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Article

El nicho ecológico como herramienta para predecir áreas potenciales de dos especies de pino

The ecological niche as a tool for predicting potential areas of two pine species

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Resumen

Modelar el nicho ecológico óptimo para determinar la distribución potencial de las especies es una opción viable en la ubicación de las mejores áreas para establecer Unidades Productoras de Germoplasma Forestal (UPGF). El objetivo del presente estudio fue modelar la distribución potencial de *Pinus pseudostrobus* y *P. oocarpa* en Chiapas, México, mediante el procesamiento cartográfico de variables topográficas, climáticas, edáficas, ecológicas y modelos de nicho ecológico (*MaxEnt*). Se utilizaron 220 datos de presencia de *P. oocarpa* y 52 para *P. pseudostrobus* obtenidos de la Red Mundial de Información sobre Biodiversidad, *Global Biodiversity Information Facility*, del *Missouri Botanical Garden* y del Herbario Nacional de México (MEXU). La distribución potencial de la especie fue modelada con 500 y 1 000 iteraciones a través de las regresiones de tipo *Logistic*, *Cumulative* y *Cloglog*. La validación estadística se realizó con 28 % de los datos para cada taxón con las técnicas *Crossvalidate* y *Bootstrap*. El modelo que mejor se ajustó fue el logístico con método de remuestreo *crossvalidate*. Los valores del Área Bajo la Curva (AUC) para los datos estimados y validados fueron de 0.882 para *P. oocarpa* y 0.947 en *P. pseudostrobus*. La variable que más influyó en la presencia o ausencia de las especies fue la altitud con 84.5 y 97.3 % para *P. oocarpa* y *P. pseudostrobus*, respectivamente. Los resultados del modelo permitieron ubicar áreas óptimas para el establecimiento de UPGF.

Palabras clave: AUC, Chiapas, germoplasma forestal, *MaxEnt*, modelos predictivos, Unidades Productoras de Germoplasma Forestal.

Abstract

Modelling the optimum ecological niche after the species potential distribution, a tool to predict potential production sites is an option for delimitation of best seed stands as Forest Germplasm Production Areas (UPGF) The aim of this study was to model the potential distribution of *Pinus pseudostrobus* and *P. oocarpa* in *Chiapas*, Mexico by mapping topographic, climatic, edaphic, ecological and ecological niche models (MaxEnt). Data for 220 site presence points for *P. oocarpa* and 52 for *P. pseudostrobus* were obtained from the World Information Network on Biodiversity, Global Biodiversity Information Facility, the Missouri Botanical Garden and *Herbario Nacional de México* [National Herbarium of Mexico (MEXU)]. The potential distribution for each species was modelled after 500 and 1 000 iterations through Logistic, Cumulative and Cloglog regressions. Statistical validation was performed with 28 % of the data for each species through the technique Crossvalidate and Bootstrap. The best fit model was the Logistic type with crossvalidate type validation. Values of area down the curve (AUC) for estimated and validated data were 0.882 (*P. oocarpa*) and 0.947 (*P. pseudostrobus*). The most influent variables for species presence or absence were altitude with 84.5 y 97.3 % for *P. oocarpa* and *P. pseudostrobus*, respectively. Results from the best model allowed the delimitation of optimum sites to establish UPGF.

Key words: AUC, *Chiapas*, forest germplasm, MaxEnt, predictive models, Forest Germplasm Production Areas.

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Introduction

The forest germplasm used in Mexico in the production of seedlings to supply the national reforestation programs comes from natural populations or from unmanaged forest plantations, in which the phenotypic and genotypic quality of the individuals for their collection is not considered (Muñoz *et al*., 2014). In addition, part of the plant produced is used indiscriminately for the reforestation of areas in edaphoclimatic conditions different from the areas of germplasm origin (Secretaría de Economía, 2016).

The wrong selection of this material and the inadequate use of the plants produced have an impact on the survival, production and yield of reforestation or commercial forest plantations (PFC) (Alba *et al*., 2005). On the other hand, by introducing forest plants in areas under environmental conditions completely different from those required by each species, they can become vectors of pests and diseases (Vanegas, 2016), alter trophic relationships and cause loss of biodiversity (Fernández-Pérez *et al*., 2013).

Since 2001, the *Comisión Nacional Forestal* (National Forestry Commission) (Conafor) has promoted reforestation for the ecological restoration of degraded areas (Vanegas, 2016). A key factor for the success of reforestations is the management and production of forest seeds, since good quality seeds ensure a higher production of plants with characteristics that guarantee a high survival in the field (Conafor, 2014).

As part of an effort to regulate the use and indiscriminate mobilization of forest germplasm, at the end of 2016 the NMX-AA-169-SCFI-2016 Mexican Standard (Secretaría de Economía, 2016) came into force, establishing the technical specifications that must be met to obtain certification during the establishment and management process of the forest germplasm producing units.

One way to contribute to the regulation of germplasm movement and increase the percentage of survival of reforestation is to model the potential distribution of forest species (Perosa *et al*., 2014). This technique allows to identify areas with biotic conditions (for example, vegetation types) and abiotic conditions (for example, temperature, slope, humidity) favorable for the permanence of a species; it can also be used to identify suitable areas to introduce species with a high ecological and / or economic value (Morales, 2012). In recent years, several tools have emerged that facilitate the modeling of the potential distribution of species, such as: GARP, Bioclim and MaxEnt, the selection of the algorithm is a function of the set and complexity of the data that is available (Conabio, 2017). Mechanistic models based on the ecological niche, such as MaxEnt, use facts (data) to predict potential distribution by some statistical methods (Kearney, 2006).

Maxent has shown to have a good predictive ability solely from presence data (Elith *et al*., 2006; Navarro-Cerrillo *et al*., 2011). The model is based on the statistical principle of maximum entropy (close to uniform) that allows making predictions with the use of incomplete information, which represents an advantage, since for most species there is no data on true absences (Phillips *et al.,* 2006).

The state of *Chiapas* is deficient in the production of forest seed; between 2008 and 2014, it produced 1 053.21 kg of seeds distributed among *Pinus* sp. (377.24 kg), *Cedrela odorata* L. (150.6 kg), *Tabebuia rosea* (Bertol.) Bertero ex A. DC. (20.73 kg) and *Chamaedorea elegans* Mart. (484.64 kg). In contrast, Conafor annually produces around 19 million plants to carry out reforestation work in the state. These data show the need to have enough forest germplasm in quantity and quality to cover these requirements. Therefore, the aim of this study was to define potential areas for the establishment of Forest Germplasm Production Units (UPGF, for its acronym in Spanish) of *P. oocarpa* Schiede ex Schltdl. and *P. pseudostrobus* Lindl. in the state of *Chiapas*, through the use of MaxEnt algorithms.

Materials and Methods

Study area

The state of *Chiapas* is located southeast of Mexico and it spreads over 73 272.3 km^2 (Inegi, 2016). Its complex relief is framed in seven physiographic regions: Coastal Plain of the Pacific, *Sierra Madre de Chiapas*, Central Depression, Central High Plateau, Mountains of the East, Mountains of the North and Coastal Plain of the Gulf. Due to these topographic conditions, *Chiapas* is one of the states with greatest biological diversity (Conabio, 2013).

Based on the WRB (World Reference Base for Soil Resources) classification, there are 19 soil units in the state (Inegi, 2006).

In *Chiapas* the humid warm climate prevails over 39.4 % of the territory, followed by the warm subhumid with 34.9 %, the humid semi-hot with 14.2 % and in lesser percentage the temperate sub-humid and the temperate humid with the 7.0 and 3.2 %, respectively (Inegi, 2008). The average annual temperature varies according to the region, from 18 °C in the *Altos de Chiapas* to 28 °C in the Pacific Coastal Plain. The total annual precipitation fluctuates between 900 to 4 000 mm and the altitudes from 0 to 4 000 m (Conabio, 2013).

Presence data

The presence of both species was obtained through the consultation of databases and platforms of specimens deposited in the National Herbarium of Mexico (MEXU) and the World Biodiversity Information Network (REMIB, for its acronym in Spanish) prepared by the National Biodiversity Commission (Conabio, for its acronym in Spanish). The bases were purified and those records that were located within a 200 m buffer area of the urban areas defined in the vectorial layer of the National Geostatistical Framework were eliminated.

For *P. oocarpa* 220 records were obtained and for *P. pseudostrobus* 52 (Figure 1); in both cases, 28 % of the total records were randomly selected to validate the model (Ibarra *et al*., 2012). A data cleansing was performed based on the maximum and minimum parameters for each variable. The small number of records used for the modeling, in this case is justified by the absence of complete data for the species in question; however, the algorithm can still be effective even when the number of sites where the presence has been documented is quite low (Costa *et al.,* 2010). For both species, the pixels occupied by more than one record were eliminated.

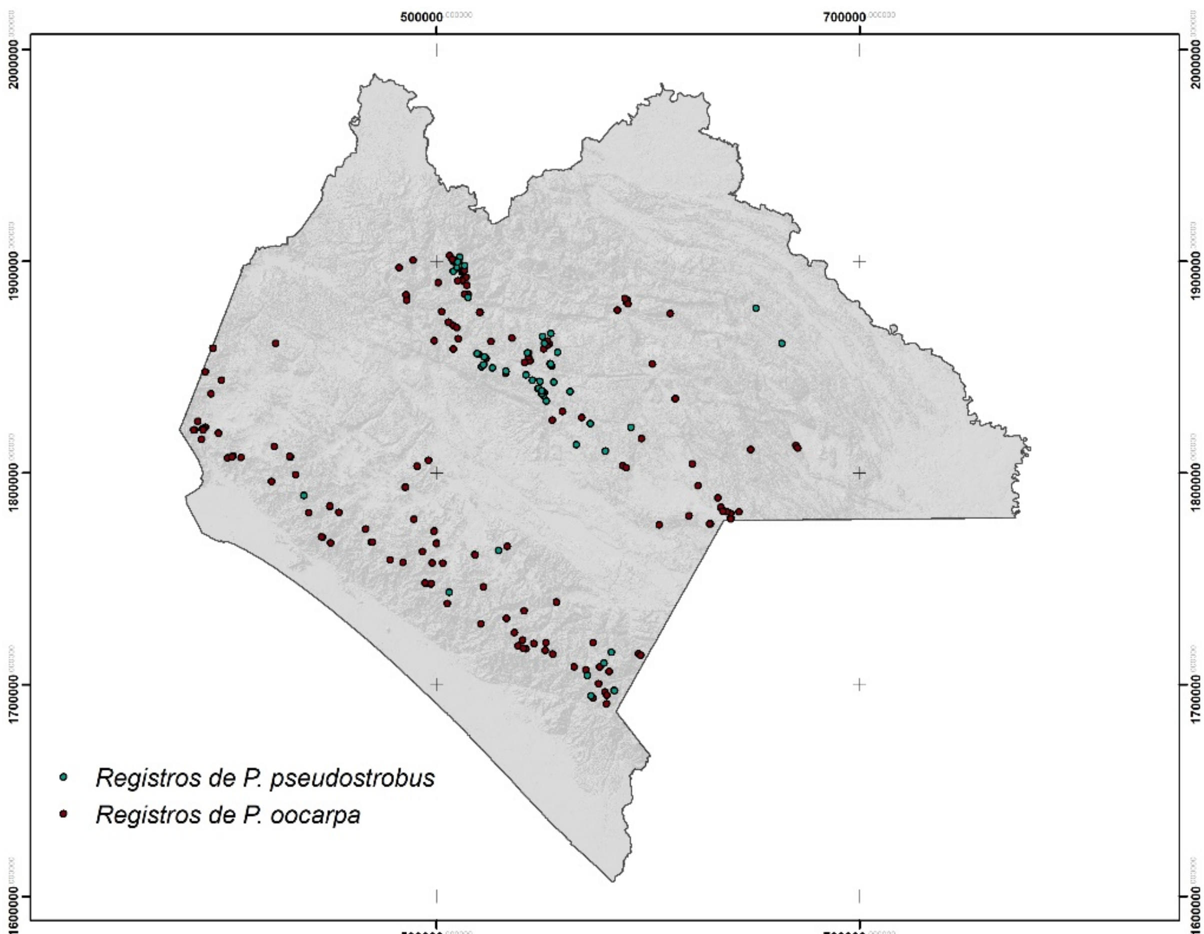


Figure 1. Presence of *Pinus oocarpa* Schiede ex Schltdl. and *Pinus pseudostrobus* Lindl.

Edaphoclimatic variables

We used 25 variables; 17 derived from the monthly values of temperature and precipitation obtained from the WorldClim platform and eight from the topographic, climatic and pedological types.

The variables used in the modeling were selected based on the most significant environmental requirements for both species, the availability of geospatial information was also considered. The variables were: temperature (Eguiluz, 1982; *Sáenz-Romero et al*., 2006), precipitation (Fierros *et al*., 1999; Sáenz-Romero *et al*., 2006), altitude (Perry, 1991; Sáenz-Romero *et al*., 2006; Viveros-Viveros *et al*., 2007), soil type (Eguiluz, 1982; Fierros *et al*., 1999), pH (Eguiluz, 1982; Rueda *et al*., 2006), climate (Rzedowski, 2006; Fierros *et al*., 1999) and soil texture (Fierros *et al*., 1999), which were obtained from Inegi Series IV (Ed.2) on a scale of 1: 250 000 (Inegi, 2006). For this study, in addition to the edaphoclimatic variables, the Normalized Difference Vegetation Index (NDVI) was included as an indicator of the percentage of plant cover and the vigor of the vegetation (Kulloli and Kumar, 2014) (Table 1).

Because the layers presented different pixel sizes, a standard size of 15 m was established through the resampling of the layers with the resample tool of Arcgis 10.4™ (ESRI, 2017), using the CUBIC method.

Table 1. Variables incorporated in the modeling of the potential distribution of *Pinus oocarpa* Schiede ex Schltdl. and *Pinus pseudostrobus* Lindl. in the state of *Chiapas*.

Key	Environmental variable
Bio2	Daytime temperature oscillation (°C)
Bio3	Isothermality (°C)
Bio4	Seasonality of temperature (standard deviation * 100) (°C)
Bio5	Average maximum temperature of the warmest period (°C)
Bio6	Minimum temperature of the coldest month (°C)
Bio7	Annual temperature oscillation (°C)
Bio8	Average temperature of the wettest month (°C)
Bio9	Average temperature of the driest month (°C)
Bio10	Average temperature of the warmest quarter (°C)
Bio11	Average temperature of the coldest four-month period (°C)
Bio13	Precipitation of the wettest period (mm)
Bio14	Precipitation of the driest period (mm)
Bio15	Seasonality of precipitation (Coefficient of variation, CV)
Bio16	Precipitation of the wettest quarter (mm)
Bio17	Precipitation of the driest quarter (mm)
Bio18	Precipitation of the warmest quarter (mm)
Bio19	Precipitation of the coldest four-month period (mm)
Alt	Altitude (msnm)
Clim	Climate (type)
Eda	Soils (type)
pH	pH (H^+)
NDVI	Normalized differential vegetation index
Pp	Average annual precipitation (mm)
Tem	Temperature (°C)
Tex	Texture (type)

The altitude map was developed using the Digital Elevation Model of Ingi (Inegi, 2016) with spatial resolution of 15 m. The cartography of average temperature, with the altitudinal gradient method (Fries *et al*., 2012), based on the historical record of 30 years of temperature and altitude of 173 stations of the National Meteorological Service (SMN, 2010). The precipitation map was obtained by interpolating data from the average annual precipitation of 173 NMS stations through the Kriging method (Delaney, 1999).

The climate layer was derived from the vector data of Inegi (Inegi, 2008), soil types, texture and pH, vector data of soil profiles and the soil erosion data set at scale 1: 250 000 (Inegi, 2006).

The NDVI resulted from processing seven Landsat 8 scenes with different dates (Pat / Row: 20/48 (09-02-2015), 20/49 (09-02-2015), 21/48 (02-03-2016), 21/49 (02-03-2016), 21/50 (01-12-2015), 22/48 (25-01-2016) and 22/49 (09-01-2016), with which a This mosaic was used to cover the state of *Chiapas*, by means of the Atmosc module of Idrisi *Selva*, the atmospheric correction of the images was made, with the purpose of reducing the effects of cloudiness and transforming the values of digital numbers to reflectance (Chávez, 1996). The calculation of the NDVI was applied equation 1.

$$NDVI = (NIR - R)/(NIR + R) \quad (1)$$

Where:

NIR = Band 5

R = Band 4

The NDVI was taken according to what was described by Huete *et al.* (1999) and used by Kulloli and Kumar (2014) and Ruiz-Huanca *et al*. (2005), in which values close to 0 indicate areas with low plant cover; on the other hand, values close to 1 mean that there is great coverage and good vigor.

The transformation of formats of the vector layers, the cuts and the homogenization of the size of the cartography, as well as the interpolations was done by means of the Kriging method in the ArcGIS 10.4™ software (ESRI, 2017).

To avoid an overfitting of the models by multicollinearity between variables (Dorman *et al.,* 2013), a Pearson correlation analysis was performed. In the selection of variables used for final modeling, those with a coefficient of 0.80 and -0.80 (Fuentes *et al*., 2016) and $p < 0.0001$ were considered. After eliminating the correlated variables, the Jackknife test was performed to know the variables that contributed the most information to the model (Phillips *et al.,* 2006).

Modeling was done with the MaxEnt 3.3.3 software. To define the model, six algorithms of the most used and recommended by various authors were executed (Elith *et al*., 2006; Plasencia-Vázquez *et al*., 2014); for each case 50 replicas were carried out:

a) Cumulative function with a convergence threshold of 1.0E-5, 1000 iterations and crossvalidate resampling method.

b) Cumulative function with a convergence threshold of 1.0E-5, 500 iterations and crossvalidate resampling.

c) The logistic function with a convergence threshold of 1.0E-5, 1000 iterations and bootstrap resampling method.

d) The logistic function with a convergence threshold of 1.0E-5, 500 iterations and bootstrap resampling method.

e) Logistic function with a convergence threshold of 1.0E-5, 500 iterations and crossvalidate resampling method.

f) Cloglog function with a convergence threshold of 1.0E-5, 500 iterations and crossvalidate resampling method.

To obtain the potential distribution map, the Equal training sensitivity and specificity threshold rule was used, since it was the one that best delimited the potential distribution area; Plasencia-Vázquez *et al.* (2014) obtained good results when modeling two Psittacine species (*Amazona xantholora* (Gray, 1859) and *A. oratrix* (Ridgway, 1887) and Liu *et al*. (2005) classify it as one of the best to establish presence thresholds or absence of modeled species.

The evaluation of the model was carried out with the value of the Area Under the Curve (UAC). The Jackknife test was carried out to know the variables that contributed the most information to the model (Phillips *et al*., 2006).

Based on the results of the model, areas with high probabilities of locating suitable areas for the establishment of UPGF were identified. Field trips were carried out with the purpose of validating the maps and delimiting suitable stands for seed production. A forest inventory was carried out within these stands in order to select and mark type 1 and type 2 trees (Secretaría de Economía, 2016); In addition, these sites were described based on the variables shown in Table 1.

Results and Discussion

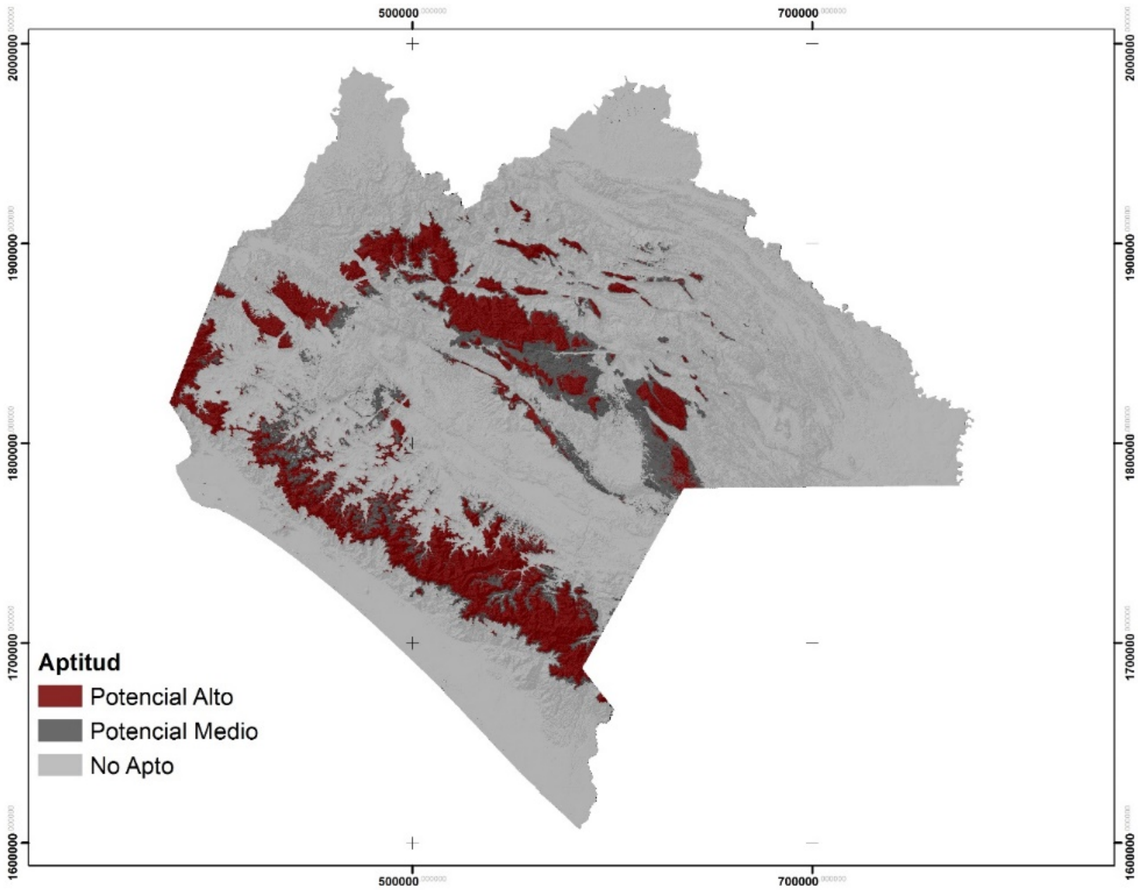
When performing the Pearson correlation tests among the 25 variables, problems were observed in 20 variables with coefficients of 0.80 and -0.80 and $p < 0.0001$, so they were eliminated. For the case of *P. pseudostrobus*, the variables considered in the model were Bio2, Alt, Eda, pH and texture, while for *P. oocarpa,* Bio2, Bio14, Alt, NDVI and pp.

Of the six tests carried out for the model's output, it was decided to use the logistic model with a convergence threshold of 1.0E-5, 500 iterations and the crossvalidate resampling method, because it was the one that delimited the areas of presence of the species. According to Phillips and Dudík (2008), the logistic output performs a transformation of the relative occurrence rate by which MaxEnt can estimate the probability of the species' presence. On the other hand, this model has been validated by several authors, Norris (2014) achieved good results when using this output *for Tapirus terrestris* (Linnaeus, 1758) and Ibarra *et al*. (2012) when modeling the ecological niche of *Microcystis* sp., among others.

Araujo and Guisan (2006) classify the accuracy of the models in five categories based on the values of AUC: values of 0.50-0.60, it is classified as insufficient; 0.60-0.70 as poor; 0.70-0.80 as average values; 0.80-0.90 as good and 0.90-1, as excellent. In this regard, Phillips *et al*. (2006) point out that models with perfect predictions reach values of 1; however, when only presence-only data are used, it is common to obtain AUC values less than 1.

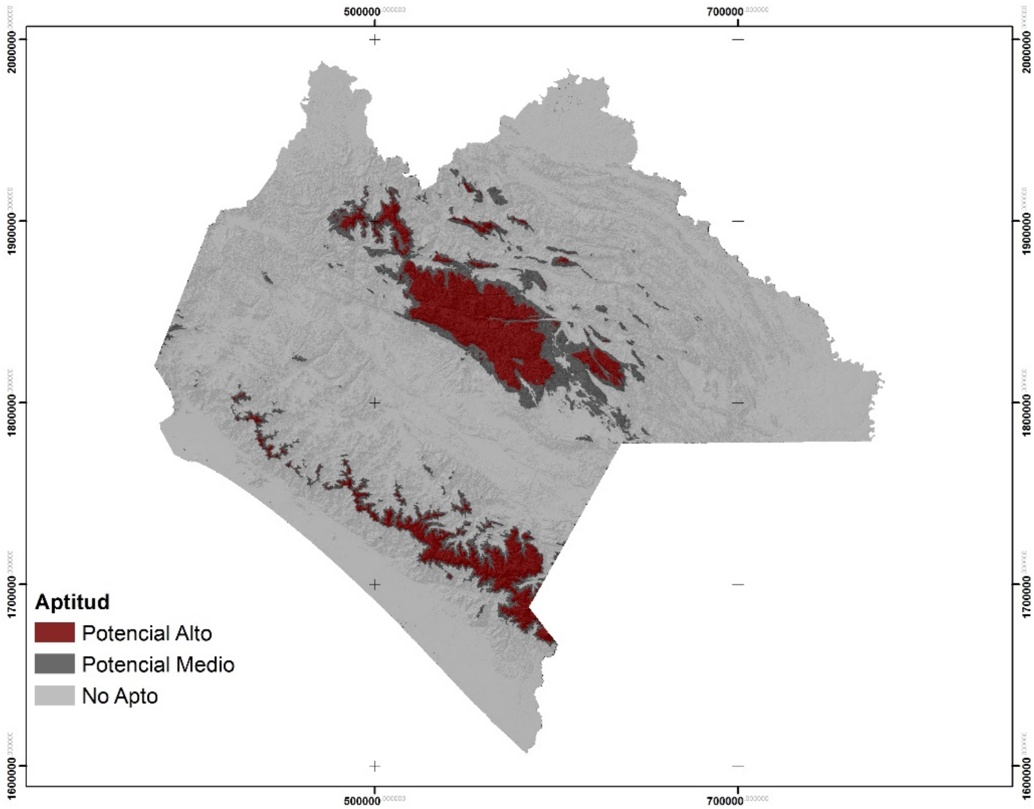
The models generated for each species showed acceptable AUC values, 0.882 for *P. oocarpa* and 0.947 for *P*. *pseudostrobus*, which shows that they can be used to predict the distribution and presence of both species with a high level of reliability (Phillips *et al.,* 2006). In other studies, values between 0.7 and 0.9 have been recorded (Wan *et al.*, 2015), so the authors conclude that they achieved precise results with the use of MaxEnt.

The potential areas for the two species are mainly concentrated in the *Sierra Madre* region of *Chiapas* and the Central Highlands (figures 2 and 3). For *P. oocarpa* an area of 874 695 ha was delimited, with a high potential for the establishment of UPGF. This species of wide distribution is located at altitudes of 300 to 3 000 m, in poor soils and temperatures between 3 and 35 °C (Eguiluz, 1982; Perry, 1991). For *P. pseudostrobus* the area was 478 493 ha; for this species, its range of altitudinal distribution is more restricted, from 1 600 to 3 200 m and it develops under minimum temperatures of -9 °C and maximum of 40 °C (Fierros, 1999). However, the limited surface area predicted by the model is mainly due to the fact that *P. oocarpa* thrives most successfully at altitudes between 900-2 600 m, minimum temperatures of 12 °C and maximum of 22 °C and at moderate soil depths to deep (Eguiluz, 1982); *P. pseudostrobus* is favored at altitudes of 1 500 to 2 400 m and with temperatures of 14 to 20 °C (Fierros, 1999).



Aptitud = Category; *Potencial alto* = High potential; *Potencial medio* = Medium potential; *No apto* = Not suitable.

Figure 2. Potential areas for the establishment of Forest Germplasm Production Areas and distribution of *Pinus oocarpa* Schiede ex Schltdl. in *Chiapas* State.



Aptitud = Category; *Potencial alto* = High potential; *Potencial medio* = Medium potential; *No apto* = Not suitable.

Figure 3. Potential areas for the establishment of Forest Germplasm Production Areas and distribution of *Pinus pseudostrobus* Lindl. in *Chiapas* State.

Regarding the variables used (Table 2), altitude was the one that contributed the greatest percentage to the training of the model of both species, this agrees with Schumann *et al.* (2016) who, when modeling the distribution of 14 species, altitude, turned out to be the most important variable for 11 of them. In other studies with different *Pinus* species, a positive correlation has been found between altitude and different morphological variables (Sáenz-Romero *et al*., 2006; Sáenz-Romero *et al*., 2012; Viveros *et al*., 2013), so it is expected that this variable contributes in an important with information for both models.

Table 2. Percentage contribution of the variables to the training of the models.

Variable	**Contribution**	
	P. oocarpa **(%)**	***P. pseudostrobus*** **(%)**
Alt	84.5	97.3
Bio2	6.9	0
Bio14	6.2	-
Eda	-	0.3
pH	-	2.4
NDVI	0.6	-
pp	1.8	-
tex	-	0

Soil pH influences the availability of most nutrients (Alcántar and Trejo, 2010); however, it is a variable scarcely used in ecological niche modeling. However, for *P. pseudostrobus*, the pH was incorporated in the modeling, since, in general, it restricts its distribution to soils with a predominantly acidic tendency, with values between 4.5 and 6.5 (Rueda *et al.,* 2006; Eguiluz, 1982), which coincides with the distribution limitations of other coniferous species (Pérez *et al.,* 2014).

Although altitude, temperature, precipitation and type of climate are variables frequently considered in the modeling of the potential distribution of species (Schumann *et al*., 2016; Qin *et al*., 2017), in this work only Bio2, Bio14 and pp were used, since these three had a low weight in the construction of the model, due to the high correlation between them (García, 2004; Fries *et al*., 2012).

The particular route followed by MaxEnt to obtain the optimal solution of the model, results in different results, since a different algorithm could obtain the same solution through a different route, which would lead to different percentage contribution values (Phillips *et al*., 2006). In this particular case, MaxEnt considered altitude to be more important compared to the rest of the variables used for modeling.

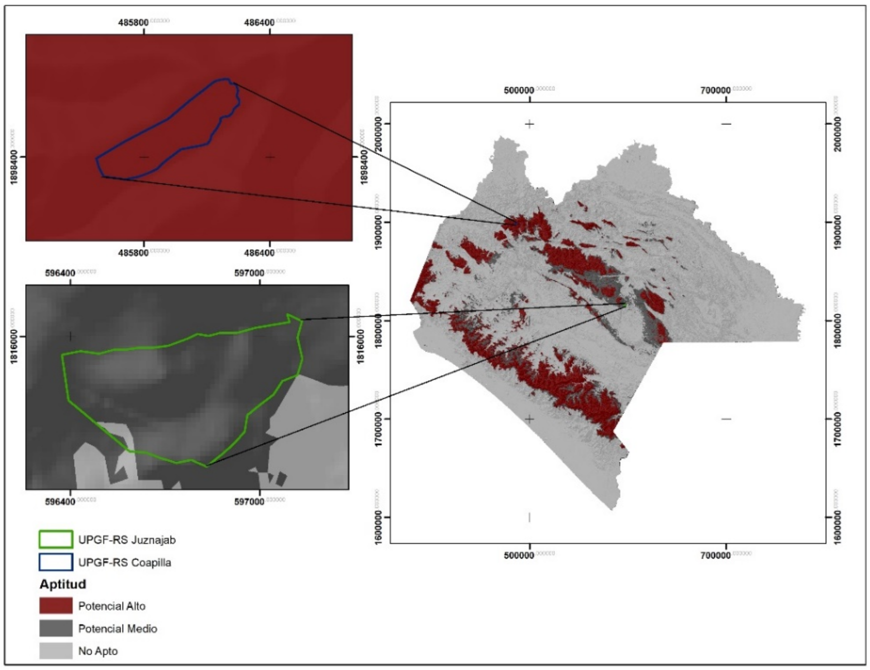
When comparing the results of Table 2, the above is confirmed, since it is observed that altitude alone has a relevant weight in the presence or absence of the two species (> 80 %). This is akin to that recorded by Cruz *et al.* (2014), with the understanding that said variable has a high percentage (> 85 %) of participation in the model of three forest species. For *P. oocarpa*, Bio2 and Bio14 showed significant participation in the model, which is similar for *Catopheria chiapensis* A. Gray ex Benth., *Quercus martinezii* H. Mull., *Telanthopora grandifolia* (Less.) H. Rob. & Brettell and *Viburnum acutifolium* G. Bentham.

The NDVI revealed to be a variable with little percentage contribution to the model. This behavior is attributable to the fact that this vegetation index reflects greenness levels of the vegetation, in this context, the high NDVI values for the study area were obtained from pasture, secondary vegetation of pine-oak forest, medium forest, forests of pine-oak and high evergreen forest. Another disadvantage of this index is saturation with leaf area index values greater than 2 (Huete *et al*., 1999; Ruiz-Huanca *et al*., 2005), which is why its use is recommended in arid and semi-arid areas where Schumann *et al*. (2016) reported good response of this variable when modeling the distribution of species in these ecosystems.

The texture of the soil was the least relevant variable, which is attributable to the level of description of the information contained in the digital cartography used, since it classifies the texture into coarse, medium and fine particles. Fierros *et al.* (1999) argue that *P. pseudostrobus* can be established in soils with sandy loam, loam-clay-sandy, clay and clay-sandy soils, while *P. oocarpa*, in soils with sandy texture, sandy-loamy, sandy-clayey with good drainage (Eguiluz, 1982); this confirms that both species are distributed indistinctly in soils with fine to coarse textures.

The results of the model and the field trips allowed the establishment and registration of two Forest Germplasm Production Units: the UPGF *Juznajab* (N-07-

019-JUZ-001/17) with the two species of interest, and the UPGF *Coapilla* (N- 07-018-COA-002/17) with *P. oocarpa* (Figure 4).



Aptitud = Category; *Potencial alto* = High potential; *Potencial medio* = Medium potential; *No apto* = Not suitable.

Figure 4. Location of the UPGF *Coapilla* and *Juznajab* in *Chiapas* State.

In *Juznajab*, 2 % of the area was classified as not suitable for *P. oocarpa* and 98 % was in the medium potential category; for *P. pseudostrobus* 100 % of the area was cataloged with high potential, which agrees with the conditions observed in the field, which is attributable to the current state of the vegetation as it is an area under forest management with an average cup coverage of 58 %. Likewise, it was confirmed that the precipitation present in this site (1 350 mm) is lower than the optimum required by the species.

Conclusions

The results of the model supported the location of areas suitable for the establishment of UPGF, decreasing the times and costs in the search for areas with optimal conditions. In addition, it is suggested that, in order to generate reliable models at the variety level, it is vital to have a large number of points of presence that correspond specifically to the variety of interest. In the same way it is required to characterize in detail the edaphic conditions and spatially represent the information at a higher spatial resolution than those used in this work.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Roberto Reynoso Santos and María Jesús Hernández Pérez: study design, methodology definition, information analysis, writing of the document; Walter López Báez: data collection in the field and review of the manscript; Jonathan Hernández Ramos: review and correction of the manuscript; Jesús H. Muñoz Flores: review and correction of the manuscript; José Vidal Cob Uicab: support in establishing the UPGF; M. David Reynoso Santos: support in field trips and in establishing the UPGF.

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