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Modeling of the spatial distribution of species of interest in agriculture for their conservation: case of *Punica granatum* L.

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Abstract: Modeling the spatial distribution of species is an important step in biodiversity conservation. The models used can be helpful in predicting the impacts of climate change on the geographical distribution of species and in identifying areas where they are most likely to occur. The purpose of this work was to model the spatial distribution of the pomegranate species (*Punica granatum* L.) in Morocco according to the principle of maximum entropy (Maxent). This modelling method is widely used in ecology and biogeography because of its ability to work with datasets, and to produce accurate predictions of species distribution. Based on agro-ecological data such as topographical factors and climatic variables and focusing on regions where pomegranate cultivation is significant, these data can be collected at different spatial and temporal scales. They are typically integrated into Geographic Information Systems (GIS) for utilization within the simulation model. The resulting model depicts the potential spatial distribution of pomegranate cultivation throughout Morocco. The model obtained agrees perfectly with the actual distribution of the species in different regions of the country, especially since it is known for its hardiness and its adaptation to variable environmental conditions. Thus, the modeling showed that other geographical areas present favorable conditions for the development of pomegranate cropping. The determination of spatial distribution constitutes a first step to predict possible evolution of the pomegranate cropping according to climate change. The importance of this process for biodiversity conservation lies in several aspects, such as the identification of areas at risk, conservation planning, and the assessment of impacts on ecosystems.

Keywords: *Punica granatum*, spatial distribution, Modeling, maximum entropy, climate change.

1. Introduction

In recent years, on a national and global scale, climate change has negatively affected various types of ecosystems and many biological species [1,2]. The impacts of climate change on biodiversity are significant, and the continued intensification of these deleterious changes has the potential to lead to the extinction of a significant number of species on a local and global scale [3]. Climate change is underway, and it is having a direct impact on biodiversity [4,5,6], forcing many species to adapt in various ways to cope with new environmental conditions, such as migrating to geographical areas where climatic conditions are more favorable to their survival, modifying their phenological cycles, or developing new physiological traits [7,8].

To prevent losses due to global warming and ensure the sustainability of certain threatened species in the future, it is essential to implement proactive measures and long-term strategies based on the prediction of the potential geographical distribution of species in the context of global climate change [9,10]. Modeling the geographical distribution of species in the context of climate change is a very important and complex tool that integrates various climatic and bioclimatic factors to predict where species might migrate in the future [10]. The ecological niche model (ENM) is an essential statistical approach for describing, understanding and predicting the geographical distribution of species as a function of different types of environmental variables and field presence data [11,12,13]. There are various ecological niche modeling (ENM) techniques for presence-only or presence-absence data, including models based on regression and machine learning: generalized linear models (GLM), artificial neural networks (ANN), generalized additive models (GAM), multivariate adaptive regression splines (MARS), classification trees (CART), genetic algorithms (GARP) and maximum entropy (Maxent) [14,15]. It is important to understand these methods in order to choose the one that best suits the specific species or study problem [16]. Maxent (maximum entropy) is an ecological niche modeling model widely can be used to predict the geographic distribution of a species as a function of presence data and environmental variables [17,18,19]. It has gained popularity in recent years due to its performance and ease of use [20,21]. One of Maxent's key features is its ability to project and generate probability maps showing how the potential distribution of a species would change under different scenarios of climate change or modifications to environmental variables. This capability makes it a valuable tool for assessing how species' habitats might evolve in the future [22,23,24].

Among the questions raised, it is important to determine extent to which the introduction of pomegranate cropping as an alternative to crops vulnerable to climate change can promote agricultural diversification and strengthen the resilience of farming communities [25,26, 27]. The aim of this study is to assess the effectiveness of this transition by examining potential new growing areas in order to achieve several objectives:(a) Identify new areas where pomegranate cultivation could be successfully introduced as a replacement for other crops vulnerable to climate change, using ecological niche modeling. Thus, assess the effectiveness of choosing pomegranate as a substitute species. This study is a first step that will help plan crop diversification as part of sustainable agricultural practices, identifying how this crop can be integrated into an existing cropping system. It will allow to reduce the risks associated with climate change by integrating more resistant crops to contribute to greater stability in agricultural production.

2. Materials and methods

2.1. study area

The study area covers the territory of the Kingdom of Morocco. It is located in the extreme northwest of Africa, between 21° and 36° north latitude and 1° and 17° west longitude. It is located at the crossroads between three vast and different environments: the Mediterranean in the north, the Atlantic in the west, and the Sahara in the south-east. The country has varied terrain, including significant mountain ranges like the High Atlas, the Middle Atlas, and the Rif, which are surrounded by fertile plains like the Gharb and the Tadlalla. The country is also home to desert areas, including the Western Sahara. Morocco's climate is highly variable due to its geographic diversity. The coastline has a Mediterranean climate with hot, dry summers, while the mountains may have severe winters. The

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southern desert areas experience extremely high temperatures in the summer and cold nights in the winter. The diversity of habitats, from mountains to deserts, contributes to Morocco's rich biodiversity. This variety of ecosystems provides shelter to a large number of species adapted to the specific conditions of each region (Figure 1).

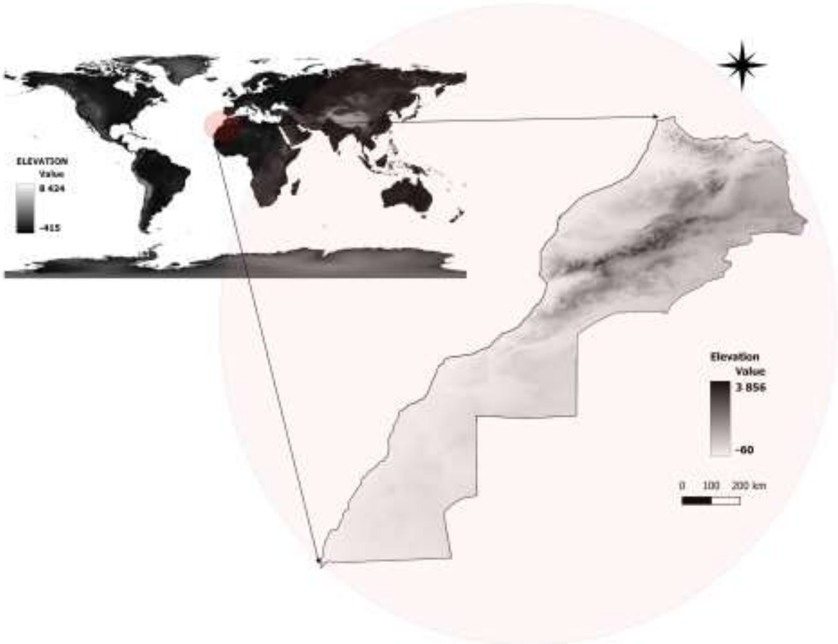

Figure 1. Location of the study area

2.2. Species data

The Global Biodiversity Information Facility (GBIF, https://www.gbif.org) and in situ data collected at the two study stations provided updated information on the distribution of grenadier [15]. All records that did not contain detailed geolocation information, such as longitude and latitude, or contained repeated records were deleted [19,12]. In total, 514 occurrences points were identified and used to build the Maxent model.

2.3. Environmental Variables

We collected 20 variables associated with its distribution, including 19 bioclimatic variables (BIO1 through BIO19) and one topography variable (elevation) [28,29,30]. Indeed, previous studies have indicated that environmental variables such as climate, topography and soil characteristics are is one of the most important factors in modeling the distribution of species [31]. All bioclimatic and elevation variable layers were obtained from the WorldClim database set at the highest spatial resolution (30 arc seconds (~1 km)). All these layers were processed using QGIS 3.26.3[20,32].

2.4. Describe and Model MaxEnt

The Maxent model was used to identify environmental variables that have an impact on the distribution of pomegranates in this study, as well as to simulate current geographical distribution

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areas and project potential future distribution areas for this species [16,19]. The data was subdivided into two sets, one for training data (75%), and a separate set for testing (25%). This division of the data makes it possible to evaluate the performance of the ecological niche model, such as Maxent, and to check how closely the predictions match the observed data [33]. Current *Punica granatum* L. presence data and environmental variables were entered into the Maxent model. Tenfold cross-validation was used to reduce spatial autocorrelation in the model [4]. A potential distribution map of the studied species was generated from the logistic output of Maxent [34]. The results obtained from Maxent were compiled in QGIS 3.26.3. A raster output was generated for further analysis [6].

2.5. Evaluation of models
In Maxent, receiver operating characteristic (ROC) and area under the ROC curve (AUC) are commonly used to assess the performance of ecological niche models [35]. The AUC value varies between 0 and 1, indicating the model's ability to distinguish correctly between areas where the species is present and those where it is absent. The performance categories are generally interpreted in Table 1 [21,20].

Table 1. The performance categories are generally interpreted.

The performance categories	**AUC Values**	**Description**
Deficient	0.5-0.6	The model has only random predictive ability, it does no better than a random draw.
Poor	0.6-0.7	The model's performance is slightly better than chance, but it remains unreliable.
Average	0.7-0.8	The model performs reasonably well and is able to correctly distinguish between the presence and absence of the species.
Good	0.8-0.9	The model has a good predictive capacity, meaning that it effectively distinguishes the distribution of the species.
Excellent	0.9-1.0	A model with an AUC performance close to 1 is considered excellent, indicating strong predictive ability.

2.6. Cartography and Spatial Analysis
The result in raster format was loaded into QGIS 3.26.3, and the distribution map was reclassified to show potentially adaptable areas, making it possible to map favorable ecological niches for the pomegranate tree in terms of both climatic conditions [8,23]. Spatial analysis made it easier to determine the area of land to be cultivated, taking into account current and future climatic conditions [16,30]. It was then possible to assess the gain or loss in the area favorable to the species on a national scale (Morocco) according to climate projections.

3. Results
3.1. Evaluation of the model
The results obtained by the maximum entropy model for predicting potential habitats for *punica granatum* L. were excellent. The mean AUC value of 0.933 was significantly higher than the value of

the random prediction (0.5) (Figure 2) [21]. This confirms that the predictions were very accurate, suggesting that the potential distribution area results obtained from MaxEnt were reliable and robust [16].

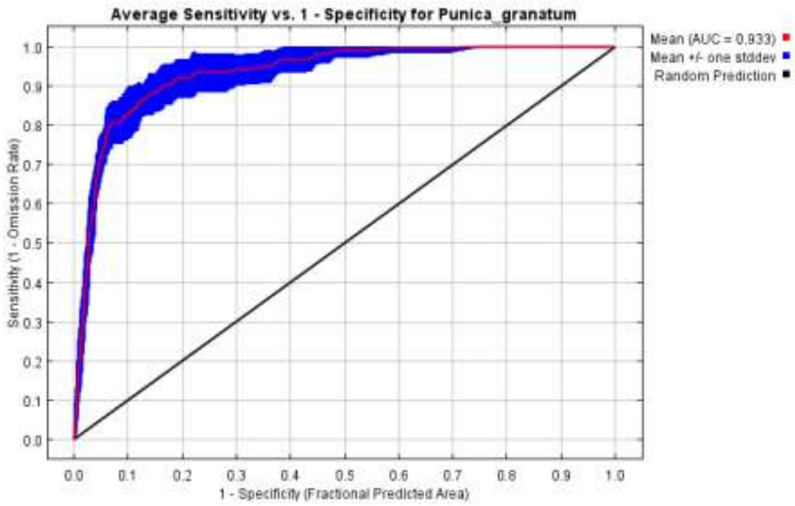

Figure 2. Reliability test of the distribution model created by the MaxEnt model for *Punica granatu*

3.2. Contribution of Environmental Variables

In an iterative process, MaxEnt calculates the contribution of the environmental factors to the prediction and adjusts the individual factors and evaluation coefficients in the prediction model [36,37]. Annual precipitation (BIO12) was shown to be the most significant variable, contributing 28.4% to model prediction. This was followed by the minimum temperature of the coldest month, with a contribution of 24.9%, then altitude at 14.7%, and finally precipitation in the coldest quarter (BIO19), with a contribution of 10.2%. These four environmental factors emerged as the main contributors influencing the distribution of *Punica granatum* L. in the different regions of Morocco. These findings are corroborated by the Jackknife test on AUC values, as illustrated in Figure 3 [38].

3.3. current distribution of favorable habitats for pomegranate

The current distribution map of *Punica granatum* L. throughout the Kingdom of Morocco is shown in figure 4. Modeling results show that the most favorable areas for this species are located mainly in the Barkan-Oujda region, the Saiss plain (Fes, Meknes, Sabaa Aiyoun, and Ain Taoujdate), the Beni Mellal region, Chichaoua, Marrakech, and Chtouka Ait Baha. In the current context, in addition to the above-mentioned rainfall and temperatures, altitude projections for habitats suitable for Punica granatum L. reveal a preference for altitudes below 500 meters. Less favorable habitats, on the other hand, are found at higher average altitudes, generally exceeding 600 meters [39,40]. This observation underlines the importance of areas suitable for pomegranate, in contrast to those currently under cultivation.

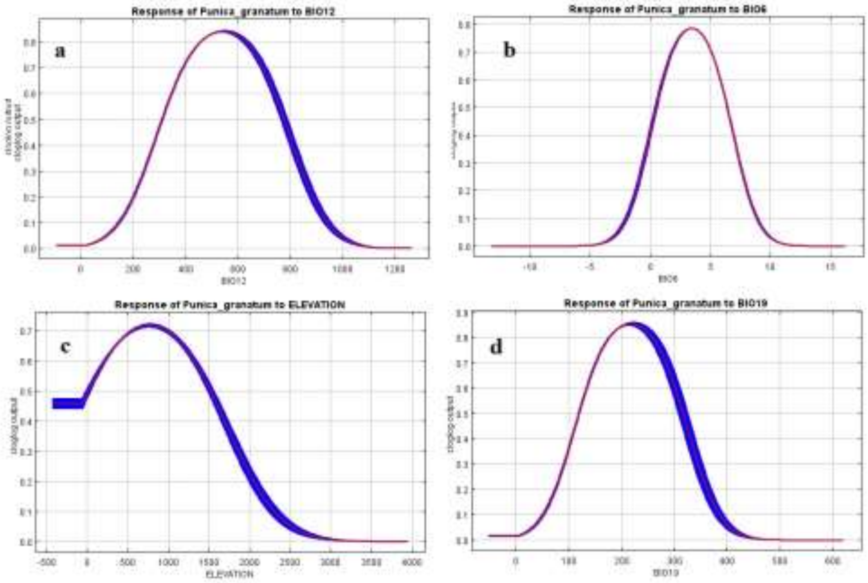

Figure 3. Relationships between top environmental predictors and the probability of the presence of (*Punica granatum* L.) in the study area: (a) annual precipitation (mm), (b) Min Temperature of Coldest Month (°C), (c) Elevation (meter), (d) Precipitation of Coldest Quarter (mm).

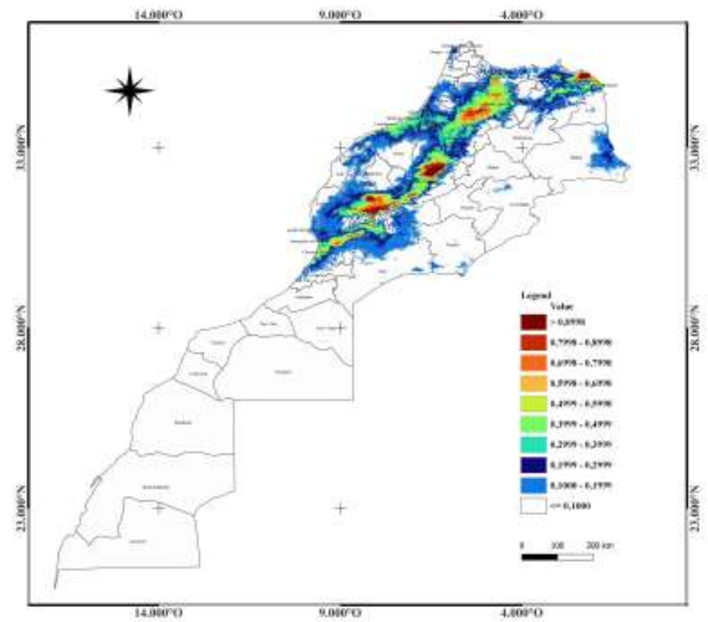

Figure 4. Current distribution model predicted by Maxent in Morocco

4. Discussion

In recent decades, modeling has become an essential tool in various fields of conservation science and ecology [18]. It plays a crucial role in biodiversity management, assessing the impacts of climate change, predicting species distribution, preventing the invasion of harmful species, and protecting ecosystem [41]. In this study, the use of modeling to represent the current geographical distribution of pomegranate as a surrogate species illustrates how each environmental variable influences the presence of this species [42]. Overall, the geographical distribution of pomegranate is restricted to central and north-eastern Morocco, with varying percentages. Field studies have demonstrated the widespread presence of pomegranates in all regions of Morocco. Our model predictions suggest that pomegranate has a wide ecological and agronomic range, which explains its tendency to become widely invasive in Morocco. The study revealed the rate of occurrence of pomegranate in different Moroccan regions and also highlighted potential dispersal pathways. The analysis of the percentage contribution of environmental variables, together with the use of jackknife procedures in MaxEnt, enabled us to identify the relative importance of different bioclimatic predictors. Interestingly, among bioclimatic variables, annual rainfall emerges as a significant environmental factor with a direct impact on the distribution of ecological niches for pomegranate. Annual rainfall plays a crucial role in favorably influencing the presence and prosperity of this plant species. More specifically, various studies indicate that annual rainfall contributes to creating an environment conducive to several key stages in the pomegranate's life cycle, including seed germination, flowering and fruiting. For pomegranates, the minimum temperature of the coldest month is significant, as it can influence several aspects of the species' biology. Minimum winter temperatures can affect the cold tolerance of plants, particularly during sensitive periods such as flowering and fruiting. Excessively low temperatures during this critical period can result in damage to buds, flowers and fruit, impacting overall yield [43]. Further studies indicate that the minimum temperature of the coldest month has a direct influence on the geographical distribution of pomegranates, as the species is sensitive to severe frosts. Regions with higher minimum winter temperatures offer better conditions for pomegranate survival and reproduction. This climatic variable therefore plays a decisive role in defining the geographical areas where pomegranates can thrive optimally. Altitude above 500 meters can have a negative effect on the geographical distribution of grenadier, so the distribution of this species is generally limited to low to medium altitude areas [39]. While precipitation in the coldest quarter can exert a considerable influence on the distribution of the pomegranate tree's ecological niche, according to our results, an estimated rainfall of between 140 and 320 mm plays a crucial role in maintaining adequate soil hydration, which is essential for root development and overall tree health. In fact, studies show that rainfall during the coldest quarter of the year is of particular importance, as it helps provide the plant with the water it needs, even during seasons when climatic conditions may be less favorable. Maintaining adequate soil hydration is vital to the tree's growth, its resilience to climatic variations, and the success of the various phases of its life cycle. To date, no study has been conducted to model the distribution of pomegranate in the study area. The aim of this study is to model the potential invasion of pomegranate, which could have significant implications for natural resource management in the region. The modeling of potential invasions will be used to guide field surveys and accurately determine the areas actually invaded by pomegranate in the region. The results of this modeling will be used to effectively detect and map areas where pomegranate has become established. The potential distribution maps will provide crucial information for the implementation of rapid management and control measures to mitigate the impact of this invasive species. Furthermore, the climatic factors influencing the potential distribution of the pomegranate can be modeled. Through projected climate change scenarios, it will be possible to anticipate the future impacts of climate variability on the distribution of this species, thus helping to plan appropriate conservation and adaptation strategies [4,6].

5. Conclusions

Assessing the impact of climate change on pomegranate distribution is essential for biodiversity conservation, natural resource management, adaptation planning and making informed decisions about planting this species as a substitute or in new areas. MaxEnt modeling is a powerful approach for modeling the ecological distribution niche of this species. The aim of this study was to identify the environmental variables relevant to pomegranates in a large geographical area and to develop distribution models for the species based solely on presence data. Our results highlight the significant importance of temperature-altitude interactions in pomegranate cultivation, leading to a more efficient distribution of this species in certain regions of Morocco. Nevertheless, in some areas, the reduction in temperature should lead to an increase in highly suitable habitats, meaning that the dominant species in these areas are likely to be linked to these environmental variables. This is a reminder of the usefulness of predicting the geographic distribution map of pomegranate. It enables us to better understand the consequences of climate change on the spatial distribution of this species and to put in place measures to minimize its negative effects in the future.

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