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Assessment of the vulnerability of forest ecosystems to climate change in Mexico

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ABSTRACT: An assessment of the vulnerability of forest ecosystems in Mexico to climate change is carried out on the basis of the scenarios projected by 3 climate models. A vegetation classification was performed according to 2 models, the Holdridge Life Zone Classification and the so-called Mexican Classification (a climate-vegetation classification based on typologies developed for Mexico). Projections of climate models were based on a doubled CO_2 concentration condition. The models used were: the CCCM, which estimates an average increase in temperature for the country of 2.8°C and a decrease in annual precipitation of 7%; the GFDL-R30, which estimates an increase in both parameters by 3.2°C and 20% respectively; and a sensitivity model in which a homogeneous increase of 2°C in temperature and a 10% decrease in precipitation are applied throughout the country. In general, the cool temperate and warm temperate ecosystems were the most affected and tended to disappear under the conditions of the 3 scenarios. In contrast, the dry and very dry tropical forests and the warm thorn woodlands tended to occupy larger areas than at present, particularly under the conditions projected by the CCCM model. However, under the GFDL-derived scenario an increase in the distribution of moist and wet forests, which would be favoured by an increase in precipitation, was predicted.

KEY WORDS: Vegetation · Mexico · Forest ecosystems · Climate change

1. INTRODUCTION

Most of the studies carried out in Mexico regarding climate change and its effects on forest ecosystems mainly address the role of the latter with regard to carbon emissions and sequestration. This is the case for the studies by Bellón et al. (1994), Masera et al. (1997), Liverman (1992) and Segura (1992), among others. Therefore, the vulnerability of the Mexican forest ecosystems to global climate change has become a subject of interest. At the international level, the methods of Shugart (1984), which were originally considered with regard to forest dynamics, are currently applied for modeling the potential responses of vegetation to global climate change (Smith et al. 1992).

The selection of methods for evaluating the potential impacts of climate change on forest ecosystems depends, to a large extent, on the information required for their application. Studies on the response of forests to environmental changes range from very specific analyses related to physiological responses, to studies addressing large scale changes, such as the mapping of ecoclimatic zones of potential vegetation and the potential impact of a doubling of CO_2 levels.

The initial step for these assessments at the national level consists in relating vegetation patterns to current climate conditions, and subsequently generating climate change scenarios and evaluating the changes in climate and vegetation. This is the approach taken in the present paper.

Two assessment models were selected for the case of Mexico: the Holdridge Life Zone Classification Model and the Mexican Classification. The Holdridge (1967) model is a climate classification scheme that relates the distribution of the major global ecosystems to climatic variables such as biotemperature, mean annual precipitation and the ratio of potential evapotranspiration to precipitation. The Mexican model is based on a correspondence between an adaptation of the Köppen classification system to the country's conditions (Gar-

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cía 1988) and a vegetation typology generated by Rzedowski (1978, 1992). This typology describes the distribution of the different types of vegetation present in the country according to their climatic and phytogeographic affinities (Fig. 1).

This study is part of a national assessment of climate change vulnerability which addressed different sectors, such as vegetation, agriculture, human settlements, industry and coastal zones (Gay et al. 1995, 1996).

2. METHODOLOGY

2.1. Model implementation

Both the Holdridge model and the climatic classification by García were applied for Mexico on a 0.5° × 0.5° latitude-longitude grid. For this purpose, the weather stations most representative of the climatic conditions in the country at that scale, which keep records of mean monthly temperature and total precipitation for a 30 yr period (1951 to 1980), were selected. Thus, a climatic database of 30-yr mean monthly temperature and total precipitation data from 365 stations was related to the 770 land cells into which the Mexican territory was divided according to the resolution defined.

Baseline scenarios for both models were created with current climate data. Prospective climate scenarios were constructed with 2 models based on a doubled CO_2 concentration condition, the GFDL-R30 (Geophysical Fluid Dynamics Laboratory) and the CCCM (Canadian Climate Centre Model), according to the results obtained by Conde et al. (1995). A model of climate change sensitivity based on the application throughout the country of a homogeneous temperature increase of 2°C and a homogeneous precipitation decrease of 10% was also applied.

2.2. Holdridge Life Zones

A computer program provided by the U.S. Country Studies Program was applied to develop the Holdridge Life Zones. The model was first run with the current climate database in order to generate a life zone map for Mexico. The 3 climate change scenarios were then incorporated for the development of the new life zone distribution maps.

2.3. Mexican Classification

A climate-vegetation correspondence was established between the Köppen climate classification as modified by García (1988) and the potential vegetation map for Mexico by Rzedowski (1992) in order to identify the climatic conditions which support each type of vegetation.

The most suitable climate conditions for the development of each type of vegetation were identified by overlapping the potential vegetation map with each one of the climatic parameters (temperature and vegetation). A Geographic Information System (GIS) was used for this purpose. The potential vegetation corresponding to each specific type of climate could thus be identified.

The 46 climate types identified by García (1988) were grouped into 16 types in order to produce a comparable correspondence between climate and the 9 vegetation types identified by Rzedowski (1992).

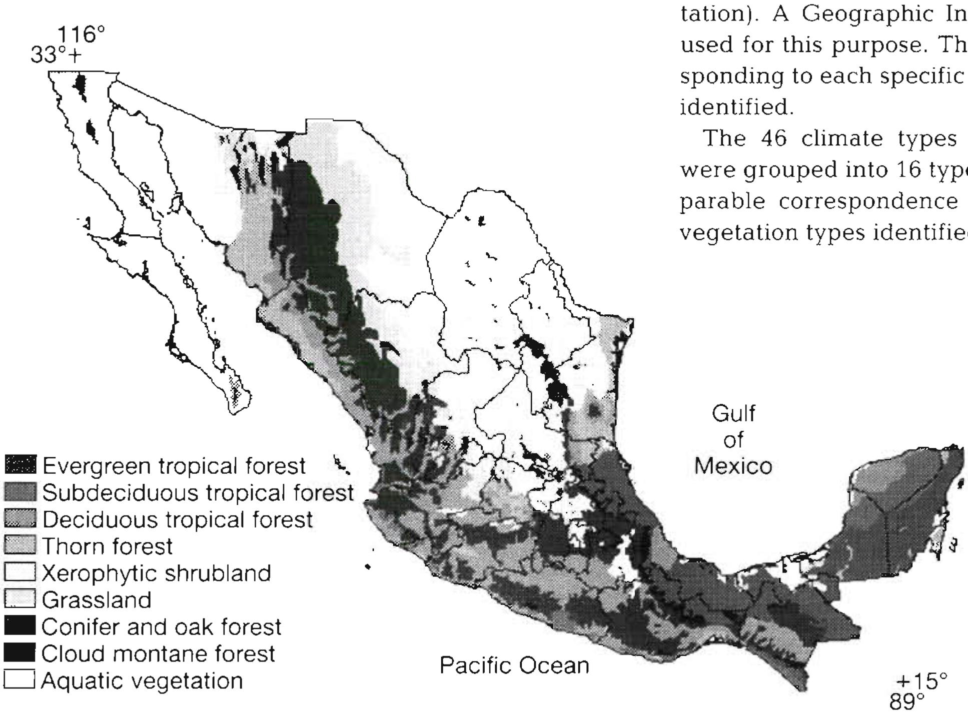

Fig. 1. Potential vegetation map for Mexico (Rzedowski 1992)

Table 1. Area (%) covered by the Holdridge Life Zones in Mexico under the current climate and climate change scenarios

Holdridge Life Zones	Current climate	Temp. +2°C, Precip. −10% scenario	CCCM scenario	GFDL scenario
15 Cool temperate moist forest	1.78	0.78	0.78	0.00
16 Cool temperate wet forest	0.53	0.00	0.00	0.00
19 Warm temperate desert scrub	0.73	0.25	0.00	0.00
20 Warm temperate thorn steppe	5.99	0.78	0.39	0.00
21 Warm temperate dry forest	4.04	1.52	1.39	1.27
22 Warm temperate moist forest	0.55	0.67	0.53	1.31
25 Subtropical desert	7.10	6.12	3.35	4.32
26 Subtropical desert scrub	7.55	11.13	11.26	4.17
27 Subtropical thorn woodland	21.76	22.64	22.43	21.47
28 Subtropical dry forest	20.35	14.53	14.27	13.58
29 Subtropical moist forest	5.27	3.64	2.77	5.35
30 Subtropical wet forest	1.35	0.26	0.26	0.82
31 Subtropical rain forest	0.00	0.00	0.00	0.13
32 Tropical desert	0.13	2.36	4.23	2.25
33 Tropical desert scrub	1.02	1.65	1.68	2.02
34 Tropical thorn woodland	1.01	4.63	4.97	3.98
35 Tropical very dry forest	4.03	11.58	12.47	9.73
36 Tropical dry forest	12.41	13.90	13.86	21.12
37 Tropical moist forest	4.40	3.55	4.95	7.49
38 Tropical wet forest	0.00	0.00	0.41	0.81

A current climate map was generated using the data from the selected weather stations. The temperature and precipitation changes derived from the climate models were subsequently applied in order to develop climate maps for each of the 3 scenarios proposed. The current and future climate maps were overlaid so as to identify the regions of the country where a climate change is likely to occur under each scenario.

The areas of the country where the climate type would vary were thus identified. The potential vegetation type which would grow under the new climate conditions was defined for each area according to the correspondence between climate and vegetation types.

Later, each future climate map was then overlaid with the potential current vegetation map by Rzedowski in order to identify the areas where the vegetation would be affected under the climate change scenarios.

3. RESULTS

3.1. Holdridge Life Zones

Eighteen life zones were identified for Mexico using this classification. They ranged from temperate moist forests to tropical desert, subtropical thorn woodland and tropical dry forest.

A synthesis of the relative areas of the country (in percent) which would be covered by the various Holdridge Life Zones, both under current climate conditions and under the 3 climate change scenarios projected, is shown in Table 1. The number of resulting life zones varied according to the climate scenario considered. Seventeen life zones were identified in the case of the sensitivity and CCCM-derived scenarios, while 16 zones were identified in the case of the GFDL-derived scenario.

According to the current-climate life zone classification for Mexico, 59% of the country is covered with tropical forests, subtropical dry forests, and subtropical thorn woodlands, with precipitation gradients lower than 2000 mm and a potential evapotranspiration ratio higher than 1.00. The temperature ranges from 17 to 24°C in the case of the subtropical forests, and is above 24°C for the tropical forests. The subtropical desert scrub and the subtropical desert are next in rank as to coverage importance (15%).

Under the conditions established for the sensitivity scenario (+2°C temperature, −10% precipitation), an 8% increase in the area covered by tropical very dry forest and a 6% decrease in the area covered by subtropical dry forest would occur. The tropical forests together with the subtropical dry forest and thorn woodlands would cover 63% of the area. As mentioned earlier, such forests occupy, under the current conditions, 59% of the area. The areas covered by temperate moist and dry forests would be significantly reduced (to less than half their size), the temperate wet forests would disappear, and the temperate steppes would be almost absent.

Under the conditions of the CCCM scenario, the warm temperate dry forests would be reduced even more drastically (with temperatures of 12 to 17°C), from a current coverage of 4% to only 1%. The warm temperate desert scrub and the cool temperate wet forest would disappear in this case. The subtropical moist forests would be sharply reduced. In contrast, the tropical dry and very dry forests would increase, as would the area covered by tropical desert scrubs.

Under the GFDL model scenario, all the cool and warm temperate forests would completely disappear. In contrast, the area with tropical dry and moist forests would increase from 12.4 and 4.4% (current coverage) to 21.1 and 7.5% respectively. Subtropical rain forest and tropical wet forest, which are not currently present in Mexico, would appear and cover a low percentage of the area. Furthermore, the area covered by the tropical moist forests would increase. Dry forests and thorn woodlands would cover almost 70% of the country.

3.2. Mexican Classification

A correspondence between the vegetation types and the climatic conditions could be identified, even though there was a difference in the scale of the 2 typologies. Although some vegetation groups are present within a wide climatic range, it was possible to determine the type of vegetation which might grow under each type of climate condition (Table 2).

The information in this table provides a basis for relating the potential changes caused by a doubling of atmospheric CO_2 to spatial modifications in the vegetation distribution.

Table 2. Correspondence for Mexico between the vegetation types according to Rzedowski (1992) and the climatic classification by García (1988). The equivalence between the climate types and the classification by García is as follows: for temperature: Hot = A, Warm = A(C) and C(A), Temperate = C; for precipitation pattern: Humid and Very Humid = m and f, Subhumid2 = w2, Sub-humid1 = w1, Subhumid0 = w0, Very Arid = BW, Arid = BS0, Semiarid = BS1

Vegetation type	Temperature		Humidity	
	Coverage (%)	Type	Coverage (%)	Type
Evergreen tropical forest	91.9	Hot	36.6	Subhumid2
			32.1	Humid
			15.7	Very Humid
Subdeciduous tropical forest	98.9	Hot	38.1	Subhumid1
			36.8	Subhumid0
			20.8	Subhumid2
Deciduous tropical forest	61.5	Hot	44.3	Subhumid0
			32.4	Warm
			22.1	Subhumid1
			11.8	Subhumid2
Thorn woodland	70.4	Hot	32.2	Semiarid
	28.4	Warm	24.5	Arid
			18.4	Very Arid
			18.0	Subhumid1
Xerophytic shrubland	60.5	Warm	48.5	Very Arid
	20.6	Hot	26.3	Arid
	18.7	Temperate	21.5	Semiarid
Grassland	65.8	Temperate	39.8	Semiarid
	31.0	Warm	27.1	Very Arid
			21.9	Arid
Temperate forest (conifer and oak forests)	49.3	Temperate	24.4	Subhumid2
	34.3	Warm	22.9	Subhumid1
	11.5	Hot	18.8	Semiarid
			18.7	Subhumid0
Montane cloud forest	55.6	Warm	44.7	Very Humid
	32.9	Hot	33.0	Humid
			17.1	Subhumid2
Aquatic vegetation	6.4	Hot	56.2	Humid
			18.2	Subhumid0

An assumption made here is that changes would occur slowly enough to enable the migration and adaptation of species. In this case the vegetation which would be covered for each scenario is as follows:

Under the sensitivity scenario conditions (+2°C in temperature and −10% in precipitation), hot climate types would increase and humidity would decrease. This would obviously affect the distribution of vegetation. The area covered by evergreen tropical forests, as well as by subdeciduous and deciduous forests present in hot subhumid climates of types 1 and 2 (mean annual temperature > 22°C and precipitation/temperature ratio between 43 and 55), would slightly increase, since these forests would be able to grow at higher altitudes than is currently the case. In this particular situation, the increase in temperature would favour the establishment of tropical communities to the detriment of the temperate oak woods and conifer forests growing in cool and temperate climates, which would disappear under the projected conditions. However, the latitudinal border of the thorn forests, which are favoured by drier conditions, would move southwards, mainly in the Pacific region. These forests would also increase towards the Gulf in the states of Tamaulipas and Nuevo León, as well as in the Pacific region, at states such as Sonora and Sinaloa or in the Cuenca del Balsas and the Itsmo de Tehuantepec. Further, the grasslands and certain types of temperate shrublands would be replaced by shrublands adapted to hot and drier climates (Table 3).

The CCCM predicts an increase in mean annual temperature for the country of 2.8°C and a decrease of 7% in the annual precipitation. Under such conditions, a trend similar to the one described for the sensitivity scenario is observed with regard to the evergreen tropical, subdeciduous and deciduous forests. The latter would occupy areas of higher altitude than is currently the case, particularly in the states of Jalisco and Guerrero. The hot and warm semiarid climates would cover a larger area, including sectors such as the Cuenca del Balsas, the Istmo de Tehuantepec, the center of Oaxaca and the north of Tamaulipas. Development of the drier types of thorn forests or deciduous tropical

Table 3. Coverage (in %) according to the climate-vegetation classification for Mexico. Mean annual temperature is >22°C in the case of hot climates, 18 to 22°C for warm climates, and 12 to 18°C for temperate climates. The humidity groups are classified according to the value of the precipitation/temperature ratio (see García 1988). The total area of the country is 1967183 km^2

Climate type (Köppen, as modified by García)	Vegetation type (Rzedowski)	Current potential	Temp. +2°C, Precip. −10% scenario	CCCM scenario	GFDL scenario
Hot humid	Evergreen tropical forest	5.86	6.40	6.67	7.85
Hot subhumid2	Subdeciduous tropical forest	3.67	1.33	1.71	6.35
Hot subhumid1	Deciduous tropical forest and subdeciduous tropical forest	17.70	20.12	20.20	22.80
Warm subhumid	Montane cloud forest	2.10	0.26	0.54	1.30
Warm subhumid2	Subdeciduous tropical forest and montane cloud forest	0.38	0.91	0.13	2.02
Warm subhumid1	Deciduous tropical forest	6.58	4.62	5.02	5.97
Temperate humid	Conifer and oak forest	0.56	0.28	0.28	0.28
Temperate subhumid2	Conifer and oak forest	2.67	1.32	1.31	2.12
Temperate subhumid1	Conifer and oak forest	3.13	2.31	2.06	1.52
Cool	Conifer forest	2.31	0.00	0.00	0.00
Semiarid hot	Thorn forest and xerophytic shrubland	11.00	19.67	18.10	18.38
Semiarid warm	Xerophytic shrubland and thorn forest	10.50	11.03	21.96	15.68
Semiarid temperate	Grassland and xerophytic shrubland	11.60	3.97	12.49	10.86
Arid hot	Xerophytic shrubland	6.07	16.88	7.96	4.33
Arid warm	Xerophytic shrubland	11.37	10.26	1.58	0.51
Arid temperate	Grassland	4.72	0.63	0.00	0.00

forests in these areas would be favoured. This would also occur in the states of San Luis Potosí, Guanajuato and Zacatecas, where temperate climate types would be replaced by warmer climate types. Under such conditions the vegetation communities in these areas would be composed by xerophytic shrublands. All the temperate climate regions, which correspond to the natural areas of distribution of grasslands, would be reduced. Some of them, such as the arid temperate, would completely disappear. Cool climate types would be replaced by warmer ones, resulting in a displacement of some conifer forests. The temperate forests, which grow in the country along the mountain chains, would be considerably diminished. This would imply a redistribution of these forests or the growth of new types adapted to drier and warmer conditions.

The scenario derived from the GFDL model was the least dramatic among those analyzed. In this case, an average temperature increase of 3.2°C and precipitation increase of 20% would take place. The impact of climate change on the different climatic types is likely to be somehow attenuated by the combined effect of temperature and precipitation increases.

The occurrence of both humid and subhumid hot climates would increase. This would favour the tropical forests, which are likely to expand their area of distribution northwards. The arid temperate and warm climate types would almost disappear. The grasslands would consequently lose space and the xerophytic shrublands would be replaced by other shrublands adapted to higher humidity and temperature conditions, or even by thorn shrublands. The conifer forests which grow in cool climates would be replaced by more temperate communities, such as oak forests, which would in turn tend to expand towards higher altitudes.

4. DISCUSSION

According to the results of the models applied, the doubling of atmospheric CO_2 would cause, in general, changes in the vegetation of large areas of the country. In the case of Holdridge Life Zones, the changes would range from 40% under conditions of +2°C in temperature and −10% in precipitation to as high as 47.4 and 46.9% under the conditions predicted by the CCCM and the GFDL models respectively.

The analysis of Holdridge Life Zones in Mexico under different scenarios shows that the most significant impact is likely to occur in the temperate zones, which include forests, scrubs and steppes. These types of forests may be dramatically reduced and even disappear under the conditions of all 3 climate change scenarios.

The sensitivity scenario (+2°C in temperature and −10% in precipitation) would entail drier conditions than the other two. Therefore, the thorn woodlands and very dry forests life zones, as well as the subtropical desert scrubs, would increase. The trend under the CCCM-derived scenario is very similar to this.

Table 4. Relative area (%) of the potential vegetation types (Rzedowski 1992) sensitive to climate change

Vegetation type	Temp. +2°C, Precip. −10% scenario	CCCM scenario	GFDL scenario
Evergreen tropical forest	20.65	20.79	21.05
Subdeciduous tropical forest	22.95	17.47	17.79
Deciduous tropical forest	50.77	46.85	44.79
Thorn forest	30.79	40.71	45.67
Xerophytic shrubland	58.87	70.92	74.95
Grassland	74.13	89.18	92.69
Conifer and oak forest	65.65	69.50	65.31
Montane cloud forest	56.49	57.96	46.02
Aquatic vegetation	11.84	8.44	13.38

The scenario derived from the GFDL model is characterized by higher humidity. The tropical life zones would be favoured in this case, leading to an increase in the area covered by dry, moist and wet forests.

The cool and warm temperate forests, which cover 13% of the country, would tend to disappear under the projected climate change conditions. In contrast, the dry and very dry tropical forests would increase under temperature conditions above 24°C. This would apply particularly to tropical very dry forests under the scenario predicted by the CCCM, and to tropical wet and moist forests under the GFDL-derived scenario.

Thus, results from the application of the 3 climate scenarios to the Mexican Classification indicate that about 50% of the country is likely to be affected by climate change. The percentage of affected area is highest (58%) under the conditions predicted by the GFDL model.

The analysis of results indicates that the affected vegetation communities may vary depending on the scenario considered, as shown in Table 4. The most sensitive vegetation communities are those which grow in temperate climate conditions, such as conifer forests, montane cloud forests, grasslands and xerophytic shrublands. The area covered by temperate forests which is likely to be affected ranges between 65 and 70%, while 46 to 58% of the area covered by montane cloud forests and up to 93% of the grasslands, as well as some temperate xerophytic shrublands, would be subject to changes.

Table 4 refers to the proportion of each type of vegetation which would be affected under each climate change scenario as compared to the current distribution of the vegetation. In order for the redistribution of the communities to take place, the vegetation would have to be able to respond by adapting or migrating within a very short time period, simultaneously with the predicted climate change.

It should be noted that this analysis did not take into account the areas which have already been subject to deforestation or to other types of land use.

5. CONCLUSIONS

The application of climate models to assess the vulnerability of ecosystems provides valuable information on the potential effects of a doubling of atmospheric CO_2. Although the predicted ranges of increase in temperature and of positive or negative precipitation changes may vary depending on the climate model used, the model-derived scenarios provide the basis for initiating a discussion of the types of measures which should be adopted in order to attenuate the effects of global climate change.

The most sensitive types of vegetation, as well as the geographical areas which are likely to be affected by the changes, can be identified under the conditions of each of the scenarios considered.

Finally, the necessity of applying a model more suited to the country's conditions as regards, for instance, information on the types of vegetation and climate in Mexico should be pointed out. Even though the results obtained with Holdridge Life Zones show trends similar to those produced using the Mexican typologies, the information resulting from the latter is more explicit and provides a better representation of the actual situation. This model also has a higher sensitivity to changes.

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