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Modelling spatial distribution of endemic Moroccan fir (*Abies marocana* Trabut) in Talassemtane National Park, Morocco

Modellierung der räumlichen Verteilung der endemischen Marokkanischen Tanne (*Abies marocana* Trabut) im Nationalpark Talassemtane, Marokko

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Keywords: *Abies pinsapo*, bioclimatic variables, endemic, MaxEnt, modelling, potential distribution area

Schlüsselbegriffe: *Abies pinsapo*, bioklimatische Variablen, endemische Arten, MaxEnt, Modellierung, potenzielles Verbreitungsgebiet

Abstract

Moroccan fir (*Abies marocana* Trabut) located in Talassemtane National Park, is endemic species of the Moroccan Rif, classified as "endangered" in the IUCN Red List of Threatened Species. Since the beginning of the last century, this species has suffered 70% habitat loss. However, despite its bioecological, economic and social importance, Moroccan fir has received little attention from researchers. Determining the potential area under current topographic and climatic conditions is a very important step to develop conservation and sustainable management strategies for this endangered endemic species. For this purpose, the potential distribution of Moroccan fir using the maximum entropy approach (MaxEnt software 3.4.1) is presented in this work. The developed models showed an excellent success level (96%). Environmental

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and topographic variables were obtained from the WorldClim project 2.1 database. Our results showed that the main variables conditioning the presence of *A. marocana* were the average temperature of the warmest quarter and the maximum temperature of the warmest month. The potential area represents a gain of 227% compared to the current distribution of the Moroccan fir forest. Suitable areas are provided allowing management for afforestation programs and carbon sequestration in Talassemtane National Park, Morocco.

Zusammenfassung

Die marokkanische Tanne (*Abies marocana* Trabut) im Nationalpark Talassemtane ist eine emblematische und endemische Baumart des marokkanischen Rif-Gebirges, die in der Roten Liste der gefährdeten Arten der International Union for Conservation of Nature and Natural Resources (IUCN) als „gefährdet" gilt. Seit Beginn des letzten Jahrhunderts hat die Art einen Rückgang ihres Lebensraums um 70% erlitten. Trotz ihrer ökologischen, wirtschaftlichen und sozialen Bedeutung hat die marokkanische Tanne bei den Forschern bisher wenig Aufmerksamkeit erhalten. Die Bestimmung des potenziellen Verbreitungsgebiets unter den aktuellen klimatischen und topografischen Bedingungen ist ein sehr wichtiger Schritt für die Entwicklung von Schutzmassnahmen und nachhaltigen Managementstrategien für diese endemische gefährdete Art. Im Rahmen dieser Arbeit wurde eine Modellierung des potenziellen Verbreitungsgebiets der marokkanischen Tanne mithilfe des Maximalentropieansatzes (MaxEnt Software Version 3.4.1) durchgeführt. Das entwickelte Modell weist eine ausgezeichnete Modelgüte (96%) auf. Die Umweltvariablen und die Höhenlage wurden aus WorldClim Version 2.1 entnommen. Die weiteren topografischen Variablen, insbesondere die Neigung und die Belichtung, wurden mit der ARCGIS-SOFTWARE Version 10.7 aus dem Rasterbild der Höhenlage extrahiert. Die wichtigsten Variablen, die das Vorkommen von *A. marocana* beeinflussten, waren die Durchschnittstemperatur des wärmsten Quartals und die Höchsttemperatur des wärmsten Monats. In dieser Studie werden geeignete Anbaugebiete der marokkanischen Tanne definiert, die ein besseres Management für Aufforstungsprogramme im Talassemtane Nationalpark in Marokko ermöglichen.

Introduction

Abies Mill. is a genus with more than fifty specific species living across the Northern Hemisphere. It is thought that this genus was formed in the Cretaceous period and then dispersed in the Eocene during cooler periods. After the retreat of the glaciated areas, some Abies species remained in the Mediterranean Basin such as *Abies pinsapo* Boiss., *Abies nebrodensis* (Lojac.) Mattei, *Abies numidica* De Lannoy ex Carrière or *Abies marocana* Trabut, among others. Nowadays, these species have a limited distribution and are considered relic species in the current distribution originating from the Quaternary period (Xiang *et al.* 2007). *A. marocana* has sometimes been confused as a subspecies of the Spanish fir (*A. pinsapo* Boiss.). Other authors suggested splitting it into two species, *A. marocana* and *Abies tazaotana* Côzar ex Hug. Villar (Arista and Talavera 1994, Farjon 2010). The taxonomic status of western Mediterranean *A. pinsapo* and *A. maroccana* is disputable and these species are often treated as independent, yet very close species (Balao *et al.* 2020; Litkowiec *et al.* 2021). Recent molecular and biometric research has suggest a separation of Moroccan and Spanish firs (Sękiewicz *et al.* 2013; Dering *et al.* 2014). In this study, we adopted the classification of Fennane *et al.* (1999) considering Moroccan fir as a single relic and endemic species. Spanish and Moroccan firs mainly differ in the leaf arrangement; *A. pinsapo* show leaves arranged radially and perpendicular to the stems, whilst in *A. marocana* they are pectinately arranged around the shoot. Female cones are much larger in *A. pinsapo* (Terrab *et al.* 2007; Alizoti *et al.* 2011; Sękiewicz *et al.* 2013; Alba-Sánchez *et al.* 2018; Alaoui *et al.* 2019). The first description of the two Moroccan varieties were made in the early 20th century. *Abies marocana* var. *marocana* was described by Ceballos & Martín-Bolaños (1930) and *Abies marocana* var. *tazaotana* by Sánchez-Cózar (1946). It is likely that the isolation of these populations from human influence until the 19th century due to access difficulties and poorer mechanical properties of fir wood compared with pine were important for their survival (Esteban *et al.* 2010).

The biodiverse mountainous areas of the Mediterranean basin (Cowling *et al.* 1996) provided shelter for several conifers such as *Abies*, *Cedrus* Duham, *Cupressus* L., *Juniperus* L. and *Pinus* L. during the glacial periods (Bennett *et al.* 1991). Many of these species have been widely used as sources of wood and food since early years of settlement (Farjon *et al.* 1993). As a result, many of these species have been overexploited and are now subject of considerable conservation concern.

The Intercontinental Biosphere Reserve of the Mediterranean (RBIM), recognized by UNESCO on October 25, 2006, is the only one cross-border reserve between two continents. It is located between the Moroccan and Spanish coast containing many natural ecosystems of great ecological value; some of them classified as Sites of Biological and Ecological Interest (SBEI) (MAMVA 1996). The Moroccan part of this reserve, concerns the mountainous zone of the Western Rif, in northern Morocco. Talassemtane National Park is part of this reserve and covers 58,000 ha (MAMVA 1996, AFD 2011). It is distinguished by its great richness in flora and its particularly remarkable woody formations; there are several endemic and interesting species such as *Pinus nigra* var. *mauretanica* Maire & Peyerimh, *Pinus pinaster* subsp. *hamiltonii* var. *maghrebiana* Villar, *Cedrus atlantica* (Endl.) Manetti ex Carrière, *Quercus pyrenaica* Willd., *Acer granatense* Boiss., etc. Thus, this area represents a true relic of the primitive forests of the Rif and a very special floristic heritage (Baumer 1977). One of the most symbolic species is Moroccan fir. This endemic species forms a globally unique ecosystem (Benabid 2000). The floristic diversity of this exceptional landscape were an important reason for the creation of this National Park (Benabid and Fennane 1999). At the beginning of the last century, Moroccan fir suffered strong degradation and reduction in density of existing stands (Benabid 2000). Today, less than 4,000 ha of *A. marocana* occur in Talassemtane National Park. In degraded areas, shrubs become dominant by *Genista* *acutifolia* Spach, and *Genista quadriflora* Munby or *Cistus* spp. (*Cistus albidus* L., *Cistus crispus* L., *Cistus ladanifer* L., *Cistus libanotis* L., *Cistus monspeliensis* L. and *Cistus varius* Pourr.).

Through its forestry strategy, Morocco aims to conserve and manage forest ecosystems as a recommendation from the Convention on Biological Diversity (CBD 2009). To achieve this objective in the context of current climate change, the study and assessment of our forests is required. Knowing the potential range of the species, as well as identifying the factors that condition it, is mandatory to gather significant information (Alba-Sánchez and López Sáez 2013).

To identify the potential distribution of the species, Ecological Niche Models (ENM) or Species Distribution Models (SDM) emerged in the last decades of the twentieth century. Considering the species occurrence and explanatory variables, a suitability map of potential distribution can be carried out (Elith and Franklin 2013; Booth 2018). Nowadays, modelling is a well-developed and robust method. Its results can be used to face the disturbances of anthropogenic areas where natural vegetation has been disturbed. MaxEnt software assigns a class to a presence (Phillips and Dudik 2008). Presence data and randomly chosen absence points can be used by the software (Elith *et al.* 2006). Outputs show the suitability of a species in the study area. Algorithms like MaxEnt, together with Geographic Information Systems (GIS) are used to manage the data from a specific area to preserve emblematic species like Moroccan fir.

The objectives of this work were; *i)* to determine a current and potential distribution of *A. marocana*, and *ii)* to obtain important results to be addressed with conservational purposes.

Material and Methods

Study material and framework

The study was carried out in the Talassemtane National Park located in the central-western Rif, in the north of Morocco (Figure 1), an area belonging to the Intercontinental Biosphere Reserve of the Mediterranean. Despite of the strong degradation of the area, it still contains unique ecosystems around the world with almost 1380 plant, more than 22% species of which are endemic (Benabid 2008).

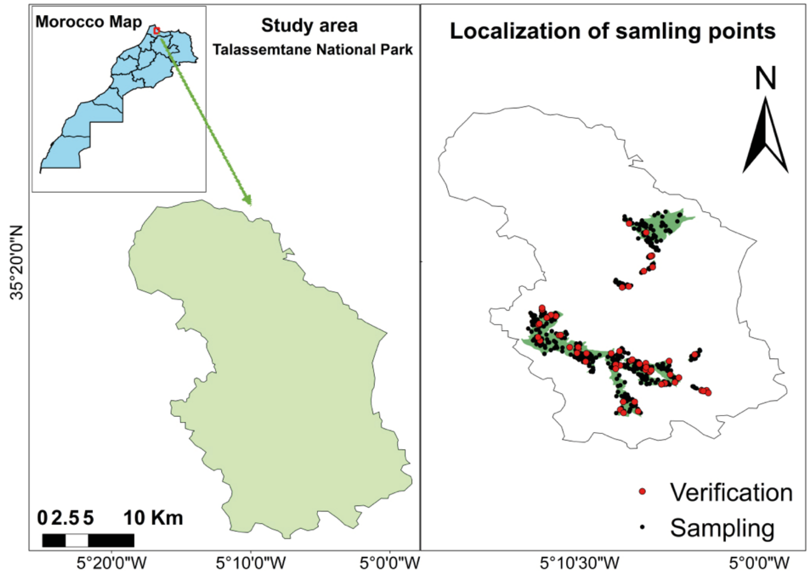


Figure 1: Study area and location of the sample points and the subsample used for verifation (authors' personal map).

Abbildung 1: Untersuchungsregion und Lage der Probepunkte und Stichprobe für Verifizierung (persönliche Karte der Autoren).

Abies marocana is one of the endemic species classified by the IUCN in the red list of endangered species as EN (Alaoui *et al.* 2011a). The main reason for the establishement of the Talassemtane National park was to protect the species from anthropogenic disturbances. Moroccan fir grows in the high peaks of the calcareous dolomitic mountains in western Rif (Benabid 1985) at altitudes between 1,400 and 2,100 m on the Chefchaouen Mountains.

At the beginning of the 20th century, *A. marocana* distribution was reduced by 70% mainly due to logging, fires, land clearing for agriculture and cannabis cultivation as well as population growth (Emberger 1938). In the 1950s, according to Boudy (1950), Moroccan fir covered a few thousand hectares: from 3,800 to 5,000 ha. Currently, the species occupies an area less than 4,000 ha.

Given the exceptional and unique bioclimatic conditions, Moroccan fir is not distributed outside the Talassemtane National Park. This species occurs in the cold and exceptionally very cold variants of the humid and perhumid bioclimates (Benabid 2000). The Moroccan fir is found either in admixture with *Quercus faginea* Lam., *Acer granatense* and *Quercus rotundifolia* Lam. on the upper Mediterranean level. At the mountain Mediterranean and supra-Mediterranean vegetation belts it can be found together with *Cedrus atlantica* (Laaribya and Belghazi 2016), *Pinus nigra* var. *mauretanica* and *Pinus pinaster* subsp. *hamiltoni* var. *maghrebiana* (Alaoui *et al.* 2011b). Regarding to edaphology, according to several authors (Baumer 1977; Boukil 1998; Benabid 2000), Moroccan fir is limited to limestone substrates. The species also settle on brown forest soils (Baumer 1977; Boukil 1998; Benabid 2000), calcimagnesic or fersiallitic soils (Benabid 2000), especially on the summits and north facing slopes (Baumer 1977; Benabid 2000).

Methods

Spatial distribution modelling software based on maximum entropy principle (MaxEnt) was used to determine the potential area of Moroccan fir. This method establishes a relationship between the species occurrence and the explanatory variables (Xavier and Maarten 2012; Torun and Altunel 2020). This algorithm represents an important predictive tool in conservation ecology (Peterson *et al.* 1999; Phillips *et al.* 2006).

In our study, we used environmental and topographic variables and occurrence data from the national forest inventory database (IFN 2005). In the first step, areas with fir present were selected from the IFN cartographic database. Then, a shape-file of the species occurrence was created. We selected as our starting random location sample a set of geolocated 600 points distributed across the entire distribution area of Moroccan fir (Figure 1). Next, we took a subsample consisting of 60 geolocated points (i.e. 10% of the initial sample) to verify in the field, that at these geographical coordinates mature Moroccan fir trees were present and not confused with other species. No error was observed, suggesting reliability of this dataset. The climatic data were extracted from WorldClim version 2.1 (Fick and Hijmans 2017). Resolution of each variable was at 30 arc-seconds, i.e. $\approx 1\ km^2$. In total, 22 explanatory variables were used to model the current suitability area of Moroccan fir (Table 1) including 19 bioclimatic variables and 3 topographic variables. It has been reported that climatic variables have an effect on the distribution of Moroccan fir (Emberger 1938; Benabid 1985; Aafi 1995; Gutiérrez Hernández *et al.* 2016). Altitude was also taken from WorldClim 2.1 version, while the other topographic variables (slope and exposure) were computed from the previous altitude raster (Altunel 2018) using ARCGIS software version 10.7. In addition to the 19 bioclimatic and topographic variables used, soil was used being one of the most important ecological factors controlling tree growth and distribution. Bioclimatic predictors, as being the most determinant of the environmental conditions, are associated with the species physiology (O'Donnell and Ignizio 2012). We then checked, whether the different types of substrates and the edaphic requirements can help explain the distribution of Moroccan fir. We produced using the Rif and Oriental soil maps, an updated map of the soil types of the Talassemtane National Park (Référentiel Pédologique 2008). In this map, we have adopted the soil nomenclature according to the international soil classification system replacing the old French soil nomenclature established in 1967. To establish a link for soil names we used the terminology of the Rif and Oriental pedological maps, the pedological reference established by the French association (Référentiel Pédologique 2008) and the World Reference Base for Soil Resources (WRB) 2014 (World Reference Base for Soil Resources 2014).

Table 1: Predictors used in the modelling process (WorldClim version 2.1) (Fick and Hijmans 2017).

Tabelle 1: Prädiktoren, die bei der Modellierung verwendet wurden (WorldClim version 2.1) (Fick and Hijmans 2017).

Code	Climatic Variables	Unit
Bio1	Annual Average Temperature	**°C**
Bio2	Average Diurnal Range (Average of monthly maximum temperature-minimum temperature)	**°C**
Bio3	Isothermality (Bio2/Bio7) (×100)	**%**
Bio4	Temperature Seasonality (standard deviation ×100)	**°C**
Bio5	Maximum Temperature of Warmest Month	**°C**
Bio6	Minimum Temperature of Coldest Month	**°C**
Bio7	Temperature Annual Range (Bio5-Bio6)	**°C**
Bio8	Average Temperature of Wettest Quarter	**°C**
Bio9	Average Temperature of Driest Quarter	**°C**
Bio10	Average Temperature of Warmest Quarter	**°C**
Bio11	Average Temperature of Coldest Quarter	**°C**
Bio12	Annual Precipitation	**mm**
Bio13	Precipitation of Wettest Month	**mm**
Bio14	Precipitation of Driest Month	**mm**
Bio15	Precipitation Seasonality (Coefficient of Variation)	**%**
Bio16	Precipitation of Wettest Quarter	**mm**
Bio17	Precipitation of Driest Quarter	**mm**
Bio18	Precipitation of Warmest Quarter	**mm**
Bio19	Precipitation of Coldest Quarter	**mm**
Bio11	Average Temperature of Coldest Quarter	**mm**
Code	**Topographic variables**	**Unit**
Altitude	Altitude	**m**
Slope	Slope	**degree**
Exposition	Exposition	

Validation of the model

The receiver-operating characteristic (ROC) plot's area under the curve (AUC) is a threshold-independent measure of the model prediction accuracy (Hanley and Mcneil 1982). The higher the value of AUC is close to one, the further we are from a random model (Phillips *et al.* 2006). The accuracy of the AUC values has been reported by Swets (1988). Here we adopt the values of Araújo *et al.* (2005) where the AUC values are interpreted as follows: the model is excellent if AUC> 0.90; good if 0.80 <AUC≤0.90; acceptable if 0.70<AUC≤0.80; bad if 0.60<AUC≤0.70 and invalid if AUC≤0.60. The Jackknife Test (Miller 1974) allows determining the variables controlling the species distribution and their predictive power. The MaxEnt model for *A. marocana* makes it possible to produce the distribution map of *A. marocana* from a classification of the results in two intervals of probability of presence "P", defined mainly by a retained threshold "S". This retained threshold "S" relates to a presence drive to the 10th percentile, representing the response that 90% of the points of presence fall within this potential area (Phillips and Dudík 2008). The ecological response curves were generated also for each model by the MaxEnt software. A Geographic Information System (GIS), ArcGIS 10.7 was used to obtain the output maps.

Results

Performance of the developed model

The AUC value was 0.958 (Figure 2) which confirms the excellence of the modelling indicating the good performance and robustness of the model selected.

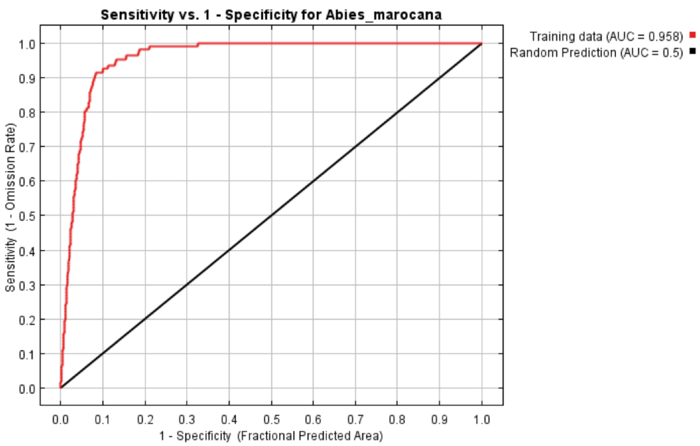


Figure 2: Calculation result of ROC and AUC.

Abbildung 2: Berechnungsergebnis von ROC und AUC.

Relative Contribution of Variables

Table 2 and Figure 3 show that the most influencing variables on the *A. marocana* presence were the average temperatures. They are the average temperature of the warmest quarter (Bio-10) and the maximum temperature of the warmest month (Bio-5) with a contribution of 44.9% and 23.7%, respectively. However, Bio-5 constitutes the environmental variable which causes a significant reduction (i.e. 83%) in the predictive power of the model when it is omitted. Therefore, it seemed to have the most information, which was not present in the other variables as shown in Table 2 and the results of the Jackknife test.

Table 2: Percentage of contribution and importance of permutation in (%) of the studied variables.

Tabelle 2: Prozentsatz des Beitrags und Bedeutung der Permutation in (%) der untersuchten Variablen.

Variable	Percentage of contribution (%)	Importance of permutation (%)
Bio-10	44.9	0
Bio-5	23.7	83
Bio-2	8.9	5.8
Bio-11	4.5	0
Exposition	3.1	0.5
Bio-9	2.5	0
Bio-1	2.3	0
Bio-8	2.1	2
Bio-15	1.8	0
Altitude	1.1	3.9
Bio-14	0.9	1.6
Bio-3	0.8	0.2
Slope	0.7	0.4
Bio-6	0.6	0.8
Bio-4	0.5	0
Bio-7	0.5	0.1
Bio-13	0.4	0
Bio-19	0.2	0
Bio-18	0.2	0.1
Bio-17	0.1	1.6
Bio-12	0.1	0
Bio-16	0	0

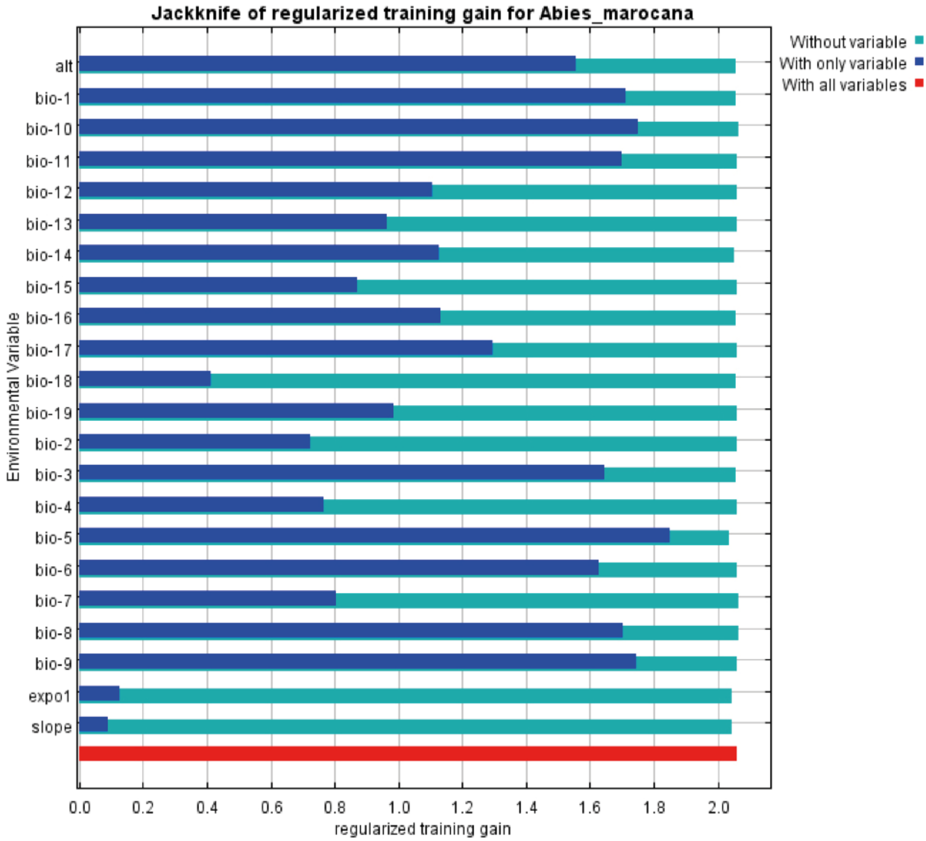
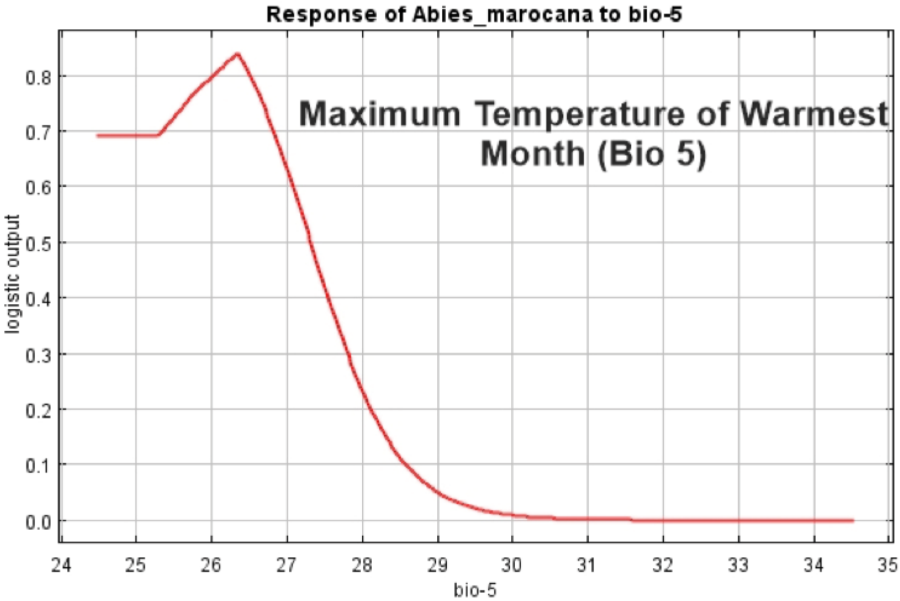


Figure 3: Results of the Jackknife Test showing the contribution of the studied variables.

Abbildung 3: Ergebnisse des Jackknife-Tests, die den Beitrag der untersuchten Variablen zeigen.

The ecological response curves of the two variables with the largest contribution showed that the presence of *A. marocana* is favourable in areas where Bio-5 (the maximum temperature of warmest month) and Bio-10 (the average temperature of the warmest quarter) is equal to 26.3 °C and 17.9 °C respectively. By contrast, the species is almost absent when Bio-5 and Bio-10 exceed 29 °C and 22 °C respectively (Figure 4 and 5).



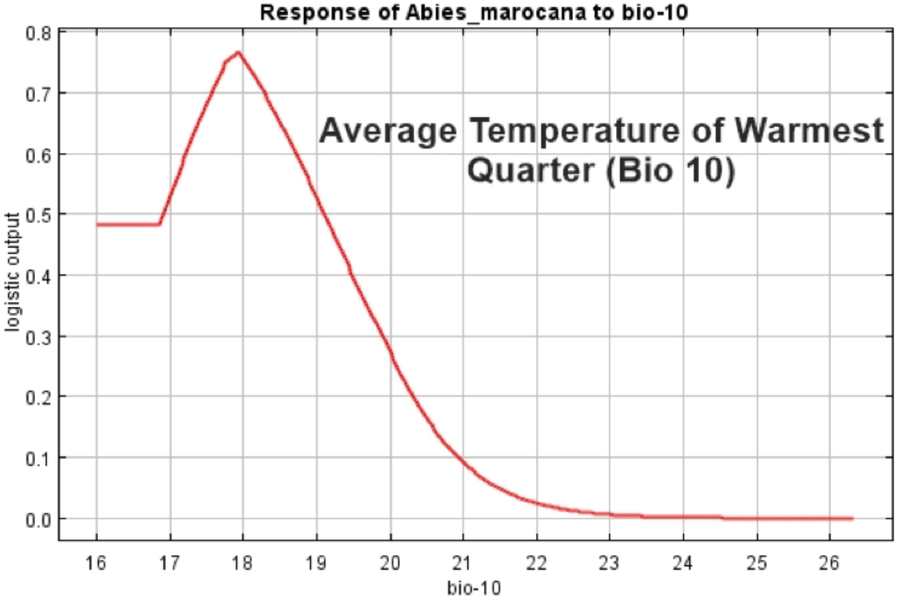


Figure 4: The ecological response curve of Abies marocana for variable Bio-5 (Maximum temperature of warmest month) and Bio-10 (Average temperature of warmest quarter).

Abbildung 4: Ökologische Responskurven von Abies marocana für die Variablen Bio-5 (maximale Temperatur des wärmsten Monats) und Bio-10 (mittlere Temperatur des wärmsten Viertels).

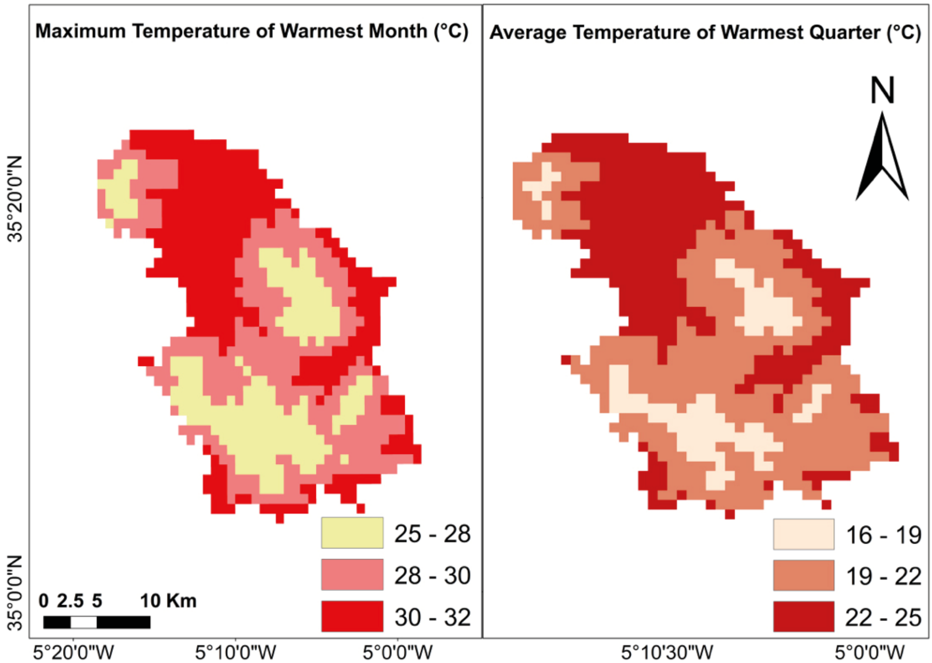


Figure 5: Map of Bio-5 (Maximum temperature of warmest month) and Bio-10 (Average temperature of warmest quarter) in the study area.

Abbildung 5: Verteilung der Variablen Bio-5 (maximale Temperatur des wärmsten Monats) und Bio-10 (mittlere Temperatur des wärmsten Viertels) im Untersuchungsgebiet.

Suitability map of *Abies marocana*

The modelling method used in this paper as well as the different related maps enabled us to make the first map of the potential distribution of *A. marocana*. Taking into account the threshold related to a presence of training at the 10th percentile which was 0.317, the suitable areas of Moroccan fir tree covers approximately 13,084 ha, including zones where the species is currently present. The superposition of the current distribution of Moroccan fir tree on the predicted potential area (Figure 6), allowed us to detect more than 9,084 ha (i.e. a forecast increase of 227%).

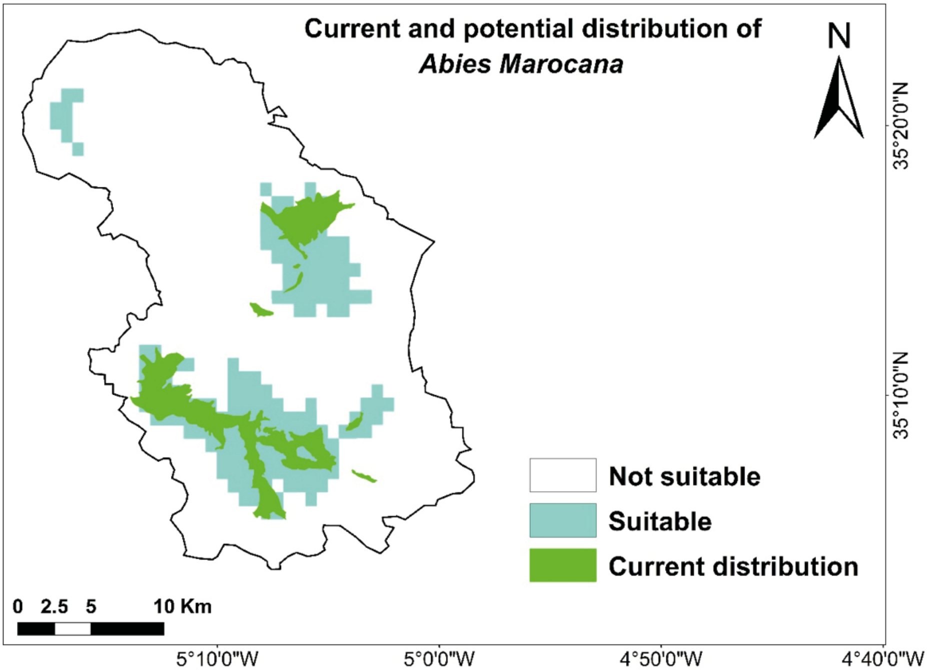


Figure 6: Current and potential distribution of Abies marocana within the Talassemtane National Park.

Abbildung 6: Aktuelle und potenzielle Verbreitung des Abies marocana im Talassemtane Nationalpark.

Edaphic factors and spatial distribution of *Abies marocana*

The soil map produced by us is consistent with the work of Baumer (1977), Boukil (1998) and Benabid (2000) confirming the growing of Moroccan fir on strictly limestone substrates, in particular on Cambisols, Rendzic Leptosols and Luvisols, corresponding with brown forest soils, calcimagnesic soils and fersiallitic soils respectively. We also found that Moroccan fir also settles on the Arenosols (Figure 7).

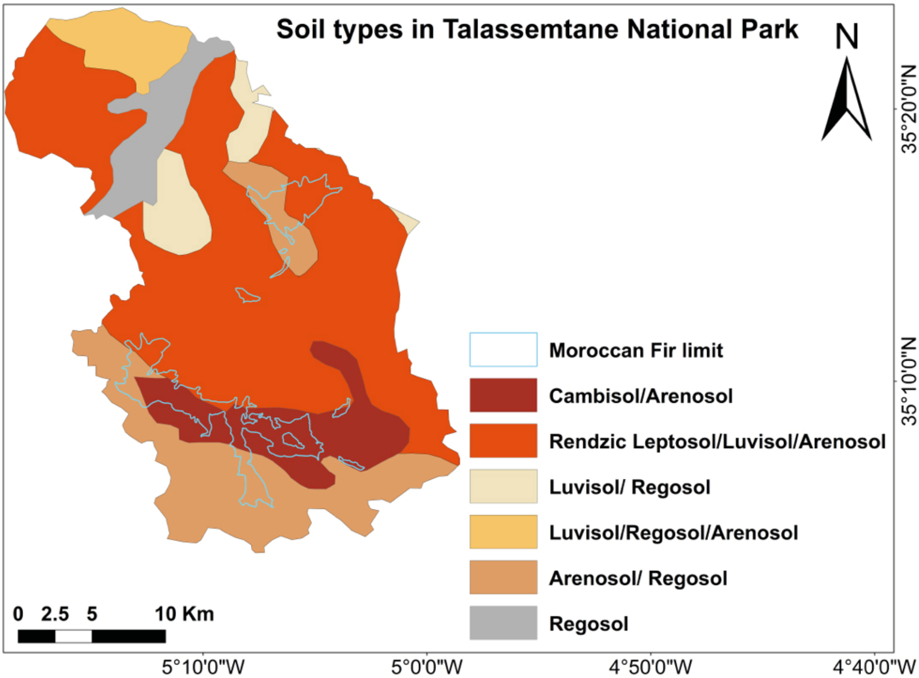


Figure 7: Soil map of Talassemtane National Park obtained based on the Rif and Oriental pedological maps (Osrhiri 2000) and referred to the International Soil Classification System (WRB 2014).

Abbildung 7: Bodenkarte des Nationalparks Talassemtane, basierend auf den Rif und Oriental pedologischen Karten (Osrhiri 2000) und unter dem Internationalen Bodenklassifizierungssystem (WRB 2014).

In fact, the exclusive and limited presence of the endemic Moroccan fir in the Talassemtane National Park may be conditioned by the combination of edaphic and climatic factors, especially the latter.

Discussion

Abies genus spread from the European continent to southward reached as far south as the zone studied in this research, and remained as some relic species today (Therhüerne-Berson *et al.* 2004). In the last years, some conifers like firs, cedars, pines, and cork oak have been modelled around the Mediterranean basin to elucidate their potential distribution (López-Tirado and Hidalgo 2014; Bouahmed *et al.* 2019; López-Tirado *et al.* 2020; Stephan *et al.* 2020; Laaribya *et al.* 2021). This study extented the knowledge on these primitive trees in which the science is focusing. AUC results confer robustness to the developed model to be used for conservation purposes.

The average temperature of the warmest quarter (Bio-10) and the maximum temperature of warmest month (Bio-5) were the most significant variables obtained in our modelling work. Moroccan fir was almost absent when Bio-5 and Bio-10 exceeded 29 °C and 22 °C, respectively, indicating that high temperatures constituted a limiting factor. This is consistent with other results obtained in *A. pinsapo* (Alba-Sánchezet *et al.* 2010; López-Tirado and Hidalgo 2014; Gutiérrez Hernández *et al.* 2016). Gutiérrez Hernández *et al.* (2016) concluded also that climatic and topographic variables determined the high suitability for the Spanish fir. Namely, high rainfall, cool temperatures (2.72 °C as the average minimum temperatures of the coldest month) and a low solar incidence (in a predominantly northern exposure). Moreover, Esteban *et al.* (2010) emphasized that *A. pinsapo* forests is facing climate change threats, forest fires, and pests' outbreaks. The limited area occupied by these forests makes them highly vulnerable to disturbance (Esteban *et al.* 2010). Indeed, the distribution of *A. marocana*, is limited to altitudes up to 2000 m and linked to the cool, cold and even very cold variants of humid and perhumid bioclimates (Benabid 2000). The mist, and high rainfall in altitudes up to 2,000 m lead to unique bioclimatic conditions in the Strait of Gibraltar and surrounding mountains (Esteban *et al.* 2007, 2010). In Morocco, these unique bioclimatic conditions are mainly characterized by the natural distribution area of Moroccan fir. This species is classified by the IUCN in the red list of threatened species and considered the first reason for the creation of Talassemtane National Park which has included all fir stands. By contrast, topographic variables (ALT, Expo and Slope) contributed very little to the prediction of the model. Nevertheless, taking into account the close relationship of the spatial variability of climatic factors with the topographic ones, we considered that the influence of the latter on the distribution of *A. marocana* is indirect. Esteban *et al.* (2010) stated that Moroccan fir grows in north facing slopes in the Baetic Range. Curiously, *Abies marocana* prospers in north, west and occasionally south slopes, influenced by the position of the mountains in relation to the incoming direction of the humid Atlantic winds.

The potential distribution of Moroccan fir represents 13,084 ha, a surplus of 227% compared to its current distribution. Several biotic and anthropogenic constraints face the conservation of Moroccan fir, in particular browsing which, with an overgrazing coefficient of 71%, limits the potential for fir plantation (HCEFLCD 2012). However, anthropogenic factors are not included in the modelling because of the difficulty in managing them as explanatory variables. Thus, it is important to emphasize that the developed model in the present paper compute suitable areas when the environmental or topographic variables were considered. The fact that a suitable area or potential distribution is found wider than the current distribution is consistent with other works (Vessella and Schirone 2013; Al-Qaddi *et al.* 2016). On one hand, this result supports the decline in the area occupied by this fir at the early 20th century, as stated by many authors (Benabid 2000; Linares *et al.* 2011). On the other hand, this work reveals the possibility of restoring Moroccan fir under the current bioclimatic conditions by its regeneration on the scale of its predicted potential area. This aim is in line with conservation and restoration programs of fir stands. In 1977, the Institution of Water and Forests began implementing the first regeneration work of *A. marocana* in the Talassemtane National Park over 300 hectares. Regeneration was programmed over 718 ha from 2014 to 2,028 ha and only 150 ha have been completed. The results of the present study support these initiatives. According to our study and field investigations, 450 seedlings per ha is the optimal average density needed for afforesting Moroccan fir. Hereof, Ben-Said *et al.* (2020) emphasized that low density of trees as well as their spatial pattern confirms weak competitive interaction and self-thinning process. However, Navarro-Cerrillo *et al.* (2020) highlighted a marked sensitivity of Moroccan fir growth to competition in pure stands which larger basal area, suggesting that competition is strongly influenced by climate. The low density planting of seedlings proposed in the present study supports the results of Ben-Said *et al.* (2020) and Navarro-Cerrillo *et al.* (2020).

Conclusion

Moroccan fir is an endemic species of the Moroccan Rif which has undergone strong degradation and a reduction in its density. It is an endangered species listed in the IUCN red list. This work provides the first map of the potential distribution of Moroccan fir based on the obtained data and current climate. The MaxEnt model was robust according to the obtained AUC value (0.958). The main variables conditioning the presence of *A. marocana*, were the average temperature of the warmest quarter and the maximum temperature of the warmest month. The potential area was 13,084 ha, which represents a gain of 227% compared to the current distribution. This original study will contribute to any strategic planning for biodiversity conservation and sustainable management of this emblematic fir in the Talassemtane National Park.

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