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Original Article

Evaluation by prediction of the natural range shrinkage of *Quercus ilex* L. in eastern Algeria

Doğu Cezayir'de *Quercus ilex* L.'nin doğal yayılış alanında azalmanın öngörülmesinin değerlendirilmesi

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ABSTRACT

The aim of this study was to evaluate by prediction of the spatial distribution of *Quercus ilex* L. in its natural range in eastern Algeria. The maximum entropy method was used for modeling the species in potentially favorable areas under environmental conditions by linking the spatial occurrence and the environmental conditions. The following three explanatory parameter groups were used for the modeling: i) edaphic variables, ii) variables related to topography, and iii) climatic variables. The established predictions demonstrated that over the horizons 2050 and 2070, we shall lose 125,000 and 147,000 hectares, respectively. The most favorable areas for *Q. ilex* L. would appear to extend between the elevations of 1430 m by 2050 and reach 1650 m by 2070. The performance of the model used in this study was confirmed by the AUC (*area under the curve*) value of 0.929. The high elevations, especially those of the Saharan Atlas, would offer climatic refuges. These results represent a decision support tool for designing the best strategy of sensitization. and planning for the conservation of the holm oak.

Keywords: Climatic forcing, Ecological niche, Species distribution model, Holm Oak, Maximum entropy

ÖZ

Bu çalışma *Quercus ilex*. L'nin Doğu Cezayir'de doğal yayılışının mekansal dağılımının öngörülmesinin değerlendirilmesine odaklanmaktadır. Maksimum entropi yöntemi, mekansal oluşum ve çevre koşullarını ilişkilendiren çevresel şartlar altında potansiyel olarak uygun türleri modellemeye olanak sağlamıştır. Modelleme için üç açıklayıcı parametre grubu kullanıldı: i) edafik değişkenler, ii) topografya ile ilgili değişkenler ve iii) iklimsel değişkenler. Öngörülere göre, 2050 ve 2070 yıllarında sırasıyla 125000 ve 147000 hektar alan kaybolacaktır. *Quercus ilex* için en uygun alanlar 2050 yılında 1430 metre rakıma ve 2070'de 1650 metre rakıma çıkacaktır. Çalışmada kullanılan modelin performansı 0,929 olan AUC değeri ile doğrulandı. Yüksek rakımlar, özellikle Sahra Atlaslarının rakımları, iklime bağlı olarak sığınaklar sunacaktır. Bu sonuçlar en iyi sensibilizasyon stratejisi ve çalı meşesinin korunmasının planlaması için verilecek kararları destekleyecek bir araç niteliğindedir.

Anahtar Kelimeler: İklimsel uyarı, ekolojik konum, tür dağılım modeli, çalı meşesi, maksimum entropi

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INTRODUCTION

Climate change has important consequences on biocenosis dynamics, affecting the structure of the community. Process disturbances have been reported to change the distribution of species (Vitousek et al., 1997; Norby, 1998; Parmesan, 2006; Önder et al., 2009; Slimani et al., 2014). Assessing the future species distribution under the anticipated climate change is a very important topical challenge (Ahmed et al., 2015). Species modeling is an approach that allows linking the spatial and temporal variations of the environmental factors and their effects on the distribution of the species ecological niche (Thruiller, 2003; Guisan and Thruille, 2005; Çoban, 2016; Ray et al., 2017).

According to Lobry and Sari (2007), modeling permits the integration of statistical methods to describe phenomena by implementing equations in a computer model, which allows simulating the possibilities of unrolling the various phenomena to be described. For this purpose, several models have been implemented, including the widely used SDM model (*Species Distribution Model*) (Kumar et al., 2014; Warren et al., 2010; Warren and Seifert, 2011). This model permits the modeling of the potential distribution of the species (Austin, 2002; Reddy et al., 2015; Matawa F, 2016). Several statistical methods can be used to implement an SDM, including the GAM (generalized additive model) (Zuur et al., 2009), boosted regression trees (De'Ath., 2007), combinatorial optimization GARP (Genetic Algorithm for Rule set Production) (Ray et al., 2017), ecological-niche factor analysis (ENFA) (Hirzel et al., 2002), and MaxEnt (maximum entropy) (Phillips et al., 2004; Phillips et al., 2006; Phillips and Dud, 2008; Zaidi et al., 2016).

Mediterranean forest ecosystems cover an area of about 81 million hectares, accounting for 1.5% of the global forest cover (M'Hirit, 1999). They are considered as biodiversity hot spots (Quézel and Médail, 2003; Mendoza-Fernández, 2010) and contain approximately 250 tree species (Quézel, 1999). The study of the circum-Mediterranean vegetation has a major interest in the context of the conservation and preservation of biodiversity (Quézel et al., 1980), as it allows the understanding of the dynamics and evolution of the Mediterranean forest (Quézel, 1999) as well as the assessment of its fragility and its vulnerability to global disturbances and changes (Al Hamndou and Requier-Desjardins, 2008).

The Algerian forests are known for a specific flora that belongs to the Mediterranean forest. Their richness contributes strongly to a climatic, ecological, and socioeconomic balance (Quézel, 1999). The protection and valorization of a forest and near-forest ecosystems has been always at the heart of the political goal of the managers (Saifi, 2015). This can be understood by the succession of action programs whose loopholes have been gradually overcome through the implementation of appropriate improvements (Merdas, 2017).

Despite the efforts made, the forest has been undergoing continuous degradation for several decades, owing to multiple uses and anthropogenic pressure (Madoui, 2002; Quézel and Médail, 2003). Forest dieback is increasingly becoming important due to the long and severe periods of drought (Ahmed et al., 2016).

Holm oak (*Quercus ilex* L.) is a slow-growing, evergreen tolerant species (Rodà, 2000) found primarily in large areas of the Mediterranean regions with cold semiarid to temperate humid bioclimates (Emberger, 1955). It is a forest tree that dominates the transition zones between the temperate forests dominated by hardwoods and the degraded form of forests (Garrigue, maquis, etc) (Terradas, 1999).

The holm oak is one of the primary species covering the Algerian forests that undergoes a strong regression. Several studies have shown a huge decrease over time of the area occupied by this species, which has been estimated to range from 679,000 ha (Boudy, 1955) or 680,000 ha prior to 1985 (Seigue, 1985) to 354,000 ha in 1997 (Ghazi and Lahouati, 1997) and to 108,000 ha in 2007 (DGF, 2007).

This study is based on the modeling of the ecological niche of the species using the maximum entropy method under the present and future climatic conditions associated with a range of variables, namely, climatic factors, factors related to topography, and edaphic and nutritional factors.

The aims of this study were to model the current distribution to determine the areas potentially favorable to the development of holm oak, identify the most contributing environmental factors among the three groups of factors that control the distribution of the holm oak by highlighting its tolerance limits, and finally, assess the impact of future climate change on the spatial distribution of holm oak in eastern Algeria.

MATERIALS AND METHODS

Study Area

The study on the distribution of holm oak was carried out in the eastern Algeria zone. This zone encompasses an enormous ecosystem diversity due to the variety of natural environments resulting from the geomorphological and climatic heterogeneity influenced by its position between the Mediterranean Sea in the north and the Sahara desert in the south, as shown in Figure 1.

In this study, the maximum entropy method was applied to spatial occurrence data of the holm oak, including 39 explanatory variables, to predict the propitious distribution. The performance of the model was statistically evaluated using AUC on the receiver operating characteristic (ROC) curve (Peterson et al., 2008), which allows the assessment of sensitivity (absence of omission errors) and specificity (absence of commission errors) (Fielding and Bell, 1997).

Spatial Occurrence Data of Holm Oak

The spatial occurrence data of the holm oak were collected on field (Figure 2) using a GPS. These data were supplemented from the Tunis–Sfax (Gaussen and Vernet, 1958) vegetation maps taken with their geographical coordinates.

Environmental Variables

The following three groups of environmental variables were used: i) Soil variables comprising the physicochemical and nutritional

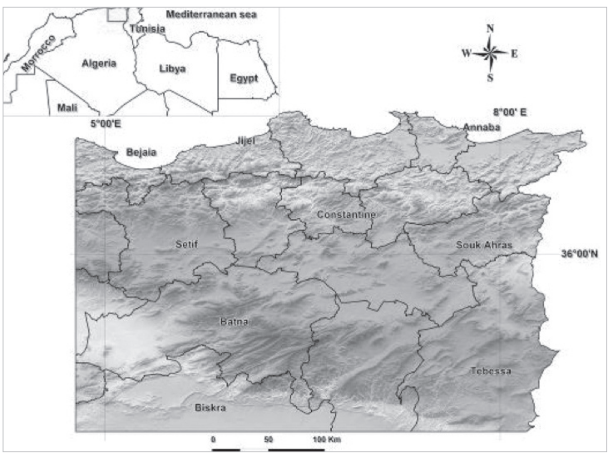

Figure 1. Study area localization

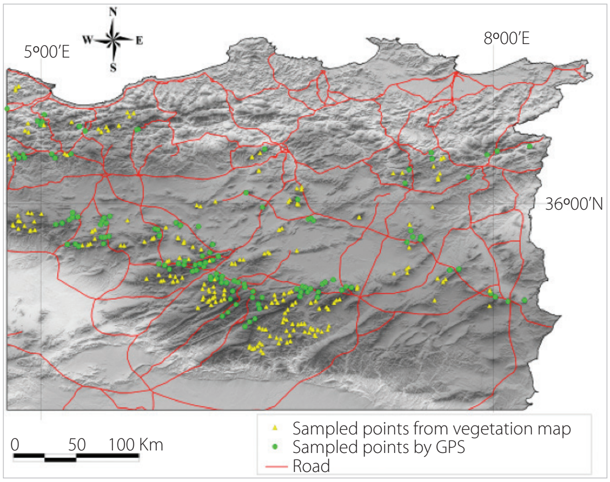

Figure 2. Occurence data of holm oak

characteristics of the soil, namely, clay percentage, silt percentage, sand percentage, organic matter content, soil bulk density, nitrogen content, limestone content, magnesium content, potassium content, sodium content, cation exchange capacity (CEC), and pH. These data were obtained from the Soilgrid database (http://soilgrids.org/: Hengl et al., 2014). The data of the six soil horizons were weighted by horizon thickness to obtain a single layer of data in ASCII Grid format for each soil parameter. ii) Variables related to topography, namely, elevation, the degree of northern orientation (Cos exposure), slope, magnitude of troughs, magnitude of Crete, topographic roughness, and global theoretical monthly radiation. In addition of the distance to the sea (the closest distance between the centroids of the pixels of the kilometric DEM grid and the coastline, these variables are generated from the digital terrain model with a resolution of 30 m (ASTER GDEM) (http://gdem.ersdac.jspacesystems.or.jp) and aggregated to 1-km resolution). iii) Climatic variables were obtained from the BioClim database for the current period (1950–2000). We used the HADGEM2-ES (Hadley Global Environment Model 2 - Earth System) model from the new simulation of climate models carried out under the inter-comparison project phase 5 (CMIP5) of global climate research (www.worldclim.org: Hijmans et al., 2005) for future climatic conditions (2050 and 2070) reflecting the expected climate forcing (IPCC., 2013).

Application of the Model

MaxEnt is a probabilistic and linear probabilistic classifier program based on maximal entropy and estimates the probability of the presence of species based on environmental variables. It requires only the data regarding the presence of species (Phillips et al., 2006).

The principle of the maximum entropy method is to estimate the true occurrence of a species, which is represented as a probability of presence varying between 0 and 1. Thus, when the probability is equal to 1, the presence is estimated as true (Phillips and Dudík, 2008).

The approach used consists of randomly dividing all data into "training" data and "test" data to obtain independent data to evaluate the performance of the model (Fielding and Bell, 1997; Guisan et al., 2003). Thus, a total of 75% of the randomly selected occurrence data was used for modeling (training data), and the remaining 25% (test data) was used for validating the model for 10 replicates of which the selection made is different for each repetition to obtain an average estimation of the model's performance for each repetition (Phillips et al., 2006; Aguirre et al., 2013; Qin et al., 2017).

Performance evaluation is an important step in the validation of the model, which consists of effectuating the omission rate and the predicted area tests to evaluate the predictive performance of the model executed if it is performed as non-random (Phillips et al., 2006).

The analysis of the ROC curve (Fielding and Belle, 1997; Philips et al., 2009) allows the evaluation of the performance of the model through the AUC (area under the curve), which varies between 0 and 1, where 1 represents the maximum performance, and is considered to be weak when the AUC is between 0.5 and 0.7, good when the AUC is between 0.7 and 0.9, and high when the AUC is greater than 0.9 (Swets, 1988; Reddy et al., 2015; Araujo et al., 2015).

RESULTS AND DISCUSSION

Analysis and Evaluation of Model Performance

The curve of the omission rate and the predicted area shows a function of the cumulative threshold, which is calculated on average over the repeated executions of the maximum entropy algorithm. The sensitivity and specificity represent the predicted rate of presence and absence, respectively, as shown in Figure 3. The ROC curve obtained shows a high performance of the model through the calculation of the mean AUC of the test, over the repeated executions of the maximum entropy, which was 0.929 (Kumar, 2014) as shown in Figures 3 and 4.

The AUC provides an independent value that estimates the degree of performance of the model versus that of random expectations (Fielding and Bell, 1997). The following three aspects were taken into account in the evaluation of the model: i) estimation of AUC to evaluate the differences of adjustment of the model, ii) comparison of the maps produced using the occurrence points of the species and the assessment of the spatial agreement of the predictions of presence and absence, and iii) comparison of the contribution of different environmental variables to the model to assess the consistency of selection and contribution of variables (Aguirre-Gutiérrez et al., 2013). The value of the calculated AUC indicates the predictive accuracy of the model, and Figure 4 shows the results of the evaluation confirming the high performance of the model with an AUC value of 0.929 (Lobo et al., 2008; Kumar, 2014; Reddy et al., 2015).

Contribution of Explanatory Variables

Among the 39 variables used, the most contributing explanatory variables to the potentially favorable distribution of *Q. ilex* in eastern Algeria were nitrogen content, elevation, annual mean temperature (bio1), and minimum temperature of the coldest month (bio6). On the other hand, the percentage of sand, the

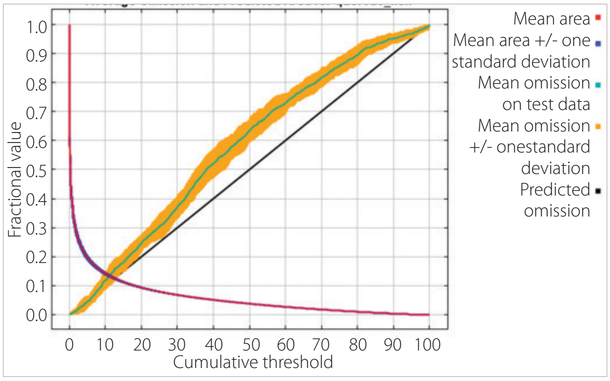

Figure 3. The omission rate of the test and predicted holm oak areas

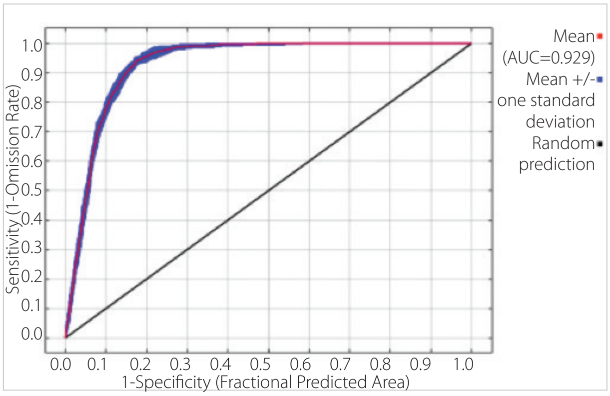

Figure 4. The receiver operating characteristic (ROC) curve

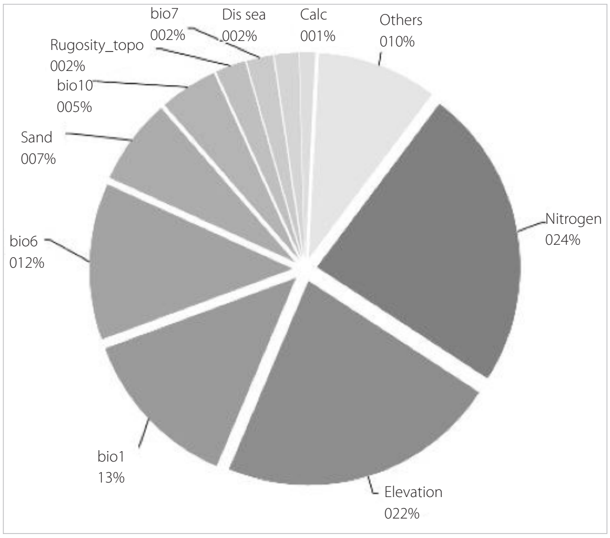

Figure 5. The contribution rate of the most convergent environmental variables for the predicted distribution

warmest quarter average temperature (bio10), topographic roughness (bio7), remoteness from the sea, and limestone content had a lower contribution. The remaining 29 variables had a total contribution of 9.5%, as shown in Figure 5 (Appendix 1).

The variables nitrogen content and elevation exerted a strong positive influence, whereas the annual mean temperature (bio1) and the minimum temperature of the coldest quarter (bio6) strongly and negatively correlated with the distribution of the species. These four variables had the most important contributions to the distribution of holm oak. At this level of perception (kilometric resolution), the climatic variables are the most decisive, with the exception of nitrogen that showed the highest contribution (23.9%).

As shown in Figure 5, *Q. ilex* is present in areas where the nitrogen content is between 1.5 and 3.1 mg/kg and occupies elevations ranging between 950 and 2230 m (Maire, 1926), where the mean annual temperature varies between 7°C and 14°C (Rivas-Martinez., 1980) and the minimum temperature of the coldest quarter varies between –6°C and 0°C (Daget, 1977; Donnadieu, 1977; Quezel, 1979). This affinity to relatively low temperatures reflects a sensitivity to global warming, more specifically to drying of the Mediterranean area, which is due to climate warming, and explains its current distribution and preference for relatively high elevations. Numerous studies have shown that climate change causes the displacement of species ranges toward higher elevations and latitudes (Parmesan and Yohe, 2003; Parry, 2007), thereby leading to new assemblages of species (Williams and Jackson, 2007).

The decrease in nutrient levels in soils, especially nitrogen, is a constraint of tree growth (Leuzinger and Hättenschwiler, 2013). Green oak by adapting and using the most abundant element nitrogen in the soil, there is a balance between the assimilation of CO_2 by the leaves and the absorption of nitrogen by the roots, in an atmosphere rich in CO_2 (Hilbert and Canadell, 1995; Merzouki et al., 1990). The expected increase in CO_2 levels accompanied by water stress affects the assimilation of nitrogen, which results in the strong contribution of this element to the modeling of the distribution of holm oak. The altitudinal shift of green oak stands in the western part of the Mediterranean Basin can be explained by the elevation (Quezel et al., 1980) between 600 and 1200 m in the High Atlas (Barbero and Loisel., 1980), between 400 and 1200 m, and 800 m in the Alpe Maritime (Ozenda., 1966), with similar conclusions being reported for the meso-Mediterranean oak forests of the Grand Atlas (Rivas-Martinez, 1979). The rise in temperature leads to an increase in both the intensity and the duration of periods of water stress, as well as the frequency of droughts (Mouillot et al., 2002). Severe water deficit affects the transport organs of the raw sap, these latter lose their ability to supply water in the conductive tissus, these latter can be filled by air which causes the wasting of the tree (Tyree and Sperry, 1988).

Holm Oak Presence Probability Maps

The propitious habitat predicted for the period 1950–2000 is spread along the Saharan Atlas, the Hodna Mountains, the Aurès Mountains, the Nememmcha Mountains, and the Tebessa Mountains. Within the Tellian Atlas, the holm oak is expected to be present in the Babor Mountains and the Constantine Mountains, as shown in Figure 6.

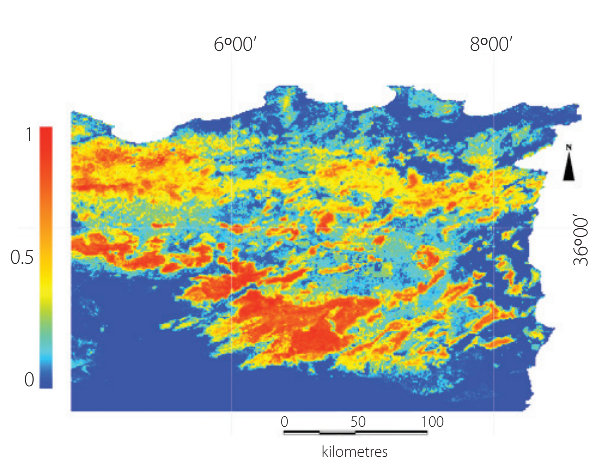

Figure 6. Holm oak distribution probabilities in eastern Algeria for the period 1950–2000

Table 1. Spatiotemporal evolution of the modeled favorable area and its altitudinal distribution

		Area (ha)	Decreased area	Rate of decrease in %	Elevation range (m)
The current period		183000	-	-	950–2230
2050	RPC26	98000	85 000	46.45	1180–2230
	RPC45	75000	108000	59.01	1250–2230
	RPC60	63000	120000	65.57	1300–2230
	RPC85	58000	125000	68.30	1430–2230
2070	RPC26	44000	139000	75.95	1500–2230
	RPC45	41000	142000	77.59	1550–2230
	RPC60	38000	145000	79.76	1600–2230
	RPC85	36000	147000	80.32	1650–2230

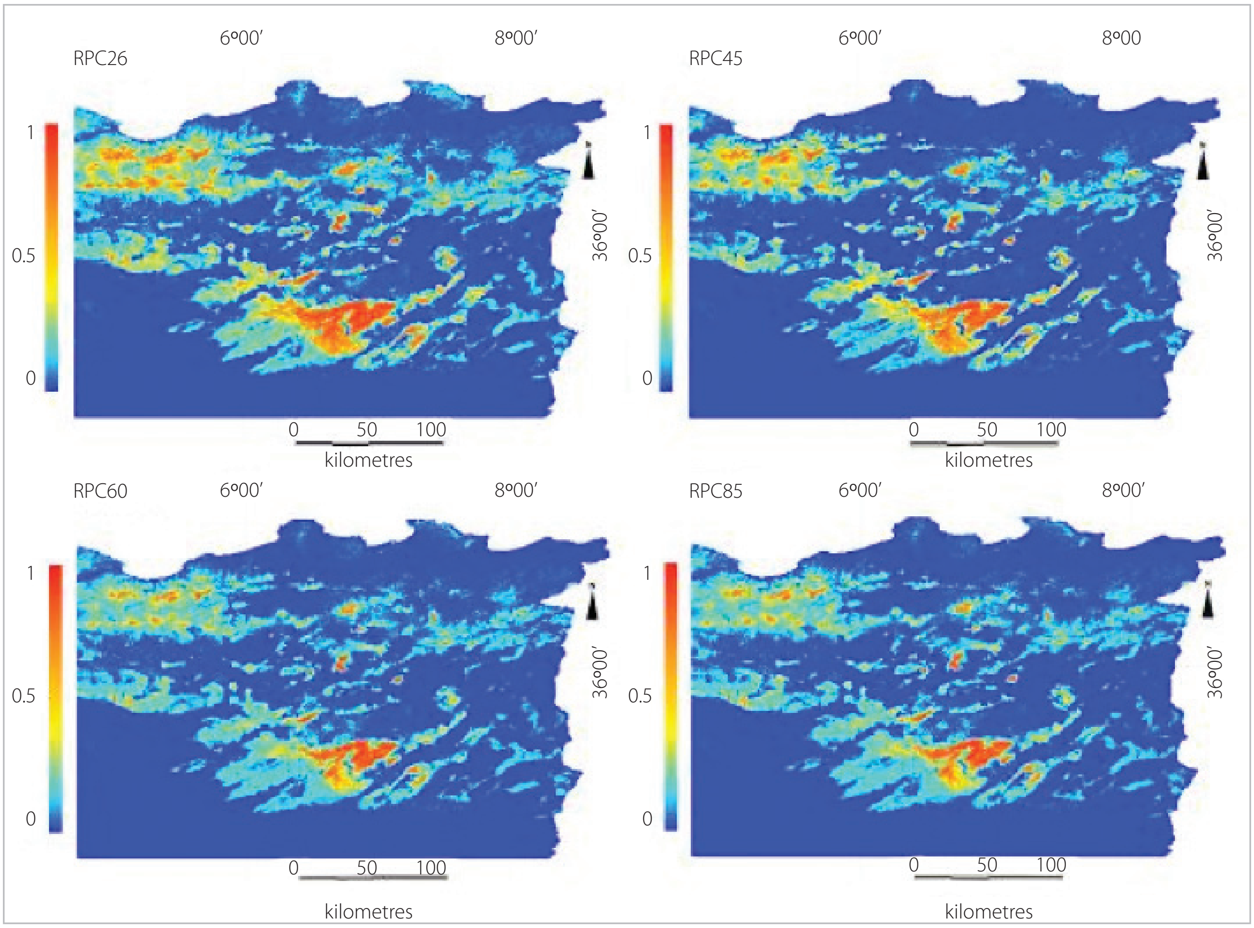

Figure 7. Probability of the presence of holm oak for the four scenarios of the 2050 horizon

The results of the prediction of distribution and the variables defining the potential ecological niches of the holm oak generally appear to be in agreement with the current knowledge of the ecological requirements of the species (Maire, 1926; Daget, 1977; Donnadieu., 1977; Quezel, 1979; Rivas-Martinez, 1980). The modeling approach has correctly predicted a suitable habitat for the holm oak in a fragmented area occupying primarily the Aurès Mountains and the high elevations of the Tellian Atlas. The predicted favorable area of the holm oak for the period 1950–2000 was estimated at 183,000 ha.

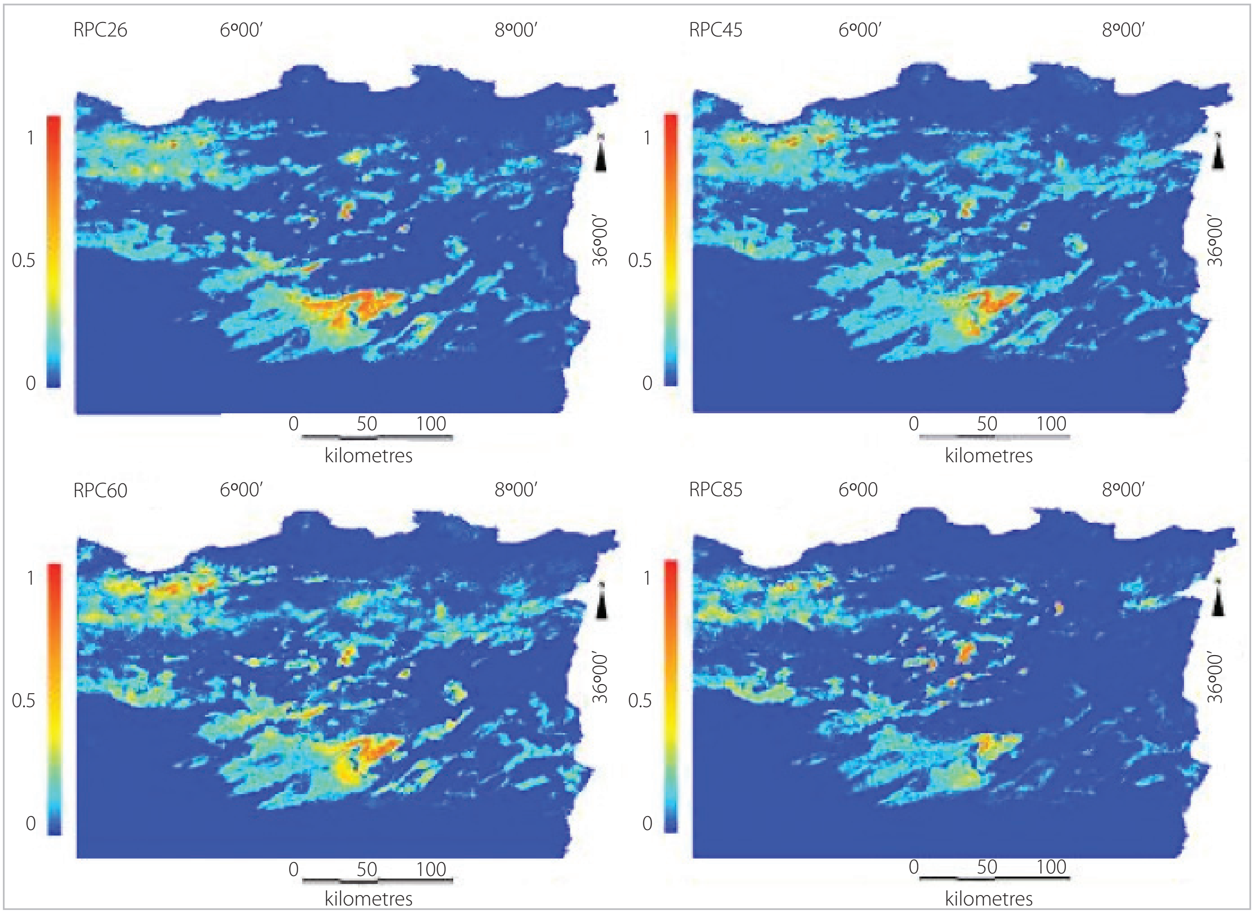

Figure 8. Probability of the presence of holm oak for the four scenarios of the 2070 horizon

The results have also allowed us to estimate the potential areas obtained under future climate projections by 2050 and 2070, as shown in Figures 7 and 8, as well as the corresponding elevation ranges. These findings highlight that the area favorable to the development of the holm oak will be strongly shrunk with retreat to high elevations, as shown in Table 1.

According to Pouteau et al. (2010), upward displacements of the vegetation levels, with respect to the present levels, of 220 m in 2050 (with a temperature rise of +1.4°C) and of 490 m in 2100 (with a temperature rise of +3.1°C) are projected under the A1B emission scenario. Consequently, the tropical subalpine zone will disappear completely before 2100. These findings are in concordance with our results describing the vertical displacements of the projected lower boundary, which are estimated at 1180, 1250, 1300, and 1430 m by 2050 and at 1500, 1550, 1600, and 1650 m by 2070 for the RPC26, RPC45, RPC65, and RPC85 scenarios, respectively, as shown in Table 1.

Laala and Allatou (2016) estimated a degradation rate of 17% for the forest massifs in eastern Algeria, of which 2.19% includes the degradation rate of holm oak for the period 2002–2011. This result describes the consequences of current climatic disturbances over a 10-year period, which supports the predictions obtained in this research for the most pessimistic future climate projections by 2050 and 2070. Furthermore, the spatial distributions of areas suitable to the development of holm oak will be sharply reduced for all scenarios (RPCs). These suitable areas are indeed estimated to decrease at the rates of 53.55%, 59.01%, 65.57%, and 68.30% of the current areas by 2050 and at 75.95%, 77.59%, 79.76%, and 80.32% by 2070 for the RPC26, RPC45, RPC60, and RPC85 scenarios, respectively (Figures 7 and 8).

In particular, the elevations of the Saharan Atlas would constitute the potential refuge for holm oak, whereas the low and moderate elevations will become less favorable.

CONCLUSION

This study has allowed us to better understand the distribution and ecology of *Q. ilex* to successfully identify its current potential habitats and to project into its future potential ecological niche. The future simulations showed a strong response of the species to climate change, with a more pronounced shrinkage by 2070, corresponding to a decrease of 80.32% of the current area for the worst-case scenario (RPC85). Such an alarming result requires a serious and relevant policy response through the establishment of effective and sustainable strategies. However, other factors that influence the distribution of forest species, such as biotic interactions and seed dispersal capabilities, must also be taken into account, including the adaptive capacities. In this study, the shrinkage results of green oak were overestimated because the method does not take into account atmospheric CO_2 levels and their effects on stomatal regulation in response to water stress, thereby limiting, on the one hand, the assimilation of CO_2 by the species and, on the other hand, the decrease in evapotranspiration caused by the increase in temperature. The high spatial resolution of the variables would allow obtaining a better understanding of the spatial distribution of the holm oak at a fine scale to draw appropriate conclusions for better conservation and decision-making.

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Appendix 1. Table showing the contribution of explanatory variables

Variable	Abbreviation	Percent contribution
Nitrogen (mg/kg)	Nitrogen	23.9
Elevation (m)	Elevation	22.2
Annual Mean Temperature (°C)	bio1	13
Minimum Temperature of Coldest Month (°C)	bio6	12.4
Sand (%)	Sand	6.8
Mean Temperature of Warmest Quarter (°C)	bio10	4.6
Rugosity Topographic	RUG	2.4
Annual Temperature Range (BIO5-BIO6)	bio7	2.1
Distance to sea (m)	Dis_mer	1.9
Total limestone (mg/kg)	Calc	1.2
Precipitation of Coldest Quarter (mm)	bio19	0.9
Maximum Temperature of Warmest Month (°C)	bio5	0.8
Precipitation Seasonality (Coefficient of Variation)	bio15	0.8
Silt (%)	Silt	0.6
Potassium (cmolc/kg)	Potass	0.5
Bulk density (kg/m^3)	Balckdens	0.5
Mean Temperature of Wettest Quarter (°C)	bio8	0.4
Organic Matter (g/kg)	Mo	0.4
Precipitation of Driest Month (mm)	bio14	0.3
Cation exchange capacity of soil (cmolc/kg)	CEC	0.3
Sodium (cmolc/kg)	Sodium	0.3
Precipitation of Warmest Quarter (mm)	bio18	0.3
Precipitation of Driest Quarter (mm)	bio17	0.3
Magnesium (cmolc/kg)	Magn	0.3
Degree of north orientation	Cos_exposition	0.2
Temperature Seasonality (standard deviation *100)	bio4	0.2
Precipitation of Wettest Quarter (mm)	bio16	0.2
Clay (%)	Clay	0.2
Isothermality (BIO2/BIO7) (*100)	bio3	0.2
Mean Temperature of Driest Quarter (°C)	bio9	0.2
Mean Temperature of Coldest Quarter (°C)	bio11	0.2
Theoretical global radiation (March) w/m^2	ReG_Fev	0.2
Annual Precipitation (mm)	bio12	0.2
Theoretical global radiation (March) w/m^2	ReG_Dec	0.1
	ReG_Aout	0.1
Mean Diurnal Range (Mean of monthly) (°C)	bio2	0.1
	ReG_Mai	0.1
Precipitation of Wettest Month (mm)	bio13	0.1
pH	pH	0.1
Magnitude Crete (m)	Magnitude crete	0.1
Slope (%)	slope	0.1
Global radiation (November) w/m^2	ReG_Nov	0.1
Theoretical global radiation (September) w/m^2	ReG_Sept	0
Theoretical global radiation (July) w/m^2	ReG_Juillet	0
Theoretical global radiation (March) w/m^2	ReG_Mars	0
Theoretical global radiation (June) w/m^2	ReG_Juin	0
Theoretical global radiation (year) w/m^2		
Theoretical global radiation (April) w/m^2	ReG_Avr	0
Theoretical global radiation (October) w/m^2	ReG_Oct	0
Theoretical global radiation (January) w/m^2	ReG_Jan	0