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Article

Modeling the Potential Distribution of *Picea chihuahuana* Martínez, an Endangered Species at the Sierra Madre Occidental, Mexico

Victor Aguilar-Soto [1], Alicia Melgoza-Castillo [1], Federico Villarreal-Guerrero [1], Christian Wehenkel [2] and Carmelo Pinedo-Alvarez [1,*]

[1] Departament of Natural Resources, Facultad de Zootecnia y Ecología, Universidad Autonoma de Chihuahua (UACH), Perif. Fco. R. Almada Km 1, 31453 Chihuahua, Chih., Mexico; E-Mails: aguilar-1@hotmail.com (V.A.-S.); amelgoza@uach.mx (A.M.-C.); fvillarreal@uach.mx (F.V.-G.)

[2] Instituto de Silvicultura e Industria de la Madera, Universidad Juárez del Estado de Durango, Constitución 404 sur, Zona centro, C.P. 34000 Durango, Dgo., Mexico; E-Mail: wehenkel@ujed.mx

* Author to whom correspondence should be addressed; E-Mail: cpinedo@uach.mx; Tel./Fax: +52-614-434-0304.

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Abstract: Species distribution models (SDMs) help identify areas for the development of populations or communities to prevent extinctions, especially in the face of the global environmental change. This study modeled the potential distribution of the tree *Picea chihuahuana* Martínez, a species in danger of extinction, using the maximum entropy modeling method (MaxEnt) at three scales: local, state and national. We used a total of 38 presence data from the Sierra Madre Occidental. At the local scale, we compared MaxEnt with the reclassification and overlay method integrated in a geographic information system. MaxEnt generated maps with a high predictive capability (AUC > 0.97). The distribution of *P. chihuahuana* is defined by vegetation type and minimum temperature at national and state scales. At the local scale, both models calculated similar areas for the potential distribution of the species; the variables that better defined the species distribution were vegetation type, aspect and distance to water flows. Populations of *P. chihuahuana* have always been small, but our results show potential habitat greater than the area of the actual distribution. These results provide an insight into the availability of areas suitable for the species' regeneration, possibly through assisted colonization.

Keywords: GIS; MaxEnt; species distribution model; reclassification and overlay method

1. Introduction

In restoring endangered species, it is necessary to determine the availability of suitable habitats [1–3]. In this regard, species distribution models (SDMs) help identify habitats for the development of populations of a species or community to prevent extinctions, especially in the face of the global environmental change [4]. The application of SDMs in the study of endangered species is particularly challenging because of the species' restricted distribution. However, there are models that are able to perform even with only 9 [5] and 11 records [6].

Statistical regression models and methods based on specific algorithms are two of the large families of SDM techniques [7]. MaxEnt is a modeling program based on a maximum entropy algorithm that shows robust results for the spatial projection of species distribution [8,9]. This program is widely accepted and commonly used; however, biological background is required in order to interpret the output [10]. Another method for local analysis is the operators of reclassification and overlay themes integrated into a geographic information system (GIS); likewise, this approach has been effective in detecting current and potential species' habitat [5].

The Chihuahua spruce (*Picea chihuahuana* Martínez) is an endemic and endangered species with a restricted habitat, small populations of this species are found only in the Sierra Madre Occidental in the Mexican states of Durango and Chihuahua [11–14]. The habitat of *P. chihuahuana* is restricted to slopes of 35% to 80%, elevations of 2150–2990 m, and aspect of N, NE and NW. The climate features are: mean annual temperature of 9–12 °C, temperature of the coldest month of 3.8–7.3 °C, temperature of the warmest month of 13.9–17.6 °C, and precipitation range from 600 to 1300 mm [12,14,15].

Ledig *et al.* [12] compared the populations of *P. chihuahuana* with those of Narvaez [16] concluding that saplings and adult trees declined in a period of 15 years; however, the presence of seedlings leads to anticipate regeneration. Recent studies indicate that the small and isolated populations of *P. chihuahuana* are in danger of disappearing due to the low genetic diversity and erosion [14,15,17,18]. In addition, these populations are restricted due to forest fragmentation and climate change [3,12,19].

A previous study [20] stressed the importance of monitoring *P. chihuahuana* populations with a higher spatial resolution. This study developed SDMs for three scales (local, state and national) to determine potential habitat where *P. chihuahuana* can be established to prevent its extinction.

2. Experimental Section

2.1. Data

Data for this study used 38 populations of *P. chihuahuana* in the Sierra Madre Occidental in Mexico recorded by Ledig *et al.* [12]. WorldClim climate data and the Normalized Difference Vegetation Index (NDVI) were used at the national and state scales analysis with a 0.943 × 0.943 km scale. For the local analysis, we used a 40-year historical data from 20 meteorological stations located in Chihuahua State on a scale of 30 × 30 m [21]. In addition, soils and vegetation data were obtained from a federal statistics organization [22].

2.2. Modeling Methods

We used two methods for the modeling the geographical distribution of *P. chihuahuana*: MaxEnt, and operators of reclassification and overlay integrated into GIS. MaxEnt is a program that estimates species' probability of occurrence based on the distribution of maximum entropy, *i.e.*, closest to uniform [23]. A condition for this program is that the expected value for each environmental variable under the estimated distribution matches its empirical average [8]. Also, it is assumed that the probability of estimated presence of a species is associated with the constraints imposed by environmental variables [9]. The parameters set were the ones given by default in MaxEnt: regularization = 1, maximum of background points = 10,000, maximum iterations = 500, convergence threshold = 0.00001 and default prevalence = 0.5.

Table 1 shows the input variables used to create the MaxEnt program. We used a total of 38 national records, 23 state, and 23 local (Figure 1). At the local scale, results of MaxEnt were compared with those generated by the method of reclassification and thematic overlay. Based on what was reported in previous research [20], 90 m resolutions do not provide enough detail for local analysis. Hence, WorldClim data were not used with MaxEnt at local scale because of their lower resolution (0.943 × 0.943 km). Climate data with higher spatial resolution (30 × 30 m) were used instead to create the model [21].

Table 1. Input variables for the MaxEnt model for *Picea chihuahuana* Martínez in Mexico at national, state and local scales.

Variables	National	State	Local
Climate (WorldClim) *	X	X	
NDVI	X	X	
Vegetation type	X	X	X
Soil type	X	X	X
Slope			X
Altitude			X
Aspect			X
Distance to water flows			X
Precipitation **			X
Mean annual temperature **			X

* 19 climate variables; ** Historical data of 40 years from 20 local meteorological stations in Mexico [21].

The method of reclassification and overlay themes uses Boolean operators overlapping various information layers or variables in GIS [24]. At the local scale, the variables of slope and aspect were obtained from a digital elevation model (DEM) with a 30 × 30 m scale. Mean annual temperature and precipitation from local meteorological stations were correlated to elevation of the sites where these stations are located. The results from the regression analysis were integrated to the DEM. In order to obtain the variable of distance to water flows, the hydrology module of ArcGIS 9.3v was used. Once all layers were generated and overlapped, the map with potential distribution of *P. chihuahuana* was created.

Figure 1. Study area for *Picea chihuahuana* Martínez in Mexico.

2.3. Evaluation of the Distribution Maps

The receiver operating characteristic (ROC) curves were used to assess the goodness of fit of the model generated by MaxEnt for the estimation of the distribution of *P. chihuahuana*. The domain and independence of the ROC curves provide a measurement of precision [25], making them a useful tool in predictions involving SDMs [26]. According to Guisan *et al.* [27] and Philips *et al.* [28], a score of 1 indicates a perfect discrimination, a score of 0.5 indicates a performance indistinguishable from random, and 0 indicates that the model has a negative predictive value (*i.e.*, a performance worse than random). When the area under the ROC curve (AUC) is greater than 0.9, the model's prediction level is considered to be in the good-excellent range [29]. In addition to the ROC curves, Jackknife analyses were performed to determine variables that reduce the model reliability when omitted.

In order to evaluate the models, we processed 10 random runs. Each run was created by randomly selecting 75% of the records of occurrence as training data and 25% as testing data. Due to the fact that the logistic output of MaxEnt generates continuous values of probability of occurrence, ranges of probability of *P. chihuahuana* presence were established. As in a previous study on an endangered species [30], we set the ranges of probability based on the *P. chihuahuana* distribution. The range 0.7 to 1 as high suitable and where most of the records of this species presence are located, 0.5–0.7 as suitable and where the rest of records were located. The range from 0 to 0.5 represented low or zero probability of *P. chihuahuana* presence.

3. Results

3.1. National Scale

The model presented a high fit at the national scale, with AUC = 0.991. At this landscape scale, variables of climate, vegetation and soils had a significant effect on the distribution of *P. chihuahuana*. Of the climate variables, the minimum temperature of the coldest month had the highest contribution (36.4%) in determining the probability of occurrence of the species (Table 2). Likewise, the precipitation of the coldest quarter contributed on 11.9%. Among the categorical variables, vegetation and soil also showed a significant contribution to fit the model with 19.8% and 14.7%, respectively. The variables with a lower percentage of contribution were precipitation of the driest month, mean temperature of the coldest quarter, and precipitation of the warmest quarter.

Table 2. Contribution of the variables to the potential distribution of *Picea chihuahuana* Martínez in Mexico at national scale.

Variable	Contribution (%)	Permutation Importance
Minimum temperature of coldest month	36.4	0.9
Vegetation type	19.8	0.1
Soil type	14.7	2.5
Precipitation of coldest quarter	11.9	2.9
Precipitation of driest month	4.4	4.0
Mean temperature of coldest quarter	3.9	35.1
Precipitation of warmest quarter	3.5	1.9
Mean temperature of warmest quarter	2.7	21.3
Mean temperature of driest quarter	0.9	0.0
Mean annual temperature	0.6	0.5
Precipitation of driest quarter	0.4	29.1

The maximum probability of *P. chihuahuana* occurrence is shown by the response curves of the most important variables (Figure 2). The minimum temperature of coldest month ranges from −3 to 0 °C. This species prefers eutric regosol as the soil type and pine forest as the vegetation type. The maximum probability for the precipitation of coldest quarter is around 100 mm.

Figure 3 shows that high values of fitness occur on the temperate forest of the Sierra Madre Occidental (states of Chihuahua and Durango). In the jackknife analysis (leave-one-out cross validation), soil type was the most important variable; if omitted, it reduces the performance of the model (Figure 4).

3.2. State Scale

The model showed an AUC of 0.989, suggesting its reliability in predicting the distribution of *P. chihuahuana* at this scale. Among the climate variables, the precipitation of the driest month contributed to 26.0% to the predictive ability of the model, while the mean annual temperature accounted for 18.3% (Table 3). Among the categorical variables, vegetation and soils contributed to 19.3% and 16.3%, respectively.

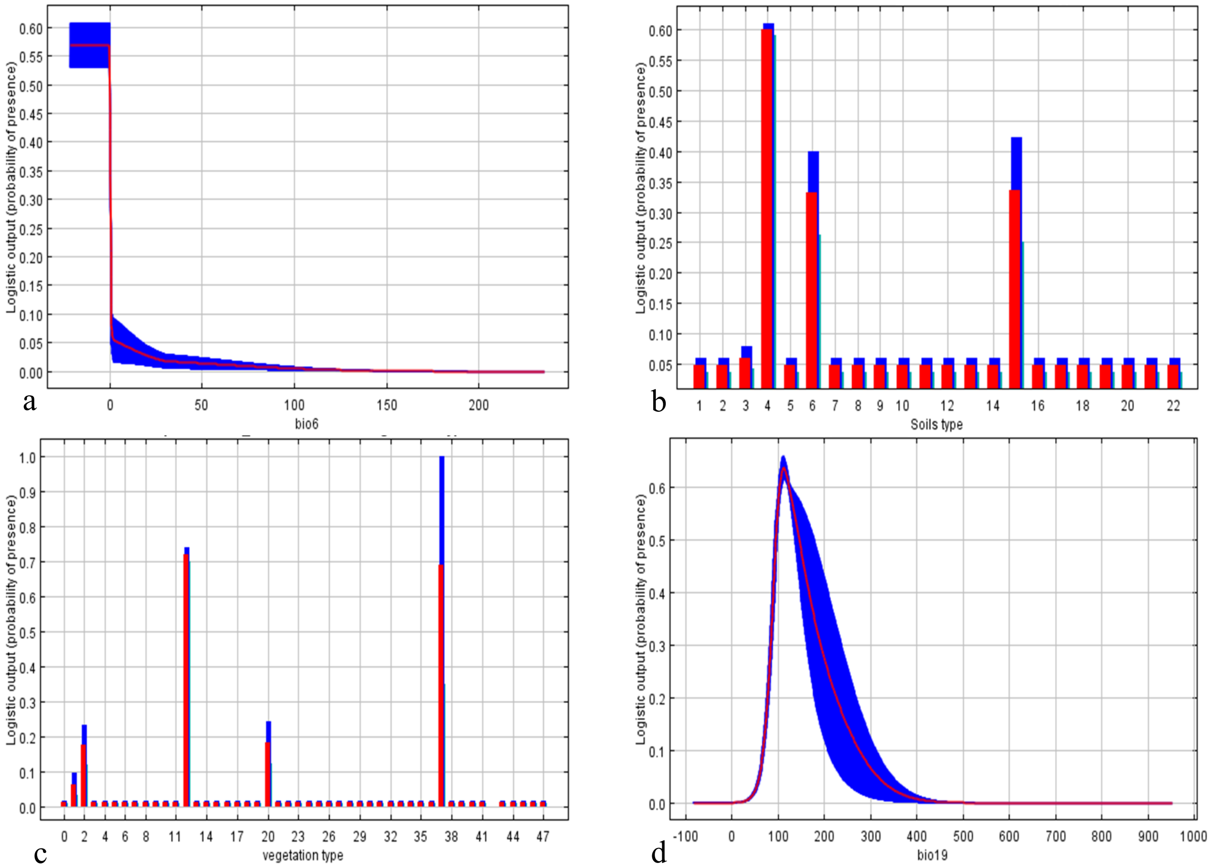

Figure 2. Response curves of the variables that most contributed to explain the potential distribution of *Picea chihuahuana* Martínez in Mexico (**a** = minimum temperature of the coldest month (Bio6), **b** = soils type, **c** = vegetation type, **d** = precipitation of the driest month (Bio19)): model at national scale.

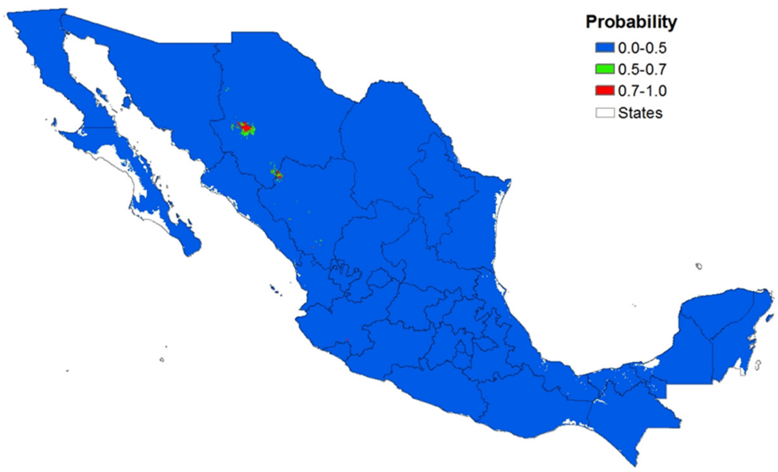

Figure 3. Map of the potential distribution of *Picea chihuahuana* Martínez in Mexico: model at national scale.

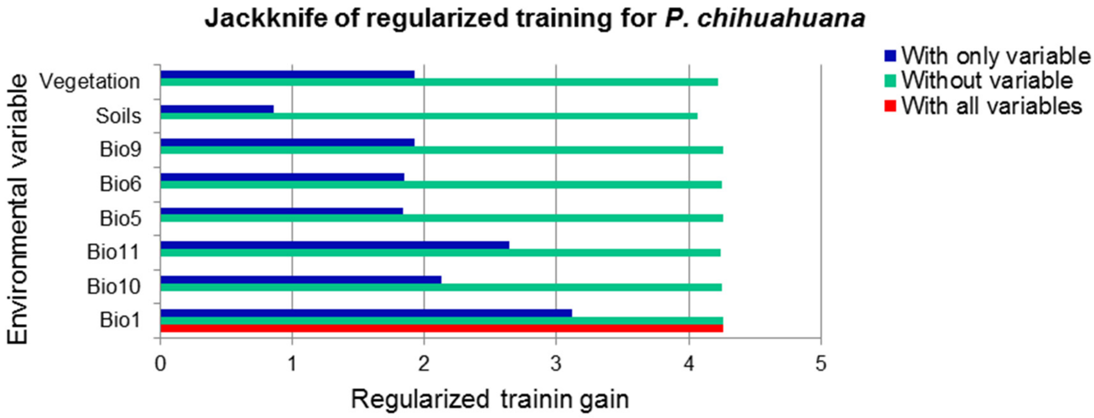

Figure 4. Jackknife of regularized training gain for Picea chihuahuana Martínez in Mexico at national scale. Bio1 = Annual Mean Temperature, Bio5 = Max Temperature of Warmest Month, Bio6= minimum temperature of the coldest month, Bio9 = Mean Temperature of Driest Quarter, Bio10 = Mean Temperature of Warmest Quarter, and Bio11 = Mean Temperature of Coldest Quarter.

Table 3. Contribution of the variables to the potential distribution of *Picea chihuahuana* Martínez at state scale in Chihuahua, Mexico.

Variable	Contribution (%)	Permutation Importance
Precipitation of the driest month	26.0	0.09
Vegetation type	19.3	1.0
Mean annual temperature	18.3	0.4
Soil type	16.3	3.4
Precipitation of the coldest quarter	5.0	13.3
Isothermality	4.3	0.1
Seasonal temperature	2.5	0.4
Diurnal mean range	1.9	18.9
Minimum temperature of the coldest month	1.6	8.4
Mean temperature of the driest quarter	1.2	27.9
Normalized difference vegetation index (NDVI)	0.9	1.0
Mean temperature of the coldest quarter	0.8	20.7
Precipitation of the warmest quarter	0.6	0.02

The maximum probability of *P. chihuahuana* occurrence is shown by the response curves of the most important variables (Figure 5). The precipitation of driest month is higher than 14 mm. This species prefers eutric regosol soil type and pine forest. The maximum probability occurs at 11 °C for the mean annual temperature.

Figure 6 shows the map of potential distribution of *P. chihuahuana* for the state of Chihuahua. A high probability of occurrence of this species was located southwest of the state. In the jackknife analysis, soil type was the most important variable as it significantly reduced the reliability of the model when it is omitted from the leave-one-out cross validation (Figure 7).

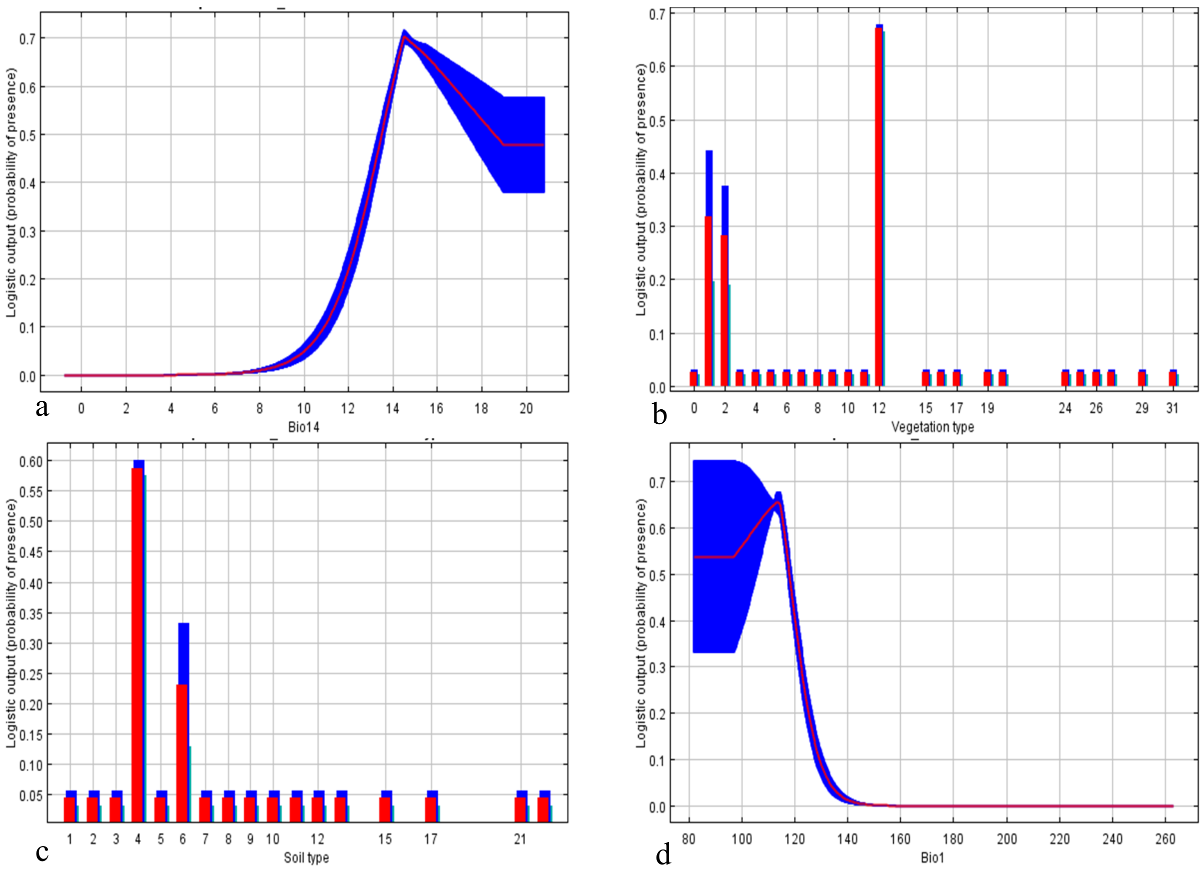

Figure 5. Response curves of the variables that most contributed to explain the potential distribution of *Picea chihuahuana* Martínez in Mexico (**a** = minimum temperature of the coldest month (Bio14), **b** = vegetation type, **c** soils type =, **d** = precipitation of the driest month (Bio1)): model at state scale.

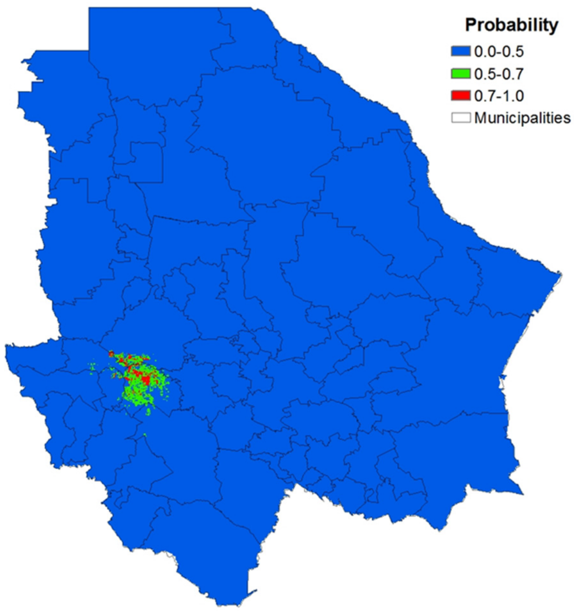

Figure 6. Map of potential distribution of *Picea chihuahuana* Martínez in Chihuahua, Mexico: model at state scale.

Figure 7. Jackknife of regularized training gain for *Picea chihuahuana* Martínez at state scale (Chihuahua, Mexico). Bio1 = Annual Mean Temperature, Bio2 = Mean Diurnal Range (Mean of monthly (max temp – min temp)), Bio5 = Max Temperature of Warmest Month, Bio8 = Mean Temperature of Wettest Quarter, Bio10 = Mean Temperature of Warmest Quarter, Bio12 = Annual Precipitation and Bio14 = Precipitation of Driest Month.

3.3. Local Scale

The results of MaxEnt model were compared with those of the method of reclassification and overlay in GIS. Both methods showed similar distribution patterns of the species, with more than 90% similarity in the estimation of the potential area for *P. chihuahuana* (Table 4).

Table 5 presents the variables that contributed the most to the MaxEnt model, with an AUC of 0.978. Vegetation, aspect and distance to water flows were the variables that contributed the most to explaining the model.

Table 4. Areas of the potential distribution of *Picea chihuahuana* Martínez at local scale estimated by MaxEnt and overlay method.

Distribution	MaxEnt		Overlay Method	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Non-potential	51,186	92.5	50,934	97.0
Potential	1,306	7.5	1,558	3.0

Table 5. Contribution of the variables to the potential distribution of *Picea chihuahuana* Martínez: model at local scale.

Variable	Contribution (%)	Permutation Importance
Vegetation type	30.9	10.0
Aspect	21.2	6.6
Distance to water flows	21.0	43.0
Precipitation	19.0	0.0
Slope	5.2	2.7
Mean temperature	1.7	36.8
Altitude	0.9	0.9

The maximum probability of *P. chihuahuana* occurrence is shown by the response curves of the most important variables (Figure 8). This species prefers eutric regosol soil type and pine forest. The aspect with the highest probability is north. The preferred distance to water flows go from zero to 200 m.

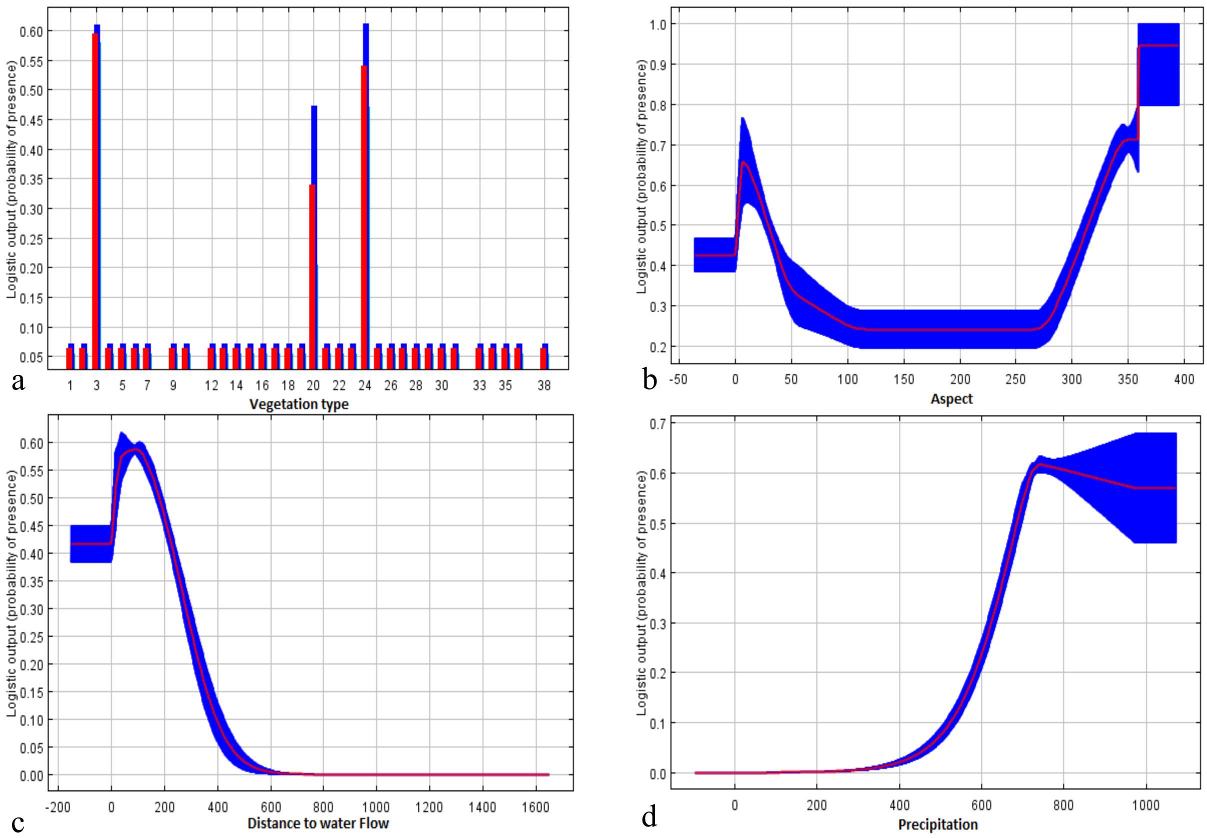

Figure 8. Response curves of the variables that most contributed to explain the potential distribution of *Picea chihuahuana* Martínez in Mexico (**a** = Vegetation type, **b** = Aspect, **c** = Distance to water flows, **d** = Annual precipitation): model at local scale.

The MaxEnt results in the local analysis were equally as robust as the results of the method of reclassification and thematic overlay. This suggests the usefulness of MaxEnt for monitoring and distribution studies of endangered species, especially those growing in small areas characterized by specific environmental conditions (Figure 9). However, under those scenarios, MaxEnt should be feed with climate data with an adequate resolution.

In the jackknife analysis, distance to water flows was the variable that most reduced the predictive ability of the model when it was omitted from the leave-one-out cross validation (Figure 10).

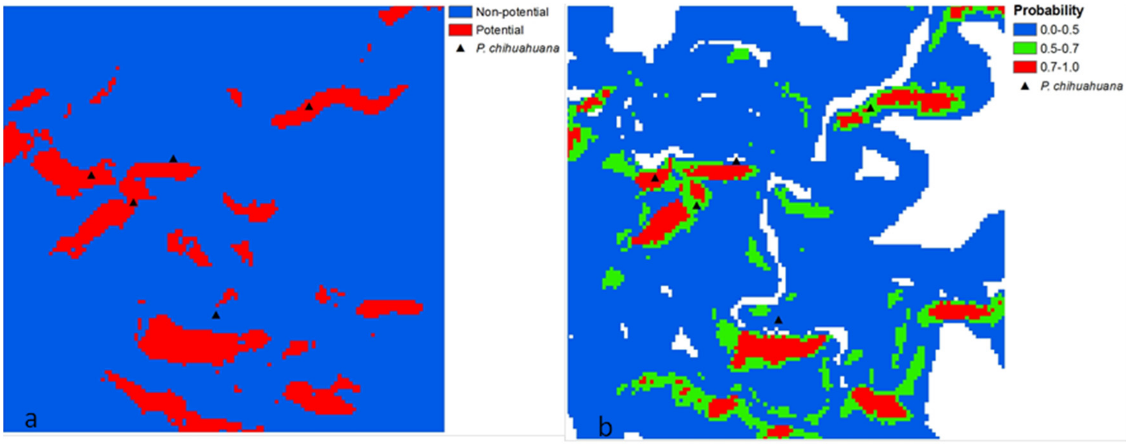

Figure 9. Maps of estimated areas of potential distribution of *Picea chihuahuana* at local scale using: (**a**) overlay method, (**b**) MaxEnt.

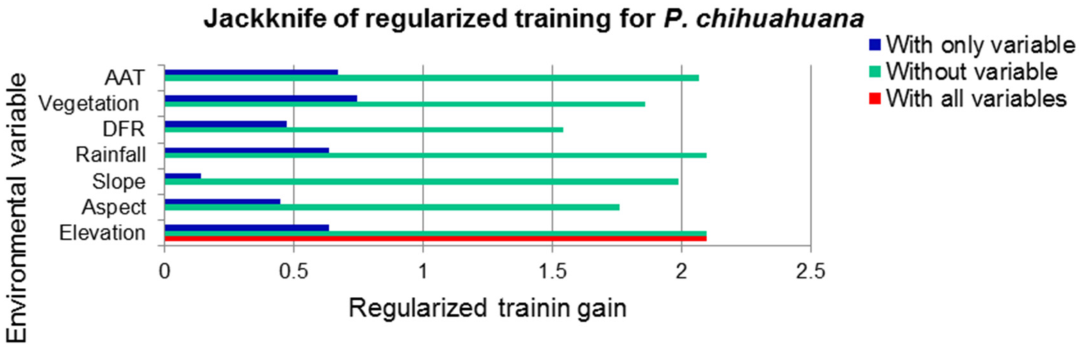

Figure 10. Jackknife of regularized training gain for *Picea chihuahuana* Martínez at local scale. AAT = Annual Average Temperature and DFR = Distance to water flows.

4. Discussion

The territorial occupation of species is limited by the availability of suitable habitat, by barriers to their distribution and by stochastic processes [31]. In this regard, species distribution models serve as important tools in the analysis of potential habitat of species, particularly in studies involving species with narrow distribution ranges and special habitat requirements [5,30,32], such as *P. chihuahuana*. In this study, the models generated by MaxEnt at three scales (national, state and local) performed well in estimating the potential distribution of *P. chihuahuana*. Our study corroborates Pearson and Dawson [33] findings, showing that at a large scale climate variables usually tend to play a more important role in modelling. On the other hand, at a higher resolution variables such as aspect, distance to water flows and vegetation type have a higher predicative power (Table 5). Additionally, when using MaxEnt at the three scales, vegetation showed a significant contribution, reflecting that the studied species has a restricted habitat. Although climate variables were important by themselves at national and state scales, the jackknife analysis showed that soil played a major role when it was omitted from the leave-one-out cross validation. Studies of specific characteristics of soil are required to explain the distribution of the *P. chihuahuana*.

The study at local scale provided a more detailed analysis because of the use of variables with a higher spatial resolution. At this scale, the most important variables were vegetation, aspect and distance to natural water flows (Table 4). These variables, in addition to slope, influence the conditions of the restricted habitat of this species, which is commonly observed in narrow canyons. Those places create an environment with specific characteristics that are favorable for the growth of this species. The fact that endangered species, such as *P. chihuahuana*, grows under specific environmental conditions increases the ability of the models to identify appropriate habitats [34]. Based on the projected area for the potential high suitable habitat (0.7–1.0) for *P. chihuahuana* by using MaxEnt and the buffer tool for the actual distribution [35], we found that it is over 10 times bigger than the actual area were this species is distributed at the three levels analyzed.

Although, MaxEnt is a program widely used for endangered species [5,14,32], limitations have been pointed out [5]. The narrow habitat due to specific environmental conditions where endangered species occur and the limited size of those populations, do not provide to the model enough variation to distinguish between potential or not potential habitat. Among solutions, once a SDM is developed, field validation can be done visiting areas where the species could be present. However, for our case, all *P. chihuahuana* populations are already inventoried and no new populations have been detected and reported over the last years of field surveys. To overcome these limitations, the SDM for this species could be fed with ecophisyological variables.

Conservation strategies should be approached in different ways (approached differently), depending on the distribution range. Our results can be used for planning biological corridors, reseeding and transplanting at southern populations, which are small, isolated and with less genetic variability [36,37]. Meanwhile, the identification of potential habitat may help *P. chihuahuana* conservation by protecting it from any threat (*i.e.*, fragmentation, logging) at northern populations. Those populations display the highest degree of genetic variation and therefore the greatest potential for adaptive evolution [14,36,38].

5. Conclusions

Our results identified new areas for the potential distribution of *P. chihuahuana* and showed the reliable performance of SDM-based methodologies for this species. The availability of habitat for the recovery of populations of *P. chihuahuana* in Mexico was shown on three scales. The potential high suitable habitat for *P. chihuahuana* is over 10 times bigger than the actual area were this species is distributed at the three levels analyzed. The resulting information can be used to support management, conservation and restoration programs for this species, which is listed in the endangered category in the Official Mexican Standard NOM–059 [13].

This data could be used to guide conservation strategies in terms of (i) establishment of artificial regeneration using reproductive local material gathered from well-selected sites outside the priority population's boundaries (but not from inside the whole population), (ii) increasing the size of the smallest populations by planting individuals at the endangered populations edges, and (iii) *ex situ* conservation along with assisted migration in response to climate change [37].

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Author Contributions

The scope of this study was developed by Carmelo Pinedo-Alvarez and Alicia Melgoza-Castillo. Victor Aguilar-Soto performed the SMD under supervision of Carmelo Pinedo-Alvarez. The first manuscript was written by Victor Aguilar-Soto and Carmelo Pinedo-Alvarez and was substantially revised by Federico Villarreal-Guerrero, Christian Wehenkel, and Alicia Melgoza-Castillo.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Funk, V.A.; Richardson, K. Systematic data in biodiversity studies: Use it or lose it. *Syst. Biol.* **2002**, *51*, 303–316.
2. Rushton, S.P.; Ormerod, S.J.; Kerbyn, G. New paradigms for modelling species distributions? *J. Appl. Ecol.* **2004**, *41*, 193–200.
3. Ledig, F.T.; Rehfeldt, G.E.; Sáenz-Romero, C.; Flores-López, C. Projections of suitable habitat for rare species under global warming scenarios. *Am. J. Bot.* **2010**, *97*, 970–987.
4. Ferrier, S.; Guisan, A. Spatial modeling of biodiversity at the community level. *J. Appl. Ecol.* **2006**, *43*, 393–404.
5. Williams, J.N.; Seo, C.; Thorne, J.; Nelson, J.K.; Erwin, S.; O'Brien, J.M.; Schwartz, M.W. Using species distribution models to predict new occurrences for rare plants. *Divers. Distrib.* **2009**, *15*, 565–576.
6. Kumar, S.; Stohlgren, T.J. MaxEnt modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. *J. Ecol. Nat. Environ.* **2009**, *1*, 94–98. Available online: http://www.academicjournals.org/JENE (accessed on 5 November 2014).
7. Pliscoff, P.; Fuentes-Castillo, T. Modelación de la distribución de especies y ecosistemas en el tiempo y en el espacio: una revisión de las nuevas herramientas y enfoques disponibles (Modeling the distribution of species and ecosystems in time and space: A review of available new tools and approaches). *Rev. Geogr. Norte Gd.* **2011**, *48*, 61–79.
8. Phillips, S.J.; Anderson, R.P.; Schapire, R.E. Maximum entropy modeling of species geographic distributions. *Ecol. Model.* **2006**, *190*, 231–259.
9. Elith, J.; Phillips, S.J.; Hastie, T.; Dudik, M.; Chee, Y.; Yates, C.A. Statistical explanation of MaxEnt for ecologists. *Divers. Distrib.* **2011**, *17*, 43–57.

10. Merow, C.; Smith, M.J.; Silander, J.A.J. A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. *Ecography* **2013**, *36*, 1058–1069.
11. Gordon, A. Ecology of *Picea chihuahuana* Martínez. *Ecology* **1968**, *49*, 880–896.
12. Ledig, F.T.; Mapula-Larreta, M.; Bermejo-Velazquez, B.; Reyes-Hernandez, V.; Flores-Lopez, C.; Capo-Arteaga, M.A. Locations of endangered spruce populations in México and the demography of *Picea chihuahuana*. *Madroño* **2000**, *47*, 71–88. Available online: http://www.fs.fed.us/psw/publications/ledig/psw_2000_ledig001.pdf (accessed on 23 November 2014)
13. SEMARNAT. *Norma oficial mexicana NOM-059-SEMARNAT-2010 que determina las especies nativas de México de flora y fauna silvestres–categorías de riesgo y especificaciones para su inclusión, exclusión o cambio–lista de especies en riesgo*; Secretaria del Medio Ambiente y Recursos Naturales, Diario Oficial de la Federación, 2nd Section: Distrito Federal, D.F., Mexico, 30 December 2010.
14. Quiñones-Pérez, C.Z.; Sáenz-Romero, C.; Wehenkel, C. Genetic diversity and conservation of *Picea chihuahuana* Martínez: A review. *Afr. J. Biotechnol.* **2014**, *13*, 2786–2795, doi:10.5897/AJB2014.13645.
15. Sáenz-Romero, C.; Rehfeldt, G.E.; Crookston, N.L.; Duval, P.; St-Amant, R.; Beaulieu, J.; Richardson, B.A. Spline models of contemporary, 2030, 2060 and 2090 climates for Mexico and their use in understanding climate-change impacts on the vegetation. *Clim. Chang.* **2010**, *102*, 595–623.
16. Narváez, F.R. Contribución al conocimiento de la ecología de *Picea chihuahuana*. Bachelor Thesis, Universidad Autónoma de Nuevo León, Nuevo León, Mexico, July 1984.
17. Wehenkel, C.; Sáenz-Romero, C. Estimating genetic erosion using the example of *Picea chihuahuana* Martínez. *Tree Genet. Genomes* **2012**, *8*, 1085–1094.
18. Ledig, E.T.; Jacob-Cervantes, V.; Hodgskiss, P.D.; Eguiluz-Piedra, T. Recent evolution and divergence among populations of a rare Mexican endemic, Chihuahua spruce, following Holocene climatic warming. *Evolution* **1997**, *51*, 1815–1827.
19. Sánchez, C.J.; Narváez, R. *Picea chihuahuana Mrtz. Una conífera en peligro de extinción*, 1st ed.; Instituto Nacional de Investigaciones Forestales y Agrícolas y Pecuarias (INIFAP): Madera, Chih., Mexico, 1983; pp. 1–17.
20. Sánchez, M.G. *Detección de áreas potenciales para la propagación del pinabete espinoso (Picea chihuahuana Martínez)*; Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP): Madera, Chih., Mexico,1996; pp: 1–28.
21. Medina, G.; Diaz, G.; Berzoza, M.; Silva, M.M.; Chavez, A.H.; Baez, A.D. *Estadísticas climatológicas básicas del estado de Chihuahua (periodo 1961-2003)*, 1st ed.; Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP): Chihuahua, Chih., Mexico, 2006; pp: 1–235.
22. INEGI. Instituto Nacional de Estadistica y Geografia. Available online: http://gaia.inegi.org.mx/NLB/mdm5.wms (accessed on 2 July 2014).
23. Loiselle, B.A.; Jørgensen, P.M.; Consiglio, T.; Jiménez, I.; Blake, J.G.; Lohmann, L.G.; Montiel, O.M. Predicting species distributions from herbarium collections: Does climate bias in collection sampling influence model outcomes? *J. Biogeogr.* **2008**, *35*, 105–116.

24. Eastman, J.R. *IDRISI Kilimanjaro Guide to GIS and Image Processing*; Clark Labs, Clark University: Worcester, MA, USA, 2003; p. 306.
25. Fielding, A.H. What are the appropriate characteristics of an accuracy measure? In *Predicting Species Occurrences: Issues of Accuracy and Scale*, 1st ed.; Scott, J.M., Heglund, P., Morrison, M.L.; Raven, P.H., Eds.; Island Press: Washington, DC, USA, 2002; pp. 271–280.
26. Reineking, B.; Schröder, B. Constrain to perform: Regularization of habitat models. *Ecol. Model.* **2006**, *193*, 675–690.
27. Guisan, A.; Graham, C.H.; Elith, J.; Huettmann, F.; NCEAS Species Distribution Modelling Group. Sensitivity of predictive species distribution models to change in grain size. *Divers. Distrib.* **2007**, *13*, 332–340.
28. Phillips, S.; Dudík, M.; Elith, J.; Graham, C.; Lehmann, A.; Leathwick, J.; Ferrier, S. Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. *Ecol. Appl.* **2009**, *19*, 181–197.
29. Wolmarans, R.; Robertson, M.P.; van Rensburg, B.J. Predicting invasive alien plant distributions: how geographical bias in occurrence records influences model performance. *J. Biogeogr.* **2010**, *9*, 1797–1810.
30. Rovzar, C.; Gillespie, T.W.; Kawelo, K.; McCain, M.; Riordan, E.C.; Pau, S. Modelling the potential distribution of endangered, endemic *Hibiscus brackenridgei* on Oahu to assess the impacts of climate change and prioritize conservation efforts. *Pac. Conserv. Biol.* **2013**, *19*, 156–168. Avaiable online: http://search.informit.com.au/documentSummary;dn=657858239256885;res=IELNZC (accessed on 25 November 2014).
31. Wiser, S.K.; Peet, K.; White, P.S. Prediction of rare plant occurrence: A southern appalachian example. *Ecol. Appl.* **1998**, *8*, 909–920, doi:10.1890/1051-0761(1998)008[0909:PORPOA]2.0.CO;2).
32. Rupprecht, F.; Oldeland, J.; Finckh, M. Modelling potential distribution of the threatened tree species *Juniperus oxycedrus*: How to evaluate the predictions of different modelling approaches? *J. Veg. Sci.* **2011**, *22*, 647–659.
33. Pearson, R.G.; Dawson, T.P. Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful? *Glob. Ecol. Biogeogr.* **2003**, *12*, 361–371.
34. Messick, J.A.; Hoagland, B.W. Potential distribution modeling of *Penstemon oklahomensis* (Plantaginaceae). *J. Bot. Res. Inst. Texas* **2013**, *2*, 891–899. Available online: http://connection.ebscohost.com/c/articles/93660005/potential-distribution-modeling-penstemon-oklahomensis-plantaginaceae (accessed on 23 November 2014).
35. Nakazato, T.; Warren, D.L.; Moyle, L.C. Ecological and geographic modes of species divergence in wild tomatoes. *Am. J. Bot.* **2010**, *97*, 680–693.
36. Jaramillo-Correa, J.P.; Beaulieu, J.; Ledig, F.T.; Bousquet, J. Decoupled mitochondrial and chloroplast DNA population structure reveals Holocene collapse and population isolation in a threatened Mexican-endemic conifer. *Mol. Ecol.* **2006**, *15*, 2787–2800.
37. Ledig, F.T. Climate change and conservation. *Acta Silvatica et Lignaria Hungarica* **2012**, *8*, 57–74.

38. Quiñones-Pérez, C.Z.; Simental-Rodríguez, S.L.; Saenz-Romero, C.; Jaramillo-Correa, J.P.; Wehenkel, C. Spatial genetic structure in the very rare and species-rich *Picea chihuahuana* tree community (Mexico). *Silvae Genet.* **2015**, in press.