https://doi.org/10.22319/rmcp.v11s2.4705

Article

Impact of climate change on the potential distribution of *Tithonia diversifolia* (Hemsl.) A. Gray in Mexico

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Abstract:

The aim of this study was to estimate the possible impact of future climate changes on the potential distribution of *T. diversifolia* in Mexico. Distribution niches were modelled with MaxEnt for the 1951-2000, 2041-2060 and 2061-2080 climatologies, considering 20 bioclimatic and two topographical variables. For future climates, a HadGEM2-ES general circulation model (GCM) was considered, with two representative concentration pathways of greenhouse gases (RCP4.5 and RCP8.5). This information was obtained from the Global Climate Data Website WorldClim and processed with the Idrisi Selva system as raster images with 2.5 arc min resolution. The environmental variables that contributed the most to explain the geographical distribution of *T. diversifolia* were the May-October mean accumulated precipitation (pa5-10) and the mean maximum temperature of the warmest month (MMAX). The 10th percentile training presence logistic threshold reported a predicted suitable area (for the reference climatology) accounting for 30.71 % of the extent of Mexico. Niche modeling under climate change scenarios reported expansion as well as retraction areas for environmental suitability; however, after computing them, suitable areas are expected to present a small increment with respect to the climate reference period, 1950-2000: 31.62 %, 31.83 %, 32.45 % and 32.45 % of Mexican territory in scenarios for 2041-2060 in RCP 8.5, 2041-2060 in RCP 4.5, 2061-2080 in RCP 4.5 and 2061-2080 in RCP 8.5, respectively. Thus, climate change would bring more benefits than constrains for *T. diversifolia* dispersion.

Key words: Climate change, *Tithonia diversifolia*, Ecological descriptors, Niche distribution.

Received: 20/11/2017

Accepted: 04/07/2018

Introduction

Food production is becoming a real challenge in a climate that is changing. Under this context, the diversification of animal feed is a key aspect to better adapt to climate change. Hence, the need to assess the impact of climate change on the presence and potential distribution of forage species. This is the specific case of *T. diversifolia*, a native species with current distribution in the lowlands of southeastern Mexico, Central and South America, and which is considered an important genetic resource and an exceptional plant as an alternative in animal feed(1,2). The future risk for many plant species due to climate change has not been well established yet.

The global temperature has increased 0.85 ° C in the period from 1901 to 2011(3). Based on climate prediction models, it has been established that the saturation pressure of the vapor has been very sensitive to temperature changes; therefore, ruptures in the global water cycle are expected to manifest in the future(4). On the other hand, the availability of water will reportedly exhibit a marked annual reduction in the southeastern United States, the Caribbean and various parts of Mexico(5). In addition, agriculture expands and is intensified mainly in the tropics(6); it is estimated that approximately 80% of the new farmland will be based on forest substitution(7). Therefore, delaying or restraining the expansion of agriculture in the tropics will reduce carbon emissions and loss of biodiversity(8).

Climate change can modify the diversity of climates, as well as the composition of ecosystems[9]; these modifications would include alterations in the distribution, phenology and an increased risk of endangered species[10]. Several components of climate change are considered to affect all levels of biodiversity, from organisms and populations to biotic areas[11]. At basic levels, climate change can reduce genetic diversity in populations due to directional selection and dynamic migration, which may interfere with the resilience and functionality of ecosystems[12]; therefore, it may cause the modification of the network of interactions at the community level[13]. In addition, an effect of climate change may induce the invasion of potentially dangerous species to an ecosystem[14]; affecting the physiology, phenology and behavior of species[15].

In the face of the above, Mexico is interested in building an inventory related to the expected effects of climate change on desirable wild species. Thus, the aim of this study was to estimate the impact of climate change on the potential distribution of *T. diversifolia*.

As reported by several authors, the use of *Tithonia* include forage production, soil erosion control, building material and bird shelter[16]. As a counterpart, *T. diversifolia* is considered an allelopathic herb with water-soluble allelochemicals in parts of the plant and with such phytotoxic potency, that it could suppress the growth and accumulation of nutrients in associated crops[17].

Material and methods

Database

Data from 52 population sites of *T. diversifolia* were considered, with current distribution in the lowlands of southeastern Mexico[1,2]. The databases were obtained from two sources: the National Forest and Soil Inventory (INFyS) of the National Forestry Commission of Mexico (CONAFOR) and the website http://www.tropicos.org/.

Potential distribution areas

In this study, the MaxEnt model (maximum entropy)[18] was utilized to model the ecological niche and predict the most likely geographic distribution of *T. diversifolia*. MaxEnt has been widely used to estimate potential plant and animal distributions with high precision; certain terrestrial groups are excellent examples[19].

In the MaxEnt model, the distribution of a species is represented by a probability function P on a set of sites X in the study area. A P model is constructed using a set of restrictions derived from empirical data on the presence of the species[20]. Restrictions are expressed as simple functions of known environmental variables. The MaxEnt algorithm forces the average of each function of each variable to approach the actual average in those areas where the species is present. Of all the possible combinations of functions, the one that minimizes the entropy function, measured with the Shannon index, is selected. The general expression of the probability function for *i* environmental variables is[21]:

$$P(x) = e^{\lambda \cdot f(x)}/Z\lambda$$

Where:

P(x)= probability function;

λ= weighting coefficient vector;

f= corresponding vector of environmental variable functions;

The P (x) values thus obtained represent values of relative suitability for the presence of the species, thus constituting the basis for a potential distribution model. A high value of the distribution function in each pixel indicates that it has favorable conditions for the species[22].

In this study, a model was generated using layers of environmental parameters and data of the occurrence of the species. 75 % of the occurrence records were used as training points, and 25 %, as validation points; in addition the AUC (area under the curve) index was used to evaluate the statistical model, since this index is one of the most commonly utilized to measure the quality of the models[20]. The settings that can be determined in the MaxEnt model affect its accuracy, since the model can work with simple or complex environmental variables.

Databases and environmental parameters

The data of monthly, seasonal and annual precipitation, maximum temperature, minimum temperature, average temperature and thermal oscillation of the 1950-2000 (reference climatology) and 2041-2060 and 2061-2080 (future climatology) periods were utilized for an environmental characterization of the sites where the species occurs. These climatic data were obtained from the WorldClim Global Climate Data website, and the images were processed in ASCII and raster formats, with a resolution of 2.5 min arc. For the 2041-2060 and 2061-2080 periods, the HadGEM2-ES GCM was considered with two representative concentration pathways of greenhouse gases: RCP 4.5 and RCP 8.5. This model has been used in the new climate change scenarios for Mexico; study presented in the Fifth Climate Change Assessment Report by the IPCC (Intergovernmental Panel on Climate Change)[23].

Other variables that were included in the modeling of the distribution of *T. diversifolia*, were the altitude and the slope of the land, images that were obtained from the National Environmental Information System (*SIAN*) of the National Institute for Research on Forestry, Agriculture and Livestock (INIFAP)[24]. The list of variables used for the space niche model were: slope of the land (%), altitude (m), mean annual maximum temperature (MAMT), May-October mean maximum temperature (MMT5-10), November -April mean maximum temperature (MAX11-4), maximum temperature of the warmest month (MMAX), mean annual temperature (MAT), mean temperature from May to October (MT5-10), mean temperature November-April (MT11-4), minimum temperature of the coldest month (MTCM), average temperature of the coldest month (ATCM), mean minimum annual temperature (MATmin), minimum average temperature from May to October (Tmin5-10), minimum average temperature November-April (Tmin11-4) , accumulated annual precipitation (Pann), accumulated precipitation May to October (P5-10) accumulated precipitation November-April (P11-4), accumulated precipitation of the driest month (Pmin), precipitation of the wettest month (Pmax), mean annual thermal oscillation (MATO), thermal oscillation from May to October (TO5-10), and thermal oscillation from November to April (TO11-4)

Areas with probability of environmental suitability

The model developed from the MaxEnt prediction for the potential distribution of *T. diversifolia* was examined with the Idrisi Selva system[25], and a map was made with the threshold values of the pixels corresponding to the 10th percentile[26]. For the calculation of the potential distribution area of the species, the areas occupied by water bodies and urban centers were not considered. These thematic layers were obtained by manipulating the use of the soil and the vegetation layer[27].

Ecological descriptors

The ecological descriptors for *T. diversifolia* were determined on the basis of environmental intervals derived from the characterization of the parameters of sites of species presence. This was done using the IDRISI system and raster images of each environmental variable and the geographic coordinates of each site where the species is present.

Results and discussion

In the model of the potential distribution niche of *T. diversifolia*, the operational curve showed satisfactory results (Figure1). When considering the training data (75 %), the area under the curve (AUC) of *T. diversifolia* was 0.979; while when the test data is used (25 %), the validation of the model reported an AUC of 0.966, which indicates that the ability of the model to represent the presence of species was satisfactory(28).

Figure 1. Operational curve for *T. diversifolia*

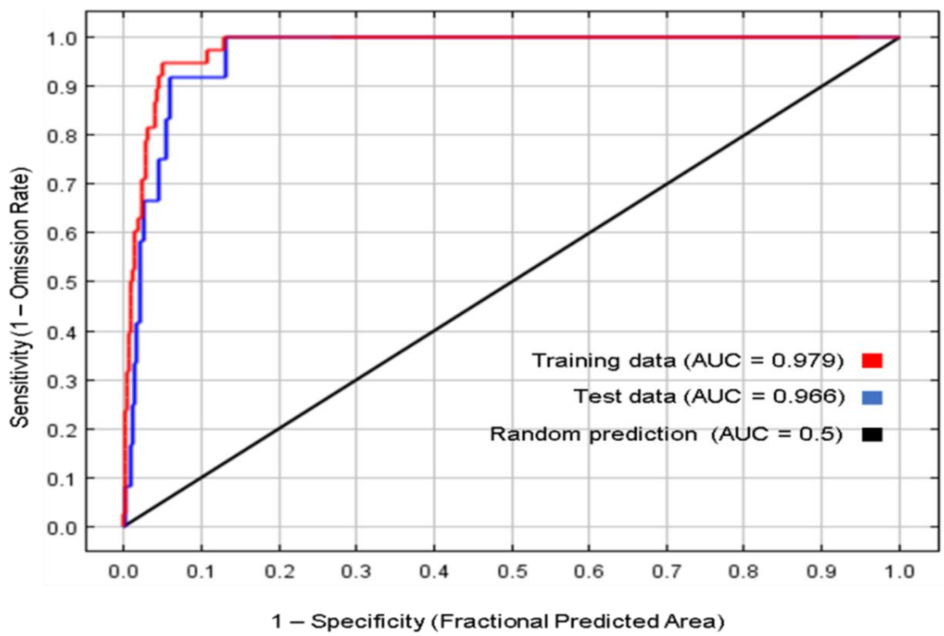
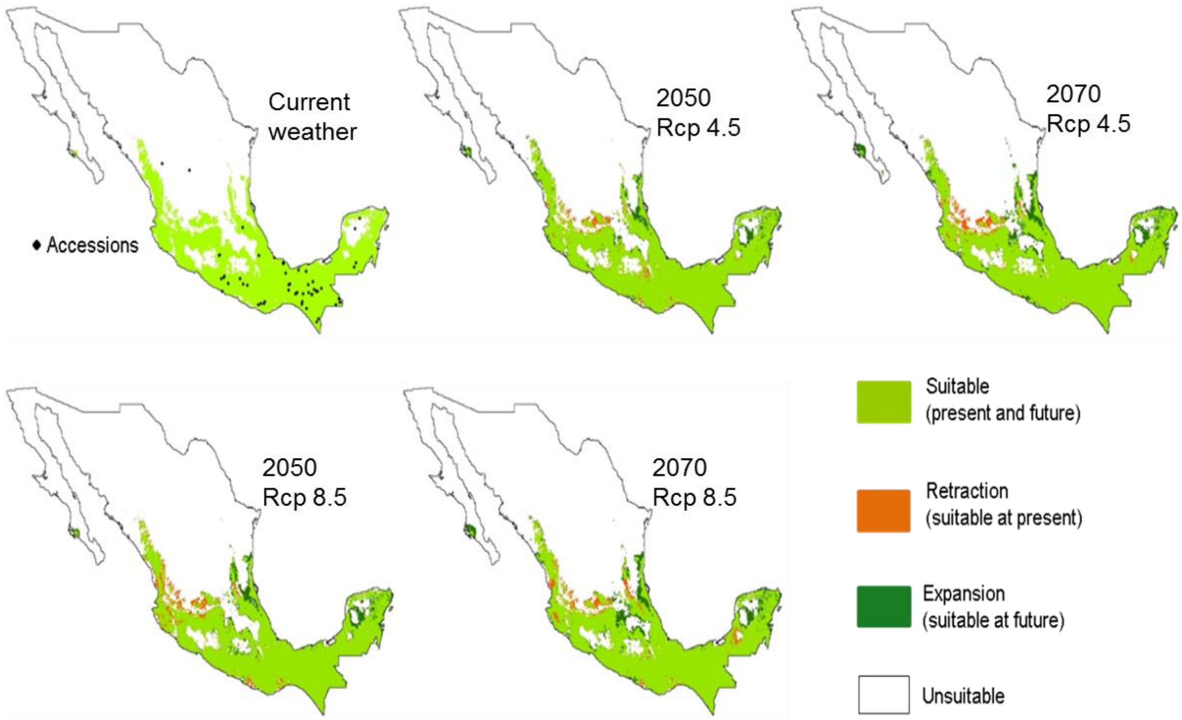


Figure 2 shows the current geographical distribution of *T. diversifolia*. Its presence is mainly in the Central-South region, the Gulf of Mexico, the Pacific coastal areas and the Yucatan Peninsula, which is the tropical part of the country (<23 ° 26 '14' 'North). Most of the populations of *T. diversifolia* are concentrated in the southeastern part of Mexico, which corresponds to the asseveration about their geographical origin (Mexico and Central and South America)(2), as well as in tropical and subtropical areas around the world, which has allowed it to grow under a wide range of environmental conditions and, therefore, develop a wide range of adaptation(29).

Figure 2. Current distribution of *T. diversifolia*, and suitable, unsuitable, retraction and expansion areas for this species under four climate change scenarios in Mexico



The ecological descriptors of *T. diversifolia* and the environmental variables that contribute to the construction of the model can be observed in Table 1. According to these results, the distribution of *T. diversifolia* is mainly determined by variable P5-10 (78.2 %), i.e., the amount of precipitation during the May-October period, which is a key element for the occurrence of this species, as well as for other species, where precipitation in small but frequent events during the summer is key for its good development(30). The descriptor of *T. diversifolia* for this variable indicates a range of 297 to 3,404 mm (for the annual rainfall of 356 to 3,828 mm), which allows for a wide variation of the spatial precipitation. These results are consistent in the sense that this species grows properly under a wide range of precipitation. However, annual rainfall limits of 600 and 5,000 mm(30) have been established. Therefore, it can be concluded that *T. diversifolia* can grow even with less seasonal and annual rainfall than that cited by the current literature.

The second most contributing ecological descriptor was MMAX (mean maximum temperature of the warmest month), and *T. diversifolia* also exhibited a broad thermal range, of 21.9 to 34.4 ° C. Given that *T. diversifolia* also has a wide range for the MTmin descriptor (mean minimum temperature of the coldest month, 1.8 to 19.8 ° C, Table 1), it can be concluded that this species is capable of exploring and colonizing thermally extreme environments. Other authors(2) had previously indicated that it adapts to different climates and altitudes.

Table 1. Ecological descriptors of environmental variables that condition the geographic distribution of *T. diversifolia* to the largest extent

Variable	Minimum value	Maximum value	Contribution (%)
P5-10, mm	297	3404	78.2
MMAX, °C	21.9	34.4	5.9
Slope, %	0	14	3
Tmin, °C	11	26.15	2.8
Pmax, mm	67	713	2.1

The results of potential niches for *T. diversifolia* under the reference climatology (1951-2000) as well as future climatologies, are also shown in Figure 2. The maps in this figure show the presence of adequate, inadequate, retraction areas and expansion for *Tithonia* diversifies compared to the scenarios of the reference climatology and future climatologies. In all future scenarios, both retraction areas and expansion areas will appear, showing the potential dynamics of the areas with environmental suitability according to the future climatic changes.

The training presence logistic threshold of the 10th percentile estimates an area with environmental suitability (for the reference climatology) that represents 30.71 % of the territorial extension of Mexico. After a balance between the areas of contraction and expansion of climate change climatologies, the optimal areas will increase to 31.62 %, 31.83 %, 32.45 % and 32.45 % of the Mexican territory, in the 2041-2060 RCP8.5, 2041 -2060 RCP 4.5 and 2061-2080 RCP 4.5, 2061-2080 RCP 8.5 scenarios, respectively. These results show that future climate changes will be apparently beneficial to *T. diversifolia*. Considering that the most significant variables in the models of the distribution niches are the accumulated precipitation from May to October and the average maximum temperature of the warmest month, it may be inferred that the combinations of these parameters under climate change scenarios will have a positive effect on areas with environmental suitability for *T. diversifolia*.

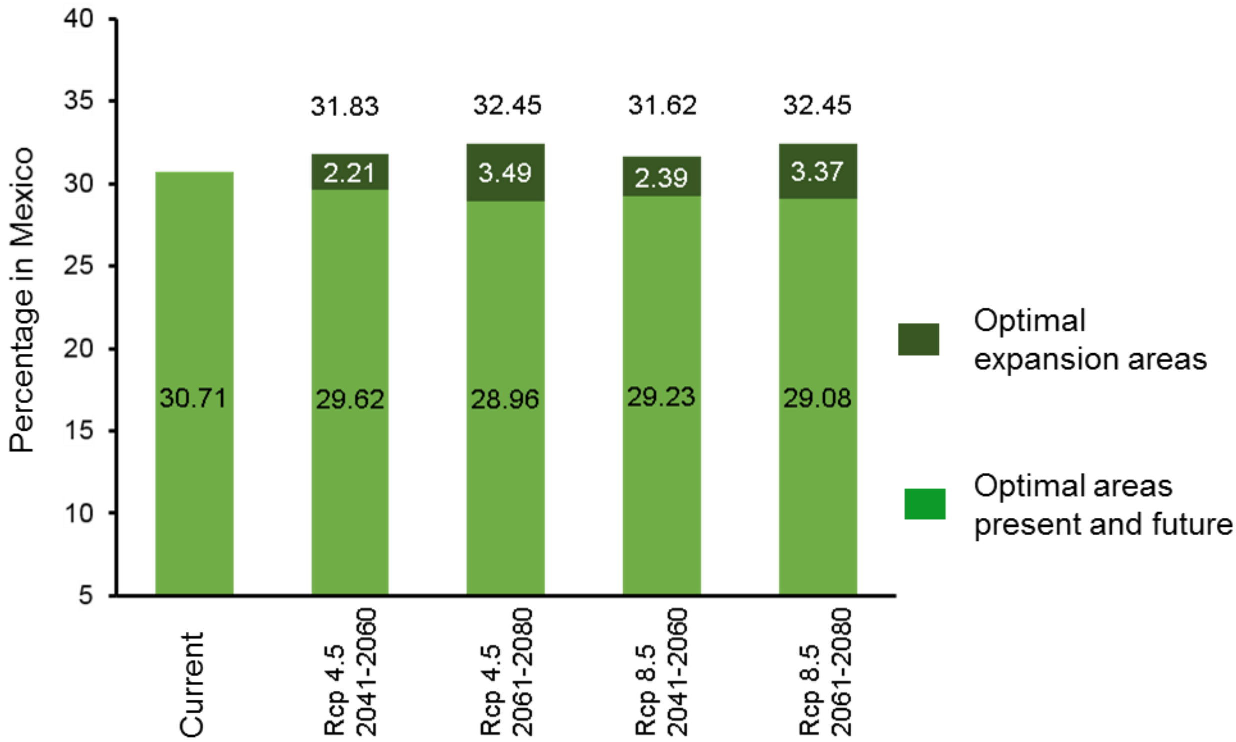
The effect of the impact of climate change on the distribution of species may result in 'winner' or 'loser' species(31). The final result will depend on their evolutionary adaptation. For example, expansions of suitable areas have been reported due to climate change for other species like *Leucospermum hypophyllocarpodendron* subsp. *hypophyllocarpodendron*(11).

Most studies on the effects of climate change on species distribution have reported negative impacts, with the retraction areas being greater than the expansion areas(32). In the present study the opposite was obtained, i.e., larger areas of expansion than the retraction areas. As can be seen in Figure 2, these two types of areas have a geographical pattern; contraction areas are mainly located in the western region of the country and near the Pacific coast, while expansion areas are located mainly on the eastern side and near the coast of the Gulf of Mexico. This fact points to two regions of the country where future weather patterns differ in environmental conditions and, therefore, in their level of suitability for *T. diversifolia*. This particular situation has already become manifest, since the region corresponding to the retraction areas has been previously reported with changes in crop patterns as a result of regional climate changes[33,34].

According to the maps exemplified in Figure 2, no current population of *T. diversifolia* appears to be affected by the retraction of environmental fitness. However, in the event that some populations of *T. diversifolia* are located in retraction areas in the coming years, it should be considered that these populations will have only two options to survive —a) migrate to more favorable environments, or b) adapt to the new climate conditions[35]—, which will depend mainly on the genetic diversity of the species[36,37]. In the case of the present study, it can be hypothesized that environmental suitability will gain a little more surface area due to climate change, and apparently this may promote the future dispersion of *T. diversifolia* to new areas. However, it is important to consider the potential capabilities of this species to compete against others in the ecosystem or against invasive species that constitute a threat to the stability of the ecosystem[38,39,40]. In addition, it must be considered that, in the future, *T. diversifolia* will also depend on its ability to adapt to climate change[41], which is a function of its ability to colonize new areas, or (when necessary) its ability to implement physiological modifications in order to adapt to the new environment[42]. The ecological plasticity of *T. diversifolia*[1,30] is a key aspect for adapting to climate change and new climates[43].

According to the results obtained, the expected climate change for both periods will have a more positive than negative effect on the environmental suitability of *T. diversifolia* (Figure 3), thus allowing its potential territorial expansion in the future. However, it is clear that this environmental advantage to be caused by future climate change will be favorable as well for other species that may compete with *T. diversifolia*. Under this type of scenario, the wide range for most of the ecological descriptors of *T. diversifolia* (Table 1) could be an advantageous feature, all the more if one considers the genetic diversity of this species in other parts of the world, which may increase the adaptation and colonization capacities of *T. diversifolia*[36,44].

Figure 3. Dynamics of the surface area with environmental suitability for *T. diversifolia* in the current climate and four future climatologies



Although the current and future climate scenarios appear to be favorable for *T. diversifolia*, measures should be taken to preserve the current populations of the species in order to ensure its presence in its natural environment. On the other hand, since it has been found that *T. diversifolia* is an allelopathic weed with water-soluble allelochemicals in various parts of the plant(17), attention should be paid to supervise its possible territorial expansion due to possible effects on associated crops. Also, the fight against the presence of *T. diversifolia* as a weed in crops should also be monitored, as it may threaten the natural populations of this species.

Conclusions and implications

At present, the areas with environmental suitability for *T. diversifolia* represent about one third of the Mexican territory, adapting to a broad range of temperature and humidity conditions. The presence and spatial distribution of this species is determined by the amount of accumulated rainfall during the May-October period, ranging from 297 to 3,404 mm. Future climate changes will cause both retraction and expansion of areas with environmental suitability in different parts of the country; an analysis between these two effects leads to the conclusion that in the present century these areas will increase slightly, between 0.91 and 1.74 %, according to the models utilized. Therefore, it may be considered that this species can be a good alternative for forage production for the future. On the other hand, given that *T. diversifolia* has been found to be an allelopathic herb, attention should be paid to the supervision of its possible territorial expansion, due to the possible effects on associated crops. The fight against the presence of *T. diversifolia* in crop fields should also be monitored in order to prevent it from constituting a threat to the natural populations of this species.

Acknowledgements

To the National Forest and Soil Inventory (INFYS) of the National Forest Commission (CONAFOR), for providing valuable information on the presence sites of *T. diversifolia* in Mexico. Also, the authors are also grateful to the National Institute for Research on Forestry, Agriculture and Livestock (INIFAP) for having allowed the use of raster images of the altitude and slope of the land of the National Environmental Information System.

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