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Article

# Distribución y conservación de *Quercus oleoides* Schltdl. & Cham. en la Reserva de la Biosfera Sierra del Abra Tanchipa

# Distribution and conservation of *Quercus oleoides* Schltdl. & Cham. in the *Sierra del Abra Tanchipa* Biosphere Reserve

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**Resumen:**

En la Reserva de la Biosfera Sierra del Abra Tanchipa, los encinares tropicales (*Quercus oleoides*) actúan como reguladores ambientales y son un recurso maderable valioso para los pobladores locales; sin embargo, las actividades antrópicas han afectado considerablemente estas comunidades vegetales. Los objetivos de este estudio fueron conocer la distribución actual y potencial de *Quercus oleoides,* sus usos actuales y definir áreas prioritarias para su conservación. Se llevó a cabo una revisión documental, se consultaron herbarios y realizó trabajo de campo, además de un análisis espacial basado en Sistemas de Información Geográfica y una modelización de la distribución potencial. La definición de sitios prioritarios se realizó mediante una evaluación multicriterio, con base en un análisis jerarquizado (AHP) y en el conocimiento de expertos. En la Reserva y en su área de influencia, *Quercus oleoides* tiene presencia relictual y dispersa a lo largo de la sierra. Su distribución está asociada principalmente a suelos delgados, pendientes suaves y elevaciones menores a 350 msnm. La superficie que podría haber ocupado esta comunidad vegetal es superior a 15 000 ha, pero la remoción de la cubierta original para dedicar los terrenos a actividades agropecuarias y el aprovechamiento irrestricto de la especie han causado una reducción crítica de sus poblaciones. Actualmente el área propicia para su conservación es de aproximadamente 200 ha, donde es posible iniciar acciones para su restauración y conservación.

**Palabras clave:** Conservación, distribución potencial, evaluación multicriterio, *Quercus oleoides* Schltdl. & Cham., *MaxEnt*, Sierra del Abra Tanchipa.

**Abstract**:

Tropical oak forests (*Quercus oleoides*) are environmental regulators and provide wood products to the local inhabitants of the *Sierra del Abra Tanchipa* Biosphere Reserve; however, some human activities have modified considerably this vegetation community. The aims of this study were to determine the current and potential distribution of *Quercus oleoides*, to know its current use and define priority conservation areas. For the current distribution, documentary and herbarium review as well as fieldwork were made, and the modeling of the potential distribution was done by means of spatial analysis based on GIS. Several criteria assessed by experts were analyzed using the analytical hierarchy process (AHP) and multi-criteria evaluation to locate sites suitable for conservation. Within the Reserve and its influence area, *Quercus oleoides* is distributed as dispersed relicts. Its current distribution is associated with thin soils, gentle slopes and elevations < 350 m asl. It is likely that oak forests occupied an area >15 000 ha in the past. However, the conversion of the original forest cover to agriculture and the intense use of this species have nearly led to its disappearance. The areas suitable for conservation comprise less than 200 ha, where protection and restoration strategies should be applied.

**Key words:** Conservation, potential distribucion, multicriteria evaluation, *Quercus oleoides* Schltdl. & Cham., *MaxEnt*, *Sierra del Abra Tanchipa*.

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# Introduction

Oaks (*Quercus*: Fagaceae) are one of the groups of woody plants of greater ecological and economic importance throughout the world (Valencia, 2004), in which Mexico occupies the second place and is the largest distribution center of these species in the world. American continent, with about 161 species of the 450 that exist throughout the planet (Nixon, 1993; Challenger and Caballero, 1998). They perform important ecological functions, acting as environmental regulators, reduce soil erosion, infiltrate water and are habitat for numerous species (Bacon, 1999; Arizaga *et al*., 2009). These forests are closely linked to mountain areas of temperate climate, although they do not limit their distribution to these areas, since they are also found in cold, warm, humid and semi-arid regions (Nixon, 2002; Rzedowski, 2006).

In the national territory, the tropical oak forests characterized by the dominance of *Quercus oleoides* Schltdl. & Cham., Are located along the coastal plain of the Gulf, from the state of *Tamaulipas* to the south of *Veracruz*, at altitudes not exceeding 600 m, generally surrounded by low and medium tropical forests (Pennington and Sarukhán, 2005; Rzedowski, 2006). Although they show great climatic affinity with the latter, the type of soil is a determining factor in their physiognomic structure and floristic composition (Márquez *et al.,* 2005).

These plant communities worked as refuges for flora and fauna during the Pleistocene, and managed to adapt to the warm climatic conditions prevailing at low altitudes, although they currently survive as isolated communities (Pennington and Sarukhán, 2005). The anthropic pressure, associated mainly with the expansion of agriculture, fires and livestock has accelerated their isolation (Challenger and Caballero, 1998; Zavala, 2000; Peña and Bonfil, 2003; Flores, 2007; FAO, 2016).

In this regard, several studies document the need to generate, specify and update information on the ecological importance, diversity, current distribution and characterization of oaks in the country, for restoration, conservation and sustainable use (Zavala, 1998; Encina *and* Villarreal, 2002; Luna *et al*., 2003; Flores and Márquez, 2004; Flores, 2007; Sabás *et al*., 2015).

Current conservation approaches indicate that it is not enough to determine the potential distribution of a species, it is also necessary to define the sites with greater aptitude for their conservation (Eastman, 2012), to discriminate more vulnerable areas or to weigh the impact of human activities (Hernández, 2014), a fact that confers it a deeper space-time analysis.

The *Sierra del Abra Tanchipa* Biosphere Reserve (RBSAT) is one of the last relicts of Neotropical flora and fauna (Ortega, 2007), where unique ecosystems stand out due to the diversity of endemic, threatened and endangered species, among which excels *Quercus ole*oides Schltdl. & Cham. This species is present in the lower parts of the sierra, and is restricted to a slope in which it is mixed with low deciduous and subdeciduous forests (Conanp, 2014; Sabás *et al*., 2015). In the RBSAT, tropical oaks were widely used by the local population for various purposes, although at present their distribution and use are little known (Reyes *et al.,* 2017).

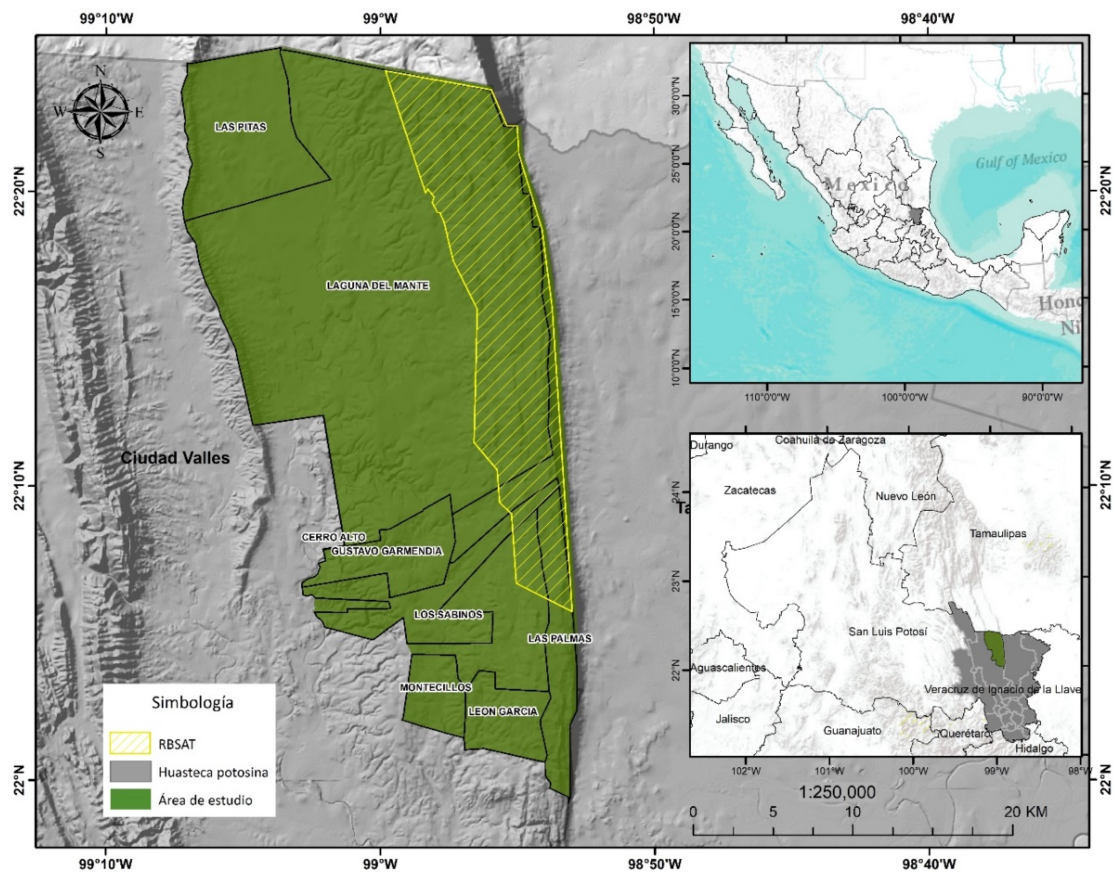
The objectives of this work were to know the current distribution and determine the potential distribution of *Quercus oleoides* in the *Sierra del Abra Tanchipa* Biosphere Reserve and its area of influence, in addition to recognizing its current uses and defining the priority areas for its conservation. It is expected that this study establishes a precedent for its application to other species, especially those in some risk category (Eastwood and Oldfield, 2007).

# Materials and Methods

## Study area

The RBSAT is located in the north-western middle portion of the Great Folded Sierra or physiographic province of the *Sierra Madre Oriental*, in *Ciudad Valles* and *Tamuín* municipalities in the state of *San Luis Potosí.* It covers an area of 21 464 ha that extends between the coordinates 22°05 'and 22°24' N and 98°52 'and 99°01' W (Semarnap, 1994) (Figure 1). Its area of influence is made up of nine localities: *Laguna del Mante, Los Sabinos Número Dos, Gustavo Garmedia (La Unión), León*

*García, El Sabino del Obispo, El Aguaje, Las Palmas, Estación Tamuín* and *Fracción la Tima* (Durán, 2018).




*Simbología* = Symbology; *Área de estudio* = Study area.

**Figure 1.** *Sierra del Abra Tanchipa* Biosphere Reserve and its influence zone.

The predominant climate in the region corresponds to the warm subhumid with summer rainfall Aw1(x ') with an average annual rainfall of 965 mm and an average annual temperature of 24.5 °C (Inegi, 2002; García, 2004). The Reserve is located in hydrological region 26 (RH26) *Pánuco* River, corresponding to the *Tamuín* River basin, although surface currents are scarce, it has underground rivers connected through various basements propitiated by fracturing and infiltration of water into calcareous rocks (Inegi, 2002). The predominant soils correspond to the Phaeozems and Leptosols (Inegi, 1983).

The dominant vegetation corresponds to the low deciduous and medium sub-deciduous forests. The first is characterized by having individuals in the arboreal stratum of 4 to 15 m that lose their leaves in the dry season, and the second by having trees up to 25 to 30 m with a dense foliage (Rzedowski, 2006; Miranda and Hernánez, 2016).

## Present day distribution

Consultation with taxonomists and vegetation experts was carried out, as well as a review and verification of *Quercus oleoides* records for the state of *San Luis Potosí*, in the *Isidro Palacios* (SLPM) Herbarium of the *Instituto de Investigación de Zonas Desérticas (IIZD) de la Universidad Autónoma de San Luis Potosí* (Desert Areas Research Institute (IIZD) of the Autonomous University of *San Luis Potosí*). The records of the species in the RBSAT were corroborated and the collection sites were georeferenced.

With these data and with the support of local guides and knowledgeable experts of the regional flora, seven field trips were made in the Reserve and its area of influence to verify the presence of the species and obtain complementary information of the sites where it grows. Additionally, 15 semi-structured interviews were applied to some inhabitants of the *Laguna del Mante, Gustavo Garmendia* and *Los Sabinos ejidos*, to know the main uses of the species, former distribution areas, its importance for the locals and actions that could be implemented for its conservation.

The points identified during the field work routes, as well as the data from the collection records were represented in the Arcgis Geographic Information System 10.3., to perform a spatial analysis and determine the main environmental characteristics of the sites where the species are found. Therefore, the following factors were considered: altitude, slope, slope orientation, soil type, geology and land uses. These layers of information with a resolution of 30 m in pixel size were obtained from the digital service of Inegi.

## Potential distribution

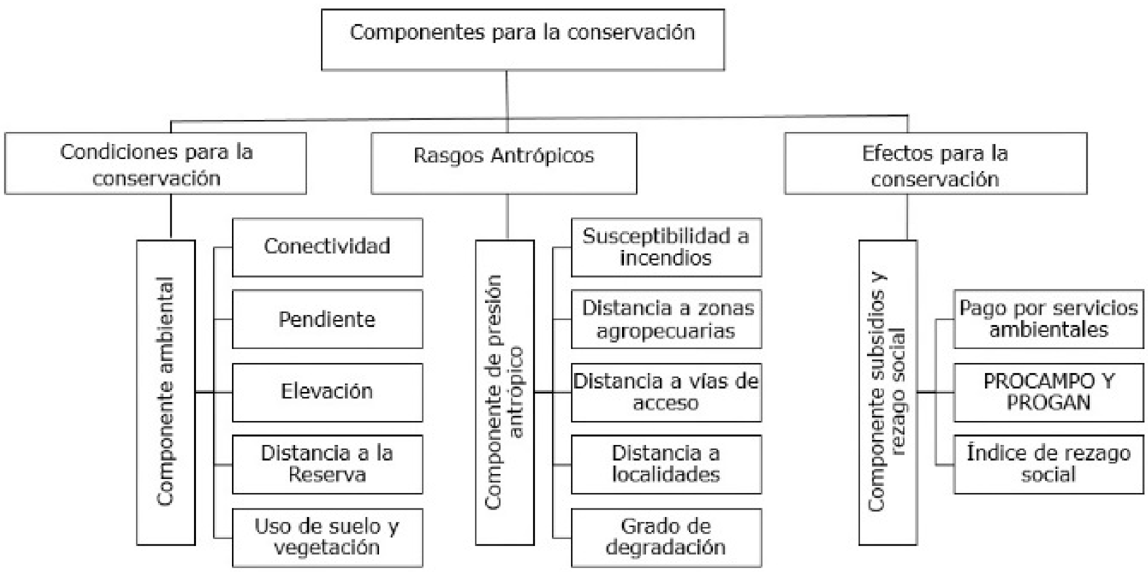
To generate the model, seven geographic records of the species obtained in the herbarium were used, as well as data from 56 georeferenced sites in the field. The main environmental variables considered in the analysis were: i) annual average temperature; ii) annual precipitation (1970-2010) obtained from the Worldclim database (Fick and Hijmans, 2017); iii) geology; iv) edaphology (Inegi, 2006); v) altitude and vi) slope, generated from the digital terrain elevation model (CEM 3.0) (Inegi, 2013). To estimate the contributions of each variable, as well as their respective parameters, the maximum entropy algorithm of the Maxent 3.4.1 program was used.

During the execution of Maxent, 35 randomized training points of maximum sensitivity were determined. The evaluation and contribution of each environmental variable to the prediction was based on the estimation of the percentages of relative contribution of Jackknife that define the most important variables for the model (Phillips *et al.,* 2006). Likewise, the evaluation test of receiver performance characteristic curve (ROC) and the area under the curve (AUC) were used, which establish the discrimination capacity of the model and the values of aptitude and performance (Hanley and McNeil, 1982). The values of the model are interpreted as insufficient in a range of 0.50-0.70; poor of 0.71-0.80: good of 0.81-0.90 and excellent of 0.91-1.0 (Araujo and Guisan, 2006).

## Areas with aptitude for conservation

A multicriteria spatial evaluation (CME) was carried out, considering continuous and categorical variables, for the selection of elements that allowed to measure and evaluate. This implied the multiplication of the value of each standardized criterion at a common scale and a range of weighting, in order to have multiple alternatives based on the previous principles (Malczewski, 1999; Eastman, 2012).

The variables chosen for the analysis were grouped into three components: environmental, anthropogenic pressure and subsidies and social lag (Figure 2) and were based on the criteria by Moffett and Sarkar (2006), Fabbro (2014) and Hernández (2014). These were: connectivity, slope, elevation, distance to the Reserve, land use, susceptibility to fires, degree of degradation, distance to agricultural areas (Inegi, 2017), distance to roads, distance to localities (Inegi, 2011), subsidies (payment for environmental services, *PROCAMPO* and *PROGAN*) and social lag index. These variables were spatially represented in the Arcgis 10.3 program, in which the UTM geographic projection was assigned. Later they were transformed into a raster format and represented in criteria maps. These layers were exported to the Idrisi Selva program, where the units of measure of all the criteria were standardized on the same numerical scale.




Componentes para la conservación = Components for conservation; Condicion*es para la conservación = Conditions for conservation; Componente ambiental = Environmental component; Conectividad* = Connectivity; *Pendiente*= Slope; *Elevación* = Elevation; *Distancia a la Reserva* = Distance to the Reserve; *Uso de suelo y vegetación* = Land use and vegetation; *Rasgos antrópicos* = Anthropic traits; *Componente de presión antrópica* = Anthropic pressure component; *Susceptibilidad a incendios* = Susceptibility to fires; *Distancia a zonas agropecuarias* = Distance to agricultural areas; *Distancia a vías de acceso* = Distance to roads; *Distancia a localidades* = Distance to localities; *Grado de degradación = Degree of degradation; Efectos para la conservación* = Effects for conservation; *Componente subsidios y rezago social = Component of subsidies and social lag; Pago por servicios ambientales* = Payment for environmental services; *Índice de rezago* = Social lag index.

**Figure 2**. Conceptual scheme used for the assessment of priority areas for conservation.

In the multicriteria evaluation module, the components were integrated in a weighted linear summation according to the following formula:

$$S=\sum W_i X_i$$

Where:

$S$ = Cell fit

$W_i$ = Asigned weight to the *i* factor

$X_i$ = *i* factor value

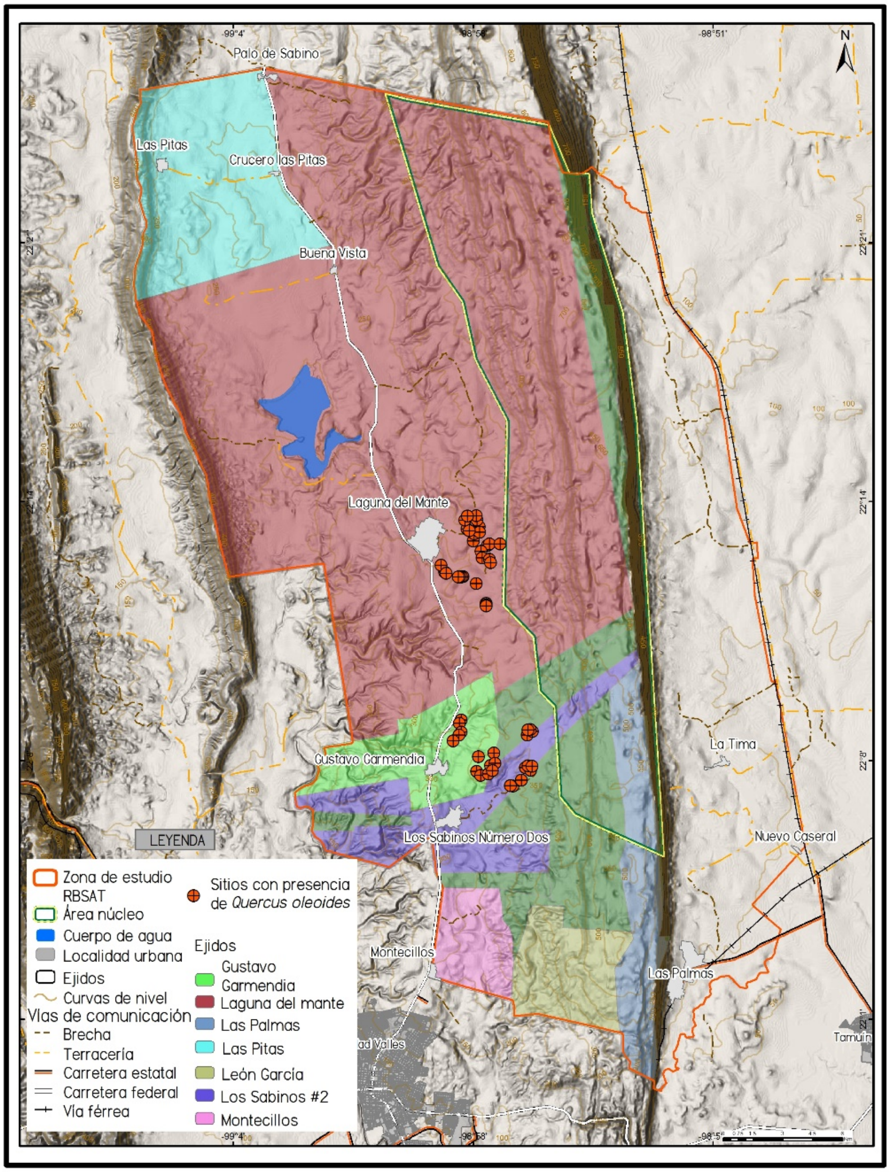
The estimation of the weights and the weighting of each criterion involved the consult of experts, technical personnel of the RBSAT Management and inhabitants. Fifteen opinion matrixes and added value were applied for each criterion. The data obtained was analyzed and verified by Analytic Hierarchy Process (AHP), which consists of evaluating direct values or pairwise comparisons and inconsistencies (Saaty, 2008). The values represented in a numerical scale (1 to 9) according to their importance, were incorporated into a comparison matrix (Eastman, 2012). The weights were integrated and calculated in the Decision Support Weight module, to average the results of all the criteria at a consistency level lower than 0.1 (Clark Labs, 2015).

The standardization consisted of transforming each criterion into comparable units in the Fuzzy module at a byte scale (0-255), where 0 represents the minimum value of the alternative and 255 the maximum value for conservation. The values of the comparison matrix (AHP) derived from each questionnaire were agreed to calculate the weighted values of relative importance. Starting from it, a cartographical composition of non -optimun values <44 and very optimum >195 were derived for conservation. Later, the information was standardized in four levels of importance (unfit, low, medium and high).

# Results and Discussion

## Distribution and use of *Quercus oleoides*

In the RBSAT and its area of influence, 56 sites with *Quercus oleoides* were identified, mainly in the *ejidos* of *Laguna del Mante, Gustavo Garmendia* and *Los Sabinos Dos* (Figure 3). In these spaces, shallow soils (Rendzic leptosols) predominate, altitudes below 350 m, flat terrains or with gentle slopes located in the lower parts of the *sierra*. The holm oaks of the RBSAT mostly develop on rocky strata of limestone and limestone-shales.




*Zona de estudio* = Study zone; *Área núcleo* = Core área; *Cuerpo de agua* = Body of wáter; *Localidad urbana* = Urban locality; *Curvas de nivel* = Level curves; *Vías de comunicación* = Communication roads; *Brecha* = Dirt road; *Terracería* = Dirt; *Carretera estatal* = State highway; *Carretera federal* = *Federal highway; Vía férrea* = Railroad track; Sitios con presencia de *Quercus oleoides* = Sites with the presence of *Quercus oleoides.*

**Figure 3.** Presence of *Quercus oleoides* Schltdl. & Cham. in the RBSAT and its area of influence.

In most of the studied sites few adult individuals (3 to 5) are regularly found. The oldest live in the *Los Sabinos ejido* with average heights of 35 m and DAP of 331 cm, while in *Gustavo Garmendia* some sites gather specimens up to 25 m in height and DAP of 220 cm. The youngest and the lowest are present in the *ejidos* of *Laguna del Mante* and *Gustavo Garmendia* where, in addition, sprouts are numerous. An environmental gradient related to the physiognomic characteristics of the individuals was identified, that is, those with the greatest size are grouped in the southern portion of the RBSAT, which has higher humidity and precipitation (Figure 3).

According to the information gathered in the interviews, in addition to the large areas covered by the oaks that were removed to give way to agricultural fields and pastures cultivated between 1960 and 1970, this species was widely used by the inhabitants of the area, to provide themselves with charcoal, and wood for the construction of houses, canvases and furniture making. Forest fires are another reason that villagers recognize as causes of their disappearance, which is argued by some authors such as Zavala (2000), Peña and Bonfil (2003) and Encina *et al*. (2007) who state that fire is a factor that favors the presence of certain oak species.

Once these forests are distroyed, the presence of fires or periodic burning and browsing of cattle in the undergrowth, make their recovery even harder to achieve (Flores, 2007), by means of growth or regeneration from the stumps, as the species' rhythm is rather slow.

This could explain why the oaks of interest only persist as dispersed relicts in the less accessible and more restricted areas of the area of influence of the RBSAT. Most of the human communities are unaware of the effects associated with deforestation, but recognize that it is a native species, which must be protected.

Currently, oak wood is used in construction of houses, furniture in general, as firewood, in addition to the production of charcoal and domestic utensils, which demonstrates the importance of this species in the tropical regions of the country (Pérez *et al.,* 2000; Pennington and Sarukhán, 2005; Rzedowski, 2006; Pérez and Dávalos, 2008; Montoya, 2009).

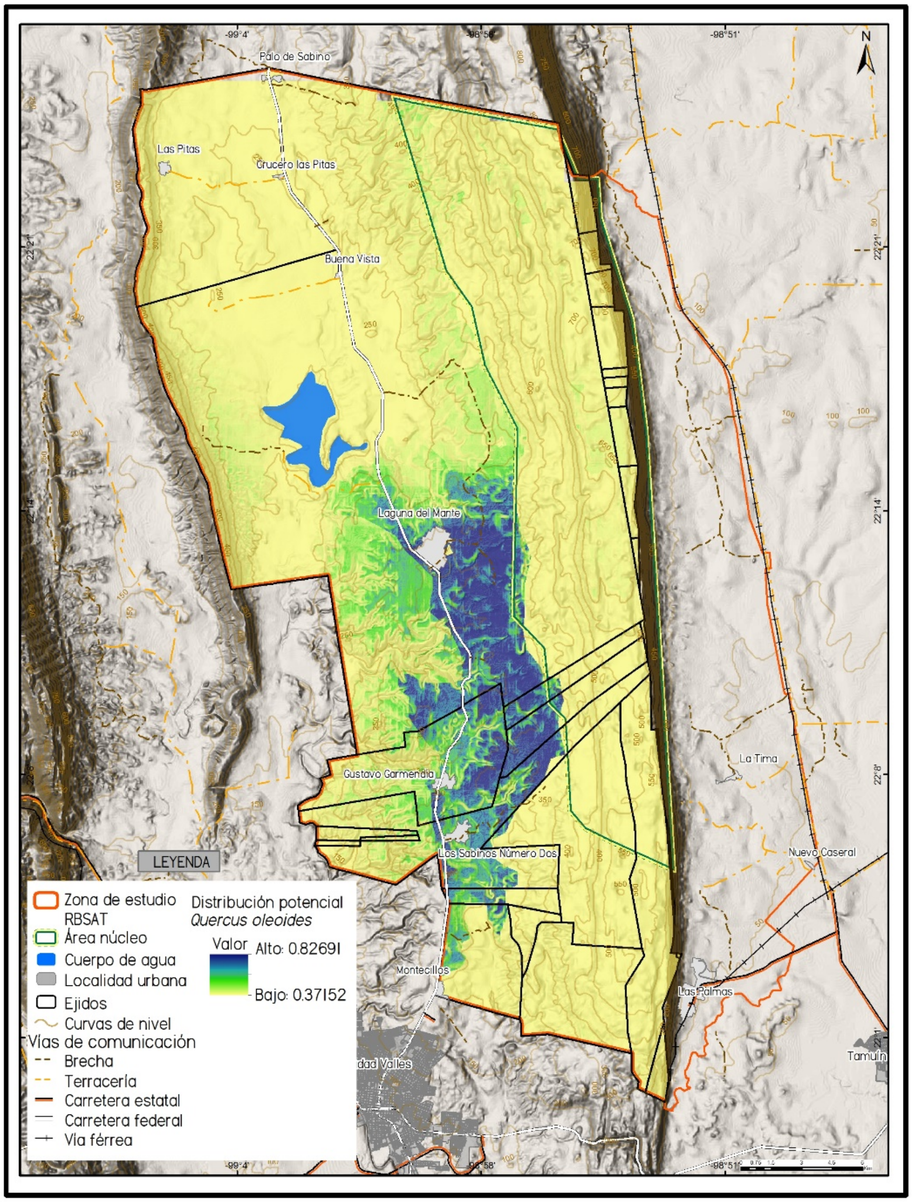
## Potential distribution

Among the different algorithms for predicting ecological niches, Maxent is one of the most widely used and its main applications allow the identification of protection and conservation zones of threatened species, the potential distribution of flora and fauna, the effects of climate change and the distribution potential for pests and infectious diseases (Guisan and Zimmermann, 2000; Dudík *et al.,* 2004; Elith *et al.,* 2006; Phillips *et al.,* 2006; Phillips and Dudík, 2008; Austin, 2007; Mateo *et al.,* 2011; Cruz *et al.,* 2014). Therefore, it was chosen to determine the potential distribution of *Quercus oleoides.*

The Jackknife test, which determines the most important variables for the model (Phillips *et al*., 2006), showed that the probability of presence of the species of interest increases in areas with shallow soils, as well as in areas of smooth or flat slope and when the altitude is less than 600 m. Of the total of the georeferenced sites in the field, 76 % are located at altitudes between 300 and 325 m. Likewise, 89 % of the field records indicate that the species develops on flat or almost flat lands, on slopes no greater than 14° where the soils are usually deeper due to the accumulation of materials. In both cases, they coincide with the points made by Rzedowski (2006) and Pennington and Sakukhán (2005).

For the model, edaphology made the largest contribution with 47.3 %, which coincides with that indicated by Márquez *et al.* (2005), Pennington and Sarukhán (2005) and Rzedowski (2006), followed by slope (17.8 %) and altitude (12.7 %). The rest of the variables contributed less than 10 %, and although the temperature and precipitation did even less, it is considered that the warm humid climates, with an annual rainfall of 965 mm and an average temperature of 24.7 °C, influence the presence of tropical holm oaks and explain their similarity to tropical forests (Pennington and Sarukhán, 2005).

The prediction capacity of the data in the distribution model showed an AUC (ROC curve) of 0.988, with a standard deviation of 0.002, interpreted as an optimal test prediction (Phillips *et al*., 2006). As a result, *Quercus oleoides* could have spread over an area of 15 528 ha parallel to the sierra, from the limits of *Ciudad Valles* to the *La Lajilla* dam (Figure 4). The most favorable areas for its eventual recovery are located northwest of the RBSAT, which coincides with that reported by Sabás *et al.* (2015), who recognize their presence in the area.




*Zona de estudio* = Study zone; *Área núcleo* = Core área; *Cuerpo de agua* = Body of wáter; *Localidad urbana* = Urban locality; *Curvas de nivel* = Level curves; *Vías de comunicación* = Communication roads; *Brecha* = Dirt road; *Terracería* = Dirt; *Carretera estatal* = State highway; *Carretera federal = Federal highway; Vía férrea* = Railroad track; Distribución potencial de *Quercus oleoides* = Potential distribution of *Quercus oleoides; Valor* = Value; *Alto* = High; *Bajo* = Low.

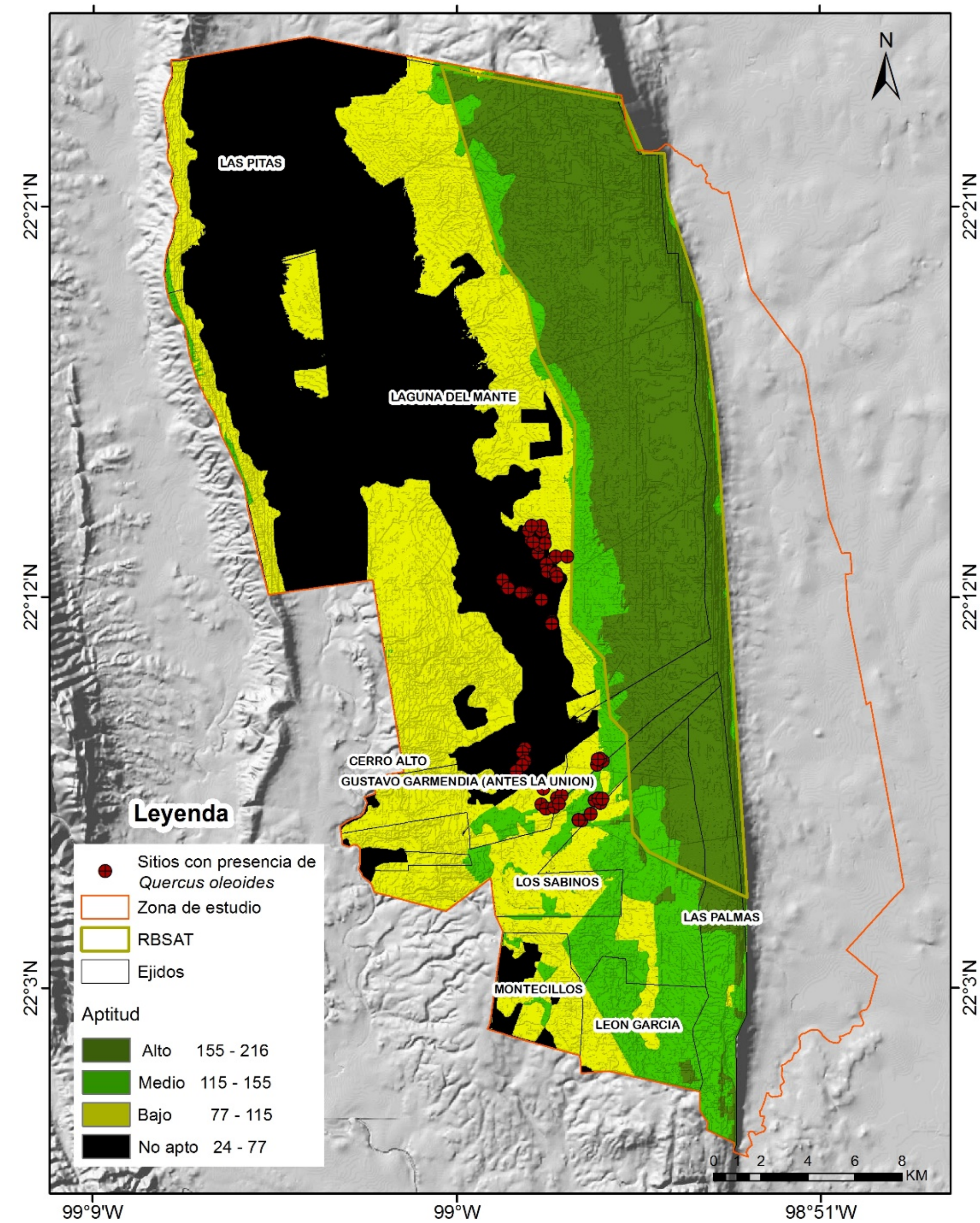
**Figure 4**. Potential distribution of *Quercus oleoides* Schltdl. & Cham. in the RBSAT and its area of influence.

In the potential distribution by *ejido*, the largest area belongs to *Laguna del Mante*, followed by *Gustavo Garmendia* and *Los Sabinos*. According to Zavala (2000), the anthropogenic factors are decisive for the presence of the species. Observations and records in the field allow inferring that human pressure and agricultural activities condition, to a large extent, the absence of this species in some places, despite the existence of the right environment for their development.

## Areas with aptitude for conservation

The identification of areas with aptitude for conservation is based on a series of stages that includes the selection of quantifiable and variable indicators to discriminate options, whose purpose is to identify places with conditions and characteristics that should be conserved (Hernández, 2014).

The procedure involves selecting criteria that can be measured and evaluated to take a decision (Eastman, 2012). A cartographic composition was derived from values <44 non-optimal and> 195 very optimal for conservation outside the protection polygon of the RBSAT. Subsequently, the information was classified into four levels of importance (not suitable, low, medium and high). The unfavorable areas for conservation were discarded, as they correspond to agricultural, livestock or urban land uses (Figure 5).




Sitios con presencia de *Quercus oleoides* = Sites with the presence of *Quercus oleoides; Zona de estudio*= Study zone; *Aptitud* = Aptitude; *Alto* = High; *Medio* = Medium; *Bajo* = Low, *No apto* = Not suitable.

**Figure 5.** Areas with greater aptitude for the conservation of *Quercus oleoides* Schltdl. & Cham.

The areas with values of 155-216 have high potential for conservation and are associated with *ejidos* supported by payment for environmental services, greater connectivity of the landscape and distance to the protected area.

The next level (115-155) indicates an average probability and is mainly associated with the connectivity and distance aspects of the protected area, which are basic for preserving priority areas (Moffett and Sarkar, 2006; Fabbro, 2014; Hernández, 2014). Values below 114 are unfit or unfavorable areas for conservation, due to their proximity to areas with agricultural activities and population growth (Challenger and Caballero, 1998; Flores, 2007; FAO, 2016).

The areas with greater aptitude for conservation are located to the southwest of the Reserve, in the *ejidos* of *Laguna del Mante, Gustavo Garmendia, Los Sabinos* and *Las Palmas* with an estimated area of 198 ha. The components that most contribute to the comparison matrix (AHP) are the environmental component by 37 %, the subsidies and the social backwardness with 34 %.

## Conclusions

*Quercus oleoides* Schltdl. & Cham. persists in isolated stands in the lower part of the *Gran Sierra Plegada*, on slightly undulating and inaccessible terrains, in shallow soils and at altitudes no greater than 325 m. The tropical holm oak forests were extensively used in past decades by the settlers; the ground of the species was removed to give way to crops and pastures. These are the reasons that explain their presence only as relicts and of a few examples restricted to the area of influence of the RBSAT.

Most of the population does not know the effects associated with deforestation, but they recognize that it is a native species, that it is important to protect it. It is necessary, then, to implement restoration and conservation actions. In the area, holm oaks could have occupied about 15 000 ha, although the optimal areas where it is possible to achieve the conservation and restoration of the oaks with greater probability of success add near 200 ha, where, in addition, the favorable environmental conditions exist for their recovery.

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## Conflict of interests

The authors declare no conflict of interests.

## Contribution by author

Luis Enrique Acosta Torres and Humberto Reyes Hernández: design of the study, definition of methodology, field work, data analysis, writing of the document; Carlos Alfonso Muñoz Robles: definition of methodology, review and correction of the manuscript; Edgar Gregorio Leija Loredo: support in field work, review and correction of the manuscript.

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