the territory with the characteristic of the population; on the other hand, these interactions make the environment more vulnerable. Combined with the variations in climate, the result can be devastating and can lead to the degradation of

Table 1 Prediction of distribution extent of European Hop Hornbeam in accordance with current and SSP2 4.5 2041–2060/2081–2100, SSP5 8.5 2041–2060/2081–2100

Suitability	Current		SSP2 4.5 2041–2060		SSP2 4.5 2081–2100		SSP5 8.5 2041–2060		SSP5 8.5 2081–2100	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Not Suitable	11,800,025	80	11,780,549	79	11,854,050	80	11,780,384	79	12,520,984	84
Marginally Suitable	1,891,390	13	1,993,724	13	1,965,911	13	1,982,064	13	1,609,743	11
Suitable	809,662	5	692,253	5	683,581	5	695,784	5	493,064	3
Highly Suitable	327,044	2	361,584	2	324,014	2	369,337	2	203,010	1
Total	14,828,122	100	14,828,110	100	14,827,555	100	14,827,568	100	14,826,801	100

Table 2 Change analysis of European Hop Hornbeam (km^2)

Change	From Current to SSP2 4.5 2041–2060		From Current to SSP2 4.5 2081–2100		From current to SSP5 8.5 2041–2060		From current to SSP5 8.5 2081–2100	
Gain	816,769	6	1,025,829	7	1,013,519	7	1,178,098	8
Loss	859,767	6	1,201,021	8	1,045,836	7	2,107,187	14
Stable	1,859,503	13	1,452,946	10	1,599,345	11	594,944	4
Not Suitable	11,292,079	76	11,147,762	75	11,168,869	75	10,946,568	74
Total	14,828,118	100	14,827,559	100	14,827,569	100	14,826,797	100

biological and ecological resources. This demonstrated the deterioration and loss of biodiversity at the level of the species and the movement of the species to less crowded places.

The model results show similarities in terms of the reliability and performance of the model. The current study's reliability results are consistent with the results of Van Zonneveld et al. (2009) and Huang et al. (2019). Hence, it can be said that the population of this valuable plant in European forests is declining. When it comes to the performance of the model, Kigen et al. (2013) and Phillips et al. (2006b) also investigated different algorithms and genetics for regulatory prediction methods considering the geographical distribution of species. Their results represent that their models were undoubtedly better than randomized models when tested for ROC removal and analysis. They also concluded that in the AUC study, MaxEnt showed better differentiation in the acceptable and not suitable areas of the species. These results are in line with the outcomes of Wan et al. (2017). Therefore, the model shows that the most profitable environmental variable, when used separately, is BIO 19. Therefore, the most useful information will be provided. BIO 5 will occur when the environmental variable reduces profit. The response curves illustrate the significant effect of modifying exactly one variable, while the model can take advantage of variable sets that shift together. These findings are in line with the findings of Kumar (2012).

Compared to other regions, climate change projections showed a particular increase for the Mediterranean region during the twenty-first century (Giorgi and Lionello 2008; Thiébault and Moatti 2016). The Mediterranean region has the most intense human occupation in the world (Thiébault and Moatti 2016). Human interactions surely affect the ecological environment and shape the territory with the characteristic of the population, but, on the other hand, these interactions make the environment more vulnerable. Combined with the variations in climate, the result can be devastating and can lead to the degradation of biological and ecological resources. This showed the degradation and biodiversity loss at the species level, but it is clearly seen that when it comes to population findings, the study showed the shift of the species to lower populated areas.

The predicted model of the study represents an obvious decline in the potential distribution of European Hop Hornbeam under the SPP2 4.5 and SPP5 8.5 climate change scenarios. Related studies confirmed that climate change has a major impact on decreasing biodiversity (Abolmaali et al. 2018; Li et al. 2020b; Liu et al. 2019; Qin et al. 2017; Zhao et al. 2020). These findings represented that Mediterranean species will shift to the north, and the plant diversity of Europe will be diminished significantly because of climate change (Cramer et al. 2018). The habitats of animals all across the world are affected by climate change. Because of climate change, animals are migrating northward and upward to higher elevations, where temperatures are cooler. However, in addition to the world's changing climate, there are also significant changes in land use that might have an influence on the habitats of many species. In actuality, the surrounding forest cover frequently restrains species transitions. With the growth in forest loss, species shift at slower rates in colder parts of the planet. On the other hand, the shifting pace is exacerbated by extensive deforestation in warmer locations like the tropics. Tropical species may therefore be particularly susceptible to the combined impacts of climatic and land-use changes. Finally, how species adapt to both habitat loss and changing climates must be carefully examined for successful conservation and global biodiversity management. Current research results showed a similar decline in the species population, even though we used RCP scenarios in our study. In this investigation, the environmental variable with the highest advantage when utilized alone is BIO 19, which tends to give the most meaningful data on its own. So, many factors could affect the distribution of the species as an environmental factor, but results showed that different bioclimatic variables affect this distribution for different kinds of species because of their uniqueness.

The current study's findings suggested that European Hop Hornbeam could be predicted using the CMIP6 project's CNRM-ESM-1 climate change model. The new model is published recently and there are very few studies about this new model. The model shows the current to next sixty years' projection. Not only the model result but also the effects of each environmental variable proved that the MaxEnt model has better performance than the random prediction. As a result, the products are more original. Bioclimatic variables were employed as environmental factors in this study to determine the changes in distribution areas. Similar studies have been conducted on the ecological features that reflect the effect of climate, such as landforms and elevation (Han et al. 2014; Lepcha et al. 2019; Raney and Leopold 2018; Song et al. 2013). Applying an environmental layer, each bioclimatic variable or ecological feature represents the main objective of the study (Khwarahm 2020). The change analysis showed how the extent of distribution in each suitability category will be shaped. The outcomes of the change analysis have indicated that climate change scenarios show the loss of habitats in the future.

Our results suggested that species distribution modeling is an extensive way of understanding biodiversity changes and spatial patterns of the species. These kinds of scientific researches provide knowledge about biodiversity and species in the future under pessimistic and optimistic climate change scenarios to create planning and management strategies for natural and environmental resources. It is therefore important to understand the response of this species to climate fluctuations and to combine distribution modeling with physiological features in order to identify the appropriate areas.

Conclusion

The purpose of this study was to estimate the existing and potential spread of European Hop Hornbeam (Ostrya carpinifolia Scop.) in Europe. The Mediterranean region is significantly important for biodiversity and species, and its ecological value is quite unique. The prediction model indicated that distribution areas of the European Hop Hornbeam in the Mediterranean region will diminish and move further northward in the next 60 years. European Hop Hornbeam, as a native species in Europe, has significant importance for Europe's biodiversity in the future. According to the findings, for the countries across Europe, this study strongly recommended taking the effects of climate change into account. We suggest that distribution modeling should be incorporated into the European Hop Hornbeam's production and conservation policy, which can direct the establishment of plantations and the protection of resources for these species. We also recommend that steps should be taken for the future by the state forestry authority, which oversees the European forests. In addition, it should be highlighted that land use plans should be established, and genetic studies should be funded in order to maintain seed sources for species continuity. We should also ensure the transition of biodiversity to potential distribution areas, along with protective measures to prevent over-grazing and over-consumption. Drought-resistant plants can be identified through genetic studies in order to ensure the species' continuity and resilience to climate change in the future. Efforts should also be made to preserve those individuals that would be less dramatically impacted by the harmful effects of climate change. In this context, our findings imply that conservation and environmental measures should be used to manage this species, and climate change models should be incorporated in land use and forest management planning. The results of this study represented a reference for creating a strategy for the protection and conservation of the species in the future. European countries need effective and innovative solutions for the climate change reality, both at ecological and social levels, to protect European biodiversity. In this regard, it is suggested that future studies examine climatic models such as the entropy model of bias and the presence of endangered specimens in European countries on a larger scale. It also emphasizes the repercussions of the loss of rare plant species, which might be addressed in future research. Future studies should focus on the range sizes of additional taxa on large biogeographic scales, as well as their dynamics under a changing climate. Assessing forest habitat value might aid in the creation of biodiversity indicators such as forest naturalness, which could influence social perceptions of the relevance of forest functions and ecosystem services. As a result, more research is needed to distinguish between the impact of forest structure, which can be managed via forestry, and the natural role of climate change in the conservation of European Hop Hornbeam species.

Author's contribution OKO and HA performed the study and developed the main text. ESA contributed to the first draft manuscript and enriched it up to the final version. ÖKA enriched it up to the final version, reviewed and edited the final version of the manuscript. ShCh, SNN and HIS reviewed, enriched and edited the final version of the manuscript.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability Once the manuscript is accepted, the data will be archived in the repository of the Süleyman Demirel University and a link will be made available.

Declarations

Conflict of interest The authors declare no conflict of interest.

References

World Clim (2020) Future climate, 2.5 minutes' spatial resolution WorldClim 1 documentation [WWW Document]. URL https://worldclim.org/data/cmip6/cmip6_clim2.5m.html (Accessed 12.1.20).

Abolmaali SMR, Tarkesh M, Bashari H (2018) MaxEnt modeling for predicting suitable habitats and identifying the effects of climate change on a threatened species, Daphne mucronata, in central Iran. Ecol Inform 43:116–123

Akhter S, McDonald MA, van Breugel P, Sohel S, Kjær ED, Mariott R (2017) Habitat distribution modelling to identify areas of high conservation value under climate change for Mangifera sylvatica Roxb. of Bangladesh. Land Use Policy 60:223–232

Akyol A, Orucu OK, Arslan ES (2020) Habitat suitability mapping of stone pine (Pinus pineaL.) under the effects of climate change. Biologia.

Arslan ES, Akyol A, Örücü ÖK, Sarıkaya AG (2020) Distribution of rose hip (Rosa canina L.) under current and future climate conditions. Reg Environ Change 20:1–13

Arzac A, Tychkov I, Rubtsov A, Tabakova MA, Brezhnev R, Koshurnikova N, Büntgen U (2021) Phenological shifts compensate warming-induced drought stress in southern Siberian Scots pines. Europ J of Forest Res 140(6):1487–1498

Austin M (2007) Species distribution models and ecological theory: a critical assessment and some possible new approaches. Ecol Modell 200:1–19

Azadi H, Taheri F, Burkart S, Mahmoudi H, De Maeyer P, Witlox F (2020) Impact of agricultural land conversion on climate change. Environ Dev Sustain 45:1–12

Bai J, Hou P, Jin D, Zhai J, Ma Y, Zhao J (2022) Habitat suitability assessment of black-necked crane (Grus nigricollis) in the zoige grassland wetland ecological function zone on the eastern tibetan plateau. Diversity 14(7):579

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F (2012) Impacts of climate change on the future of biodiversity. Ecol Lett 15:365–377

Booth TH (2018) Species distribution modelling tools and databases to assist managing forests under climate change. Forest Ecol Manage 430:196–203

Boucher O, Servonnat J, Albright AL, Aumont O, Balkanski Y, Bastrikov V et al (2020) Presentation and evaluation of the IPSL-CM6A-LR climate model. J Advanc Model Earth Sys 12:e10

Caudullo G, Welk E, San-Miguel-Ayanz J (2017) Chorological maps for the main European woody species. Data Brief 12:662–666

Garzón MB, Dios RS, de Ollero HS (2008) Effects of climate change on the distribution of Iberian tree species. Appl Vegetation Sci 11:169–178

GBIF (2022) GBIF Occurrence Download F, Lionello P (2008) Climate change projections for the Mediterranean region. Global and Planet Change 63: 90–104. Doi: https://doi.org/10.15468/dl.kdm9nuGiorgi

Han H, Cho S, Song J, Seol A, Chung H, Kim J, Chung J (2014) Assessing the potential suitability of forest stands as Kirengeshoma koreana habitat using MaxEnt. Land and Ecol Eng 10:339–348

Harrison S (2020) Plant community diversity will decline more than increase under climatic warming. Philos Trans R Soc B 375(1794):20190106

Huang Z, Xie L, Wang H, Zhong J, Li Yanchen Liu J, Ou Z, Liang X, Li Yongshan Huang H (2019) Geographic distribution and impacts of climate change on the suitable habitats of Zingiber species in China. Indust Crops and Prod 138:e111429

Ilari A, Fabrizi S, Foppa Pedretti E (2022) European hophornbeam biomass for energy application: influence of different production processes and heating devices on environmental sustainability. Resources 11(2):11

IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

IPSL (2020) Institut Pierre Simon Laplace Climate Modelling Center. URL http://cmc.ipsl.fr/ipsl-climate-models/ipsl-cm6/ (Accessed 12.7.20).

Jamshidi O, Asadi A, Kalantari K, Azadi H, Scheffran J (2019) Vulnerability to climate change of smallholder farmers in the Hamadan province. Iran Clim Risk Manage 23:146–159

Khwarahm NR (2020) Mapping current and potential future distributions of the oak tree (Quercus aegilops) in the Kurdistan Region. Iraq Ecol Proc 9:56

Kigen C, Okoth P, Konje M, Shivoga W, Ochieno D, Wanjala S, Agevi H, Onyando Z, Soy B, Kisoyan P (2013) Modeling the Spatial Impact of Climate Change on Grevy's Zebra (Equus grevyi) niche in Kenya.

Kiliç M, Pürlusoy I, Kurnali M (2018) Measuring the surface roughness values of european hop-horn beam (Ostrya Carpinifolia Scop.) wood. Wood Research 63(2): 343–352.

Korkut S (2009) Gürgen Yapraklı Kayacık (Ostrya carpinifolia Scop.) Odununun Bazı Mekanik Özelikleri Üzerine Isıl slem Sıcaklık ve Süresinin Etkisi. Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi 5:121–130

Kulac S, Filiz E, Cicek E, Degermenci Z, Vatansever R (2016) Assessment of genetic diversity in natural European hophornbeam (Ostrya carpinifolia Scop.) populations in Turkey. Biotechnol Biotechnol Equip 30(5):948–955

Kumar P (2012) Assessment of impact of climate change on Rhododendrons in Sikkim Himalayas using Maxent modelling: limitations and challenges. Conserva 21:1251–1266

Lepcha DL, Pradhan A, Chhetri DR (2019) Population assessment and species distribution modeling of Paris polyphylla in Sikkim Himalaya. India. Biodivers J Biol Div 20:87

Li J, Fan G, He Y (2020a) Predicting the current and future distribution of three Coptis herbs in China under climate change conditions, using the MaxEnt model and chemical analysis. Sci Total Environ 698:134141

Liu Y, Huang P, Lin F, Yang W, Gaisberger H, Christopher K, Zheng Y (2019) MaxEnt modelling for predicting the potential distribution of a near threatened rosewood species (Dalbergia cultrata Graham ex Benth). Ecol Engin 141:105612

Madeleine JB, Hourdin F, Grandpeix JY, Rio C, Dufresne JL, Vignon E, Boucher O, Konsta D, Cheruy F, Musat I, Idelkadi A, Fairhead L, Millour E, Lefebvre MP, Mellul L, Rochetin N, Lemonnier F, Touzé-Peiffer L, Bonazzola M (2020) Improved representation of clouds in the atmospheric component LMDZ6A of the IPSL Earth system model IPSL-CM6A. J of Adv in Model Earth Sys. https://doi.org/10.1029/2020MS002046

Maharaj SS, Asmath H, Ali S, Agard J, Harris SA, New M (2019) Assessing protected area effectiveness within the Caribbean under changing climate conditions: a case study of the small island, Trinidad. Land Use Policy 81:185–193

Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E (2020) Environmental and health impacts of air pollution: a review. Front Public Heal 8:87

Marsberg A, Kemler M, Jami F, Nagel JH, Postma-Smidt A, Naidoo S, Slippers B (2017) Botryosphaeria dothidea: a latent pathogen of global importance to woody plant health. Mol Plant Pathol 18(4):477–488

McMahon SM, Harrison SP, Armbruster WS, Bartlein PJ, Beale CM, Edwards ME, Kattge J, Midgley G, Morin X, Prentice IC (2011) Improving assessment and modelling of climate change impacts on global terrestrial biodiversity. Trends in Ecol Evol 26:249–259

Nunez S, Arets E, Alkemade R, Verwer C, Leemans R (2019) Assessing the impacts of climate change on biodiversity: is below 2° C enough? Clim Change 154(3):351–365

Pasta S, de Rigo D, Caudullo G (2016) Ostrya carpinifolia in Europe: distribution, habitat, usage and threats. European Atlas of Forest Tree Species, J. San-Miguel-Ayanz, D. De Rigo, G. Caudullo, T. Houston Durrant, Und A. Mauri,(HRSG.) Publ. Off. EU: Luxembourg. e01fd3d.

Pearson RG, Raxworthy CJ, Nakamura M, Townsend Peterson AJJ (2007) Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. J Biogeogr 34:102–117

Pearson RG, Stanton JC, Shoemaker KT, Aiello-Lammens ME, Ersts PJ, Horning N, Fordham DA, Raxworthy CJ, Ryu HY, McNees J (2014) Life history and spatial traits predict extinction risk due to climate change. Nat Climate Change 4:217–221

Phillips SJ, Anderson RP, Schapire REJE (2006) Maximum entropy modeling of species geographic distributions. Ecol Modell 190:231–259

Qin A, Liu B, Guo Q, Bussmann RW, Ma F, Jian Z, Xu G, Pei S (2017) Maxent modeling for predicting impacts of climate change on the potential distribution of Thuja sutchuenensis Franch., an extremely endangered conifer from southwestern China. Glob Ecol Conserv 10:139–146

Raney PA, Leopold DJ (2018) Fantastic wetlands and where to find them: modeling rich fen distribution in New York State with Maxent. Wetlands 38:81–93

Rather TA, Kumar S, Khan JA (2020) Multi-scale habitat modelling and predicting change in the distribution of tiger and leopard using random forest algorithm. Sci Rep 10(1):1–19

Rosencranz A, Singh D, Pais JG (2009) Climate change adaptation, policies, and measures in India. Geo Int'l Envt L Rev 22:575–590

Sayyadi F, Moghaddasi R, Yazdani S (2019) How climate change affects land use pattern: an Iranian provincial experience. Int J of Environ Res 13(1):67–75

Shaw K, Roy S, Wilson B (2014) Ostrya carpinifolia. The IUCN Red List of Threatened Species 2014: e.T194280A2309186. https://dx.doi.org/https://doi.org/10.2305/IUCN.UK.2014-3.RLTS.T194280A2309186.en. Downloaded on 14 October 2020.

Sinclair SJ, White MD, Newell GR (2010) How useful are species distribution models for managing biodiversity under future climates? Ecol Soc 15:87

Song W, Kim E, Lee D, Lee M, Jeon SW (2013) The sensitivity of species distribution modeling to scale differences. Ecol Modell 248:113–118

Sun S, Zhang Y, Huang D, Wang H, Cao Q, Fan P, Yang N, Zheng P, Wang R (2020) The effect of climate change on the richness distribution pattern of oaks (Quercus L.) in China. Sci Total Environ 744:140786

Thiébault S, Moatti JP (2016) The Mediterranean region under climate change: a scientific update.

Thrippleton T, Lüscher F, Bugmann H (2020) Climate change impacts across a large forest enterprise in the Northern Pre-Alps: dynamic forest modelling as a tool for decision support. Europ J Forest Res 139(3):483–498

Thuiller W (2007) Climate change and the ecologist. Nature 448:550–552

Tytar VM (2019) Climatic limits for the present European distribution of hornbeam (Carpinus betulus), with special reference to Ukraine. bioRxiv 506428.

Ueda K (2020) iNaturalist research-grade observations. iNaturalist.org. Occurrence dataset accessed via GBIF.Org. 2020–12–07. Doi: https://doi.org/10.15468/ab3s5x

Urban MC, Bocedi G, Hendry AP, Mihoub JB, Pe'er G, Singer A, Bridle J, Crozier L, De Meester L, Godsoe W (2016) Improving the forecast for biodiversity under climate change. Sci 353.

Vallese Ch, Nascimbene J, Giordani P, Benesperi R, Casazza G (2021) Modelling range dynamics of terricolous lichens of the genus Peltigera in the Alps under a climate change scenario. Fungal Ecol 49:101014

Van Zonneveld M, Koskela J, Vinceti B, Jarvis A (2009) Impact of climate change on the distribution of tropical pines in Southeast Asia. Unasylva 60:24–28

Wan JZ, Wang CJ, Yu FH (2017) Spatial conservation prioritization for dominant tree species of Chinese forest communities under climate change. Clim Change 144:303–316

Wang YL (2012) Predicting the potential geographic distribution of crofton weed (Ageratina Adenophora) around the world using maxent modeling. Vegetos 25:324–335

Ward DF (2007) Modelling the potential geographic distribution of invasive ant species in New Zealand. Biol Invasions 9:723–735

Warren R, Price J, VanDerWal J, Cornelius S, Sohl H (2018) The implications of the United Nations Paris agreement on climate change for globally significant biodiversity areas. Clim Change 147(3):395–409

Yang XQ, Kushwaha S, Saran S, Xu J, Roy P (2013) Maxent modeling for predicting the potential distribution of medicinal plant, Justicia adhatoda L. in Lesser Himalayan foothills. Ecol Engin 51:83–87

Yuan HS, Wei YL, Wang XG (2015) Maxent modeling for predicting the potential distribution of Sanghuang, an important group of medicinal fungi in China. Fungal Ecol 17:140–145

Zhao H, Zhang H, Xu C (2020) Study on Taiwania cryptomerioides under climate change: MaxEnt modeling for predicting the potential geographical distribution. Glob Ecol Conserv 24:e01313