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EFFECT OF CLIMATE CHANGE ON THE DISTRIBUTION OF *MAGNOLIA SCHIEDEANA*: A THREATENED SPECIES

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Abstract: The effects of climate change on biodiversity are imminent, and these turn out to be particularly alarming for the tropical montane cloud forest. The disappearance of fragments of this forest is expected, along with some of their most characteristic species, such as *Magnolia schiedeana*. Mexico, through the National System of Protected Natural Areas, must consider protection strategies for those species distributed within the Protected Natural Areas that will be affected by the climate change. This study delimits the distribution of *M. schiedeana* in Mexico, through ecological niche and future distribution modeling under two periods: years 2040 and 2080. These distribution models tend to move towards northeastern Mexico. The potential distribution of this species declines by 0.36% and 1.94% in the first and second periods, respectively. From this result, the future role of National System of Protected Natural Areas in the long-term conservation of *M. schiedeana* was analyzed, prompting a proposal to focus conservation efforts on the following Protected Natural Areas: (1) At the federal level: Biosphere Reserve Sierra Gorda and Cañón de Metztitlán, Cuenca del Río Necaxa and El Potosí, National Park El Chico, Cofre de Perote, Pico de Orizaba and Los Mármoles, and Nevado de Toluca. (2) At the state level: Cerro de las Culebras, Cerro de la Galaxia, Cerro de Macuiltepetl, El Tejar Garnica, Francisco Javier Clavijero, La Martinica, Molino de San Roque, Pacho Nuevo and Predio Barragán.

Key words: bioclimatic models, conservation, endangered species, potential distribution.

Resumen: Los efectos del cambio climático sobre la diversidad biológica son inminentes, y resultan especialmente alarmantes para el bosque mesófilo de montaña. Se prevé la desaparición de fragmentos de bosque y de algunas especies más características, como *Magnolia schiedeana*. México, mediante el Sistema Nacional de Áreas Naturales Protegidas, debe considerar estrategias de protección para aquellas especies en áreas naturales protegidas que resultarán afectadas a causa del cambio climático. Este estudio delimita la distribución de *M. schiedeana*, por medio del modelado del nicho ecológico, en México, y su distribución futura en dos periodos: al año 2040 y al año 2080. Los resultados muestran que los modelos de distribución tienden a desplazarse hacia el noreste de México. En el primer periodo, la distribución potencial disminuye 0.36% y, en el segundo periodo decae hasta 1.94%. Con base en la distribución potencial, se analizó la función que el Sistema Nacional de Áreas Naturales Protegidas desempeñará en la conservación de *M. schiedeana* a largo plazo, con lo cual se propone centrar los esfuerzos de conservación en las siguientes áreas naturales protegidas: (1) A nivel federal: Reserva de la Biosfera Sierra Gorda y Barranca de Metztitlán, Cuenca del Río Necaxa, El Potosí, Parque Nacional El Chico, Cofre de Perote, Pico de Orizaba y Los Mármoles, y el Nevado de Toluca. (B) A nivel estatal: Cerro de las Culebras, Cerro de la Galaxia, Cerro de Macuiltepetl, El Tejar Garnica, Francisco Javier Clavijero, La Martinica, Molino de San Roque, Pacho Nuevo y Predio Barragán.

Palabras clave: conservación, distribución potencial, especies en peligro de extinción, modelos bioclimáticos.

Anthropogenic activity has led to global temperature rises, affecting ocean temperatures, ice and snow coverage, and cooling of the lower stratosphere (Magaña, 2004). It has also caused the concentration of atmospheric CO_2 to rise from 280 ppm to 370 ppm since the mid-nineteenth century (IPCC, 2001). These are changes that will have dramatic consequences for ecosystems by altering the abundance and distribution of their constituent species (Hardy, 2003; Tews, 2007; Aitken *et al*., 2008), as well as causing a gradual decline in the environmental services they provide. These environmental changes make it possible to predict that 11% of the world's endemic biota could become extinct within the next 100 years (Malcolm *et al*., 2006). Using species distribution models and future scenarios, it is possible to predict the response of species to such climate change and thus, propose adaptation and mitigation measures at both the ecosystem and species level (Hilbert *et al*., 2004; Magaña *et al*., 2004; Li and Hilbert, 2008; Tejeda, 2009).

It is intended for tropical montane cloud forest (TMCF) of Mexico, a shift towards lower latitudes and higher altitudes (Foster, 2001). Likewise Estrada-Contreras (2010) found an impairment in the potential distribution of *Quercus skinneri* Benth (endemic to this forest) with a decrease of 100% in current distribution, and a decrease of 50% for the following seven species *Cinnamomum effusum* (Meisn.) Kosterm., *Miconia glaberrima* (Schltdl.) Naudin, *Oreopanax xalapensis* (Kunth) Decne. et Planch., *Palicourea padifolia* (Humb. et Bonpl. ex Schult.) C.M. Taylor et Lorence, *Quercus germana* Schltdl. et Cham., *Q. xalapensis* Bonpl., and *Ulmus mexicana* (Liebm.) Planch. Consequently, there will be three options for these species: migrate to optimal zones for survival, adapt to the prevailing environmental conditions, or become extinct (Holt, 1990; Lindenmayer *et al*., 1996; IPCC, 2001).

The TMCF in Mexico is known for its archipelago-type distribution, and is located in an altitude range between 1,000 and 3,000 masl. Its main features are the flora, consisting of a mixture of the neotropical and holarctic species, and extended periods of fog cover (Rzedowski, 1978, 1996). Villaseñor (2010) reports 6,790 species of vascular plants, 1,625 genera, 238 families, including 2,361 endemic species; characteristic genera of this ecosystem are *Carpinus*, *Engelhardtia*, *Fagus*, *Liquidambar*, *Magnolia*, and *Ostrya*, among others. It is an ecosystem in danger of extinction that features high levels of disturbance and fragmentation, with 83 species in danger of extinction, 206 threatened, and 175 vulnerable (CONABIO, 2010; SEMARNAT, 2010; Villaseñor, 2010; González-Espinosa *et al*., 2011).

In Mexico, there are 21 species of the family Magnoliaceae, specifically *Magnolia schiedeana* Schltdl. It is found exclusively in TMCF, in the central portion of the watershed of the Gulf of Mexico, and is categorized as threatened to become extinct because of the destruction of its habitat (Cicuzza *et al*., 2007; Jiménez-Ramírez *et al*., 2007; SEMARNAT, 2010; Vázquez-García *et al*., 2012). The populations are found dispersed within remnants of TMCF, which are being steadily absorbed by uncontrolled urban expansion.

When the climate scenarios are added to this situation, TMCF appears highly vulnerable on account of the predicted fluctuations in temperature and precipitation (Markham, 1998; Pounds *et al*., 1999; Foster, 2001; Midgley *et al*., 2002; Bubb *et al*., 2004; Sáenz-Romero *et al*., 2010; Ponce-Reyes *et al*., 2012; Rojas-Soto *et al*., 2012), and many of its species are likely to suffer local extinctions.

Protected Natural Areas (PNA) has been considered the best option for biodiversity conservation (Bruner *et al*., 2001). However, this option requires reassessment in the face of climate change, with an examination of the reserve network and its efficiency relating to the long-term conservation of flora and fauna (Halpin, 1997; Hannah *et al*., 2007; Lawler, 2009), as well as the provision of environmental services (Torres and Guevara, 2002; Bezaury, 2009). It is estimated that PNAs contain 15% of the terrestrial carbon and provide ecosystem services for the reduction of disasters, supply of water, food, and public health (Dudley *et al*., 2010).

In Mexico, only 12% of the national territory is allocated to biodiversity conservation (CONANP, 2011) and, in the state of Veracruz, conservation efforts are focused on 19 PNAs decreed at the federal level and 18 at the state level (SEDEMA, 2012a, b). Nevertheless, these PNAs are harmed day by day from human activities, and some have been absorbed by the urban development with no knowledge, in many cases, of the species within the territories apportioned for conservation in Veracruz (CONABIO, 2010).

The species distribution models and future scenarios predict the shift in the distribution of species; therefore, it can be inferred that species can enter and leave the territory allocated to conservation (Téllez-Valdés *et al*., 2006; CONANP, 2010). For this reason, it is important to analyze the effects of climate change on species distribution and monitor their future displacement with respect to the PNAs (Téllez-Valdés and Dávila-Aranda, 2003; Hannah *et al*., 2005, 2007; Mansourian *et al*., 2009; Contreras-Medina *et al*., 2010). Currently, ecological niche modeling has become an essential tool for determining the potential distribution and ecological requirements of species (Soberón and Peterson, 2005; Irfan-Ullah *et al*., 2007; Peterson, 2009).

The BAM diagram of Soberón and Peterson (2005) mention that the modeling of the ecological niche is governed by the fundamental niche and realized niche. The fundamental niche is defined as the geographic area with the appropriate combination of abiotic factors allowing the species to survive, grow, and reproduce; and the realized niche is the geographic area in which the interaction takes place with other species (Soberón and Peterson, 2005).

Different software for modeling potential species distribution including GARP, BIOCLIM, DOMAIN, MaxEnt, to name a few, and it has been proven that MaxEnt has a method with greater yield and reliability than other software (Elith *et al*., 2006). MaxEnt is a statistically used algorithm to make predictions or inferences from incomplete information, and estimates the species distribution through the search of the probable distribution of maximum entropy (nearest the occurrence data of the species; Phillips *et al*., 2006).

The principle of maximum entropy guarantees that the

MaxEnt distribution probability meets all the restrictions of the data distribution of species presence. The probability of unknown π distribution is on a finite combination X (pixel combination in the study area). The π distribution assigns a $\pi(x)$ probability that is not negative on each point x and these probabilities add up to 1, with ln being the natural logarithm. The π approach is also the $\hat{\pi}$ distribution approach. The $\hat{\pi}$ entropy is defined by the following formula:

$$H(\hat{\pi}) = -\sum_{x \in X} \hat{\pi}(x) \, \mathrm{In} \, \hat{\pi}(x)$$

Entropy is not negative and the natural logarithm of the number is the element X. The procedures applied in this software are described in detail by Phillips *et al*. (2006).

In this study, we evaluated the potential effects of climate change on populations of *Magnolia schiedeana*, considering the MDI-ECHAM5 scenario in two periods (years 2040 and 2080), using potential distribution models at a spatial resolution of 1 km^2. We also identified protected areas suitable for long-term preservation.

Methods

Current potential distribution of Magnolia schiedeana. The area distribution of the species was constructed using a database that includes 335 records of *M. schiedeana*, and which was pieced together from the specimens found in the following herbaria: XALU from the Universidad Veracruzana, Xalapa campus, XAL from the Instituto de Ecología, A.C., and MEXU from the Universidad Nacional Autónoma de México, as well as the online databases Tropicos from the Missouri Botanical Garden and REMIB-CONABIO (Red Mundial de Información sobre Biodiversidad/World Information network on Biodiversity - National Commission for Knowledge and Use of Biodiversity/Comisión Nacional para el Conocimiento y Uso de la Biodiversidad).

Mean monthly values of minimum and maximum temperatures and precipitation recorded from a standard network of meteorological stations were interpolated, using the Thin-Plate Smoothing Spline method of the ANUSPLIN 4.1 package (Hutchinson, 1991, 1995a, b, 1997; Hutchinson and Gessler, 1994; Houlder *et al*., 2000). Specifically, 4,200 stations for temperature and 6,218 stations for precipitation were used to produce the digital climatic layers (Téllez *et al*., 2011). The spatial resolution of the layers and the digital elevation model was 1 km^2 from the GTOPO 30 project (https://lta.cr.usgs.gov/GTOPO30).

The BIOCLIM software of the package ANUCLIM 6.1 was used to generate 19 bioclimatic variables (Table 1) from the combination of the mean monthly layers of temperature and precipitation above referred, from which the bioclimatic profile of *Magnolia schiedeana* was also extracted (Lindenmayer *et al*., 1991; Téllez-Valdés and Dávila-Aranda, 2003; Téllez-Valdés *et al*., 2004, 2006; Villaseñor and Téllez-Valdés, 2004).

The records where the species is found were used along with the 19 bioclimatic variables to perform a principal component analysis to identify those variables that provide the greatest explanation of the variance of the climatic values in which the species records are distributed and to reduce the autocorrelation.

The seven resulting bioclimatic variables highlighted by the principal component analysis were converted to the ASCII format according to the MaxEnt 3.3.3a software requirements (Table 1), to generate the potential distribution for the species in question.

To generate the current potential distribution models of *Magnolia schiedeana*, first we generated a model using the jackknife analysis to identify which of the seven selected variables contributed most as regards percentage to the explanation of the variance in which the sample is distributed (species records). The models were calibrated from a random sample of 75% to generate the model. The remaining 25% was used to assess the accuracy of the model, and compared using the ROC curve (the AUC index). The models produced were evaluated in order to verify whether the performance differed from that obtained by chance. The model was checked by reducing the environmental space from 10,000 (per omission) to 1,000 cells.

Furthermore, MaxEnt was prevented from extrapolating

Table 1. Bioclimatic variables and values used to generate the current and future potential distribution of *Magnolia schiedeana* (Minimum - Maximum values, Mean ± Standard Deviation). * = Bioclimatic variables with higher variance explained through which distributes the sample (records of the species).

	Bioclimatic variables	Values
1	Annual mean temperature (ºC)	10.1 - 22.6 (16.90±1.34)
2	Mean diurnal range (ºC)*	8.20 - 13.6 (9.60±0.639
3	Isothermality (ºC)	0.55 - 0.66 (0.59±0.01)
4	Temperature seasonality (coefficient of variation, %)*	0.44 - 1.11 (0.66±0.05)
5	Max temperature of warmest period (ºC)	18 - 33.4 (25±1.30)
6	Min temperature of coldest period (ºC)*	2 - 12.70 (8.7±1.29)
7	Temperature annual range (ºC)*	14.6 - 22.9 (16.3±0.91)
8	Mean temperature of wettest quarter (ºC)	10.6 - 25.1 (18±1.52)
9	Mean temperature of driest quarter (ºC)*	8.7 - 19.3 (15±0.95)
10	Mean temperature of warmest quarter (ºC)*	11.6 - 26 (19±1.40)
11	Mean temperature of coldest quarter (ºC)	8.4 - 17.9 (14.2±1.17)
12	Annual precipitation (mm)	589 - 1948 (1561±117.21)
13	Precipitation of wettest period (mm)	32 - 115 (75±5.75)
14	Precipitation of the driest period (mm)	0 - 14 (9±3.97)
15	Precipitation seasonality (coefficient of variation, %)	53 - 84 (68±3.14)
16	Precipitation of wettest quarter (mm)	265 - 979 (715±54.91)
17	Precipitation of driest quarter (mm)*	47 - 193 (158±17.96)
18	Precipitation of warmest quarter (mm)	177 - 573 (448±44.25)
19	Precipitation of coldest quarter (mm)	50 - 217 (170±20.56)

or applying the clamping option (this is how we did the fastening), to prevent an overestimation. This is based on the proposal in BAM diagram, in which M represents the ability of relocation or spread of the species (Soberón and Peterson, 2005; Peterson, 2009).

The model was refined with a maximum of 1,000 points of environmental background (0.0083°, approximately 1 km^2). Five replicates were run using the bootstrap algorithm. We decided to run 2,000 iterations, since most of the previous exercises finished in fewer than 1,500 iterations. The logarithmic scale of the prediction values was broken where the values of sensitivity and specificity of training were equal, selected using the average model produced by replicates (Phillips *et al*., 2006).

Potential future distribution of Magnolia schiedeana. Given the uncertainty regarding the magnitude of the effects of climate change, two different periods were proposed (years 2040 and 2080). The first is a conservative scenario, expected for the year 2040, implying temperature increases of 2 to 3.5 °C and a 5% reduction in precipitation. The second is a more drastic scenario, expected for the year 2080, where the temperature increase is of 2.5 to 4 °C with a 10% reduction in precipitation.

To obtain the potential future distribution model was used *Magnolia schiedeana* mpi_ECHAM5 (Jungclaus *et al*., 2005) in two periods (years 50 and 80) in stage A1B, chosen based on the guidance of climate change scenarios at regional scale (Conde *et al*., 2011), downloaded from the website of Downscaling Global Circulation Model (GMC) (http://www.ccafs-climate.org/). The A1B scenario suggests a future where emissions are medium-high, intervening human activities, such as the increase in population and economy globalization, technology, the use of fossil sources and alternative energy (IPCC, 2007).

Comparison of current and future models with the Protected Natural Areas. Current and future models of *Magnolia schiedeana* distribution were compared against the polygons of federal and state level PNAs in order to determine the current potential distribution area within the PNAs, as well as to predict what this may become following application of the climate change scenarios. The potential future expansion/contraction of these areas was determined.

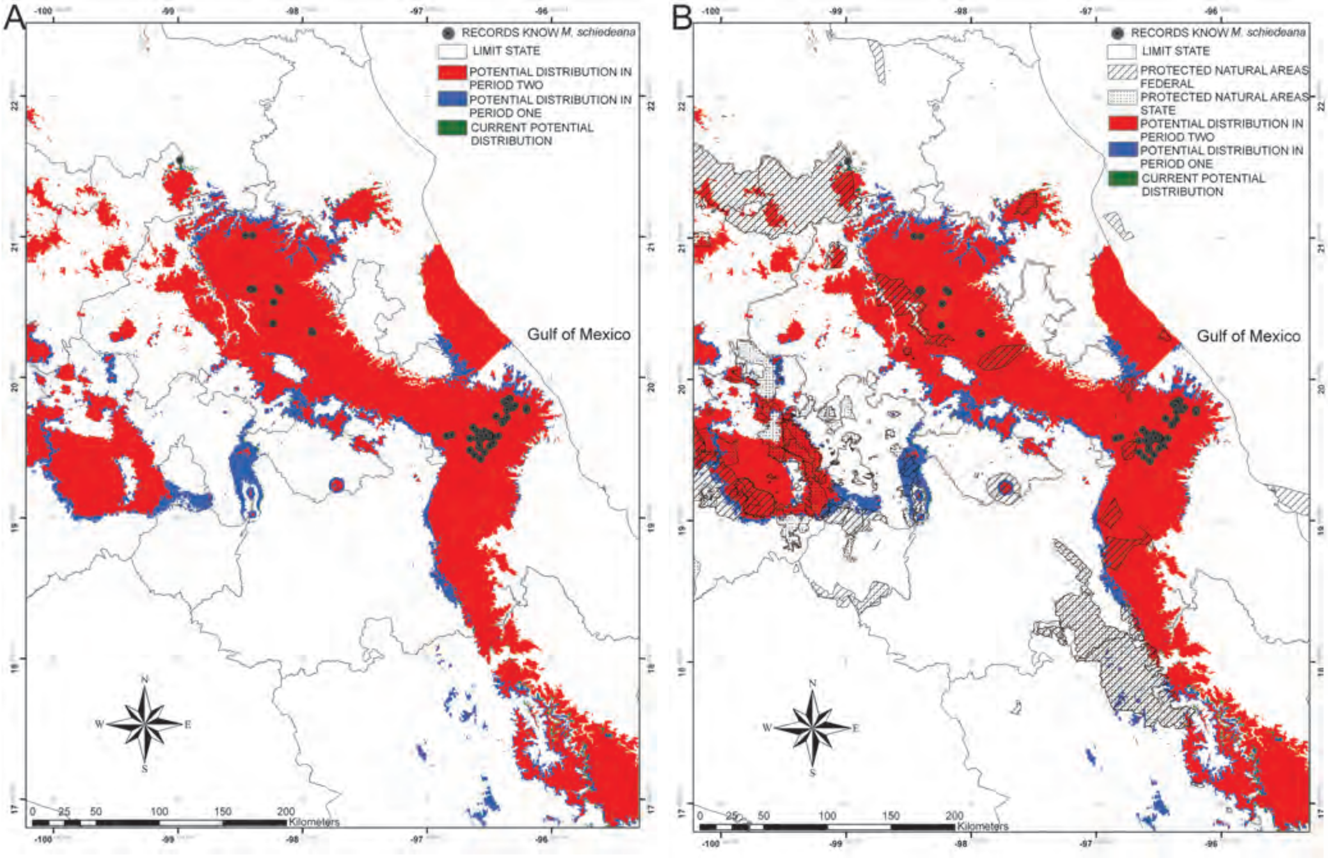

Figure 1. Distribution models of *Magnolia schiedeana* at *ca*. 1 km^2. Current potential distribution (green) and potential distribution under period 1 (blue: year 2040) and under period 2 (red: year 2080). A) Current potential distribution compared with both periods. B) Comparison between distribution models and Federal and State enacted Protected Natural Areas.

Data analysis. The current and future models were overlapped with the digital elevation model at the same resolution, in order to identify potential expansion or contraction within the altitudinal variation for the periods with respect to the current potential distribution of *Magnolia schiedeana*. We performed a variance analysis with a Tukey multiple comparisons test, considering the current model as an independent variable and the two periods as dependent variables, using the software JMP 7.0.1 (SAS Institute Inc., 2007).

Comparison of the current and future models with the PNAs, using GIS ArcView 3.2 (ESRI, 1999), allowed the placement of the PNAs within the current and future distribution areas. The future latitudinal and altitudinal displacement of *Magnolia schiedeana* distribution within the PNAs was estimated.

Results

The distribution of *Magnolia schiedeana* corresponds to that of the TMCF, occurring in gullies or humid slopes where the average annual temperature ranges between 10-21 ºC, and annual precipitation is between 589 and 1,743 mm. Table 1 shows the bioclimatic variables that explain the distribution of *M. schiedeana*, in which seven bioclimatic variables contributed almost 98% to the explanation of the variance in which the sample is distributed (species records), with variables four, six, and 17 adding more than 70% together.

Comparison of the current and future distribution of Magnolia schiedeana. Our model, in the MaxEnt 3.3.3a, projects potential changes in the distribution areas of *M. schiedeana* as a consequence of climate change during both periods. The current potential distribution is estimated at 84,640 km^2, decreasing to 84,333 km^2 in the first period (year 2040) and to 82,995 km^2 in the second period (year 2080). Considering the current potential distribution as a base, a displacement of 36.5 km^2 to the northeast and a contraction of 5.2 km^2 in the west are observed in the first period (year 2040). In the second period (year 2080), a displacement of 6.5 km^2 in the east is observed along with a contraction in the west of 54.4 km^2 (Figure 1A).

The current potential distribution is at altitude of 1,433-2,135 masl, with an average of 1,882 ± 687 m, decreasing to 1,426-2,118 masl with an average of 1,876 ± 693 (range: 498-5,471 m) in the first period (year 2040), and to 1,291-2,052 masl with an average of 1,710 ± 594 m in the second period (year 2080), which differs significantly under the second period ($P < 0.0001$) (range: 709-4,837 masl). Figure 2 shows the elevation of the current and future potential distribution of *M. schiedeana* in which the box on the diagram indicates the greatest potential distribution in both periods (50% of the distribution on the data), and the median corresponding to the center of the box, only being observed in a symmetrical distribution in the second period.

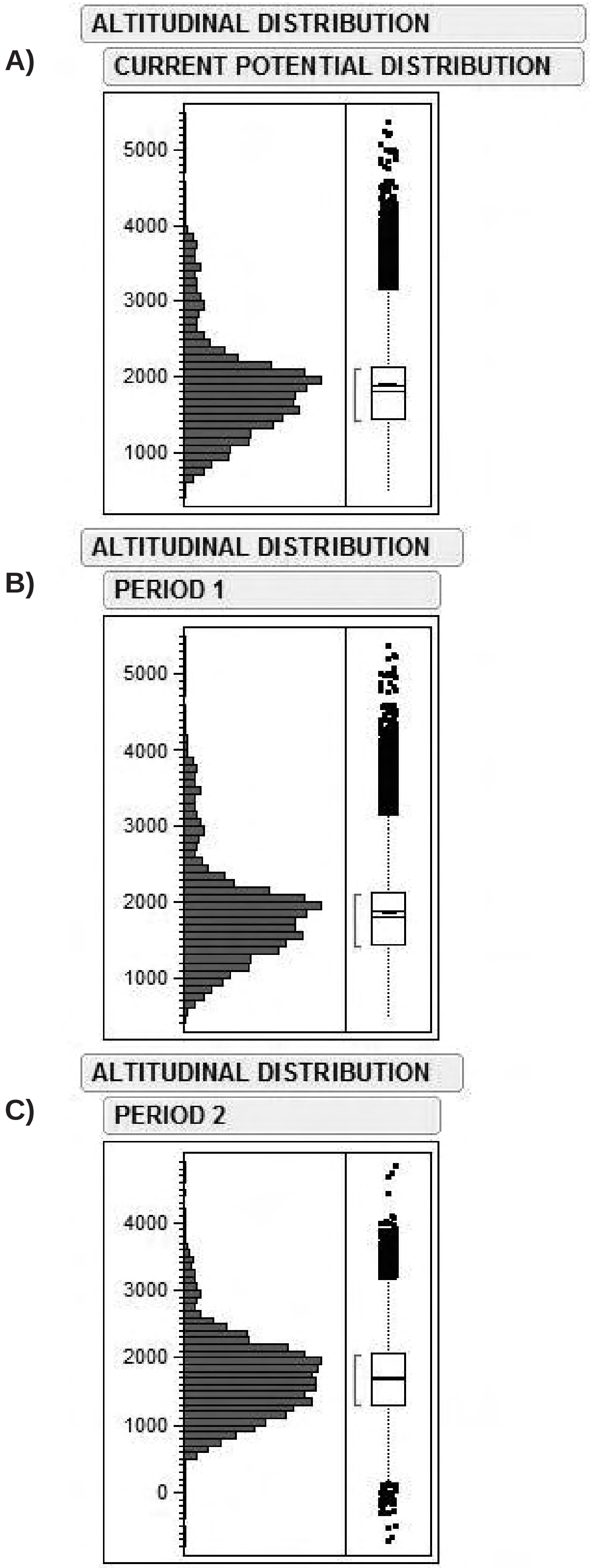

Figure 2. Altitudinal distribution of the current potential distribution models produced under two periods for *Magnolia schiedeana*. A) Current potential distribution. B) Period 1 (year 2040). C) Period 2 (year 2080).

Table 2. Potential distribution of *Magnolia schiedeana* produced under two periods within Protected Natural Areas in Mexico. Area measurements in km^2 and percentage of total area (%).

Protection level	Protected Natural Area	Potential distribution current		Distribution under period 1 (year 2040)		Distribution under period 2 (year 2080)	
		Area	(%)	Area	(%)	Area	(%)
Federal	Barranca de Metztitlán	945.23	98.41	946.48	98.54	952.17	99.13
	Benito Juárez	11.01	40.22	11.01	40.22	2.86	10.44
	Bosencheve	85.46	81.92	96.43	92.43	70.78	67.84
	Cañón del Río Blanco	489.65	87.92	493.17	88.55	450.42	80.87
	Cañón del Sumidero	34.38	15.77	26.46	12.14	8.41	3.85
	Cerro de Garnica	9.36	96.69	9.96	100	9.96	100
	Ciénegas del Lerma	-------	-------	0.53	1.75	-------	-------
	Cobio Chichinautzin	53.56	14.35	82.99	22.24	3.61	0.96
	Cofre de Perote	117	100	117	100	117	100
	Cuenca Hidrográfica del Río Necaxa	398.49	95.72	401.13	96.35	405.88	97.49
	Cumbres de Monterrey	496.63	27.99	388.83	21.91	303.47	17.10
	Cumbres del Ajusco	9.2	100	9.2	100	9.2	100
	Desierto de los leones	15.29	100	15.29	100	15.29	100
	El Chico	27.39	100	27.39	100	27.39	100
	El Cimatario	0.89	3.63	2.8	11.43	0.95	3.88
	El Potosí	20.45	95.87	21.33	100	20.38	95.54
	El Tepozteco	5.26	2.26	12.11	5.20	-------	-------
	El Gogorrón	21.58	8.63	23.34	9.33	20.49	8.19
	Insur. José María Morelos	-------	-------	1.04	2.40	0.08	0.18
	Insur. Miguel Hidalgo y Costilla	15.8	100	15.8	100	15.8	100
	Iztaccíhuatl-Popocatépetl	269.84	67.76	269.84	67.76	8.03	2.01
	Lagunas de Monte bello	41.17	68.36	22.2	36.86	17.12	28.42
	Lagunas de Zempoala	38.16	79.66	47.25	98.64	11.39	23.77
	Los Mármoles	158.05	68.27	158.05	68.27	149.02	64.37
	Malinche o Matlalcuéyatl	126.12	27.59	125.25	27.40	54.77	11.98
	Mariposa Monarca	456.73	81.18	467.97	83.18	429.97	76.42
	Montes Azules	3.33	0.10	5.53	0.16	22.33	0.67
	NAHA	23.22	60.35	29.93	77.80	30.32	78.81
	Nevado de Colima	25.72	26.79	24.07	25.07	8.03	8.36
	Nevado de Toluca	467.84	100	467.84	100	467.84	100
	Pico de Orizaba	197.5	100	197.5	100	197.5	100
	Pico de Tancítaro	4.68	1.99	5.06	2.16	-------	-------
	Rayón	0.1	40	0.1	40	0.1	40
	Selva del Ocote	65.35	6.45	67.99	6.71	61.34	6.05
	Sierra de Álvarez	96.64	57.18	97.52	57.70	91.82	54.33
	Sierra de Arteaga	1,208.2	61.28	1,128.8	57.25	1021.4	51.81
	Sierra fría	181.62	16.20	190.98	17.03	4.4	0.39
	Sierra Gorda, Querétaro	755	19.69	733.47	19.12	689.77	17.98
	Sierra Gorda, Guanajuato	367.6	15.51	399.28	16.85	404.03	17.05
	Sierra del Laurel	1.77	0.92	2.58	1.34	0.44	0.22
	Tehuacán-Cuicatlán	357.24	7.28	362.52	7.39	170.92	3.48
	Valle de bravo, Malacatepec, Tilostoc y Temascaltepec	879.17	62.85	952.34	68.08	678.71	48.52
State	Volcán de Tequila	1.13	1.32	1.13	1.32	1.13	1.32
	Cerro de la Galaxia	0.32	100	0.32	100	0.32	100
	Cerro de las Culebras	0.35	100	0.35	100	0.35	100
	Cerro de Macuiltépec	0.28	100	0.28	100	0.28	100

Table 2. Continuation

Protection level	Protected Natural Area	Potential distribution current		Distribution under period 1 (year 2040)		Distribution under period 2 (year 2080)	
		Area	(%)	Area	(%)	Area	(%)
State	Ciénega del Fuerte	42.69	100	42.69	100	42.69	100
	El Tejar Garnica	0.92	100	0.92	100	0.92	100
	Francisco Javier Clavijero	0.89	100	0.89	100	0.89	100
	La Martinica	1.18	100	1.18	100	1.18	100
	Molino de San Roque	0.17	100	0.17	100	0.17	100
	Pacho Nuevo	0.02	100	0.02	100	0.02	100
	Pancho Poza	0.56	100	0.56	100	0.56	100
	Predio Barragan	0.01	100	0.01	100	0.01	100
	Río Filobobos y su Entorno	93.68	88.98	105.28	100	92.32	87.68
	San Juan del Monte	6.09	100	6.09	100	6.09	100
	San Pedro del Monte	4.40	100	4.40	100	4.40	100
	Sierra de Ontontepec	151.52	100	151.52	100	151.52	100

Comparison of the current and future distribution with the Protected Natural Areas. Neither the current potential distribution nor that presented under either periods of climate change, coincide with the distribution of federally decreed PNAs in the state of Veracruz. However, they coincide with such PNAs in states that include: Guanajuato, San Luis Potosi, Hidalgo, Tlaxcala, Puebla, Estado de Mexico, among others (Table 2). According to the state Protected Natural Areas in central Veracruz, we can observe a coincidence of 100% in the area decreed in 14 PNAs (Figure 1B).

Discussion

Problems of TMCF in Mexico. The future climate scenarios are alarming for TMCF and are expected to contribute to the decrease in the distribution of many species (Foster, 2001). According to Ponce-Reyes *et al*. (2012), the TMCF in Mexico has a distribution of 17,320 km^2, of which only 11% (2,045 km^2) are protected by ANPs. It is expected that by the year 2080 this protected area of 11% will be reduced between 68-76%, with a distribution remaining of only between 1,390-1,554 km^2 within them. Specifically, for the region of the Sierra Madre Oriental, the TCMF is expected to decrease from the remaining 45% of its distribution to 0.87% (decreased from 1,694 to 33 km^2 respectively) due to climate change, along with the current rate of land use change (Tejeda, 2009; Ponce-Reyes *et al*., 2012).

Current condition of Magnolia schiedeana. This species occurs in the later stages of succession, so this requires mature stages of succession for its establishment (Vázquez *et al*., 1995; Sánchez-Velasquez *et al*., 2008). Unfortunately, their populations of *M. schiedeana* are small (between 40 and 380 individuals) and distributed in small fragments of TMCF in the center of the Veracruz state (Vásquez-Morales *et al*., unpubl. data), and have varying degrees of disturbance and edge effects (Williams-Linera *et al*., 2002).

The Mexican law for the protection of species (NOM-059-2010) includes *Magnolia schiedeana* as a threatened species. Its habitat (TMCF) is also highly threatened due to heavy anthropogenic pressures caused by the changes in land use, to the point of concluding they could well be extinct this century (SEMARNAT, 2010; Ponce-Reyes *et al*., 2012; Rojas-Soto *et al*., 2012).

On the other hand, *Magnolia schiedeana* shows a very specific reproduction system through its relationship with the endemic beetle *Cyclocephala jalapensis* Casey (Dieringer and Espinosa, 1994). However, according of one ongoing study (for three years) in two small populations of *M. schiedeana* in the center of the state of Veracruz, the growth rates (λ) were > 1, indicating the persistence and growth of both populations and no significant decrease over time (Vasquez-Morales *et al*., unpubl. data).

Impact of climate change on Magnolia schiedeana. So far, there are few studies about the impact of global climate change on the great biodiversity of Mexico (Trejo *et al*., 2011). In recent decades, studies have focused on modeling the impact of climate change on ecosystems (Still *et al*., 1999; Estrada-Contreras, 2010; Rojas-Soto *et al*., 2012), populations (Téllez-Valdés *et al*., 2006; McKenney *et al*., 2007), and species distribution, among others (Téllez *et al*., 2007; Lira *et al*., 2009).

Similar studies from other countries (South Africa, India) have made it possible to foresee the expansion of conservation areas and endemic species of commercial interest (Hannah *et al*., 2005), as well as endangered species (Irfan-Ullah *et al*., 2007). Some researchers have questioned this type of studies (Pearson and Dawson, 2003; Pearson, 2006); however, the results are considered useful because they allow visualizing the potential effect of climate change will have on biodiversity (Levinsky *et al*., 2007).

The results obtained in this study suggest a decrease in the range of *Magnolia schiedeana* with respect to both periods (0.36 and 1.94%), well below contractions reported for the distribution of *M. macrophylla*, *M. virginiana*, and *M. acuminata* in a range of 36-93% with three general circulation models (The Canadian GCM, the UK based Hadley GCM, and the Australian-based Commonwealth Scientific and Industrial Research Organization GCM), in two emission scenarios (A2 and B2; Iverson and Prasad, 1998; McKenney *et al*., 2007).

Magnolia schiedeana for the periods 2040 and 2080 would suffer a shift to the North and Northeast of Veracruz, Mexico, retaining more than 90% of its potential distribution. Future environmental conditions favorable for *M. schiedeana*, were in the areas of the Biosphere Reserve Sierra Gorda in Querétaro, Barranca de Metztitlán in Hidalgo, National Park Los Mármoles and El Chico in Hidalgo, and Protected Area Cuenca del río Necaxa in Hidalgo and Puebla. So, these sites should be considered strategic for *in situ* conservation programs.

Conservation measures. We propose *Magnolia schiedeana* reintroduction programs and rehabilitation of the following natural protect areas (PNA) in the central Veracruz State: Cerro de las Culebras, Cerro de la Galaxia, Cerro de Macuiltépetl, El Tejar Garnica, Francisco Javier Clavijero, La Martinica, Molino de San Roque, Pacho Nuevo and Predio Barragan. In the future, PNAs will be refuge and genetic conservation of *M. schiedeana* (Hannah *et al*., 2007; Newton *et al*., 2008; CONABIO, 2010; CONANP, 2010). Therefore, it is necessary to create new protected areas in central Veracruz that could be used as biological corridors, taking into account the benefit of the bird dispersion, allowing the movement of *M. schiedeana* in both periods (Newton *et al*., 2008).

Limitations of bioclimatic models. Levinsky *et al*. (2007) recognize the limitations of bioclimatic models, although these are useful tools that provide a means of understanding the geographical distribution of the species in the present and future (Téllez-Valdés *et al*., 2006; Iverson and McKenzie, 2013). They also represent an option to plan the distribution of geographical areas for the conservation of biodiversity (Irfan-Ullah *et al*., 2007; Tingley *et al*., 2010).

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