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Research Article

Climate change impact on *Olneya tesota* A. Gray (Ironwood) distribution in Sonoran desert using MaxEnt Modeling approach

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Abstract
Based on different climatic scenarios, the distribution of the *Olneya tesota* A. Gray (Ironwood) has been modeled using the MaxEnt modeling approach in the Sonora State of Mexico. Maximum Entropy Species Distribution Modeling was used to predict distribution probability. 71,168 presence data and BIO1 to BIO19 variables of Worldclim BIOCLIM dataset for the present time, 2050 and 2070 used for modeling. The model was performed with an acceptable range of sensitivity for training data (AUC=0.927) and random prediction (AUC=0.5). The results demonstrated that the high contributed variable on the presence of the *O. tesota* A. Gray is BIO17 Precipitation of Driest Quarter (48.3%) and the low contributed variable is BIO2=Mean Diurnal Range (Mean of monthly (max temp - min temp)) (0.9%). This means that the presence of the species is highly dependent on dry months precipitation which doesn't have high fluctuations according to the used climate change scenario. Temperature fluctuations have not affected *O. tesota* A. Gray presence as it is known as a resistant species for extremely high temperatures. Therefore the probability of the presence of the species shows a significant increase on high altitudes mountains on the north-east of the Sonora state. Finally, the study concludes that climate change will affect the distribution of the *O. tesota* A. Gray as an extinction risk and the same time will help the expansion of the species presence probability on the region. And it has been encountered new regions to recommend this valuable species as a reforestation alternative for conservation and management strategy like Soyopa, Aguaprieta, and Sahuaripa municipalities among the others.

Keywords: Ironwood, Distribution, Climate change, Sonoran desert, Mexico.

Introduction
Extinction and invasion risks of species is an important issue on natural resources conservation and management all over the world (Walker 2014). Climate change's impact on natural resources is an important driver of extinction and invasion risk and these kinds of studies are highly recommended to formulate more efficient bio-informatics conservation and management strategies (Peterson *et al*. 2015). Many types of research are indicating that the extinction risk is rising because of climate change impact (Thomas *et al*. 2004; Pearson *et al*. 2014) and anthropogenic activities

unsustainable increasing (Leão *et al*. 2014). The global average of the extinction ratio of the species that mainly caused by climate change impact globally is around 1% of the species per year, and many important scientific journals papers like Nature Journal mention the extinction rate of the species will increase to more than 10% per year on 2050, and some of the calculating for Mexico biodiversity it will be more than the global average and even 35% of biodiversity on 2050 will extinct (Thomas *et al*. 2004; Peterson *et al*. 2015). For Mexican deserts, this problem is more visible because of agricultural expansion and other inadequate use of water resources among the others. Therefore, it is crucial to put special emphasis on desert keystone species.

For various reasons, even in developed countries, identification, sampling, and real mapping of the natural resources still remain a difficult issue for each species (Del Barrio *et al.* 2006) on actual time and their changes with the currently high climate changes fluctuations and anthropogenic activities impact on the populations and distributions of the species (Peterson *et al.* 2015). Unfortunately, Mexico as a mega-biodiverse country with more than 40% territory superficies' as arid and semiarid zones with continuous increasing of desertification and deforestation (Vázquez-Méndez *et al.* 2008) and categorized with a high rate of desertification on international scientific communities. On the other hand, these areas' key species' have special importance on ecology, ecosystem, and human life (Medeiros and Drezner 2012). There are few studies about the Mexico flora species distribution with an evaluation of climate change impact on their distribution and almost there is no study about climate change impact on the distribution of desert species like O. *tesota* A. Gray (Del-Val *et al*. 2015).

Species Distribution Modeling (SDM) models are one of the useful instruments to study niche modeling, extinction and invasion risk, micro and macrohabitat suitability, and climate change impact on their distribution among the others (Araújo *et al*. 2005, Phillips *et al*. 2006). There are different models developing day by day in this area of science with using different algorithms such as BIOMAPPER (ecological niche factor analysis), GARP (genetic algorithm), GRASP (generalized linear model), SPECIES (Artificial neural network) (Austin 2007, Pearson *et al.* 2011) and many others. One of the most common presence data-only used is MaxEnt (Maximum Entropy) model (Phillip *et al*. 2004, Khanum *et al*. 2013) that has shown good results on distribution prediction and model evaluation (Matyukhina *et al*. 2015, Elia *et al.* 2015). Worldclim BioClimatic database is well-known to use as a principal database as environmental layers inputs on SDM modeling. As coming in this paper the world climate provided data from the global climate change modeling scenarios are also common for future distribution modeling of the species. And also it is proved that using the collection of different species sampling geographical coordination is also applicable for modeling for the enriching of the observational database for any SDM modeling like MaxEnt.

O. tesota A. Gray (Ironwood) is one of the high value and key species s as a principal pattern distributed on Sonoran desert ecosystem (Shupe 2005) which illegally cut by people for different uses such as handicrafts and coal production among the other purposes (Zuñiga and Suzán 2010). This species is an endemic one that is classified as being in extinction risk treat and encountered under the special protection of NOM. 056. 2010 of Mexico and it is recommended numerous times to conservation, rehabilitation, and as a reforestation alternative on the Sonoran desert (Verónica and Humberto 2014). Due to the high costs and risks of reforestation and rehabilitation on desert regions, generating useful and applicable knowledge on the local scale about the future suitable environment for its presence is necessitated as a management strategy planning (Medeiros and Drezner 2012). Unfortunately, there are only a few studies about *O. tesota* A. Gray and other desert species' actual distribution and suitable environmental conditions considering climate change impact to know future distribution (Zuñiga and Suzán 2010). Therefore, in this study, it is hypothesized that climate change or global warming is a strong threat of the extinction of *O. tesota* A. Gray on Sonoran desert. Therefore they are many questions about *O. tesota* A. Gray species that may respond by MaxEnt modeling. Our study focused on finding some confinable responses for following questions:

1-How is the actual probable presence distribution of the species on the Sonora State of Mexico according to all historical presence data of it on Sonora State? 2) How will affect global warming (climate change) in 2050 and 2070 on the distribution of the species? or whether climate change is an extinction risk treat for it? or will affect the suitability of environmental conditions for it in the future at Sonora State? 3) Which environmental factors are more important in the actual and future distribution of the species at Sonora State? And why? 4) What kinds of recommendations may give to conservation and management strategy for this species on Sonora State? Where are locally recommended reforestation or conservation areas?

Therefore, the objective of this study was to estimate actual and future probable distribution macrohabitat of *O. tesota* A. Gray (Ironwood) on the Sonora State of Mexico, using MaxEnt conventional model to study the climate change impact on its distribution to discuss efficiently conservation and management strategies of the species. The hypothesis of the study was that climate change has no significant impact on the same level of anthropogenic activities impact. Finally, it also discusses the extinction and invasion risks by regions and possible future immigration of the species by climate change and changes in its habitat suitability.

Material and methods

Study area

Sonora State located in the northwest of Mexico is the principal part of the global habitat of the *O. tesota* A. Gray species with 179,355 km2 area considered as an area of study. This region has an elevation from 0 m to 2,620 m of the elevation expanded from Baja California Gulf to Sierra Madre Occidental Mountains that includes 3 types of climate Variety to consider as the principal demonstrative habitat of the *O. tesota* A. Gray (Fig. 1).

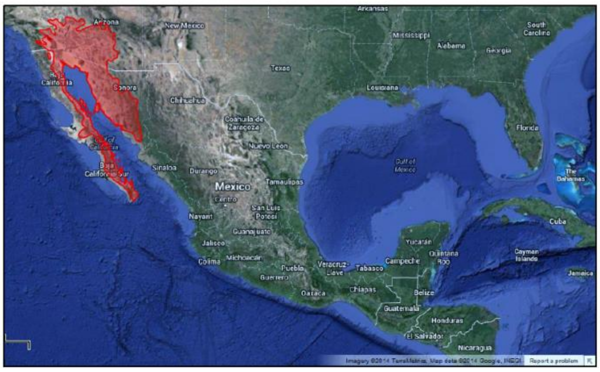

Figure 1. Delimitation of distribution of the species (http://globalspecies.org/kmlserver/getkml/*Olneya_tesota*/range).

The strongly altered habitat patch, 'Falkenbergwiese' (hereafter FB), was an isolated 5-ha meadow in the north of Vienna (48°18'N, 16°22'E; elevation 318 m). The native dry grassland vegetation had been altered when alfalfa (*Medicago sativa*) was sowed several years before the study. The landscape adjacent to the study area consisted of a mixed oak forest (N), a huge conventionally cultivated vineyard (E), a transmitting station including buildings and transmission masts (S), and an intensively managed arable field (W). The study population was isolated from the next nearest ground-squirrel colony by the vineyard in the east. The study site belongs to an area of excursions, with the daily presence of people running their dogs, hikers, bikers, and picnickers. Ground squirrels were sampled on a focal area of about 1 ha size.

Presence data of species

Different sources of observation data from various projects as described in Table 1 has been used. A total of 71,161 observation data of presence only for *O. tesota* A. Gray and other species have been extracted from INIFAP

(Mexican National Institute of Research for Forestry Agricultural and Livestock), CONAFOR (Mexican National Commission Forestry), CONABIO (Mexican National Biodiversity Commission) and field sampling converted in .csv format to use in MaxEnt Modeling for the Sonora State of Mexico. The observation data have a different types of sampling methods with the different G.P.S instruments but with spatial resolution error of about 5 m, and according to environmental variables created a database 200 m×200 m resolution each pixel, the error margin was acceptable. The sampling methods for different resources were different, for example, the INIFAP database was sampled by 32 systematic stratified circle polygons per site as coming on Fig. 2.

Table 1. Presence-absence observation data's of *O. tesota* A. Gray on the Sonora State of Mexico.

No.	Number and details of the sampling	Project name
1	8,411 observation data of 18 species s on north-west of Mexico;	Sonoran Coastal areas producers association NGO, 2014.
2	60,000 observational data of Just *O. tesota* A. Gray;	National inventory of forestry CONAFOR Project, 2004-2009 observation.
3	6,500 observational data of 26 forestry species´ on Sonora	Martínez-Salvador M. 2013. INIFAP Project
4	250 Personal Observation of *O. tesota* A. Gray on Hermosillo city of Sonora State	2015.

Present and future BioClimatic or environmental variables layers Worldclim BioClim database (consulted in 2015) from their webpage with ~ 1 km spatial resolution as commonly used in MaxEnt modeling used for environmental layers database. They have been downloaded and clipped for Sonora State with about 1km spatial resolution and then extrapolated to 200 m resolution .asci format raster layers with ArcView v.10.2 Desktop®, for all nineteen BIOCLIM (BIO1 to BIO19) as coming on Table 2 for the present time (average for 1950 to 2010), 2050 (average for 2041-2060) and (average for 2061-2080) (Khanum, *et al.* 2013). Between the existed different future climate scenarios as a base of future BioClimate data, the Greenhouse Circulation Modeling (GCM) model outputted BioClimate data are named (RCPs), Rcp85 (IPCC, 2013) as a Global extreme climate change scenario (Pearson *et al.* 2014) used for 2050 and 2070 environmental layers.

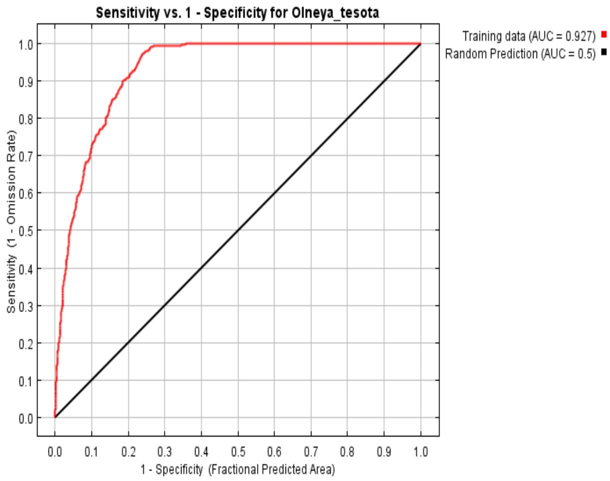

Figure 2. Sensitivity diagram of the MaxEnt model for *O. tesota* A. Gray.

MaxEnt Modeling

The maximum entropy MaxEnt (version 3.3.3e) developed in 2011 (Philips *et al.* 2006, Elith 2011) used as a modeling system. MaxEnt uses presence-only data to predict the distribution probability of the species based on the theory of maximum entropy with attempting to similarity comparison of environmental conditions automatically (Matyukhina *et al.* 2015). The other raster calculations and mapping of the results were done with ArcView v.10.2®, to adequate observation data, probability equations among the others.

2.5 Model evaluation

To execute the MaxEnt model, 80% of *O. tesota* A. Gray observation data are used as a training dataset and 20% as a testing one and jackknife test used to obtain the portion of contribution and importance of the variables of each BIOCLIM variable on the *O. tesota* A. Gray distribution (Philips 2006, Khanum *et al.* 2013).

Results

MaxEnt model performed with training data

AUC of 0.927 and random prediction AUC of 0.5 as sensitivity indices of the model demonstrate that the modeling results are acceptable (Phillips *et al.* 2006, Matyukhina *et al.* 2015) tuning of the model for the present time, 2050 and 2070 as it shown on sensitivity diagram Fig. 2 on the following as acceptable run according to various authors (Khanum *et al.* 2013). As a first result, the contribution portion of all nineteen BIOCLIM variables from Bio1 to Bio 19 has been obtained and given in Fig. 3, the calculation for 80% of the observation training data, it is observed the first high value contributed variable is BIO17 = Precipitation of Driest Quarter and lowest contributed variable is BIO2=Mean Diurnal Range (Mean of monthly (max temp - min temp)).

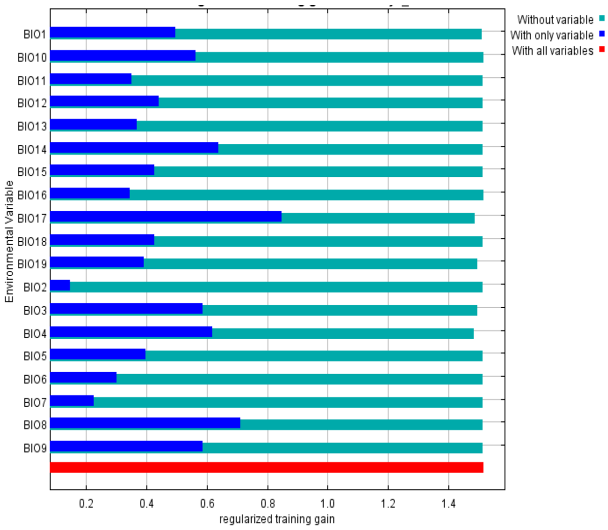

Figure 3. Relative predictive power of different BioClimatic variables based on Jackknife regularized training in the MaxEnt model for the species.

As it can be seen in Fig. 4 as a response to the presence of the *O. tesota* A. Gray to Bio17 as a high contributed variable, the function of the presence is close to the normal distribution curve, but for Bio2 it is not closed to it and contribution is too low. As it mentioned in the Materials and method part, BIO17 = Precipitation of Driest

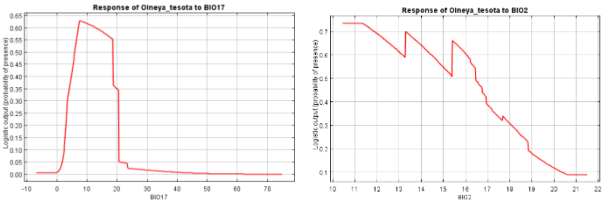

Figure 4. The response of the Distribution probability of *O. tesota* A. Gray.

Quarter and it means the presence of the *O. tesota* A. Gray highly depended on dries four months of year precipitation and BIO2=Mean Diurnal Range (Mean of monthly (max temp - min temp)) as extreme rises of temperature will not affect its presence in the future that is agreed in with other studies about this species (Zuñiga and Suzán 2010, Verónica 2014).

It may discuss other BioClimatic data's contribution and response for different modeling of *O. tesota* A. Gray distribution. As a principal result, it has been obtained the predicted probability of the presence of *O. tesota* A. Gray on Sonora State for the present time which shows the present distribution is close to the coastal area where is the elevation encountered between 0m to 1000m (Zuñiga and Suzán 2010).

These results agree with different studies about *O. tesota* A. Gray population's distribution. Therefore, it is confinable modeling results for actual distribution delamination of the *O. tesota* A. Gray on the Sonora State of Mexico (Fig. 5).

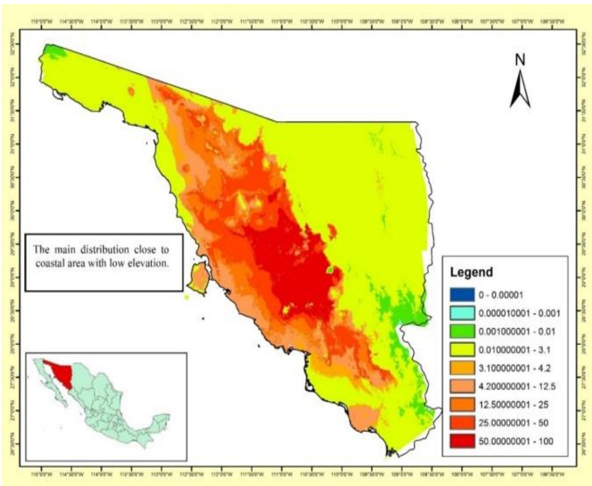

Figure 5. Presence probability prediction of the species, present time, Sonora State of Mexico.

The results of the simulation with the climate change scenario for 2070 is showing that the suitability of the ambient is expanding for the highly elevated areas of the Sonora State of Mexico. It means that climate change will help the species to immigrate to places with different geographical variables bypassing the time. As it showed in Fig. 6, it is observable on the map, the expansion of the distribution on the northeast part of the Sonora State mountainous areas of Sierra Occidental Madre is increased. The difference of the probability of the presence between the present time and 2070 to observe the rate of increasing the suitability of the environment for presence with from blue to red colors on Fig. 7.

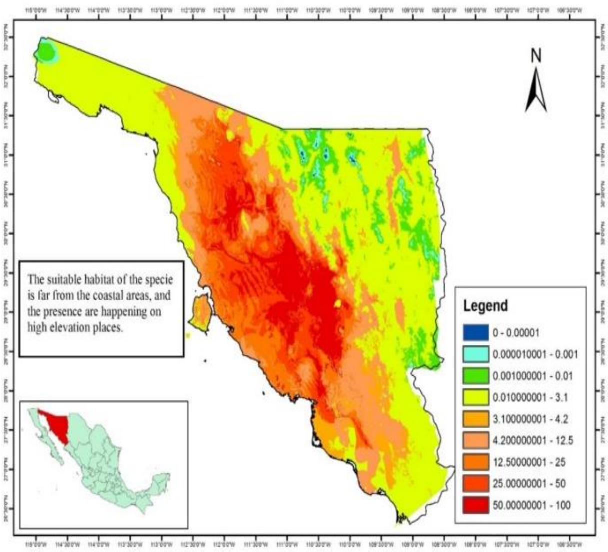

Figure 6. Presence probability prediction of the species on 2070, Sonora State of Mexico

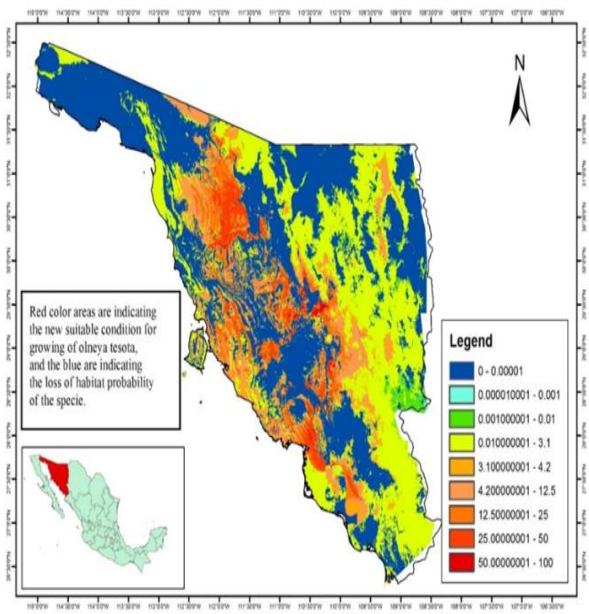

Figure 7. Difference of presence probability prediction of the species between 2010 and 2070, Sonora State of Mexico.

Based on Fig. 8 it can be seen that new municipalities such as Bacanora, Agua Prieta, Fronteras, Huasabas, Nacozari de Garcia, Onavas, Sahuaripa, San Pedro de la Cueva, Soyopa, Suaqui Grande and Villa Hidalgo that there is not a report about the presence of the *O. tesota* A. Gray in these regions.

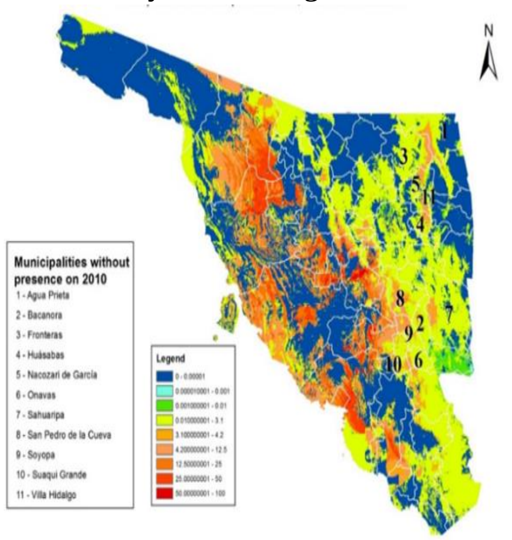

Figure 8. Difference of presence probability prediction of the species on 2070 in different municipalities that were not present at the present time, Sonora State of Mexico.

Discussion

There are some studies about the evaluation of the presence adaptability of the species and generating useful information about conservation and management strategies in other regions with other species (Elia *et al.* 2015) that permit us to discuss in *O. tesota* A. Gray presenting in this region. The high priority of introducing the species is calculated by categorizing the probability of presence increases that helps to provide the rehabilitation and reforestation strategies. It may help to future studies about the species adaptation with new high altitudes among the other studies. The conclusion is according to the used climate change scenarios, climate change will affect as extinction risk threat on some part of the populations of the *O. tesota* A. Gray on the Sonora State of Mexico and it will help to the expansion of favorable environment to the growth of it in high altitudes.

We may claim that *O. tesota* A. Gray as a key species on Sonoran desert is a good alternative for ecosystem rehabilitation and reforestation from now to the future in altitudes higher (more than 1000 meters) than its recognized habitat indicator as a habitat constructor, nurse of big number of flora and fauna and protector of the ecosystem. Ultimately, *O. tesota* A. Gray will immigrate rapidly to geographically high altitudes as climate change impact its distribution, therefore it is recommended to introduce this species in other parts of Sonora as an adaptation study for conservation and management studies of the species. Moreover, we recommend the germplasm collection of the species on the negative affect estimated area as valuable genetic recourses to have the possibility of use on future rehabilitation and reforestation programs.

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