

available at www.sciencedirect.comjournal homepage: www.elsevier.com/locate/biocon

Short communication

The cost of postponing biodiversity conservation in Mexico

Trevon Fuller^a, Víctor Sánchez-Cordero^b, Patricia Illoldi-Rangel^b, Miguel Linaje^b,
Sahotra Sarkar^{a,*}

^aBiodiversity and Biocultural Conservation Laboratory, Section of Integrative Biology, University of Texas at Austin, 1 University Station, #C0390, Austin, TX 78712-1180, USA

^bDepartamento de Zoología, Instituto de Biología, Universidad Nacional Autónoma de México. Apto. Postal 70-153, México D.F. 04510, Mexico

ARTICLE INFO

Article history:

Received 1 June 2006

Received in revised form

19 August 2006

Accepted 30 August 2006

Keywords:

Conservation areas

Land use

Mexico

Natural protected areas

Optimization

Reserve selection

ABSTRACT

Though Neotropical countries are the most species rich in the world, their biodiversity is threatened by the loss of native vegetation. Land conversion in Mexico during the last 30 years has been extensive and is representative of that of other developing countries. However, the effects of land use change on the required size and configuration of an adequate biological conservation area network are largely unknown. It is shown here that endemic mammals in Mexico could have been protected considerably more economically if a conservation plan had been implemented in 1970 than is possible today due to extensive conversion of primary habitats. Analysis of the distributions of 86 endemic mammal species in 1970, 1976, 1993, and 2000 indicates that the distributions of 90% of the species shrank during this 30-year period. At each time step, optimal conservation area networks were selected to represent all species. 90% more land must be protected after 2000 to protect adequate mammal habitat than would have been required in 1970. In addition, under a realistic conservation budget, 79% fewer species can be represented adequately in a conservation area network after 2000 compared to 1970. This provides an incentive for rapid conservation action in Mexico and other biodiversity hotspots with comparable deforestation rates, including Burma, Ecuador, Indonesia, the Philippines, and Sri Lanka. Due to ongoing habitat degradation, the efficiency of a conservation plan decreases with delays in its implementation.

© 2006 Elsevier Ltd. All rights reserved.

1. Introduction

Planning problems that arise in the context of the design of conservation areas are often formulated as constrained optimization (minimization or maximization) problems (Csuti et al., 1997; Ando et al., 1998; Sarkar et al., 2006). The objective of the minimization is to pick as few sites as possible to serve as conservation areas subject to the

constraint that the selected sites protect sufficient habitat for each species of conservation concern. The objective of the maximization is to protect as many species as possible subject to the constraint that the cost of the selected sites is less than a budgetary ceiling. The optimization problem may also include constraints to ensure that the conservation areas have a suitable spatial configuration (Onal and Briers, 2002).

* Corresponding author. Tel.: +1 512 232 7101/7122; fax: +1 512 471 4806.

E-mail address: sarkar@mail.utexas.edu (S. Sarkar).

0006-3207/\$ - see front matter © 2006 Elsevier Ltd. All rights reserved.

doi:10.1016/j.biocon.2006.08.028

The selection of conservation areas via optimal or heuristic methods is just one stage of systematic conservation planning (Margules and Pressey, 2000; Sarkar, 2005). Systematic planning recognizes that species' ranges change dynamically in response to management policies or anthropogenic disturbance and stipulates that conservation areas be reassessed periodically after their establishment to quantify whether management goals are being satisfied within a suitable time frame (for examples, see Dirzo and Garcia, 1992; Bojórquez-Tapia et al., 2003; Bojórquez-Tapia et al., 2004). Species may disperse away from conservation areas due to climate change (Peters and Darling, 1985; Davis and Zabinski, 1992; Rutherford et al., 1999; Davis et al., 2000; Peterson et al., 2002; Burns et al., 2003), deforestation (Brooks et al., 1999; Fisher, 2000; Benning et al., 2002; Koh et al., 2006), or the spread of agriculture (Bomhard et al., 2005). If environmental changes destroy suitable habitat of a species or significantly reduce habitat quality inside the conservation areas, the conservation areas established before the environment changed will no longer be optimal (Halpin, 1997; Hannah et al., 2002; Midgley et al., 2003). Thus, rather than assuming that species' ranges are fixed, biodiversity management should be an adaptive and iterative process in which new sites are added to the conservation area network as deemed necessary by the monitoring plan.

This note analyzes the implication for biodiversity conservation of distributional shifts of endemic mammals in Mexico in the recent past. It is shown that the accelerating pace of land conversion in Mexico since 1970 has reduced and fragmented mammal habitat in such a way that the amount of land that must be placed under protection to represent mammalian biodiversity today is significantly greater than the amount that would have been required to protect mammals at equivalent levels 30 years ago. Thus, because of these land cover changes, the cost of adequate conservation increases during this period. (This assumes a positive correlation between the total area of a conservation area network and the cost of implementing such a network.) Land conversion in Mexico during the last 30 years has been extensive and is representative of that of other developing countries. Tropical and temperate forests in Mexico are disappearing at high annual rates (Masera et al., 1997; Mendoza et al., 1999) accompanied by an increase in agricultural lands, shrubs, and pastures for cattle (Bocco et al., 2001). Some Mexican fauna such as butterflies can persist despite substantial reductions in forest cover, but these reductions extirpate many vertebrates such as mammals and birds (Sarukhán et al., 1996; Peterson et al., 2006). In addition, conversion to agricultural use creates habitat unsuitable for threatened mammals (Ceballos et al., 2005; Sánchez-Cordero et al., 2005; Stoleson et al., 2005). This is particularly critical because Mexico's mammal fauna ranks second worldwide and is 30% endemic (Fa and Morales, 1993). Moreover, Mexican endemic mammals are of special conservation concern because they are underrepresented in international treaties about threatened species (Ceballos et al., 2002).

Recently, a database with remote-sensed data were created for the extent and rate of land use/land cover change in Mexico since the 1970s (Sorani and Alvarez, 1996; Mas et al., 2004). The database includes nationwide land use and vegetation maps for 1976, 1993, and 2000; the last three dates

correspond to the time slices in the land cover database for the *Inventario Nacional Forestal* (2000). However, such data do not indicate how land conversion affects strategies for the conservation of mammals (Kinnair et al., 2003). In particular, the effects of land use change on the required size of an adequate biological conservation area network are largely unknown.

To quantify these effects, the present analysis combined the database on land conversion with ecological niche modeling of 86 endemic mammals projected as species' distributions using the 1970, 1976, 1993, and 2000 land use and vegetation maps (see below). The ecological niche of endemic mammals was modeled using a computer genetic algorithm (GARP, genetic algorithm for rule set-prediction; Stockwell and Peters, 1999), a machine-learning algorithm that has provided accurate coarse-grained distributional predictions for Mexican mammals (Iloldi-Rangel et al., 2004; Sánchez-Cordero et al., 2005). The 1970 vegetation map was selected as a starting point because it pre-dates the most recent phase of extensive deforestation in Mexico (Rzedowski, 1986; Carabrias et al., 1994). This study analyzes distributional shifts of endemic mammals in Mexico in the recent past by quantifying the impact of land use patterns on species' distributions from 1970 to 2000 and assessing how distributional shifts affect optimal conservation area networks.

2. Methods

Mexico was divided into 71 248 rectangular sites at the 0.05° scale (hereafter "sites"). The mean area (\pm SD) of each site was 3091.1 (\pm 2.1) ha. A multi-date database on land cover in Mexico (Sorani and Alvarez, 1996; Mas et al., 2004) with seven classes (primary temperate forest, secondary temperate forest, primary tropical forest, secondary tropical forest, scrubland, other vegetation covers, and human-made covers; scale 1:250,000) was generated by digitization of aerial photography (average date: 1976), and visual interpretation of Landsat TM color composites (1993), and Landsat ETM + (2000). Accuracy assessment of the database indicated digitization accuracy of 96% and accuracy of class identification of >90% (Mas et al., 2004).

2.1. Ecological niche modeling and species' distributions

Mammal distributions were modeled using point occurrence data from museum voucher specimens, environmental coverages and a GIS platform. The mammal database was compiled from national and international museum scientific collections (see Acknowledgements), following Villa and Cervantes (2003) for taxonomic nomenclature. The environmental coverages (raster GIS layers at 0.04° \times 0.04° pixel resolution) summarized potential vegetation types, elevation, slope, and aspect, according to the Hydro 1K data set (United States Geological Survey, 1998), and climatic parameters including mean annual precipitation, mean daily precipitation, maximum daily precipitation, minimum and maximum daily temperature, and mean annual temperature obtained from Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (hereafter "CONABIO") (CONABIO, 1998).

To model the ecological niche of each species, occurrence points for the species were divided evenly into training and testing data sets. GARP works in an iterative process of rule selection, evaluation, testing, and incorporation or rejection: a method is chosen from a set of possibilities (e.g., logistic regression, bioclimatic rules) and applied to the training data to evolve a rule. Predictive accuracy is evaluated based on the testing data. Change in predictive accuracy between iterations is used to evaluate whether particular rules should be incorporated into the model; the algorithm runs 1000 iterations or until convergence (Stockwell and Peters, 1999).

As GARP produces different models in each iteration, model performance was optimized by developing 100 replicate models of ecological niches for each endemic mammal. A 'best subset' of these models was chosen based on optimal error distributions for individual replicate models (see Anderson et al., 2003). This consisted of finding the 20 models with the lowest omission error and retaining the 10 with predicted area closest to the median area of the 20 models with the lowest commission error. The spatial predictions of these 10 models were summed to provide a summary of potential geographic distributions; methodological details of model refinement used in the GARP runs are described elsewhere (Sánchez-Cordero et al., 2005). For 1976, 1993, and 2000, GARP predictions were further refined by clipping to areas with primary or secondary vegetation as defined by the land cover database. Habitats transformed into agriculture or other anthropogenically transformed areas (for example, urban areas) are unsuitable for the long-term population persistence of threatened mammal species (Ortega-Huerta and Medley, 1999; Ceballos et al., 2005; Sánchez-Cordero et al., 2005; Stoleson et al., 2005) and were therefore excluded from the analysis.

2.2. Conservation area network selection

At each time step optimal conservation area networks were selected to represent all species. Optimal solutions to the minimization and maximization problems were obtained using a branch-and-bound algorithm (see "Place Prioritization for Biodiversity Representation" in the Supplementary material). The target level for each species is the percentage of the species' distribution to be represented in the selected sites. Targets were generated from the 1970 distribution because the distributions of 90% of the species' contracted after 1970. Setting targets based on the contracted distributions would give the false impression that the selected sites contain adequate habitat for the species even when the size of the distribution has decreased significantly.

As an initial test, the minimum amount of land required to represent a targeted percentage of the habitat of each species at each of the four times was determined. The rationale for the minimization is to make the economic impact of the plan as low as possible, which is important because rural human populations in Mexico are concentrated in areas of mammal endemism (Sánchez-Cordero et al., 2005; Stoleson et al., 2005). First, at each time, all sites in the decreed natural protected areas of Mexico were selected (hereafter "natural protected areas") then sites were added to satisfy the species'

targets. Several target levels were examined beginning with the 10% target conventionally used in conservation planning (International Union for the Conservation of Nature, 1994). This quantifies the economy with which the natural protected areas represent mammal fauna. Second, the optimization was started from scratch and sites were selected without taking the natural protected areas into consideration. In this paper, the term "conservation area network" is used to refer to the set of sites selected to represent all species at their target levels either with or without including the natural protected areas.

As a more realistic test, budgetary constraints were incorporated in the site-selection to model the limited funds available to conservation planners for acquiring and managing land. Here, the optimization problem was to maximize the number of species represented at their target levels in the selected sites, subject to a budgetary ceiling on the amount of land that could be protected. Estimates of the percent of Mexico's land in actively managed natural protected areas range from 6.9% (Brandon et al., 2005) to 10% (Gómez-Pampa and Kaus, 1999). Both of these percentages were used as budgets in the optimization.

Finally, to quantify the effects of land conversion on the size the species' distributions, the total number of sites occupied by each species in 1970, 1976, 1993, and 2000 was calculated and a spatial point process model was developed to explain the shape of each species' distribution. The inhomogeneous Poisson process with intensity function $\lambda(x, y) = \exp(a + b \cdot x)$ provided a highly significant fit to the distributions of most species ($n = 48$) at all four times (Supplementary material Table 3). The intensity function represents the expected number of occurrences of the species per site (Schabenberger and Gotway, 2005). The coefficients a and b were estimated via maximum likelihood and x represents longitude.

3. Results and discussion

When site selection is initiated with the natural protected areas, significantly more land is required to represent mammal habitat in 2000 than when sites are selected with the 1970 distribution (41.19–88.91% more depending on the target level; Figs. 1 and 2, Table 1, and Supplementary material Fig. 1). 60.79% of the optimal conservation areas selected in 1970 had neither primary nor secondary vegetation by 2000. The diseconomy of the 2000 conservation plan compared with the 1970 plan can be attributed to spatial thinning of the species' distributions caused by land conversion (Fig. 3). Of the endemic mammals considered here, 78 species' distributions showed areal reductions from 1970 to 2000 (Supplementary material Table 1). The mean (\pm SE) number of species per site was 4.59 (\pm 0.019) in 1970 but 4.07 (\pm 0.017) in 2000 (median: 3 species/site in 1970, 2 species/site in 2000). At the national scale, the mean number of occurrences of each species predicted by the spatial model declined from 167.95 (\pm 7.8) in 1970 to 152.18 (\pm 7.89) in 2000 (Fig. 4 and Supplementary material Table 4). For this reason, if a conservation area network had been implemented even as late as 1970, mammal habitat could have been protected in a considerably smaller set of sites than what is required today owing

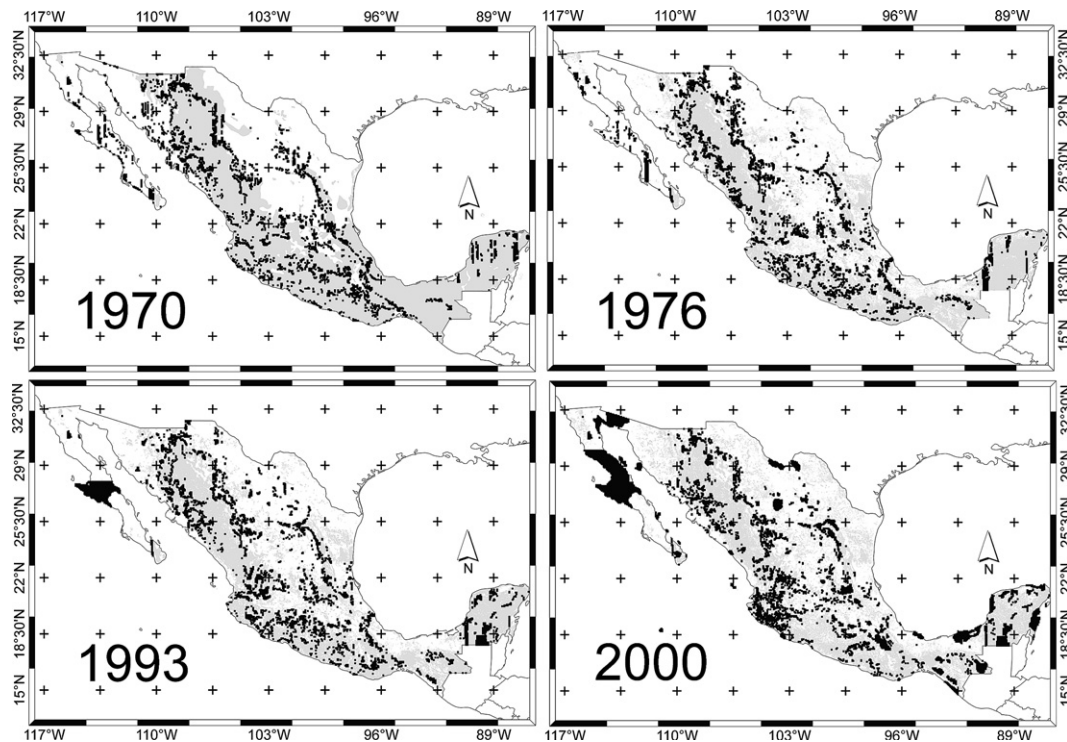


Fig. 1 – Optimal conservation areas for Mexican endemic mammals (black sites) obtained by solving the minimization problem with a target of 10% of each species' distribution. Sites in gray have primary or secondary vegetation. The optimizations were initialized with the natural protected areas.

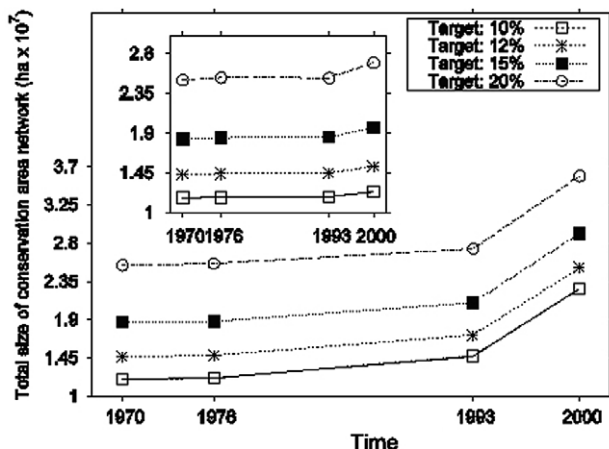


Fig. 2 – Increasing diseconomy of Mexican conservation area networks (1970–2000). The minimum amount of land required to represent mammal habitat at each time step is shown. Inset: minimization results without incorporating the natural protected areas.

to land degradation and concomitant thinning of species' distributions. The natural protected areas also performed poorly when sites were selected to represent as many species as possible subject to budgetary constraints (Fig. 5 and Table 2). At the higher budget, 32.53% fewer species are represented at their target levels in 2000 compared to 1970. At the lower budget, 79.45% fewer species are so represented. This is because

the natural protected areas take up 97.8% of the land that can be selected under the lower budget. Consequently, if the conservation area network had been implemented in 1970, substantially more species could have been represented than can be represented today.

The diseconomy of conservation plans selected after 1970 appears to be correlated with the loss of forest cover documented in the vegetation database. In particular, across all target levels, the percent increase in the minimum amount of land required to represent the species was greatest between 1993 and 2000 (Table 1). Loss of tropical forest cover and the increase in pasture and cropland habitat unsuitable for wildlife were also greatest between 1993 and 2000. This may be due to a 1992 Mexican law that relaxed regulations on the timber industry (Stoleson et al., 2005).

When site selection (minimization) does not incorporate the natural protected areas, only slightly more land is required to represent mammal habitat in 2000 than when sites are selected with the 1970 distribution (5.79–7.77% more depending on the target level; Fig. 2 and Table 1). This means the natural protected areas do not represent biodiversity as economically as would a conservation area network started from scratch, presumably because they contain many sites unsuitable for endemic mammals. The amount of land in natural protected areas has increased from 1970 to 2000 (Supplementary material Table 2), as has the diseconomy of conservation plans that include the protected areas. Importantly, the cost of postponing biodiversity conservation is much lower if the optimal conservation plan does not incorporate the natural protected areas. For example, the optimal

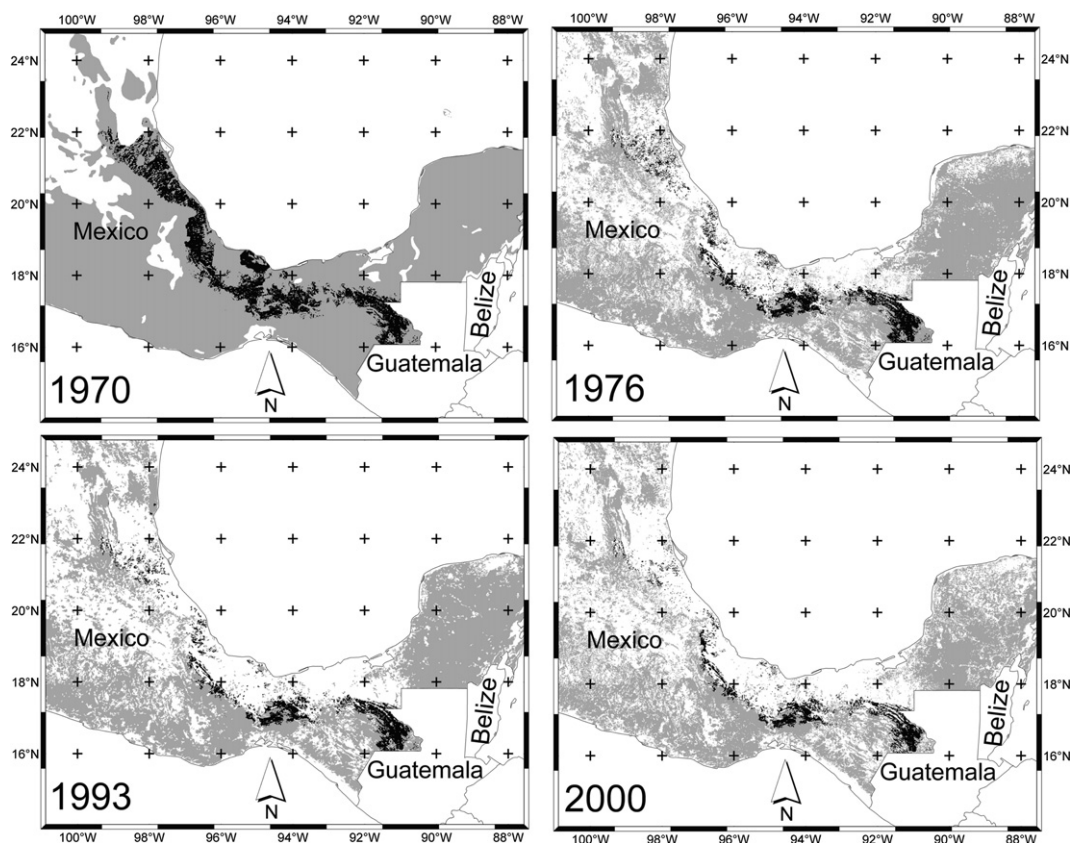


Fig. 3 – The effect of land conversion on the size of mammal distributions in Mexico. Sites in black are the habitat of the Mexican agouti (*Dasyprocta mexicana*), a charismatic and economically important mammal that typically inhabits rainforest. Gray sites have primary or secondary vegetation. The modeled distribution of *D. mexicana* shrank 33.5% from 1970 to 2000 (Supplementary material Table 1).

Table 1 – Percent increase in the minimum number of hectares required to represent endemic mammal habitat in Mexico (1970–2000)^a

	Target							
	10%		12%		15%		20%	
	NPA	No NPA	NPA	No NPA	NPA	No NPA	NPA	No NPA
1970–1976	1.46	0.45	1.01	0.82	0.71	0.65	0.77	1.02
1976–1993	21.28	0.6	16.15	0.44	11.5	0.28	6.77	–0.06
1993–2000	53.51	4.69	45.97	4.99	38.91	5.62	31.24	6.75
1970–2000	88.91	5.79	71.25	6.31	55.98	6.61	41.19	7.77

a "NPA" means the site selection algorithm was forced to select all cells in the decreed natural protected areas. "No NPA" means the natural protected areas were not taken into consideration during the site selection.

conservation plan selected with the 2000 data represents 2.74% fewer species than the optimal plan selected with the 1970 data. However, the conservation plan selected with the 2000 data that includes the natural protected areas represents 79.45% fewer species than the plan selected with the 1970 data (Table 2).

The comparison of Mexico's natural protected areas with conservation area networks constructed from scratch supports previous work indicating that the former do not repre-

sent biodiversity effectively. Neither the existing natural protected areas nor the expanded set recently proposed by CONABIO represent floristic diversity adequately (Villaseñor et al., 1998; Cantú et al., 2004a). In northeastern Mexico, the existing Biosphere Reserves contain habitat for three-quarters of the region's bird and mammal species (Ortega-Huerta and Peterson, 2004), but the Biosphere Reserves and other natural protected areas in this part of the country do not represent floristic, herpetofaunal, or physiographic diversity at

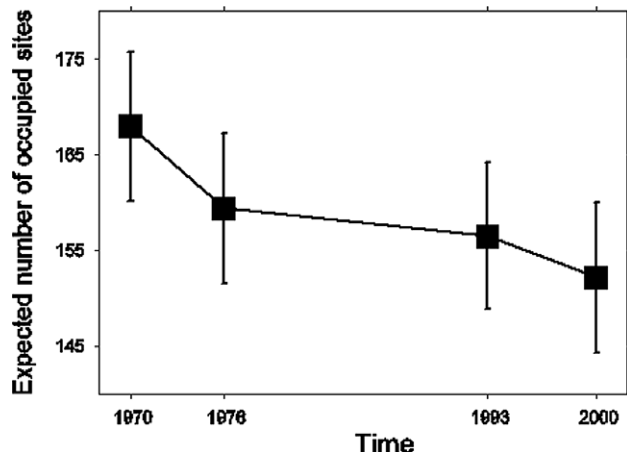


Fig. 4 – Thinning of the distributions of Mexican mammals (1970–2000). A spatial point process model was developed to explain the shape of each species' distribution in 1970, 1976, 1993, and 2000. The expected number of occurrences of each species in each $0.05^\circ \times 0.05^\circ$ site was derived from the model (see [Supplementary material](#)). The data are for the 78 species whose distributions contracted from 1970 to 2000 (\pm SE).

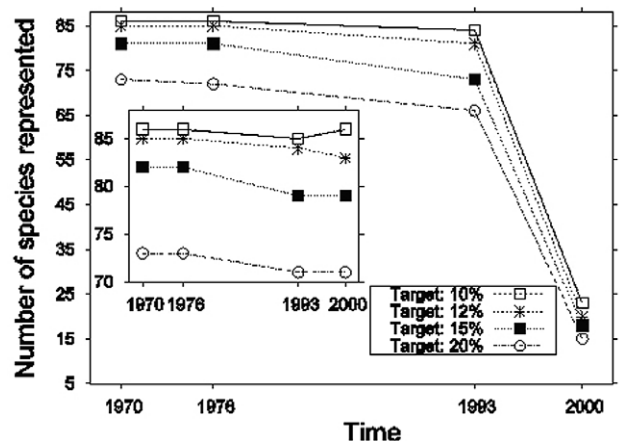


Fig. 5 – Declining representativeness of Mexican conservation area networks (1970–2000). At each time step, the maximum number of mammals that can be represented under a limited budget (6.9% of the land in Mexico) is shown. Inset: maximization results without incorporating the decreed natural protected areas.

sufficient levels (Cantú et al., 2003; Cantú et al., 2004b). Nevertheless, the natural protected areas have been important for biodiversity conservation in Mexico since the 1970s to the extent that deforestation rates are lower inside the protected areas (Alcérreca et al., 1989; Mendoza et al., 1999). Due to the significant resources invested in the natural protected areas, particularly the 21 Biosphere Reserves, it would not be practical to discard these protected areas and start from scratch.

The most recent data presented here is from 2000, but these results are probably representative of the effects of land conversion on mammal fauna as well as birds in Mexico today (Fuller et al., 2006; Peterson et al., 2006). Projections based on the 1976–2000 time series predict continued declines in primary temperate forests and increases in human-made covers from 2000 to 2020 (Mas et al., 2004). Proposed remedies for the ongoing loss of forest cover include training in sustainable agro-forestry for indigenous communities and liberalization of maize subsidies, among others (Deininger and Minten, 1999; Castillo et al., 2005).

Though multivariate data on land cover change are not available for most developing countries, the results presented here probably also apply to other biodiversity hotspots with defor-

estation rates as high as Mexico's, including Burma, Ecuador, Indonesia, the Philippines, and Sri Lanka (Myers et al., 2000; United Nations Food and Agriculture Association, 2005). Like Mexico, the natural protected areas of many biodiversity hotspots are known to have been selected in an ad hoc manner, without consideration for biodiversity contents (Pressey, 1994). The results presented here underscore the importance of promptly implementing a conservation area network because the cost of the network, measured by the (absolute) amount of land required for representing targeted percentages of the species' habitat, increases with the delays in implementation due to continued land conversion. In addition, the number of species that cannot be represented at their target levels in the set of selected sites increases as land conversion continues.

Acknowledgements

Specimen data were obtained in part via the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). The following museum collections were consulted: Colección Nacional de Mamíferos, Universidad Nacional Autónoma de México; Colección de Mamíferos, Universidad Autónoma Metropolitana-Iztapalapa; Centro Interdisciplinario de

Table 2 – Percent decrease in the maximum number of species represented in the conservation area network (1970–2000)

Budget (%)	Target							
	10%		12%		15%		20%	
	NPA	No NPA	NPA	No NPA	NPA	No NPA	NPA	No NPA
6.9	73.26	0	76.47	2.35	77.78	3.66	79.45	2.74
10	3.49	0	12.79	1.16	20.93	1.16	32.53	3.62

Investigación y Desarrollo Regional de Oaxaca; University of Kansas Natural History Museum; American Museum of Natural History, New York; National Museum of Natural History, Washington, DC; Field Museum of Natural History, Chicago, Illinois; Museum of Zoology, University of Michigan, Ann Arbor; Michigan State University Museum, East Lansing; Museum of Vertebrate Zoology, University of California, Berkeley; Texas Tech University Museum, Lubbock; Texas Cooperative Wildlife Collections, Texas A&M University, College Station. This work was supported by the Consejo Nacional de Ciencias y Tecnología and Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT-CONACyT Project 2002-C01-314-A1, and PAPIIT-UNAM Project IN-218706 to V.S.-C.).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2006.08.028.

REFERENCES

- Alcérreca, C., Consejo, J., Flores, O., Gutiérrez, D., Hentschel, E., Herzig, M., Pérez-Gil, R., Reyes, J.M., Sánchez-Cordero, V., 1989. Fauna Ailvestre y Áreas Naturales Protegidas. Universo Veintiuno, México, D.F.
- Anderson, R.P., Lew, D., Peterson, A.T., 2003. Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecological Modelling* 162, 211–232.
- Ando, A., Camm, J., Polasky, S., Solow, A., 1998. Species distributions, land values, and efficient conservation. *Science* 279, 2126–2128.
- Benning, T.L., LaPointe, D., Atkinson, C.T., Vitousek, P.M., 2002. Interactions of climate change with biological invasions and land use in the Hawaiian islands: modeling the fate of endemic birds using a geographic information system. *Proceedings of the National Academy of Sciences of the United States of America* 99, 14246–14249.
- Bocco, G., Mendoza, M., Velázquez, A., 2001. Remote sensing and GIS-based regional geomorphological mapping – a tool for land use planning in developing countries. *Geomorphology* 39, 211–219.
- Bojórquez-Tapia, L.A., Brower, L.P., Castilleja, G., Sánchez-Colón, S., Hernández, M., Calvert, W., Díaz, S., Gómez-Priego, P., Alcantar, G., Melgarejo, E.D., Solares, M.J., Gutiérrez, L., del Lourdes Juárez, M., 2003. Mapping expert knowledge: redesigning the monarch butterfly biosphere reserve. *Conservation Biology* 17, 367–379.
- Bojórquez-Tapia, L.A., de la Cueva, H., Díaz, S., Melgarejo, D., Alcantar, G., Solares, M.J., Grobet, G., Cruz-Bello, G., 2004. Environmental conflicts and nature reserves: redesigning Sierra San Pedro Mártir National Park, Mexico. *Biological Conservation* 117, 111–126.
- Bomhard, B., Richardson, D.M., Donaldson, J.S., Hughes, G.O., Midgley, G.F., Raimondo, D.C., Rebelo, A.G., Rouget, M., Thuiller, W., 2005. Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. *Global Change Biology* 11, 1452–1468.
- Brandon, K., Gorenflo, L., Rodrigues, A., Waller, R., 2005. Reconciling conservation, people, protected areas, and agricultural suitability in Mexico. *World Development* 33, 1403–1418.
- Brooks, T.M., Pimm, S.L., Kapos, V., Ravilious, C., 1999. Threat from deforestation to montane and lowland birds and mammals in insular South-east Asia. *Journal of Animal Ecology* 68, 1061–1078.
- Burns, C.E., Johnston, K.M., Schmitz, O.J., 2003. Global climate change and mammalian species diversity in US national parks. *Proceedings of the National Academy of Sciences of the United States of America* 100, 11474–11477.
- Cantú, C., Wright, R.G., Scott, J.M., Strand, E., 2003. Conservation assessment of current and proposed reserves of Tamulipas state, Mexico. *Natural Areas Journal* 23, 220–228.
- Cantú, C., Wright, R.G., Scott, J.M., Strand, E., 2004a. Assessment of current and proposed nature reserves of Mexico based on their capacity to protect geophysical features and biodiversity. *Biological Conservation* 115, 411–417.
- Cantú, C., Wright, R.G., Scott, J.M., Strand, E., 2004b. Assessing biodiversity in Nuevo Leon, Mexico: are nature reserves the answer? *Natural Areas Journal* 24, 150–153.
- Carabrias, J., Provencio Durazo, E., Toledo, C., 1994. Manejo de Recursos Naturales y Pobreza Rural. Universidad Nacional Autónoma de México, México, D.F.
- Castillo, A., Torres, A., Velázquez, A., Bocco, G., 2005. The use of ecological science by rural producers: a case study in Mexico. *Ecological Applications* 15, 745–756.
- Ceballos, G., Arroyo-Cabrales, J., Medellín, R.A., 2002. The mammals of México: composition, distribution, and conservation status. *Occasional Papers, Museum of Texas Tech University* 218, 1–27.
- Ceballos, G., List, R., Pacheco, J., Manzano-Fischer, P., Santos, G., Royo, M., 2005. Prairie dogs, cattle, and crops: diversity and conservation of the grassland-shrubland habitat mosaic in Northwestern Chihuahua. In: Cartron, J.-L.E., Ceballos, G., Felger, R.S. (Eds.), *Biodiversity, Ecosystems, and Conservation in Northern Mexico*. Oxford University Press, New York, pp. 425–438.
- Comisión Nacional Para el Conocimiento y Uso de la Biodiversidad (CONABIO), 1998. *La Diversidad Biológica de México: Estudio de País*. CONABIO, México.
- Csuti, B., Polasky, S., Williams, P., Pressey, R., Camm, J., Kershaw, M., Kiester, A.R., Downs, B., Hamilton, R., Huso, M., Sahr, K., 1997. A comparison of reserve selection algorithms using data on terrestrial vertebrates in Oregon. *Biological Conservation* 80, 83–97.
- Davis, M.B., Zabinski, C., 1992. Changes in geographical range resulting from greenhouse warming: effects on biodiversity in forests. In: Peters, R.L., Lovejoy, T.E. (Eds.), *Global Warming and Biological Diversity*. Yale University Press, New Haven, CT, pp. 297–308.
- Davis, M., Douglas, C., Calcote, R., Cole, K.L., Winkler, M.G., Flakne, R., 2000. Holocene climate in the Western Great Lakes national parks and lakeshores: implications for future climate change. *Conservation Biology* 14, 968–983.
- Deininger, K.W., Minten, B., 1999. Poverty, policies, and deforestation: the case of Mexico. *Economic Development and Cultural Change* 47, 313–344.
- Dirzo, R., Garcia, M.C., 1992. Rates of deforestation in Los Tuxtlas, a neotropical area in southeast Mexico. *Conservation Biology* 6, 84–90.
- Fa, J., Morales, L., 1993. Patterns of mammalian diversity in Mexico. In: Ramamoorthy, T., Bye, R., Lot, A., Fa, J. (Eds.), *Biological Diversity of Mexico: Origins and Distribution*. Oxford University Press, Oxford, pp. 319–364.
- Fisher, D.O., 2000. Effects of vegetation structure, food and shelter on the home range and habitat use of an endangered wallaby. *Journal of Applied Ecology* 37, 660–671.
- Fuller, T., Munguía, M., Mayfield, M., Sánchez-Cordero, V., Sarkar, S., 2006. Incorporating connectivity into conservation planning: a multi-criteria case study from central Mexico. *Biological Conservation* 133, 131–142.

- Gómez-Pampa, A., Kaus, A., 1999. From pre-Hispanic to future conservation alternatives: lessons from Mexico. *Proceedings of the National Academy of Sciences of the United States of America* 96, 5982–5986.
- Halpin, P.N., 1997. Global climate change and natural-area protection: management responses and research directions. *Ecological Applications* 7, 828–843.
- Hannah, L., Midgley, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D., Woodward, F.I., 2002. Conservation of biodiversity in a changing climate. *Conservation Biology* 16, 264–268.
- Illoldi-Rangel, P., Sánchez-Cordero, V., Peterson, A.T., 2004. Predicting distributions of Mexican mammals using ecological niche modeling. *Journal of Mammalogy* 85, 658–662.
- International Union for the Conservation of Nature, 1994. *World Conservation Strategy: Conservation for Sustainable Development*. Worldwide Fund for Nature, Gland, Switzerland.
- Inventario Nacional Forestal, 2000. *Vegetación y Uso del Suelo – 2000 – Inventario Forestal*. <<http://infoteca.semarnat.gob.mx/Metadatos/inventario2000.html>>. Last accessed May 31, 2006.
- Kinnair, M.F., Sanderson, E.W., O'Brien, T.G., Wibisono, H.T., Woolmer, G., 2003. Deforestation trends in a tropical landscape and implications for endangered mammals. *Conservation Biology* 17, 245–257.
- Koh, M.C.K., Sodhi, N.S., Lim, S.L.H., 2006. High sensitivity of montane bird communities to habitat disturbance in Peninsular Malaysia. *Biological Conservation* 129, 149–166.
- Margules, C., Pressey, R., 2000. Systematic conservation planning. *Nature* 405, 243–253.
- Mas, J.-F., Velazquez, A., Diaz-Gallegos, J.-R., Mayorga-Saucedo, R., Alcantara, C., Bocco, G., Castro, R., Fernandez, T., Pérez-Vega, A., 2004. Assessing land use/cover changes: a nationwide multirate spatial database for Mexico. *International Journal of Applied Earth Observation and Geoinformation* 5, 249–261.
- Masera, O.R., Ordóñez, M.J., Dirzo, R., 1997. Carbon emissions from Mexican forests: current situation and long-term scenarios. *Climatic Change* 35, 265–295.
- Mendoza, E., Fay, J., Dirzo, R., 1999. Deforestation in Lacandonia (southeast Mexico): evidence for the declaration of the northernmost tropical hot-spot. *Biodiversity and Conservation* 8, 1621–1641.
- Midgley, G.F., Hannah, L., Millar, D., Thuiller, W., Booth, A., 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation* 112, 87–97.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. *Nature* 403, 853–858.
- Onal, H., Briers, R.A., 2002. Incorporating spatial criteria in optimum reserve network selection. *Proceedings of the Royal Society of London B* 269, 2437–2441.
- Ortega-Huerta, M.A., Medley, K.E., 1999. Landscape analysis of jaguar (*Panthera onca*) habitat using sighting records in the Sierra de Tamaulipas, Mexico. *Environmental Conservation* 26, 257–269.
- Ortega-Huerta, M.A., Peterson, A.T., 2004. Modelling spatial patterns of biodiversity for conservation prioritization in North-eastern Mexico. *Diversity and Distributions* 10, 39–54.
- Peters, R.L., Darling, J.D.S., 1985. The green house effect and nature reserves. *Bioscience* 35, 707–717.
- Peterson, A.T., Ortega-Huerta, M.A., Bartley, J., Sánchez-Cordero, V., Soberón, J., Buddemeier, R., Stockwell, D.R.B., 2002. Future projections for Mexican faunas under global climate change scenarios. *Nature* 416, 626–629.
- Peterson, A.T., Sánchez-Cordero, V., Martínez-Meyer, E., Navarro-Sigüenza, A., 2006. Tracking population extirpations via melding ecological niche modeling with land-cover information. *Ecological Modeling* 195, 229–236.
- Pressey, R.L., 1994. Ad hoc reservations: forward or backward steps representative reserve systems. *Conservation Biology* 8, 662–668.
- Rutherford, M.C., Powrie, L.W., Schulze, R.E., 1999. Climate change in conservation areas of South Africa and its potential impact on floristic composition: a first assessment. *Diversity and Distributions* 5, 253–262.
- Rzedowski, J., 1986. *Vegetación de México*. Editorial Limusa, Mexico, D.F.
- Sánchez-Cordero, V., Illoldi-Rangel, P., Linaje, M., Sarkar, S., Peterson, A.T., 2005. Deforestation and extant distributions of Mexican endemic mammals. *Biological Conservation* 126, 465–473.
- Sarkar, S., 2005. *Biodiversity and Environmental Philosophy: An Introduction*. Cambridge University Press, New York.
- Sarkar, S., Pressey, R.L., Faith, D.P., Margules, C.R., Fuller, T., Stoms, D.M., Moffett, A., Wilson, K., Williams, K.J., Williams, P.H., Andelman, S., 2006. Biodiversity conservation planning tools: present status and challenges for the future. *Annual Review of Environment and Resources* 31, 123–159.
- Sarukhán, J., Soberón, J., Larson-Guerra, J., 1996. Biodiversity conservation in a high beta-diversity country. In: Di Castri, F., Younès, T. (Eds.), *Biodiversity, Science and Development: Towards a New Partnership*. CAB International, Wallingford, Oxon, UK, pp. 246–263.
- Schabenberger, O., Gotway, C.A., 2005. *Statistical Methods for Spatial Data Analysis*. Chapman & Hall/CRC Press, London/Boca Raton, FL.
- Sorani, V., Alvarez, R., 1996. Hybrid maps: a solution for updating of forest cartography with satellite images and existing information. *Geocarto International* 11, 17–23.
- Stockwell, D.R.B., Peters, D., 1999. The GARP modelling system: problems and solutions to automated spatial prediction. *International Journal of Geographical Information Science* 13, 143–158.
- Stoleson, S.H., Felger, R.S., Ceballos, G., Raish, C., Wilson, M.F., Búrquez, A., 2005. Recent history of natural resource use and population growth in Northern Mexico. In: Cartron, J.-L.E., Ceballos, G., Felger, R.S. (Eds.), *Biodiversity, Ecosystems, and Conservation in Northern Mexico*. Oxford University Press, New York, pp. 52–86.
- United Nations Food and Agriculture Association, 2005. *State of the World's Forests*. United Nations Food and Agriculture Association, Rome, Italy.
- United States Geological Survey, 1998. *GTOPO30 Global 30 Arc-second Digital Elevation Model*. <<http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html>>. Last accessed May 30, 2006.
- Villa, B., Cervantes, F.A., 2003. *Los Mamíferos de México*. Instituto de Biología, UNAM-Grupo Editorial Iberoamérica, México, D.F.
- Villaseñor, J.L., Ibarra, G., Ocana, D., 1998. Strategies for the conservation of Asteraceae in Mexico. *Conservation Biology* 12, 1066–1075.