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Potential Future Changes of the Geographic Range Size of *Juniperus phoenicea* in Algeria based on Present and Future Climate Change Projections

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Abstract—MaxEnt (Maximum Entropy), a Species Distribution Modelling (SDM) method, was applied in the current study in order to assess present and future spatial distribution of the Phoenician juniper (*Juniperus phoenicea*). Potential future changes in the geographic range size of *J. phoenicea* in Algeria was determined for the two horizons 2050 and 2070 based on CCSM4 model of the IPCC. Three types of data were used in SDM namely: 21 edaphic factors, 10 topographic parameters, and 19 climatic factors. The AUC value (Area Under Curve) scored 0.966, which showed the high performance of the MaxEnt model. The most contributing variables were: total soil carbon (22.1%), Bio14: driest month precipitation (19.2%), slope (11.1%), Bio15: seasonality of precipitation (coefficient of variation) (10.3), total soil nitrogen (7%), soil available water capacity during summer (6.3%). The presence probability map obtained shows a narrowing of the favorable area of the species by about 52.5% by the year 2070. Such a result asserts the vulnerable state of this species toward the climate change, which results in altitudinal, longitudinal and latitudinal species distribution range shift as a response reflecting the becoming of unfavorable changes of the Phoenician juniper habitats. Based on these results, it is necessary to adopt necessary planning measures for the protection and conservation of the species regarding its vulnerability to climate change.

Keywords: species range, North African forests, Phoenician juniper (*Juniperus phoenicea*), species distribution modelling, climate change, range size

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1. INTRODUCTION

Climate change is considered as one of the major concerns for both the scientific community and common society (Bulkeley and Newell, 2015). Recent studies have emphasized the starring role of climate change in habitat destruction, species loss and rapid decline in terrestrial biodiversity (Bellard et al., 2012). According to IPCC (2014), the average global air temperature increased by 0.85°C between 1880 and 2012, and it is expected to continue increasing by 4.8°C in 2100. The period after 2010 is considered as the hottest period of all man history (Hansen et al. 2010). The IPCC forecasted an increase of extreme events such as drought, heatwaves and rainfall irregularity (Seneviratne et al., 2012; Stocker et al., 2013), which might lead to the alteration of biogeochemical cycles and, therefore, may possibly affect the structure of plant communities and the functioning of ecosystems (Etterson et al., 2016; Pecl et al., 2017).

As adaptive mechanisms to climate change, plant species shift their climatic niche by adjusting their geographic distribution range (Bellard et al., 2012). Many studies have already reported contractions in distribution range sizes and shifts northward or upward of elevation for several species (e.g. Hulin et al., 2009; McGuire et al., 2016; Arar et al., 2020). However, very few studies have investigated geographic distribution range shifts of plant species inhabiting North African ecosystems (Tabet et al., 2018; Arar et al., 2019; Bouahmed et al., 2019).

Ecological niche modelling called SDM (Species Distribution Modelling) or HSMs (habitat suitability modelling) (Graham and Kimble, 2019), are used to generate potentially favorable habitat maps for species (Elith and Leathwick, 2009; Elith et al., 2010). Nevertheless, these technics have been used modestly in North Africa, specifically in Algeria where the community ecology only started recently benefiting from the application of SDMs in the field of forest ecology (e.g. Tabet et al., 2018; Arar et al., 2019; Bouahmed et al., 2019). Among SDMs, the Maximum Entropy 'MaxEnt' is widely used due to its flexibility and performance in modelling presence-only data using various types of explanatory variables (continuous or categorical) (Phillips et al, 2006, 2009). MaxEnt is a valuable research tool for understanding and forecasting the response of species to global change and for developing science-based management strategies (Booth, 2017).

Mediterranean forests occupy a special place among all forests of the world because they host a considerable taxonomic richness with high endemism scores (Mittermeier et al., 2004). They are ranked among the world's eight hottest biodiversity hotspots as they are subject to particular human threats and climate change (Myers et al., 2000; Véla and Benhouhou, 2007). North African forests represent fragile ecosystems undergoing continuous decline due to the combined effects of natural factors like soil erosion and droughts and human activities like forest fires, deforestation for expanding urban/agricultural lands and wood production (Barbero et al., 1990; Allen, 2001; Arar et al., 2009; Arar and Chenchouni, 2012). A typical example of forest ecosystems at serious threat of degradation in Algeria are Phoenician juniper (*Juniperus phoenicea* L.) woodlands which occur mainly in semi-arid and arid regions along the northern limits of the Sahara Desert. In addition to human pressure i.e. uses of wood and leaves of Phoenician juniper for industrial and medicinal purposes, this species is suffering from repeated drought episodes especially in sensitive regions i.e. arid and semi-arid environments (Kabiel et al., 2016), which may lead to the extinction of many populations of this species and/or a possible shift of its geographic distribution range in response to global warming.

In the present study, we used Maximum Entropy modelling method to identify the main environmental factors that shape the distribution of Phoenician juniper in Algeria, ands forecast the future distribution of this species under two scenarios of Representative Concentration Pathway (RCP) namely RCP4.5 and RCP8.5. We hypothesize that the distribution range size of Phoenician juniper is going to experience significant shrinking in the future due to climate change. We expected also latitudinal and altitudinal shifts of species geographic distribution range in response to global warming (Freeman et al., 2018). This change in species distribution might increase with the increase of frequency and duration of severe drought episodes, especially in arid and semi-arid environments.

2. MATERIALS AND METHODS

2.1. Studied Species and Study Area

Juniperus phoenicea is a large shrub or small tree, although its geographical distribution range covers a large part of the Mediterranean region, from Canary Islands, Portugal and North Africa at the West to Saudi Arabia and Jordan to the East, this species prospers in semi-arid and arid regions of north-western Africa (Mazur et al., 2010). The Phoenician juniper is a rustic and resistant species, with little specific ecological demands; it survives at low precipitation 200–400 mm/year and can reach an elevation of 2000 m (Quézel and Gast, 1998). In Algeria, *Juniperus phoenicea* has a scattered distribution though it occupies a wide range of environments between the coastal lands to the mountain tops of the Atlas range (Quézel and Gast, 1998; Quézel and Médail, 2003).

The current study investigated *Juniperus phoenicea* potential distribution in Algeria. The study area covered an area of 488,457 km^2 and is located between the meridians 2°13′4.8″W and 8°40′59.5″E and the parallels 32°58′31.1″N and 37°5′31.2″N (Fig. 1). It is limited to the North by the Mediterranean Sea, to the South by the Sahara Desert, whereas the Tunisian and Moroccan borders represent its Eastern and western limits, respectively (Arar et al., 2020).

2.2. Species Occurrence Data

Field surveys were conducted throughout the study area in order to have a comprehensive representation of Phoenician juniper populations over its distribution range in Algeria. Before proceeding with field surveys and collecting species presence data, species distribution areas were documented in the literature in order to determine surveying routes and thus avoid wasting time and efforts. Using a global positioning system (GPS), species occurrence data were collected along with latitude, longitude and elevation above sea level. Inspection of inaccessible areas was proceeded using Google Earth Engine and Vegetation map of the region to identify and localize species occurrence points. Each presence point was considered as a sample, with clustered samples were removed using only one record per grid cell (pixel of 1 km$^{2)}$ to ensure the absence of any spatial autocorrelation which is the dependence between geographical values of environmental conditions in excessively sampled areas (Zhang et al., 2019), because when environmental variables are autocorrelated, tests of model performance yield overestimated results (Elith and Leathwick, 2009; Bahn and McGill, 2013). In total, 850 occurrence records of *Juniperus phoenicea* were retrieved and included in the analysis (Fig. 2).

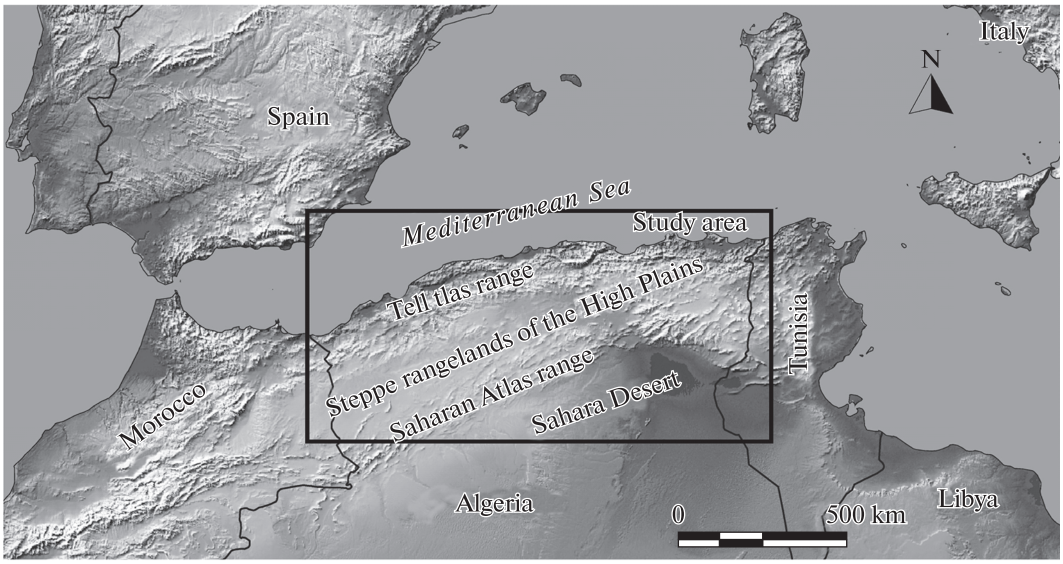

Fig. 1. Location the study area (Black rectangle) with the main geographic forms in northern Algeria.

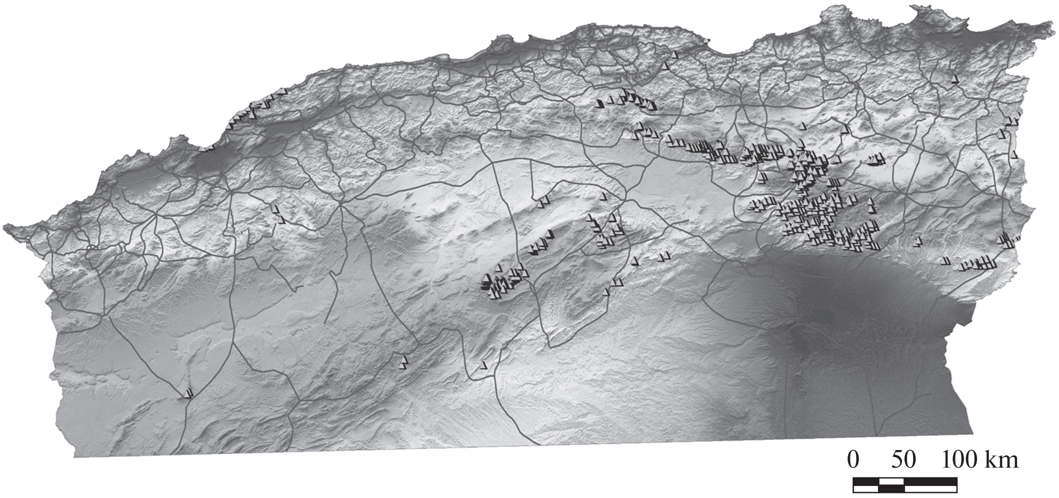

Fig. 2. Occurrence points (points as a triangle) of *Juniperus phoenicea* in northern Algeria. Red lines represent the main roads.

2.3. Environmental Variables

In total, 50 environmental variables, divided in three groups (climatic, edaphic, and topographic data), were used in this study. After carrying out a collinearity analysis in order to eliminate variables with high correlations (i.e. $|r| \geq 0.8$, Kouba et al. 2011), 32 variables were retained to run the SDM (Appendix Fig. S1).

Out of 19 climatic variables obtained from WorldClim (http://worldclim.org/version1), eight were selected for three periods 1950-2000 (hereafter referred to as “current period”), year 2050 and 2070. These variables included: mean diurnal range (mean of monthly (max temperature – min temperature)) (tagged Bio2), isothermality (Bio3), temperature seasonality (Bio4), min temperature of coldest month (Bio6)), mean temperature of wettest quarter (Bio8), mean temperature of driest quarter (Bio9), precipitation of driest month (Bio14), precipitation seasonality (Bio15), and precipitation of wettest quarter (Bio16) (Hijmans et al 2005). Future forecasts of climatic data were obtained following two scenarios (RCP4.5 and RCP8.5) of CCSM4.0 model (Community Climate System Model 4) in the context of Coupled Model Intercomparison Project (CMIP). The two RCPs represent distinct pathways for greenhouse gas and aerosol concentrations: RCP4.5 is an intermediate emission scenario with medium concentrations and RCP8.5 is a pessimistic scenario with the higher atmospheric concentrations (Makino et al., 2015).

Out of 21 soil parameters acquired from global SoilGrids (https://soilgrids.org), 17 physicochemical and nutritional variables were retained: clay content (%), sand content (%), total organic carbon (TOC, in g/kg), total organic nitrogen (TON, in g/kg), total carbon to total nitrogen ratio (C/N), concentrations of four exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+, in cmolc/kg), electrical conductivity (EC, in dS/m), cation exchange capacity (CEC, in $cmol_c/kg$), bulk density (in kg/m^3), pH, porosity (percent), the sum of exchangeable bases to the CEC ratio (S/T). Furthermore, using precipitation and temperature of WorldClim data and SoilGrids data, available water capacity 'AWC' of summer (AWCsumm) and spring (AWCspr) were computed for the current period and for the two future projections 2050 and 2070. Topographic variables included altitude (m), slope (%), aspects, global theoretical solar radiation of summer (Rad_spring) and spring (Rad_summ) (in WH/m^2), and nearest distance from the sea (in km), topography-related data were derived from the version 2 of ASTER GDEM database (https://asterweb.jpl.nasa.gov/gdem-wist.asp) that presents a Global Digital Elevation Model.

2.4. Model Implementation

The modelling of *Juniperus phoenicea* potential distribution was realized using the Maximum Entropy method (MaxEnt, version 3.4.1, Phillips et al., 2006) which is a machine learning algorithm. Although it uses presence-only data, MaxEnt performs better than other methods in terms of predictive accuracy (Phillips et al., 2006; Elith et al., 2011; West et al., 2016). In SDM, the assessment of the model performance and the validity of the results is usually done through the calculation of discrimination capacity (Guisan et al., 2017) with using the Receiver Operating Characteristic (ROC) curve as a proxy. ROC estimates the probability that a true presence (sensitivity) and a true absence (specificity) are correctly discriminated by the model (Chen et al., 2015). The significance of this curve is quantified by the Area Under Curve (AUC) score. In the present study, AUC was calculated and cross validated based on ten repetitions. The dataset was split into ten subsets, of which one will be kept as test data for the ten replicates of the model, for each repetition the rest 90% of the data is used as training data. Accordingly, the resulting AUC value is the average of ten-fold cross-validation tests (West et al., 2016; El-Gabbas and Dormann, 2018). AUC ranges between 0 and 1: when $AUC \leq 0.5$, the model has no predictive capacity, whereas the model presents the maximum performance when $AUC=1$. The model predictive performance is considered low for AUC ranging between 0.5-0.7, from 0.7 to 0.9 the performance is good, higher than 0.9 the model is highly efficient (Bahn and McGill, 2013; Guisan et al., 2017). The final mapping of the potential species distribution is represented as a spatialization of occurrence probability values ranging from 0 to 1 (Elith and Leathwick, 2009).

2.5. Examining Spatiotemporal Shifts in Species Distribution Range

Results of *Juniperus phoenicea* potential distribution were exploited to evaluate any possible changes between the current period and future climate changes in 2050 and 2070 for both RCP4.5 and RCP8.5 scenarios. For each pixel produced in each scenario map, longitude, latitude and altitude information were extracted for the class with high potential of species occurrence (probability of occurrence ≥0.6). The variations in longitude, latitude and altitude between the selected pixels from each scenario-map and those of the current potential distribution were tested using generalized linear models (GLM)). Each GLM was fitted to a Gaussian distribution error with 'Identity' link using the function *glm* from R package {stats}. If the variation between two scenarios is statistically significant (i.e. $P \leq 0.05$)), this means that *Juniperus phoenicea* distribution range will be shifting. The range shift can be longitudinal, latitudinal or altitudinal.

3. RESULTS

3.1. Model Performance

The performance of the model was calculated by the independent thresholds method through the ROC curve, the latter allowed us to obtain the sensitivity curve (true positive rate) in relation to specificity (false positive rate), the mean value of AUC obtained from the ten-repetition runs was 0.954. This model converged after 5000 iterations, and showed a high performance compared to the random prediction which equals 0.5.

3.2. Variable Contributions in the Predicted Model

Six environmental variables were highlighted in the selected model as the most important factors with the strongest influences on the spatial distribution of Phoenician juniper in Algeria (Fig. 3). The selected variables were total soil carbon with a contribution 22.1% in the predicted model, precipitation of driest month (contribution = 19.2%), terrain slope (contribution = 11.1%), seasonality of precipitation (contribution = 10.3%), total soil nitrogen (contribution = 7%), and soil water available content during summer and spring (contribution = 6.3%). According to response curves of these variables (Fig. 3), the rest of the variables have negligible contributions in the model, the sum of their contributions is 24%.

The potential occurrence of Phoenician juniper increased with the decrease of the water available content of summer, seasonality of precipitation, and driest month precipitation. Phoenician juniper occurs mainly in areas with regular rainfall (coefficient of variation in seasonal precipitation between 0 and 40%, Fig. 3c) and precipitation of the driest month between 0 and 10 mm (Fig. 3b). The species prefers areas with negative or small amount of soil available water capacity during summer-spring period (Fig. 3e). Total soil carbon and nitrogen and terrain slope showed positive effects on the likelihood of Phoenician juniper occurrence, which indicates that suitable habitats of the Phoeni-

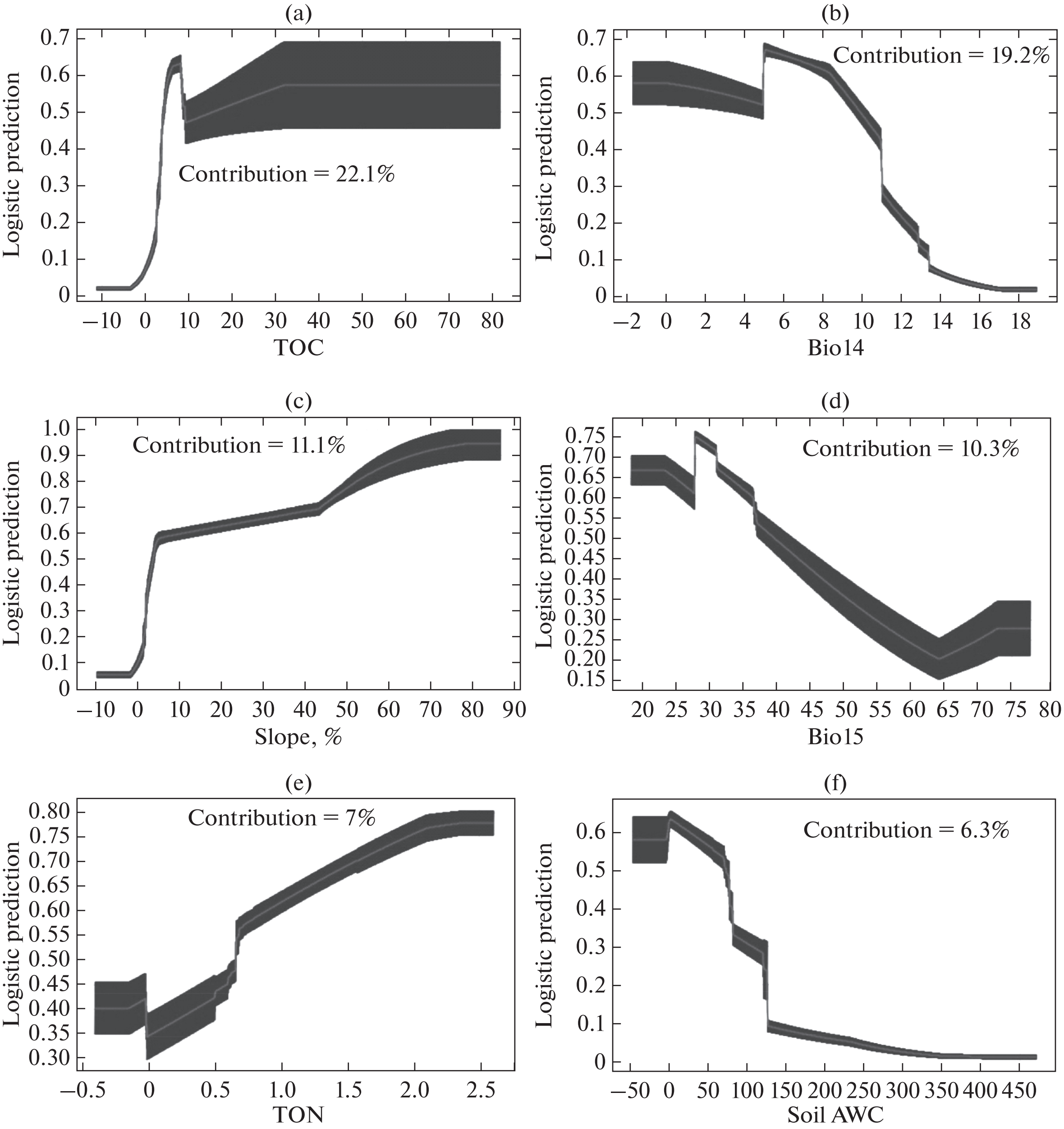

Fig. 3. Response curves of Phoenician juniper potential distribution to the most contributing environmental variables. The value shown on the y-axis (i.e. Logistic prediction) is predicted probability of suitable conditions, as given by the logistic output format, with all other variables set to their average value over the set of presence localities. TOC: total soil organic carbon, Bio14: precipitation of driest month, Bio15: seasonality of precipitation, TON: total soil organic nitrogen, AWC: available water capacity of summer. The contribution (average of 10 repetitions) of each variable to the predicted model is also included.

cian juniper have high values of total soil carbon (Phoenician juniper was distributed on soils with TOC > 4 g/kg and can exceed 60 g/kg, Fig. 3a). SDM results indicated also that the probability of Phoenician juniper occurrence increased with the increase of terrain slope, where the species prefers terrains with steeper slopes up to 80%, Fig. 3f; and total soil nitrogen (the species prefers areas with TON varying between 0.7 and 2.5 g/kg, Fig. 3d).

3.3. Current and Future Potential Distributions

The predicted suitable habitats for the Phoenician juniper in Algeria under current climate conditions and future projected scenarios were mapped (Fig. 4). The predictions showed that the eastern part of Algeria had a higher potential of Phoenician juniper occurrence compared to western Algeria (Fig. 4). For forecasts of the current period, SDM showed that suitable

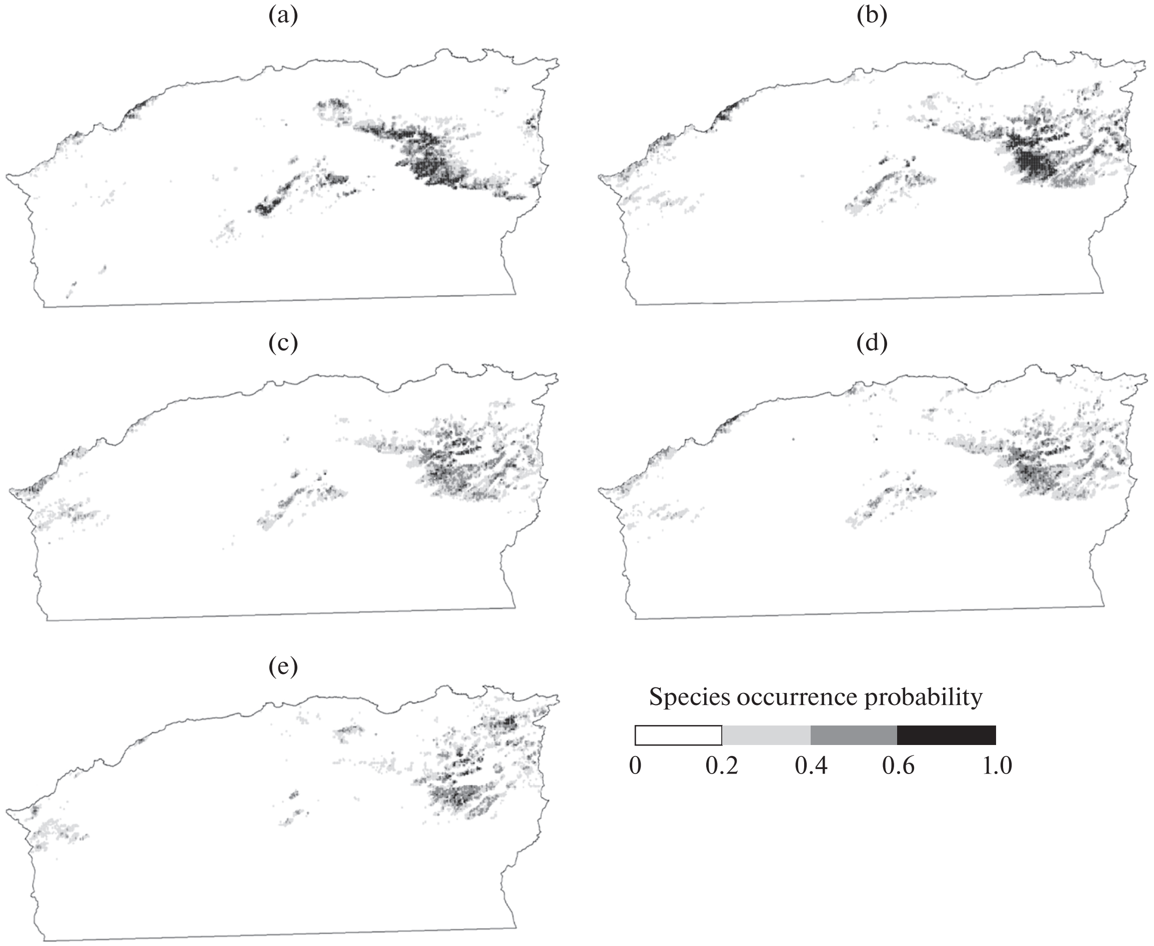

Fig. 4. Predictive maps of Phoenician juniper (*Juniperus phoenicea)* potential distribution in Algeria based on relative occurrence probabilities. Potential distribution range (a) for the current period, (b) in 2050 based RCP4.5 scenario, (c) in 2050 based RCP8.5 scenario, (d) in 2070 based RCP4.5 scenario, and (e) in 2070 based RCP8.5 scenario. RCP: representative concentration pathway.

habitats with high and good potential of Phoenician juniper occurrence (AUC = 0.6–1) covered an area of 5.892 km^2 (1.21% of the total study area), whereas about 9.583 km^2 (1.96% of the total) have medium potential (AUC = 0.4–0.6), while the remaining 472.982 km^2 (96.83%) of the study area have less potential (AUC = 0–0.4) of Phoenician juniper occurrence. Except the predicted distribution range size during 2050 with scenario RPC4.5 which revealed a potential increase in the area of suitable habitats, all the other future climate scenarios suggested that the suitable environments for Phoenician juniper are expected to decrease with shrinkage of distribution range size. This loss of potential distribution is expected to be more accentuated in 2070 than 2050 (Fig. 5).

Future predictions under all climate change scenarios demonstrated that suitable environmental conditions for Phoenician juniper are going to change in a way that triggers spatial shifts in species geographic distribution range. These shifts are expected to occur latitudinally northward and longitudinally eastward with more pronounced magnitude in 2070 for RCP8.5 scenario. RCP4.5 and RCP8.5 scenarios predicted opposite altitudinal shifts, while RCP4.5 predicted a shift of Phoenician juniper toward high elevations, the RCP8.5 forecasted that species range to descend to lower elevations (Fig. 6).

4. DISCUSSION

This study made it possible to quantify and present the climate change effects on the Phoenician Juniper species distribution, given that environmental risks are among the most important in Algeria as one of the other Mediterranean countries (Arar & Chenchouni, 2014; Mihi et al, 2019). In Algeria if not in all the distribution areas of this species, this study is one of the first studies using the modeling approach to predict the future distribution according to potential climate change forecast by IPCC. The present work made it possible to provide information on the vulnerability of the species to extinction, this information allowed us to identify and quantify the species suitable habitats and their potential changes over time, including future forecasts which

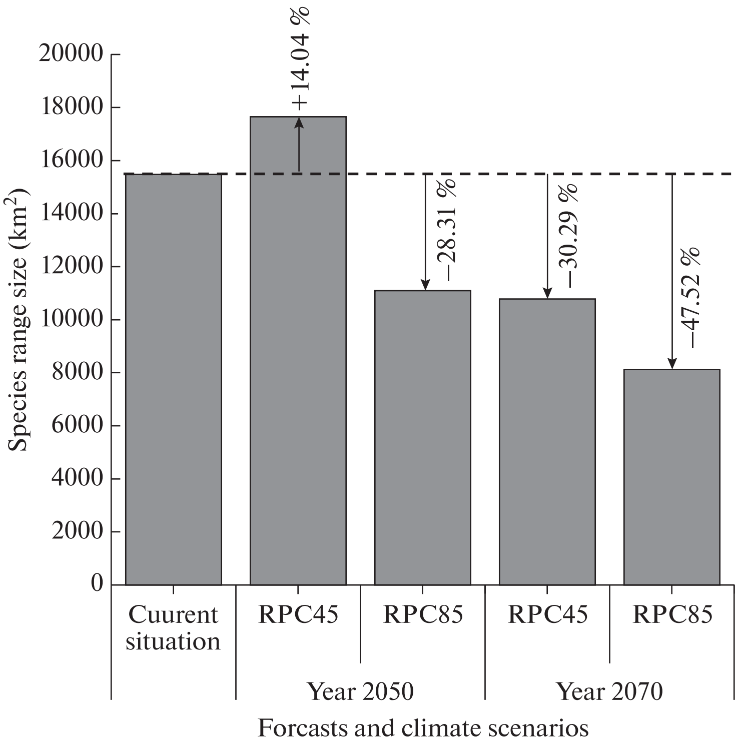

Fig. 5. Range size change of Phoenician juniper (*Juniperus phoenicea)* woodlands in Algeria under future climate scenarios. RCP: representative concentration pathway.

provide valuable information for the development of planning strategies against forest degradation.

4.2. Performance of the Model

The area under the curve ROC (AUC) was used as a measure of accuracy at an independent threshold (Linden, 2006). The final model of the 10 runs has reached an “excellent” and “accurate” level with an AUC value of 0.954. Through the AUC the model’s discrimination capacity is measured by calculating the omission errors (which is the probability that a real presence is correctly classified by the model (sensitivity)) and the commission error (which is the probability that a real absence is correctly classified (specificity)), the AUC > 0.9 class means that the model have a high performance indicating a perfect fitting (Guisan et al., 2017).

4.3. Analysis of Environmental Variables Contributions

The distribution range of *Juniperus phoenicea* is strongly influenced by intra-seasonal climate fluctuations (Altieri et al., 2015). SDM results indicated that precipitation traits have the highest contributions in model construction, where precipitation of the driest month (contributions = 19.2%) and seasonality of precipitation (contributions = 10.3%) have more influence on species distribution.

Due to precipitation limitations in arid and semiarid climatic zones, *Juniperus phoenicea* is exposed to significant water stress during months of the hot dry season (Diaz Barradas et al., 1999). This species is particularly influenced by the precipitation of the driest months due to the poor development of its roots which remain superficial influencing its water state by the rapid exhaustion of the surface horizons and the direct evaporation of these horizons, nevertheless, the hardy and stress tolerant characters of this species allow it to withstand the severe periods of drought (Martínez-Ferri et al., 2000; Baquedano and Castillo, 2007; Alteiri et al., 2015),

The direct negative influences of summer temperatures associated with strong global solar radiations, and water deficit (low soil water available content) on Phoenician juniper growth and water use have limited the assimilation of carbon (Alteiri et al., 2015). This disturbance occurs when plants are subjected to severe stress conditions, such as heat and / or drought (Allen et al., 2010), which weakens the functioning of photosynthetic organs and directly disrupts the process of plant biomass building and therefore disturbs the entire carbon footprint inside the plant (Larcher, 2000; Arena et al., 2008), this explains the major carbon requirement of this species, according to the response curve of our study, at a dosage of 4 g/kg of soil carbon, a quick increase of presence prediction is observed, the carbon needs remain stable even at doses

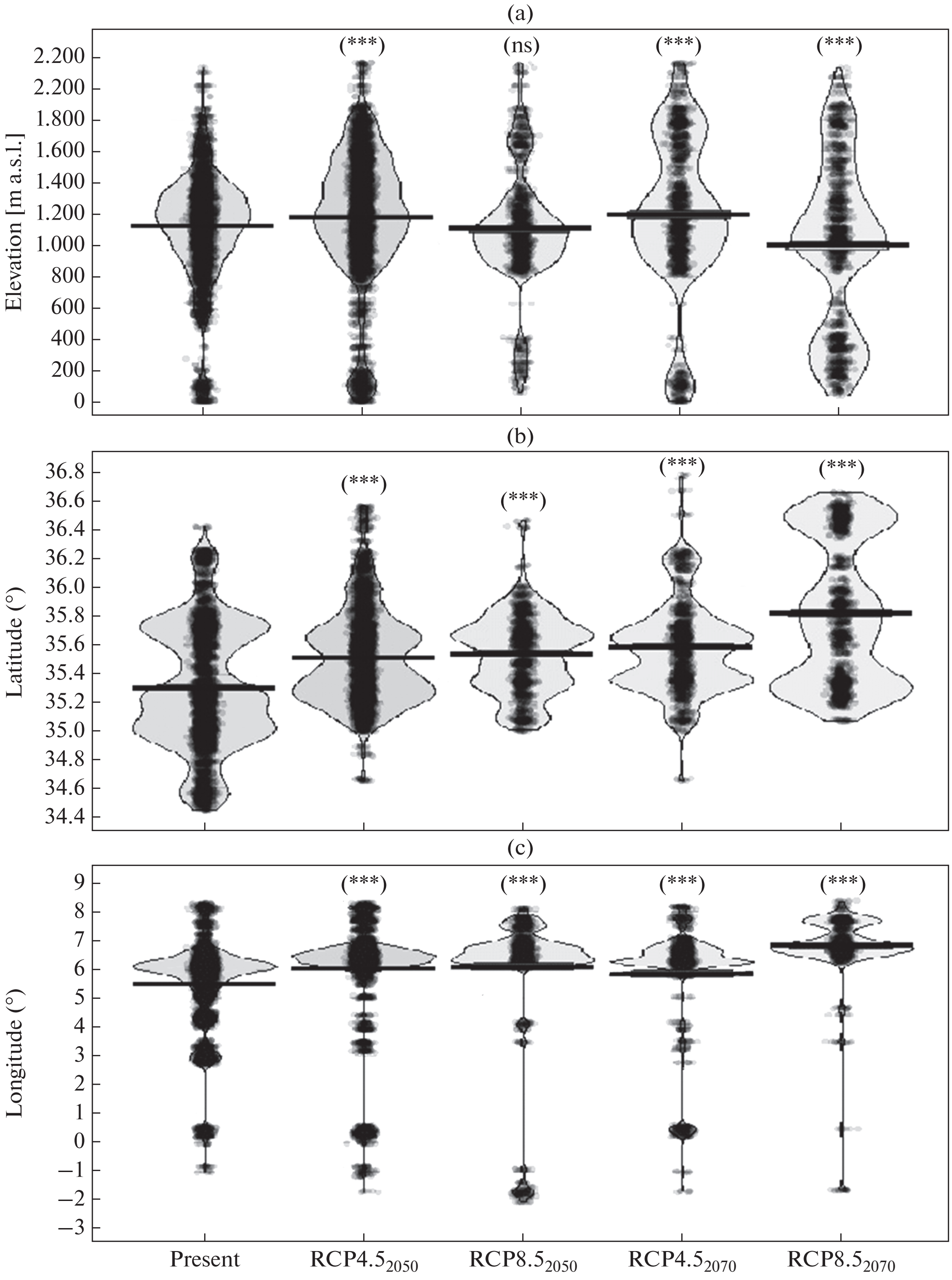

Fig. 6. Pirate plots comparing elevations (a), latitudes (b), and longitudes (c) of Juniperus phoenicea distribution (probability of occurrence >0.6) between the current potential range (Present) and each of the future potential ranges based on future climate change scenarios of the representative concentration pathway (RCP4.5 and RCP8.5).

greater than 80 g/Kg. Thus, the high doses of carbon induce a reaction of plants, the reaction results in the modification of the conductance of the stomata, the respiratory metabolism and the allocation of nitrogen (Field et al., 1992; Curtis 1996).

According to Schimel and Bennett (2004) and Delgado-Baquerizo et al. (2011), nitrification dominated in soil nitrogen transformation processes of semi-arid Mediterranean ecosystems, which is favored by the low availability of carbon. Starting at 0.7 g/kg as the lower soil total nitrogen dosage, Phoenician juniper show a rapid and immediate increasing of the occurrence probability, reaching its maximum and stabilize at about 2.3 g/kg. The relationship between resistance to severe conditions and plant size and growth can be interpreted by the ability of large trees to store more nutrients and carbon compounds and/or develop more efficient root systems for absorption of deeper waters (Filella and Peñuelas, 2003).

The spatial distribution of *Juniperus phoenicea* seems to be more influenced by the topography (El-Bana et al., 2010). Indeed, terrain slope contributed with 11.1% in SDM of *Juniperus phoenicea*. Consequently, the sloping areas with aspects receiving high global solar radiations are suitable habitats for the installation of Juniperus phoenicea in order to collect the maximum of solar radiations, because of the reduced size of its leaves having a low capacity of interception of solar radiation (Denden and Lemeur, 2000).

4.4. Distribution Range Shift in Response to Climate Change

SDM results of the current period data show that the total area occupied by *Juniperus phoenicea* is approximately 15475 km^2 which is 3.16% of the total study area. Species distribution range for the projected (hypothetical) future scenarios is expected to decrease considerably by almost 52.5% by 2070 to cover an area of 8121 km^2 (1.66% of the total area) (Figs. 5, 6). Overall, according to occurrence probabilities, the spatiotemporal change in Phoenician juniper potential distribution over time seems ecologically logical. Since 1970s, forest formations of *Juniperus phoenicea* present high risk of dieback (Kabiel et al., 2016) which resulted from the combined and synergetic effects of (1) periodic drought episodes marked by strong fluctuations of rainfall, (2) species physiological characteristics like shallow and less extensive root system of species that limit access to deep water, and (3) bad soil characteristics (very shallow horizons with low holding capacity and law AWC). The results confirm the risk of dieback that is attributed to the long-term changes in climate conditions associated with global warming (Chenchouni, 2010), which is consistent with the future of climate change predicted by the IPCC (Team et al, 2014). It is noteworthy mentioning that other factors not included in SDM, such as human disturbances, may influence the regional *Juniperus phoenicea* distribution.

Under different climatic scenarios, the eastern part of northern Algeria is more suitable than habitats of western Algeria, which can be mainly attributed to the climate characteristics that are less-unfavorable in eastern compared to western Algeria, which leads to a longitudinal shift to the East associated with a Northward shift due to the aridity which is accentuated along a south-to-north gradient (Benslimane et al., 2009). In addition, western Algeria is less suitable for the establishment of *Juniperus phoenicea* due to the combined effects of the relief features, the distance from the sea, and anthropogenic pressures mainly livestock grazing (Touazi and Laborde, 2004; Rhanem, 2010; Arar et al., 2020). Generally, for vegetation, it is at the extremities of the distribution areas that the climate change induces changes both in altitude and latitude (Bénichou and Le Breton, 1987; Coudun and Gégout, 2006). At the level of the Mediterranean perimeter, according to Médail and Quézel (2003) the global changes should be the origin of the displacements of the species distribution ranges lower limits upward to high altitudes, these changes are mainly linked to the increase in the drought conditions, and as drought stress reduces the regeneration capacity of species, the ecological response logically consists in moving at high altitudes to the wettest floors where the temperatures is ambient to ensure the sustainability of populations in the most optimal conditions for regeneration and growth (Fyllas and Troumbis, 2009), this is consistent with our findings, however, an expansion of the Phoenician juniper distribution area downward will take place according to scenario 8.5 for the year 2070, making suitable habitats return to low altitudes, this could be caused by changes in other characteristics of climate than mean temperature, like precipitation seasonality and an increase of precipitation regime and water balance, during the winter despite the dominance of droughts during the rest of the seasons, affecting the tolerance limits of the species, therefore, these areas are classified like suitable by the model (Zimmermann et al., 2009; Lenoir et al, 2010).

5. CONCLUSION

SDM of *Juniperus phoenicea* established statistical links between spatialized environmental factors and species occurrence and helped to understanding species potential distribution range and suitable habitats in Algeria. The ecological niche modelling of *Juniperus phoenicea* identified various environmental factors involved in species establishment across dry sclerophyllous scrublands of Algeria. Under future climate scenarios predicted by the IPCC, our findings showed that species geographic distribution range will shift toward north latitudes, east longitudes and high altitudes. Global warming was found to hinder potential favorable habitats of the species, which will force its populations in the future to use high elevations and northern latitudes as climatic refugia. The current study enriched the existing information on the state of North African forests and contributed to deepen our understanding on the effects of large-scale environmental conditions on forest distributions and how these forests are going to react to future climate change. Predicting and mapping current and future potential range of forest species represent very useful tools for both conservation planners and decision makers. Algerian forests located near the limits of the Sahara Desert are at high risk of dieback and desertification. Accordingly, urgent and planned interventions are needed in order to preserve ecosystems and mitigate degradation of forests located at desertification-sensitive and drought-prone areas.

APPENDIX

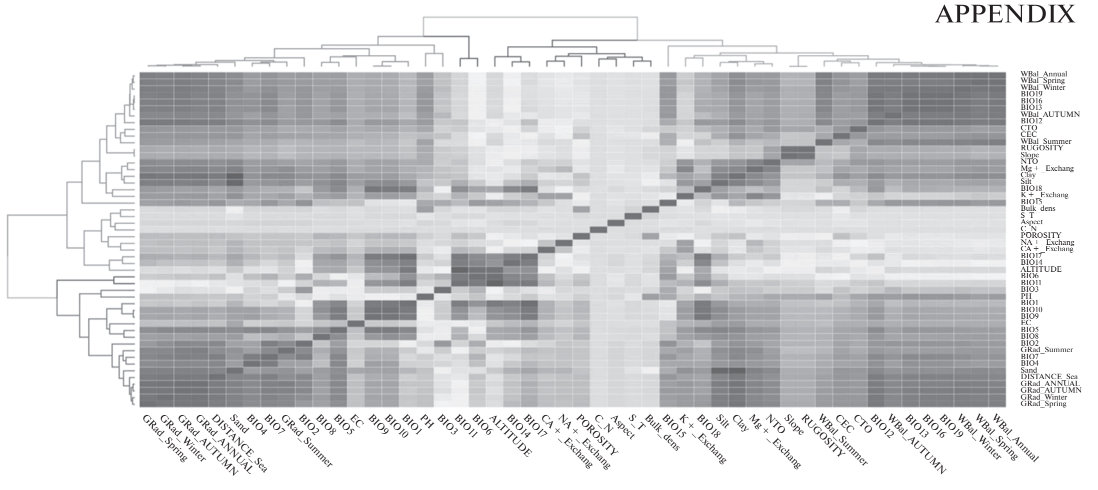

Fig. S1. Heatmap showing the correlation matrix between the 50 environmental variables used in ecological niche modeling of potential distribution of Phoenician Juniper (*Juniperus phoenicea*) forests in Algeria. Values of Pearson correlation coefficients are displayed by color and intensity of shading, with dark blue represents $r = +1$, and dark red indicates $r = -1$.

COMPLIANCE WITH ETHICAL STANDARDS

Conflicts of interests: The authors declare that they have no conflict of interest.

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Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

All authors have approved the manuscript and agree to its submission.

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