

# CLIMATE CHANGE IMPACTS ON THE DISTRIBUTION OF *STIPA TENACISSIMA* L. ECOSYSTEMS IN NORTH AFRICAN ARID ZONE – A CASE STUDY IN TUNISIA

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**Abstract.** *Stipa tenacissima* L. (Alfa grass) is an important perennial grass species in Tunisia and Northern Africa which dominates wide arid ecosystems offering multiple services. The focus of this study is to explore how the distribution of suitable habitat for *Stipa tenacissima*, might shift under climate change. To investigate the potential effects of climate change on the target species we used Maxent modeling algorithm for two representative concentration pathways (RCPs) lower emission scenario (RCP 2.6) and higher emission (RCP 8.5) climate forcing scenarios in 2050 and 2070. Results of the analysis showed a negative impact of climate change on the *S. tenacissima* ecosystem. There is a decrease in suitable habitat for alfa through time and across space with an increase in greenhouse gas. Suitable habitat was projected to decline through time from 64% to 70% by 2050 for RCP 2.6 and RCP 8.5 respectively and from 86% to 92% by 2070 for RCP 2.6 and RCP 8.5 comparatively to the current state. Across space, when projecting model into the future, the area of predicted suitable habitat of Tunisian alfa grass would dramatically reduce in the central area, and disappear from the Southern area. Therefore, global warming associated with climate change by the years 2050 and 2070 might affect the suitable bioclimatic habitat of *S. tenacissima* with a severe loss of habitat suitability.

**Keywords:** *global warming, ecological niche, Maxent, suitable habitat, plant ecology*

## Introduction

In recent years, climate change caused dramatic shifts in species' distributions and extinctions, particularly across fragmented or vulnerable ecosystems (Hilbert et al., 2007). Many researches anticipate that changes in environmental condition, such as precipitation patterns and temperature fluctuations will alter the suitability of natural ecosystem in the coming decades. Faced with these potential impacts, understanding how species will respond to the projected future climate change is of fundamental importance for effective management and conservation of biodiversity (Hannah et al., 2002a).

In order to manage and mitigate future impacts, it's necessary to predict them (Andersen, 2010). Predictions of future geographic ranges require gathering information on species and relevant environment variables, and combining this information with new environmental conditions (Rehfeldt et al., 2012). This information will be very important to answer the frequently asked questions (Andersen, 2010): What are the climatic conditions in which a species is currently found? And where those conditions will be found in the future?

As we try to understand and prepare for climate change in the coming decades, it is imperative to link regional processes to global climate system through accurate regional modeling that captures climate impacts on regional ecosystem scales (Kafatos, 2012). In this study, the analysis focused on the specific region where *S. tenacissima* is currently

grown. We have used prediction of the future climate to predict the suitability of alfa growing areas.

*S. tenacissima* species, which is the focus of this study, is a perennial tussock grass widely distributed in arid and semiarid ecosystems of the South and Western Mediterranean Basin (Suárez et al., 1991). Most of the steppes in the Maghreb and semiarid regions of Spain are dominated by alfa grass or plant communities associated with it (Puigdefabregas and Mendizabal, 1998), they represent an intermediate state of desertification (Le Houréou, 2001). This plant plays important ecological role, several authors argued that *S. tenacissima* has a positive influence on soil, as it binds the soil surface with their root, minimizes runoff lengths and sediment movement along slopes (Puigdefabregas and Mendizabal, 1998). Furthermore, it forms a dense clump which captures sediments and plant debris, provides shelter for other species to grow in (Maestre et al., 2001; Garcia-Fayos and Gasque, 2002). Besides *S. tenacissima* protects soil against erosion (Sánchez and Puigdefabregas, 1994; Bochet et al., 1998), it resists to long drought periods (Pugnaire et al., 1996), and it has ecological capacity to grow in nutrient deficient soils (Le Houérou, 1969). Furthermore *S. tenacissima* grasslands have served humans for a long time.

As they have been long used and managed by humans, Cortina et al. (2009) evoked that *S. tenacissima* steppes constitute an excellent system model to expand our knowledge of ecosystem dynamics in arid lands because of their broad geographical distribution and their strong long-term links with human activities. According to Intergovernmental Panel on Climate Change IPCC (2000) scenarios, temperature and rainfall will change considerably in Africa within the next decades (IPCC, 2007; Richardson et al., 2009) and the Mediterranean basin is classified among the most vulnerable to climate change (Giorgi and Lionello, 2008). From this perspective, this study attempts to identify the environmental variables with the most influential effect on the distribution of *S. tenacissima* and to investigate how the expected changes in climatic conditions would affect this distribution.

Different modeling approaches have been extensively applied to study flora and fauna distribution. They were used to project species' responses to land-use, climate change, predict invasive species geographic limits and establish biodiversity reserve networks (Araujo and Guisan, 2006; Ficetola et al., 2007; Rodriguez-Estrella, 2007). The purpose of many species distribution modeling techniques is to model a species' ecological niche (Grinnell, 1924; Hutchinson, 1957), which is then used to predict its potential distribution over geographic space (Soberon and Peterson, 2005). They are spatially explicit, providing a visual map (Guisan and Thuiller, 2005; Elith et al., 2006). The ecological niche of a species is defined as the set of environmental conditions capable of maintaining populations without immigration from other areas (Levine et al., 2007; Peterson and Nakazawa, 2008).

Ecological niche models (ENMs) have been used as a tool to assess the impact of both land use and environment change on the distribution of species (Lischke et al., 1998; Guisan and Theurillat, 2000). An ecological niche model can be described as the probability distribution of a species as defined by a set of environmental variables and species localities of known occurrence (Peterson, 2001; Santiago, 2005). This probability distribution can then be integrated into a geographic information system (GIS) to identify geographic regions containing environmental conditions that could be suitable for the species (Elith et al., 2006; Papes and Gaubert, 2007).

In this study, we examined the impact of climate change using the applied Maximum Entropy Modeling “Maxent” (Phillips et al., 2006) to look at habitat suitability for *S. tenacissima* under two different carbon emission scenarios for 2050 and 2070. The Maximum Entropy method is based on the use of presence-only data for modeling species distribution. Modeling techniques that require only presence data are extremely valuable (Graham et al., 2004) when absence occurrence data are not available for the development of models, since false absences can decrease the reliability of the predictive models (Phillips et al., 2006).

Within this paper, our goal was to: (i) generate a Species distribution model for *S. tenacissima* to predict areas of suitable habitat (ii) determine the environmental variables that most influence the estimated distribution of *S. tenacissima* and (iii) model the impact of climate change on the target species.

## Materials and Methods

### *Study area*

The study area covers the country of Tunisia, situated in Northern Africa with an area of 164 000 km<sup>2</sup>. It lies between the two following geographical coordinate ranges: latitude 30°14' to 37°13' N and longitude 7°32' to 11°36' E (*Fig. 1*), with Mediterranean climate characterized by dry and hot summers and cold and wet winters. Precipitation is extremely variable along and between years and the rainfall considerably varies from the North (>1000 mm) to South (<100 mm). According to Emberger (1960), Tunisia has five bioclimatic stages, going from the most arid to the most humid. Based on rainfall, Tunisia comprises several natural regions including forests areas in the northeastern part, steppic areas in the center and desert areas in the South. The analysis focused on the specific regions where *S. tenacissima* is currently-grown. This geographic area includes parts of steppes, which constitute one of the most representative ecosystems which have been continually exploited as fiber for paper mills and fodder.

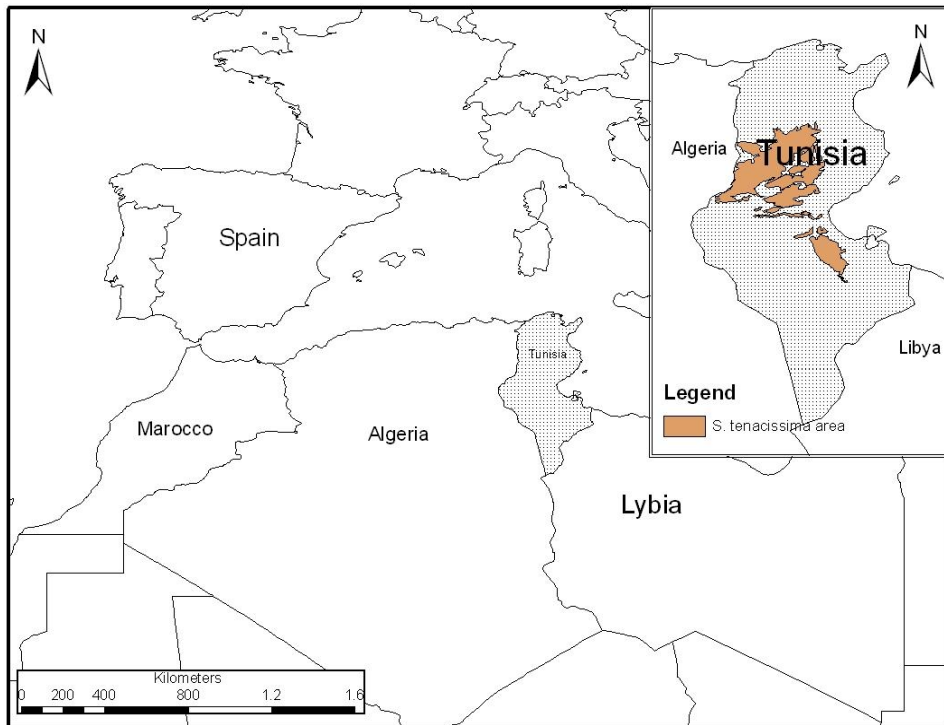
### *Species data*

*Stipa tenacissima* (Alfa grass) is widely distributed in arid and semi arid ecosystems around the Mediterranean basin (Suárez et al., 1991), derive from grasslands and woodlands that have been subjected to long-term exploitation and degradation by human activities such as fiber and wood harvesting, grazing, and repeated burning (Puigdefabregas and Mendizabal, 1998). Alfa is a perennial tussock grass belongs to the family poaceae (*Fig. 2*), occupies large areas in the Iberian Peninsula and North Africa. Within Tunisia, *S. tenacissima* is mainly found in Midwest regions with some scattered populations in the Southeastern part of the country. *S. tenacissima* occurrence data were obtained from the National Forest and Pastoral Survey in Tunisia (1995).

### *Environmental variables*

The environmental predictors that best describe the *Stipa* ecological niche were selected based on knowledge of the ecology of the species. Vegetation arid areas have been significantly shaped by temperature and precipitation gradients. Initially, a total of 19 variables were selected. To avoid multi-collinearity effects, Variance Inflation Factors (VIF) were calculated and the variable with the highest VIF (>10) were

removed. The final predictors were a set of 7 variables, used for developing the species distribution modeling (*Table 1*), including 5 climatic variables and 2 topographic variables.



**Figure 1.** The study area is the Tunisian country locales in the North of Africa



**Figure 2.** *Stipa tenacissima* L. a perennial tussock grass growing in steppic regions in Tunisia

**Table 1.** Environmental layers used in modeling the distribution of *Stipa tenacissima* in Tunisia

Abbreviation	Definition	Units	VIF
bio3	Isothermality (Mean Diurnal Range/Temperature Annual Range)*100		1.395
bio5	Maximum temperature of warmest month	°C*10	1.650
bio6	Minimum temperature of coldest month	°C*10	4.715
bio8	Mean temperature of wettest quarter	°C*10	1.164
bio12	Annual precipitation	mm	3.203
Alt	Altitude (above sea level)	m	3.318
Slope	Slope	%	1.139

Climatic variables for modeling were downloaded from the World Climate database ([www.worldclim.org](http://www.worldclim.org)). This database provides 19 global climatic layers generated by the interpolation of global climatic data (Hijmans et al., 2005) at 30 arc-sec resolution of approximately 1 km<sup>2</sup>. The data provided by Worldclim is a compilation of interpolated historical data from weather stations all over the world, collected between 1950 and 2000. We added to the model two topographic variables: altitude and slope. These two variables were added as they are potentially important for explaining the distribution of *S. tenacissima* and may present distributional constraint on its range. Slope was calculated using the Digital Elevation Model at a resolution of 30 m. It was calculated with the slope tools in the Spatial Analysis Tools of ArcGIS 9.3.

To predict potential changes in the habitat distribution of *S. tenacissima*, under a hypothetical climate change scenario, we re-projected the model using a new environmental data for the years 2050 and 2070. The Fifth IPCC Assessment Report (AR5) published in 2013, came out with a new set of scenarios. Four Representative Concentration Pathways (RCPs) were coded representing the full bandwidth of possible future emission trajectories. The model was run under two representative concentration pathways, RCP2.6 it's a low emission scenario of greenhouse gas and RCP8.5 it's a very high emission scenario. We used the climatic projections from the General Circulation Model (GCM) from the Met Office Hadley Centre (HadGEM2-ES). Our selected future climate data sets were downloaded from the World Climate Database.

### ***Species distribution modeling***

In this study, we used Maximum Entropy modeling (Maxent version 3.3.3a) to create a species distribution model for *Stipa tenacissima* across Tunisia. Maxent software is available for free from <http://www.cs.princeton.edu/schapire/maxent/> (Philips et al., 2006). Maxent is a machine learning method that estimates the optimal probability distribution to assign continuous probabilities of the occurrence of the species to each pixel in a grid, providing informative biogeographical information and discrimination of suitable vs. unsuitable habitat for the study area (Philips et al., 2006). This algorithm estimates species distributions based on presence-only data by finding the distribution of maximum entropy, subject to the constraint that the expectancy of each environmental variable under this estimated distribution should match its empirical average (Philips et al., 2006; Cardona and Loyola, 2008). Maxent probability of distribution can be represented mathematically as:

$$q\alpha^{(x)} = \frac{e^{\alpha \cdot f(x)}}{Z\alpha} \quad (\text{Eq.1})$$

Where:

- $\alpha$  is a vector of  $n$  real valued coefficients or feature weights
- $f$  denotes the vector of all  $n$  features and  $Z\alpha$  is a normalizing constant that ensures that  $q\alpha$  sums to 1.

It is one of the species distribution models that required presence-only data as response variable (Baldwin, 2009). This algorithm takes as input a set of point locality data (samples) and a set of measurement of environmental variables, and produces a probability map (Anderson et al., 2003). The resulting model provided a map of habitat suitability values or probability distribution.

### ***Model evaluation***

Validation is required to assess the predictive performance of a distribution model (Araújo and Guisan, 2006; Terribile et al., 2010). In order to evaluate the performance of model, we used the area under the Receiver Operating Characteristic (ROC) Curve, or the AUC using the testing dataset. AUC is a threshold independent statistic that informs about the ability of a model to discriminate between presences and absences from the study area (Lobo et al., 2008). Therefore, dataset was divided randomly in two: 75% of all presence records were used to build the model and 25% were withheld for model evaluation, with 10 replications averaged. With a value of 0.5 indicating the results could be random (Fielding and Bell, 1997), while the AUC value of 1 indicates the perfect fit (Baldwin, 2009).

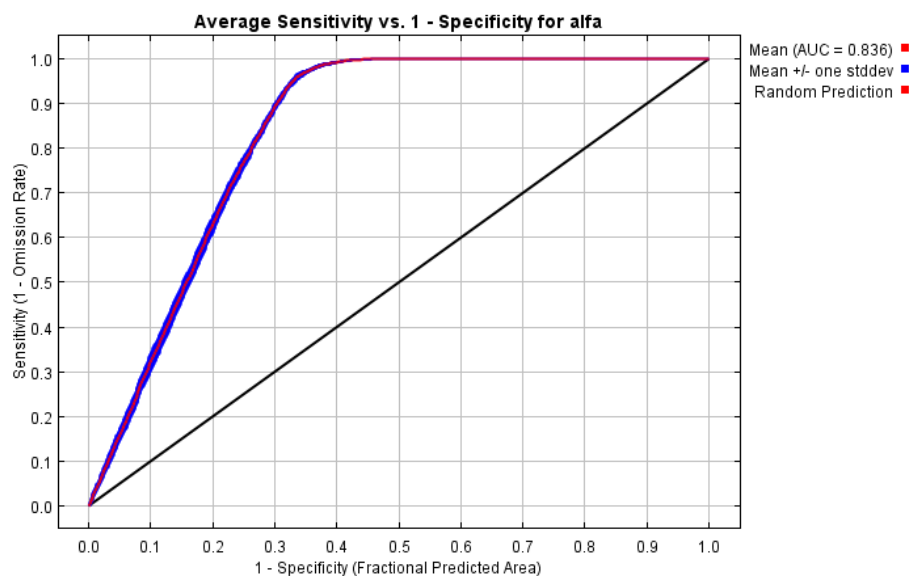
### ***Mapping current and future suitable habitats***

Suitable habitats for *S. tenacissima* under current and future climatic conditions generated with Maxent model, were mapped using ArcGIS 9.3. The logistic probability distributions generated by the model were used to measure the level of habitat suitability across the study area. The 10<sup>th</sup> percentile training logistic threshold was used to create a distribution map of potential, areas with an occurrence probability below that value were deemed unsuitable for the species (Scheldeman and van Zonnevel, 2010). On the other hand, occurrence probabilities higher than the 10<sup>th</sup> percentile were deemed suitable. We used this map to estimate the amount of suitable habitat of *S. tenacissima* within the study area and utilize it to determine the range shifts under climate change.

## **Results**

### ***Model validation and influencing variables***

We have used an ecological niche modeling approach based on species presence-only data to, First, reveal current distribution of *S. tenacissima* in Tunisia and the environmental determinants that underlie this distribution, and secondly to investigate how climate change may affect the future potential distribution. The Maxent model, used in this study, showed good predictive ability with an average training AUC value of 0.836 ( $\pm 0.003$ ) and an average test AUC value of 0.835 ( $\pm 0.003$ ) (Fig. 3).



**Figure 3.** Cross-validated areas under the receiver operating characteristic curve (AUC) of *Stipa tenacissima* habitat suitability model based on Maxent method

The 10<sup>th</sup> percentile training logistic threshold value for discriminating suitability level was 0.414. The percentage of variables contribution in the *S. tenacissima* habitat suitability using Maxent model (Table 2) reveals that the annual precipitation (bio12) and maximum temperature of warmest month (bio5) were the strongest predictors of *S. tenacissima* distribution with 73.8% and 12.4% respectively, slope and altitude also proved to be important variables in the prediction, but with smaller individual contributions (6.5% and 5.6%).

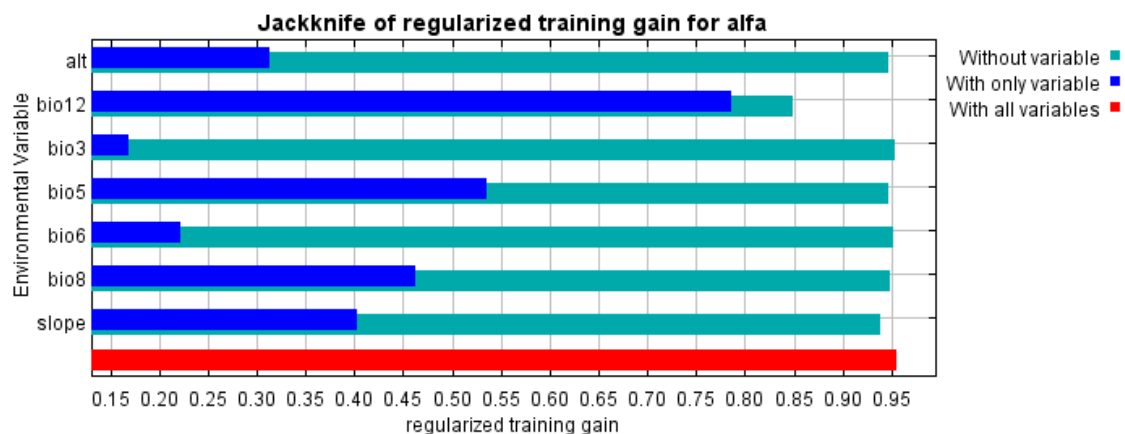
**Table 2.** Relative contribution of climatic and topographic variables to Maxent model for *Stipa tenacissima*

Variable	Definition	Percent contribution
bio12	Annual precipitation	73.8
bio5	Maximum temperature of warmest month	12.4
Slope	Slope	6.5
Alt	Altitude	5.6
bio8	Mean temperature of wettest quarter	0.9
bio6	Minimum temperature of coldest month	0.7
bio3	Isothermality (Mean Diurnal Range/Temperature Annual Range)*100	0.1

Thus, climatic parameters underlie the *S. tenacissima* pattern in comparison to the topographic variables. However, there were no important effects of the isothermality (bio3) variable. This is mainly because alfa has developed various mechanisms to be adapted to seasonal changes in temperature (Pugnaire et al., 1996).

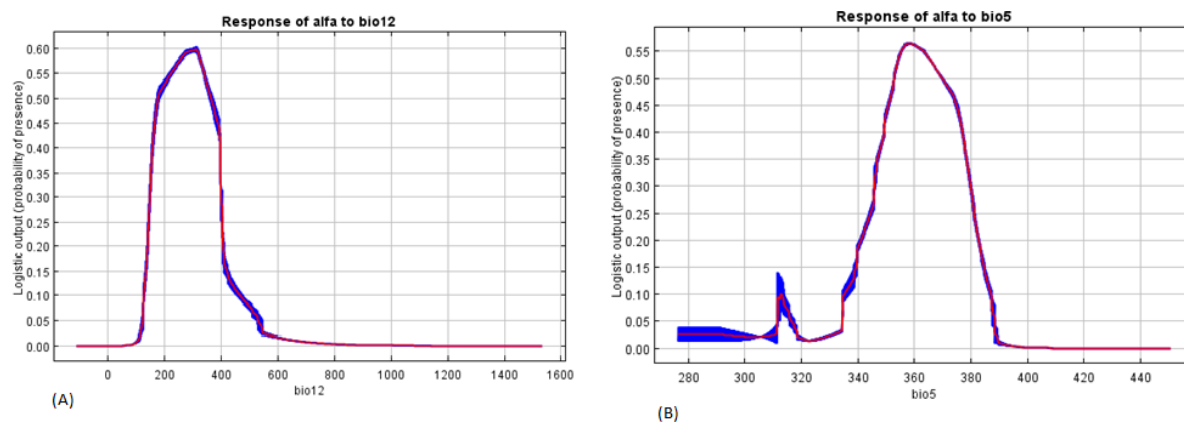
Further, the Jackknife test showed that bio12 was one of the most important factors in habitat distribution prediction for *S. tenacissima* in the study area (Fig. 4), produced the highest gain when used in isolation, suggesting this variable contributed the most

useful information. In terms of gain, omitting this variable decreases the gain considerably, indicating that it is also the most uniquely informative variable: Alfa have ecological requirements dependent on annual precipitation, obviously having a negative effect, higher levels (>400 mm) decreased the predicted presence probability, whereas levels less than 100 mm force the probability down to zero (desert limit). The second bioclimatic variable widely affecting suitable habitat for *S. tenacissima* is bio5.



**Figure 4.** Relative importance of different environmental variables based on results of a Jackknife test for regularized training gain for *Stipa tenacissima*

In order to illustrate the effects that the most important explanatory variables on the Maxent distribution we have included response curves for the main two contributing variables. The relationship between the probability of *S. tenacissima* and annual precipitation (bio12) was non-linear (Fig. 5A). The response curve shows that highest predicted suitability is in areas of low to medium precipitations (150-400 mm). The probability of presence increased substantially as the precipitation reaches 270 mm after which it begins to decrease. The correlation between Maximum temperature of warmest month (bio5) and habitat suitability was bell-shaped (Fig. 5B), with a maximum around 36°C, probability dropped sharply with maximum temperature of warmest month exceeding 38°C. This is agrees with the preference of *S. tenacissima* habitats, which support arid areas related to the Mediterranean climate.

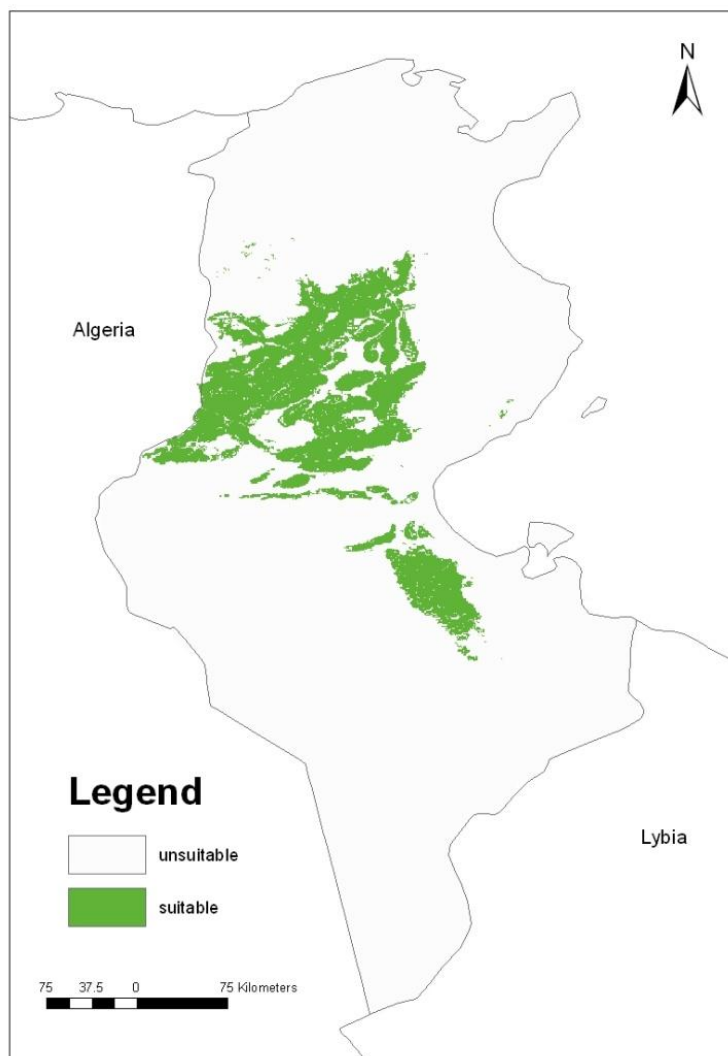


**Figure 5.** (A) The response curves for variable bio12. (B) The response curves for variable bio5 in the prediction model of *Stipa tenacissima*



### ***Habitat suitability of Stipa tenacissima***

The results of the Maxent model were represented both graphically and numerically. Graphically, suitable habitats for *S. tenacissima* under current and future climatic conditions generated with Maxent were mapped using ArcGIS 9.3. When looking at current climate variable, Maxent produced 19304 km<sup>2</sup> as suitable for *S. tenacissima* (Fig. 6), it occurs over a large area extending from the center-Western to the South east of the country. In the North regions, habitat suitability is being mapped as completely unsuitable. These areas are seemingly wet, having the highest annual precipitation throughout the country. *S. tenacissima* showed preference for less rainfall and high tolerance to very dry conditions. The probability of presence increased sharply after about 100 mm, it's the lower boundary which corresponds to the Southern border. Probability of presence decreased up to 400 mm, which corresponds to the Northern limit of *S. tenacissima*; habitat suitability was higher in areas with annual precipitation (bio12) around 270 mm. 19304 km<sup>2</sup> deemed suitable for *Stipa tenacissima*.



**Figure 6.** Predicted habitat suitability under current bioclimatic conditions using Maxent

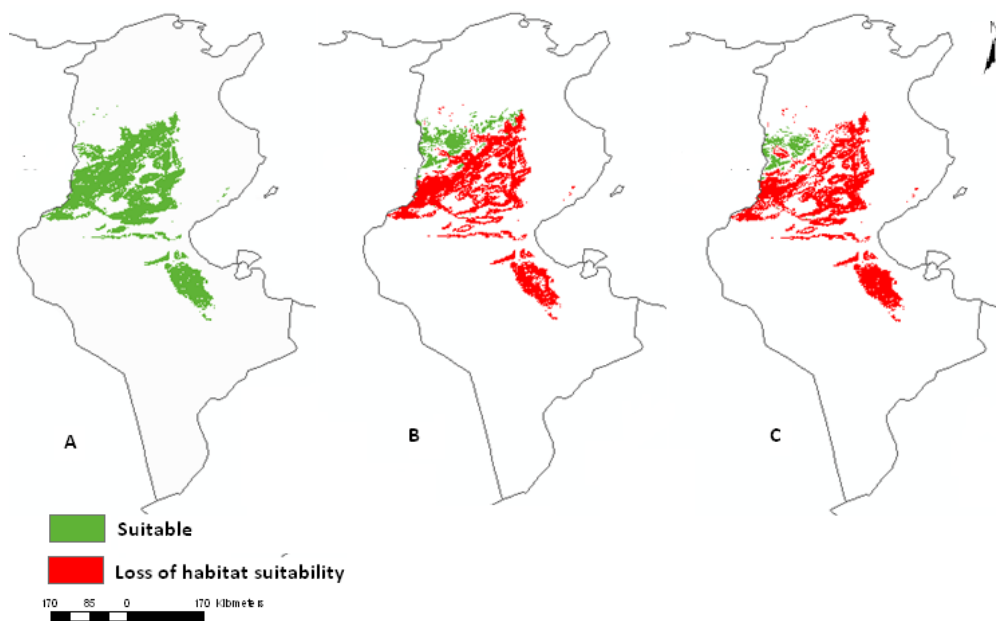
### Perceived severity of climate change impacts

Under RCP2.6, climate change would result in a suitable habitat decrease of 64% by 2050 and 86% by 2070. While, under RCP8.5, the suitable habitat would decline by 70% by 2050 and by 92% by 2070 (Table 3). RCP8.5 showed a great decline in the predicted area of suitable habitat. In addition, when looking into future, the Southern regions would suffer the most severe loss under future climate change. However, in the central part, results demonstrated a shift toward the higher altitude.

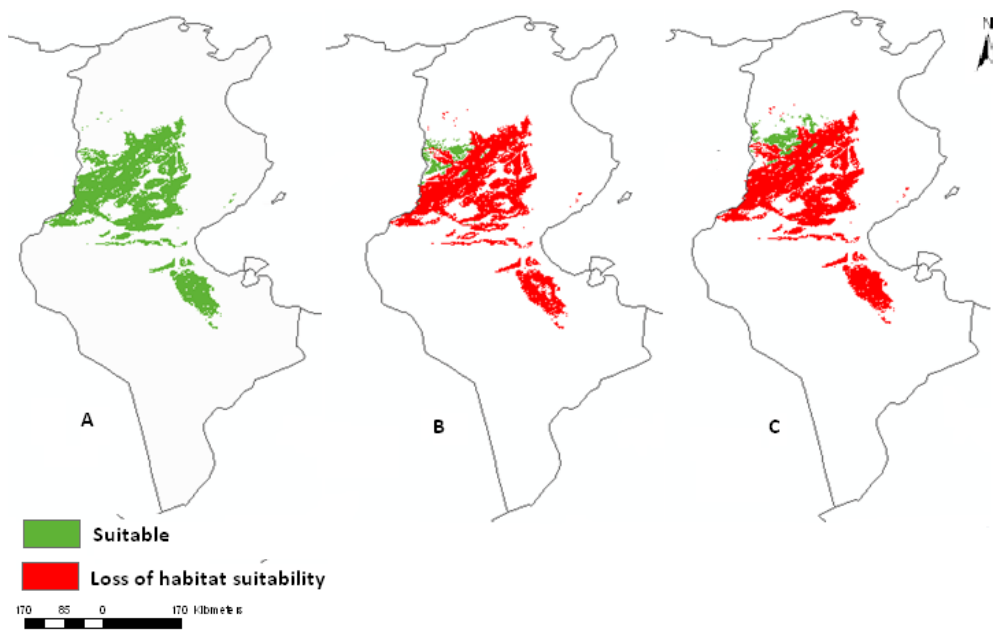
**Table 3.** Suitability habitat change from the currently suitable habitat to 2050 and 2070 using RCP2.6 and RCP8.5 scenarios

RCP scenarios	2000	2050		2070	
	Current	RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
Area (km <sup>2</sup> )	19304	6920	5840	2630	1615
Percent decrease	0	64%	70%	86%	92%
Loss of suitable habitat (km <sup>2</sup> )	0	15163	15065	17965	19260
Shift in range habitat (km <sup>2</sup> )	0	2779	1601	1291	1570

Using the future climate layers, analysis predicted that the Southern suitable areas will become unsuitable. Species is projected to extend its range towards the North. So model projected suitable areas along the higher elevations, where species has not been observed. *S. tenacissima* will reach the areas currently suitable for *Pinus. Halepensis* (Figs. 7 and 8). In support of this, Le Hou  rou (2001) suggested that the great extension occupied by the steppes of *S. tenacissima* in Northern Africa is the result of the regressive succession from open forest dominated mainly by *P. halepensis*.



**Figure 7.** Suitability habitat change from the currently suitable habitat (A) to 2050 using RCP2.6 (B) and RCP8.5 (C) scenarios: The pattern of habitat change caused by climate change for *S. tenacissima* resulting from Maxent model shows a high loss of habitat suitability and thin shift.



**Figure 8.** Suitability habitat change from the currently suitable habitat (A) to 2070 using RCP2.6 (B) and RCP8.5 (C) scenarios: The pattern of habitat change caused by climate change for *S. tenacissima* resulting from Maxent model shows a high loss of habitat suitability and thin shift.

## Discussion

The modeling results will go a long way to help in identifying suitable areas for *S. tenacissima* in Tunisia. Potential distribution under current conditions agrees firmly with what has been published in literature. In 1906, Manchicourt spoke of “sea of alfa”, showing the importance of its plant cover. In Tunisia, *S. tenacissima* steppes are widespread in central and the Southeast, where alfa covers 4330 km<sup>2</sup>. These are the rest of an estimated 1000 to 1200 million km<sup>2</sup> area occupied by this species some decades ago (Boudy, 1952). Despite its area diminishment, alfa is still used in Tunisia, where it provides fiber for paper mills and pastures.

Maximum entropy modeling approach has proved to be a method for predicting the potential distribution of *S. tenacissima* and it enable to identify the most variables that would predict areas of suitability. Our findings were consistent with previous results; Precipitation and temperature are consistently highlighted as influential in the distribution of plants (Xu et al., 2013; Springate and Kover, 2014), mainly precipitation exerts primary control of plant productivity and composition in semi-arid and arid land plant community (Passey et al., 1982; Graetz et al., 1988). In the study area, the distribution of *S. tenacissima* seemed to be driven by a range of predictor variables of which the most important are annual precipitation, and maximum temperature of warmest month. The results show that the climatic factors emerge as strong predictors for distribution of the species, unlike biophysical variables, altitude and slope that have least contribution. This implies that, at large spatial scales, the distribution of *S. tenacissima* is mainly influenced by climatic factors. This result seems to confirm that the direct influence of climate parameters such as precipitation, temperature is most effective when modeling species distribution concerns a large scale (Thuiller et al.,

2004), whilst for indirect parameters, such as altitude and topography, the influence of these factors would be taken at a finer scale (Guisan and Zimmermann, 2000). However, the low predictive power of biophysical variables can be also related to aggregation 30 seconds resolution, which reduces the amount of details they bring to the model (Guisan and Hofer, 2003). *S. tenacissima* mainly occurs in arid and semi-arid steppe grows on shallow soils between the 200 and 400 mm annual rainfall isohyets (Barber et al., 1997), but it can be found above and below these limits (Boudjada, 2003). It presents several morpho-physiological adaptations to resist water stress and high drought resistance (Pugnaire et al., 1996).

Based on the most recent projections, global warming that is caused by the increase in concentrations of greenhouse gases, is likely to increase global mean temperature by 1 to 3.7°C (IPCC, 2013), shift precipitation patterns and exacerbate extreme climate events (Christensen et al., 2007; Smith, 2011) This study applied Maximum Entropy modeling processes to look at habitat suitability for the *S. tenacissima* under future climate scenarios. The results showed that climate changes will have a profound effect on the *S. tenacissima*. Alfa steppes face significant threats throughout their habitat suitability. According to the Maxent model maps, the area with high suitability will be differing between current and future, current distribution would decrease during the 21<sup>st</sup> century. All climate projection scenarios showed a change in the alfa's range across the study area. Projected future distribution showed that there will be both expansion and contraction of suitability areas under 2050 as well 2070 climatic conditions. However, substantial amount of current suitability areas will be lost. A gain in range can be observed in the higher altitudes which suggest a shift to Northern higher altitudes contraction was more important, extent of change follows the northward movement under climate change as observed by other researchers. Some species migrate toward altitude to achieve more suitable areas (Parmesan and Yohe, 2003). Model projected suitable areas along the higher elevations, where species has not been observed. *S. tenacissima* will reach the areas currently suitable for *Pinus halepensis*. In support of this, Le Houérou (2001) suggested that the large extension occupied by the steppes of *S. tenacissima* in Northern Africa is the result of the regressive succession from open forest dominated mainly by *P. halepensis*. However, the ability of a species to migrate would involve seed dispersal, seed size, dispersal distance and age of reproduction (Ouled Belgacem and Louhaichi, 2013).

In our case, climate change is expected to cause species to shift northwards at short term, but at long term there is potential for extinction entirely from the Southern part or in portions of its range. It is notable that projections of ecosystem structure suggest a negative response of vegetation to the warming and drying trends.

The projected distribution of *S. tenacissima* under 2050 and 2070 climate scenarios showed considerable effects. Model has predicted a total decline of *S. tenacissima* distribution area in Tunisia. Climate projections, on future periods, indicated that the suitable area for alfa decrease significantly beyond 2050 and 2070. The decrease of the area of the *S. tenacissima* is explained mainly by the projected decline in rainfall. These results seem not to be contradictory with earlier works that announced the negative impact of changes in climate on biodiversity (Pearson and Dawson, 2003; Thomas et al., 2004a). Mediterranean ecosystems are quite vulnerable to rising temperatures and reduced water availability (Usedomenech et al., 1995). Whatever the cause of its decline, disappearance of such species may have dramatic consequences on the ecological balance of the whole ecosystem.

This study has tried to provide some useful information on the distribution of *S. tenacissima*. This information can be used to develop conservation strategies for the species and improved adaptive capacities of local people to reduce their vulnerability to climate change.

However, other factors influencing the distribution of species such as biotic interactions, genetic adaptation and the species dispersal abilities should be taken into account in order to draw relevant conclusions to enable better conservation guided and oriented decisions.

*S. tenacissima* is considered among the endangered species, that currently occupies a large areas in Tunisia, is projected with loss of more than 60% its range at mid-century. The combined effects of anticipated climate change and human long-term use may have significant negative impact on alfa steppes. *S. tenacissima* is likely to come under greater danger and presents a very high vulnerability to climate change. From the viewpoint of conserving biodiversity, results from this study will be useful in developing future alfa steppe management guidelines, which can be used to guide to develop conservation strategy for this species, by protecting current alfa suitable areas.

The Maxent modeled output appears to have predicted the distribution of *S. tenacissima* with a certain degree of accuracy. Moreover, the projection is made under the assumption that species cannot adapt to new conditions, which is not the case for several species, which have a strong evolutionary adaptation rate. Results need cautions though, as the approach does not furnish information about the evolutionary dynamics of a species. In addition, climate is neither the only determinant of species' ecological niches, nor even the most important, threat to the persistence of most endangered species. However, despite the environmental factor, the distribution of species is also influenced by evolutionally changes, biotic interactions and the species dispersal abilities. Thus, further experiments are required to find out physiological thresholds for *S. tenacissima* and the model outcome could be significantly improved by integrating soil parameters.

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