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Analysis of the effects of climate change on plant communities and mammals in México

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RESUMEN

En el presente estudio se proponen dos enfoques metodológicos para el análisis del efecto del cambio climático sobre la biodiversidad, uno a nivel de zona bioclimática y otro a nivel de especie. Las salidas de tres modelos de cambio climático para el horizonte de tiempo 2050, se aplicaron a nueve zonas bioclimáticas de México y a 61 especies de mamíferos: ECHAM5/MPI, UKHADGEM1 y GFDL CM 2.0, cada uno con dos escenarios de emisiones, el A2 y el B2. Para el caso de las zonas bioclimáticas se utilizó un modelo logit multinomial basado en información de muestreos de vegetación, datos de clima e información de suelo para obtener las probabilidades de ocurrencia. En el caso de las especies de mamíferos se generaron para cada uno de ellos modelos de nicho ecológico y de sus distribuciones en el país dentro de cada zona bioclimática. Los resultados muestran que el ECHAM y Hadley coinciden en la tendencia hacia condiciones más secas fundamentalmente en el norte de México, en contraste con el GDFL con respuestas menos severas. Se observan diferencias de acuerdo a los escenarios de emisiones aplicados. Las respuestas a nivel específico coinciden a grandes rasgos con sus correspondientes zonas bioclimáticas. En general se prevé que para el 2050 casi la mitad de las especies analizadas perderán alrededor del 50% de su área de distribución como resultado del impacto del cambio climático.

ABSTRACT

The current study proposes two methodological approaches for analyzing the effects of climate change on biodiversity, one at the level of bioclimatic zone, and the other one at the species level. Three general circulation models were applied to nine bioclimatic zones and 61 species of mammals in México for the 2050 time horizon: ECHAM5/MPI, UKHADGEM1 and GFDL CM 2.0, each one with two emissions scenarios, A2 and B2. In the case of bioclimatic zones a multinomial logit model was used based on data from surveys of vegetation, climate data and soil information in order to obtain probabilities of occurrence. In the case of mammals, ecological niche models were made for each of them as well as models of their distribution in the country within each bioclimatic zone. The results show that ECHAM and Hadley coincide with tendencies towards drier conditions mainly in northern México, in contrast with GDFL with less severe results. Differences are noticed according to the applied emission scenarios. Results at a specific level coincide roughly with their corresponding bioclimatic zones. By 2050 it is generally expected that almost half of all analyzed species will lose around 50% of their area of distribution as a result of the impact of climate change.

Keywords: bioclimatic zones, logit model, ecological niche, distributional shift, range dynamics.

1. Introduction

Ecosystems are the product of hundreds of thousands of years of evolution and adaptation, throughout processes of ecological succession. With the loss of species, there is a partial or total interruption of one or more of the natural processes that maintain the flow of matter and energy of which the integral functioning of the ecosystem depends (DeLeo and Levin, 1997). The effects of species loss is not limited only to spatial and temporal scales but to trophic relationships, since changes in diversity in a level can lead to significant impacts on feedback from other species (Héctor *et al.*, 2001).

In recent years it has become clear that the level of disturbance that ecosystems have been subjected to, has committed their long-term persistence, but above all the resilience capacity has been affected by the overexploitation of resources, land cover transformation, pollution, fires, among other types of disturbances. Under these conditions, one of the main concerns is the evidence of biodiversity loss, with species extinction rates of magnitudes not previously documented, except in the isolated cases of catastrophic mass extinctions (Dirzo and Raven, 2003; Balmford *et al.*, 2005; Millennium Ecosystem Assessment, 2005). It is recognized that contemporary extinctions are related to human activities that have transformed the natural systems in agricultural and livestock fields, as well as urban and industrial areas (Vitousek *et al.*, 1997; Lambin *et al.*, 2003; O'Rourke, 2006).

According to the Intergovernmental Panel on Climate Change (IPCC, 2001, 2007), the intense transformations of humans on the environment has increased greenhouse gas emissions to the atmosphere, causing an increase of the Earth's temperature, particularly noticeable in the last 100 years, recognized as global warming. The Fourth Assessment Report of the IPCC (2007) documents significant statistical effects in natural systems not explained under natural climatic variability, but rather relate to the anthropogenic effect on current global warming episode, and add to the direct impact of the loss of species due to land cover transformation. The effects of climate change on biodiversity are becoming better known as well as the changes observed in the environment that affect all levels of organization, from populations and species, to communities and ecosystems (Root *et al.,* 2003).

It is expected that the impact of climate change on ecosystems will alter abundance and distribution of species (Hughes, 2000; Peterson *et al.*, 2005; Root *et al.*, 2005; Parmesan, 2006), direct loss of some species and populations (Walther *et al.*, 2002; Thomas *et al.*, 2004), as well as gradual or rapid depletion and decline of the services that these offer (Millennium Ecosystem

Assessment, 2005). The acceleration of degradation processes observed in recent years has led to the conclusion that if the increase in global temperatures exceeds 2 or 3 ºC above pre-industrial levels, this would drive to risk of extinction between 20 and 30% of species, as well as changes in ecosystems (Fischlin *et al.*, 2007).

This is a topic of particular interest for México, recognizing that the country hosts high levels of diversity. This natural richness has placed México in the status of one of the mega-diverse countries (Mittermeier and Mittermeier, 1992), as it occupies top places in species' richness of different groups of animals and plants (CONABIO, 2006). Also known for its high level of endemism, for example, it is estimated that about 50% of the vascular plants species known in México are endemic and, for some plant families, this number is even greater (Villaseñor, 2003). Furthermore, within the country it is possible to find practically all the major types of vegetation that are known in the planet (Rzedowski, 1991).

Information concerning effects of climate change on the different elements of biodiversity in the country is scarce. There are assessments about the effects over forest ecosystems (Villers and Trejo-Vázquez, 1997, 1998) and punctual studies about some groups (Téllez-Valdés and Dávila-Aranda, 2003; Téllez-Valdés *et al.*, 2006), but it is important to expand these efforts.

The aim of this piece of work is to apply models of climate change to the main terrestrial plant ecosystems in México and some species of mammals found in these ecosystems in order to assess the impact of climate change.

2. Methods

The current study addresses the issue of biodiversity from two methodological approaches: i) the first at the national level, analyzing the effect on plant communities as discrete units, from building a statistical model that considers the likely potential distribution of these in current and modified conditions according to the selected scenarios; ii) at the species level, specifically for mammals, applying models based on the ecological niche theory, which identifies the bioclimatic conditions requiring the species to survive and subsequently modify the proposed conditions under climate change scenarios.

2.1 Base scenario: bioclimatic zones

As part of the concept that plant communities associate to environmental conditions, nine bioclimatic zones were defined: 1) Coniferous forests, dominated mainly by pine and fir species; 2) Broadleaved forests, composed of oaks and other broadleaved species, this includes the so called cloud or mesophile forests; 3) Humid and sub-humid tropical forests, tropical tree communities that retain their leaves most of the year; 4) Tropical dry forests, tropical communities that loose their foliage during the dry season; 5) Semi-arid shrublands, bush vegetation, some species have thorns and the presence of cacti is noticed; 6) Arid shrubland includes communities with low bushes or species with rosettes; 7) Halophytic vegetation, established communities in saline or gypsum covered environments; 8) Hydrophilic vegetation, which mainly contains the mangroves and cattail marshes in flooded areas, and 9) Grasslands, vegetation dominated by native grasses.

To recognize what the environmental conditions prevail within bioclimatic zones, information about vegetation and environmental variables was used:

1. Vegetation: a total of 83 235 field sampling sites describing the vegetation type and land cover distributed throughout the country. These sites were drawn from two sources: a) the Inventario Nacional Forestal y de Suelos (National Forest and Soil Inventory), data provided by the Gerencia de Geomática (Geomatics Management) of the Comisión Nacional Forestal (National Forest Commission) and which comprise a set of points distributed throughout the country; and b) verification points in the field provided by the Intituto Nacional de Estadística y Geografía (National Institute of Statistic and Geography, INEGI) during the preparation of maps concerning land cover and vegetation (INEGI, 2000) that includes a total of 7 412 records.

2. Environmental variables: a) climatic: weather station databases with historical records (1961-1990) obtained with ERIC II (IMTA, 2005). Temperature includes: annual average isotherms (García - CONABIO, 1998a); average maximum isotherms (García - CONABIO, 1997a); average minimum isotherms (García - CONABIO, 1997b). Total annual precipitation (García - CONABIO, 1998b) 1:1000 000 scale. b) soil, extracted from the INEGI soil chart (1:250 000 scale) and c) Digital Elevation Model (30 m of resolution) carried out by the INEGI, including the slope.

In a GIS, we assigned elevation, soil type, mean, minimum, and maximum annual temperatures, and annual precipitation. This information was used as a base to provide a multinomial logit model describing the a priori probabilities of occurrence of each one of the considered bioclimatic zones.

The multinomial logit model is based on a non-linear adjustment, with which it is possible to obtain the probabilities of occurrence according to the alternatives proposed by the incorporated variables and discriminating a particular group. This model was applied to the definition of nine bioclimatic vegetation zones in México to describe the current probability of occurrence of each one of these zones, according to the general environmental characteristics. The environmental parameters taken into consideration as the explicative variables to discriminate between the groups and thus assign a category were: altitude, temperature (average, maximum and minimum), precipitation, and soil type.

The parameters of the model were estimated using the maximum probability and obtained a result that explained 63.5% of the total variance of the data. The model was later applied to the data layers in a GIS to build the probability of occurrence map for each of the nine bioclimatic zones considered. Finally, each one of the pixels (250 m of spatial resolution) was assigned the category that had the highest probability of occurrence and a map was made to show the potential surface of the nine bioclimatic zones in the country under the current environmental conditions.

2.2 Base scenario: fauna

Ecological niche and geographic distributions were modeled for mammal species associated to the nine bioclimatic zones described previously. It was decided to select the group of mammals because there are relatively complete and validated databases for this group (Arita and Ceballos, 1997), also for this group there is enough knowledge to understand their environmental affinities and associate them to specific vegetation types (Sánchez-Cordero *et al*., 2005).

The niche and geographic distribution models were built with the maximum enthropy method, implementing in the MaxEnt program, version 3.2.19 (Phillips *et al.*, 2006), that has been recognized as a robust technique for modeling species' niches and distributions with presence-only data (Elith *et al.*, 2006). MaxEnt is an evolutionary computation method that detects non-random relationships between the presence of the species and the environmental conditions, using the presence points of the species and the environmental layers to characterize the ecological niches of these, by maximizing a uniform distribution in the environmental space to the average of the values of the input data. Later, once the niche model has been built, it is taken to the geographical space to produce a probabilistic map representing the potential distribution of the species (Phillips *et al.*, 2004, 2006).

Models were built using the information on collected records for 61 mammal species (Table I), obtained from the databases of mammals in México (Arita and Ceballos 1997). The selected species were those that had a clear affinity with types of vegetation in the different bioclimatic zones defined in the analysis at an ecosystem level, and for which we had a minimum of 20 spatially unique records to produce reliable models (Phillips and Dudík, 2008). The species' records were reviewed in order to eliminate from the analysis those whose identification and georeferencing was doubtful.

From climatic variables corresponding to monthly averages of minimum and maximum temperatures, as well as the total monthly precipitation, we derived 19 bioclimatic variables (Table II), as implemented in the WorldClim database (/www.worldclim.org/; Hijmans *et al.*, 2005), which represent annual, stationary and extreme aspects of the climatic patterns. Base monthly data to generate the 19 bioclimatic variables were provided by the Centro de Ciencias de la Atmósfera, UNAM (Conde *et al*., 2008).

2.3 Implementation of climate change scenarios

Three general circulation models (GCM) were chosen to model the climatic change impacts on biodiversity to the future: ECHAM5/MPI, UKHADGEM1 and GFDL CM 2.0., which show, along with different results, the scale of uncertainty of the climate change estimations. Models were downscaled to México using Magicc-Scengen software version 5.3 (Conde *et al.*, 2008). Additionally, two emission models were selected from among those already proposed in the Third IPCC Assessment Report (TAR) that is A2 and B2. These models were applied solely for the 2050 horizon.

Thus, for each species, a distribution model for the base scenario and six models of climate change were created. Finally, each of the climate change scenarios was superimposed on each model to estimate the area expected to be maintained, gained or lost by each scenario, identifying the species which will result most affected from climate change.

In the case of the bioclimatic zones, the proposed changes for the climate change models to the layers of the average minimum temperature, average maximum temperature, annual average temperature, and annual average precipitation were applied uniformly. The probabilities of occurrence per pixel of each bioclimatic zone were recalculated and new maps were made regarding the potential vegetation distribution for the scenarios of the modified climate.

3. Results

3.1 Climate change effects on bioclimatic zones

Table III shows the proportion of the land area in the country occupied by each one of the bioclimatic zones according to the base scenario and according to the changes proposed by climatic conditions for the applied models. The most noticeable changes and coincidences found in the 6 models were the reduction of the area covered by coniferous forests and the increase of favorable conditions for the tropical dry forest.

Table I. Association that mammal species used in this study have with bioclimatic zones in México.

Coniferous and Latifoliate Forests N = 17	Thickets N = 13	Pastures N = 7	Dry Rainforests N = 9	Humid and sub-humid Rainforests N = 15
Anura geofroyyi	*Antrozus pallidus*	*Antilocapra americana*	*Artibeus hirsutus*	*Alouatta palliata*
Chaetodipus goldmani	*Dipodomys gravipes*	*Bison bison*	*Balantiopteryx plicata*	*Alouatta pigra*
Cratogeomys merriami	*Euderma maculatum*	*Cynomys ludovicianus*	*Megasorex gigas*	*Ateles geoffroyi*
Cryptotis goodwini	*Lepus californicus*	*Cynomys mexicanus*	*Musonycteris harrisoni*	*Cabassous centralis*
Eptesicus brasiliensis	*Myotis vivesi*	*Lepus callotis*	*Rhogeessa alleni*	*Caluromys derbianus*
Glaucomys volans	*Neotoma leucodon*	*Lepus flavigularis*	*Sciurus colliaei*	*Chironectes minimus*
Hylonycteris underwoodi	*Notiosorex crawfordi*	*Taxidea taxus*	*Spilogale pygmaea*	*Cyclopes didactylus*
Megadontomys thomasi	*Odocoileus hemionus*		*Tlacuatzin canescens*	*Heteromys desmarestianus*
Microtus umbrosus	*Ovis canadensis*		*Xenomis nelsoni*	*Mazama pandora*
Myotis velifer	*Spermophilus tereticaudus*			*Orthogeomys grandis*
Neotomodon alstoni	*Sylvilagus audobonii*			*Tapirus bairdaii*
Peromyscus melanotis	*Thomomys umbrinus*			*Tayassu pecari*
Romerolagus diazi	*Vulpes macrotis*			*Trachops cirrhosus*
Sorex oreopolus				*Tylomys nudicaudus*
Sorex saussurei				*Vampyrum spectrum*
Sylvilagus cunicularius				
Ursus americanus				

Table II. Bioclimatic variables used for ecological niche modeling.

Annual mean temperature	Mean temperature of coldest quarter
Temperature diurnal range	Annual precipitation
Isothermality	Precipitation of most humid month
Temperature seasonality	Precipitation of driest month
Maximum temperature of warmest month	Precipitation seasonality
Minimum temperature of coldest month	Precipitation of most humid quarter
Annual temperature range	Precipitation of driest quarter
Mean temperature of most humid month	Precipitation of warmest quarter
Mean temperature of most humid month	Precipitation of coldest quarter
Mean temperature of warmest quarter	

Table III. Potential distribution in bioclimatic zones of México, according to base scenario and three climate change models and two emissions scenarios for 2050 time horizon.

Bioclimatic zone	Bas	MPIECHAM A2	MPIECHAM B2	GFDLCM2 A2	GFDLCM2 B2	HADGEM A2	HADGEM B2
	Occupied surface (%) in the country						
Coniferous forest	8.13	6.27	6.74	7.77	7.82	4.82	6.88
Breadleaf forest	24.60	21.45	22.53	25.95	25.80	24.64	23.49
Arid shrubland	20.12	20.72	19.69	14.36	14.75	19.69	17.42
Semi-arid shrubland	17.57	16.97	16.76	18.45	18.23	16.75	17.44
Grassland	1.97	2.46	2.45	2.48	2.43	2.42	2.32
Humid forest	16.65	14.50	15.61	15.99	16.44	15.75	16.67
Dry forest	7.39	13.98	12.72	11.69	11.23	12.61	12.46
Halophyte vegetation	0.97	0.64	0.65	0.66	0.68	0.63	0.58
Hydrophyte vegetation	2.59	3.00	2.85	2.65	2.61	2.70	2.73

ECHAM and Hadley models match the trend towards drier conditions mainly in northern México, in contrast to the results observed in the case of GFDL, where the expansion of broadleaf forests is evident over areas where the base scenario correspond to arid shrubland. Data show that tropical dry forests extend northward on both the Pacific and Gulf sides, in zones currently covered by semi-arid shrub and broadleaf forests.

In all models the loss of coniferous forests was evident. However, in the case of GFDL the rate reaches figures lower than 5%, for ECHAM the loss ranges between 14 and almost 20%, but the biggest decrease is registered with the B2 scenario with the Hadley model, since the probability of occurrence of coniferous forest decreases up to 41%.

Broadleaf forests are affected differentially according to the models. ECHAM and Hadley show a decrease in the area, ranging from 4 to 18%; however, the proposed conditions with GFDL would favor this type of temperate communities. The decrease in the area covered by this vegetation types is contrasted by an increase of arid and semi-arid shrublands, grasslands and tropical dry forests.

The dry shrubland is favored in the case of ECHAM with both emission scenarios, but it experiences important losses with the imposed conditions by GFDL, where part of the occupied land by this type of vegetation is replaced by semi-arid shrublands, grassland and even broadleaf forests. Similarly, the semi-arid shrublands decrease in surface area in different magnitudes for all models, with the highest values produced by the ECHAM model (8%).

Grasslands are favored according to almost all models, because many areas covered preferable by broadleaf forests are expected to be replaced with natural grasses. In the humid and sub-humid tropical forests the probability of occurrence remains practically in the same proportion in all models applied.

The tropical dry forest showed the highest proportions of change, recording important increases, being the lowest one with the GFDL model, ranging from 13 to almost 20% in scenarios B2 and A2, respectively. In ECHAM and Hadley the expansion of tropical dry forests ranges from 52 to 70%, almost twice the size of land, according to the base conditions of this type of forests. Halophytic vegetation, despite being more closely related to soil characteristics, also records losses of around 50% in all models. In contrast the hydrophilic vegetation records slight increases from the original status.

3.2 Effects of climate change on fauna

Our results indicate that species' responses to expected climate changes are idiosyncratic; that is, because each species has individual physiological tolerances to climate, their expected responses are in the same fashion. Thus, we see that there are species in almost all bioclimatic zones that will be affected negatively in terms of their geographical distributions and others that are favored (Fig. 1). In general, the results indicate that by 2050 nearly half of mammalian species analyzed (N = 30) will lose 50% or more of their current distribution area, according to at least 3 of the 6 models; of these, 9 species are expected to lose more than 80% of their historic area of distribution, according to 4 or more models: *Romerolagus diazi*, *Lepus flavigularis*, *Orthogeomys grandis*, *Megadontomys thomasi*, *Megasorex gigas*, *Sylvilagus cunicularius*, *Lepus callotis*, *Cratogeomys merriami*, and *Cynomys ludovicianus*, all endemic or quasi-endemic to México.

It is important to note that the species identified in the most critical situation is the volcano rabbit (*Romerolagus diazi*), given that all 6 climate change models predicted that the niche of the species will disappear by 2050. On the other hand, only 21% of species (N = 13) are expected to increase according to 3 or more models, and 3 of them would double or more their historical distributions (*Cabassous centralis*, *Chaetodipus goldmani* and *Vampyrum spectrum*).

4. Discussion and conclusions

Despite differences in the approaches, both methods and inputs applied in this study derive from the fact that the presence of a vegetation type or a species depends on certain environmental conditions. In this way, the analyses seek to describe the probability of occurrence of a determined type of vegetation or mammal under current and future environmental conditions.

It is acknowledged that the distributions of species and communities are strongly determined by the climatic conditions under which they have developed (Pearson and Dawson, 2003; Gray, 2005;

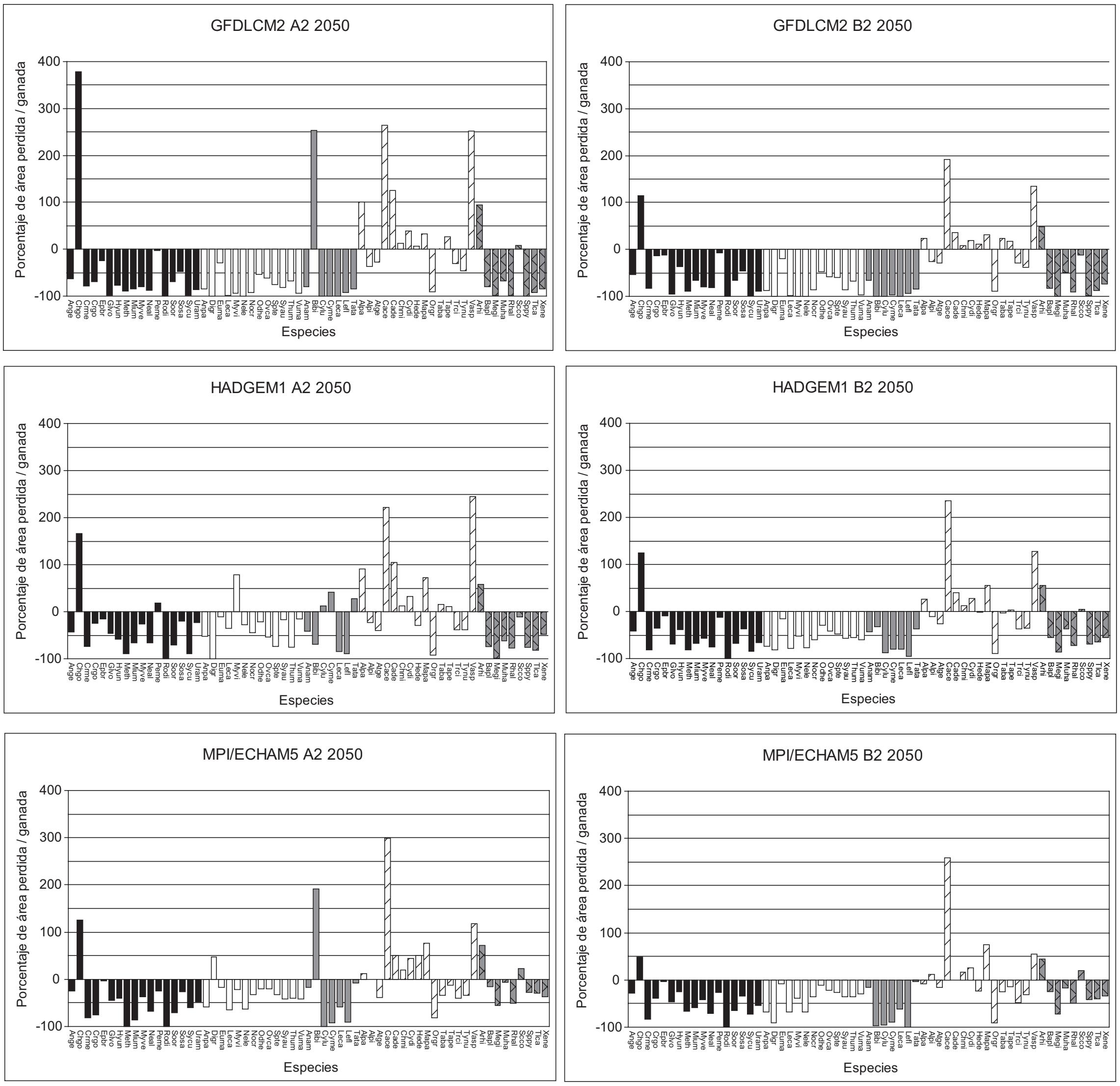

Fig. 1. Percentage of area (gained or lost) for mammal species.Bar colors correspond to bioclimatic zones: ■ = Coniferous and Bradleaf forest; □ = Arid and semiarid shrublands; ■ = Natural grasslands; ▨ = tropical dry forest; and ▩ = Tropical humid and subhumid forests.

Lomolino *et al.*, 2005), and climate also controls global patterns of the structure and productivity of vegetation (Maslin, 2004); affecting not only the composition of plant and animal species (Gitay *et al.*, 2002), but also aspects such as phenology, migratory processes, and the temporal dynamics of distributional ranges (Hughes, 2000; Rosenzweig *et al.*, 2007).

In previous studies for México (Villers and Trejo-Vázquez, 1997, 1998), there have been reports that communities of temperate affinities, like coniferous and broadleaf forests, are more vulnerable to increases of temperature. Plant communities at mountain tops have more imposing restrictions by the increase in temperature, as well as a reduction in the available area because the peaks of mountains occupy smaller spaces (Beniston, 2003), which restrict the migration of species to areas with favorable conditions for their development. For the coniferous and broadleaf forests and 17 mammal species studied herein that inhabit areas with cold temperatures, according to the models their areas of distribution will be reduced drastically. In four of such species, namely *Romerolagus diazi* (volcano rabbit), *Lepus flavigularis* (tropical jackrabbit), *Orthogeomys grandis* (giant pocket gopher), and *Megadontomys thomasi* (Thomas' giant deer mouse), the models indicate that the climatic conditions in their areas of distribution will be reduced between 80 and 100%, which could seriously commit them with extinction.

Also, according to the models, areas covered with natural grasslands (natural grasslands, *huizachal*-grasslands) tend to increase; however, it is important to note that for the establishment of these new grasslands, conformal species require to migrate, involving processes such as seed dispersal that in many instances require animal vectors, which may not be able to keep the pace of changing conditions. Interestingly, for the 7 studied mammals inhabiting this vegetation type, models indicate that suitable conditions will be reduced, three of them more than 80% of their area: *Cynomys ludovicianus* (black-tailed prairie dog), *Lepus callotis* (white-sided jackrabbit), *Lepus flavigularis* (tropical jackrabbit). This apparent contradiction indicates that not only vegetation structure affects mammalian distributions, but temperature and precipitation too. Similarly, the results for tropical dry forests, which include deciduous and thorny forests, are also significant, because according to the models, the changing conditions will favor their probability of occurrence. However, at the species' level, in the case of the 9 mammals studied there it is expected a reduction in the areas of distribution, except for *Artibeus hirsutus*.

The arid shrubland shows the effect of the drier conditions in the north of the country, which ECHAM proposes, with a consequent increase in this type of vegetation at the expense of temperate forests. In the semi-arid shrubland changes are not as drastic, but are reflected in the 13 species of mammals studied in both types of bushes, because in all cases the result of applying the six models resulted in a reduction in their areas of distribution.

Finally, in regard to the humid and sub-humid tropical forests, the change does not seem apparent in the six models used. However, most but two of the mammals of these vegetation types loose a significant area of distribution, namely *Cabassous centralis* (northern naked-tailed armadillo) and *Vampyrum spectrum* (spectral bat), who the rates of increase in their areas of distribution would be in more than double the currently known.

This combined analysis shows that in terms of bioclimatic zones there are some patterns of change that are even consistent with results of previous studies. Due to the increase of temperature, plant communities with temperate affinities will be the most affected. It is noteworthy that these arrangements of species that make up plant communities, as we know them today, are susceptible to experience changes and these are subject to the individual responses of species, as shown in the results and, depending on the magnitude of the change of climatic variables, the effects will be from changes in species composition, to the possible disappearance of some (Fischlin *et al.*, 2007).

Responses of species to climate change at the level of their distributions are individualistic and depend on the characteristics and the ability for each of them to change and adapt. Note that species with restricted distributions with small populations and those with long generation times present the highest risk (Walther *et al.*, 2002). It is also necessary to consider their dispersal ability, which might make them more or less susceptible to the adverse effects of climate change (Martínez-Meyer *et al.*, 2004).

One of the advantages of using different models of climate change is getting a picture of what could happen in the face of the expected changes. The results with selected models do not show a homogenous trend in the changes, but zones can be identified that consistently are affected by the new climate conditions. In general, the north of the country shows the most evident changes, as well as the ecotones of the bioclimatic zones.

The information obtained by these methods allows the identification of changing areas and the direction of this change, which may be useful to design adaptation and mitigation measures related with the conservation of ecosystems, which is a particularly relevant point in context with the great diversity in México, as well as its high level of endemism.

Besides the direct effect of climate change on the country's ecosystems, the synergy with the potential increase of other perturbation agents caused by changes in climate, particularly the possibility of more forest fires due to increase in temperatures and less humidity, increases the risk of a greater loss and fragmentation of natural areas. It is also important to consider a revision of the protected areas system (Sistema Nacional de Áreas Naturales Protegidas, SINAP) that are found in those places in order to take timely measures to reduce the negative effects of climate change on the patterns of plant and animal distribution.

Finally, it is necessary to recognize that the obtained results are influenced by the methods used to model the distributions of ecosystems and species, and that often there are important differences when compared with results obtained with other methodological approaches (Peterson *et al*., 2005; Pearson *et al.*, 2006). It is important to develop methods to evaluate and incorporate these changes and the uncertainty associated with results (e.g., Araújo and New, 2006). Climate change is here and we need to act with solvency to produce robust information that can guide decision making.

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