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Deforestation and extant distributions of Mexican endemic mammals

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Abstract

Deforestation threatens biodiversity conservation worldwide, but little quantitative information is available on how it affects individual species' distributions. We modeled potential distributions of 85 continental endemic Mexican mammal species using ecological niche modeling, and produced testable predictions of species' extant distributions by limiting ecological niches to remnant untransformed habitat based on the Inventario Nacional Forestal 2000. We included point occurrence data for all endemics only from collecting localities prior to 1970, before wide areas of habitat transformation occurred nationwide. Most endemics (61 of 85, 72%) showed a high proportion of transformed habitat (34.5%) at the national level. More than one-fourth of the endemics (23 out of 85, 27%) lost more than 50% of untransformed habitat within their potential distributions; two showed drastic areal loss of more than 90%; another two showed a loss of more than 80%. Only 34 of the endemics are listed as endangered or threatened in the Mexican Norma Oficial Mexicana (NOM). No significant association existed between proportional loss and conservation status as assigned in the NOM, nor are correlations significant between original distributional area and area of remnant untransformed habitat. Both findings suggest that geographic location determines extinction risks rather than area per se. Endemics in the state of Veracruz and in the Transvolcanic Belt suffered the most drastic niche reductions and thus appear to be at high extinction risk from further deforestation.

Keywords: Deforestation; Ecological niche; Endangered; Endemic mammals; Habitat; Mexico; Species' distributions

1. Introduction

High rates of deforestation threaten biodiversity conservation worldwide. Of major concern are impacts of anthropogenic habitat transformation on individual species' distributions and, consequently, their conservation status (Wilson, 1988; Reaka-Kudla et al., 1997; Mace et al., 1998). One approach by which this issue has been addressed is by quantifying deforestation of dominant vegetation types and relating habitat loss with biodiversity loss. Numerous studies have identified vegetation types with high species richness and endemicity that have suffered considerable deforestation; such hotspots occur primarily in tropical and montane regions (Myers, 1998; Kinnaird et al., 2003; Rodrigues et al., 2004). Well-known examples involve tropical rainforest habitats, of which over 70% has been deforested, with this loss particularly concentrated in several regions of the world (Myers, 1998; Laurance and Bierregaard, 1997; Heaney et al., 1999). Other dominant vegetation types in tropical as well as temperate regions are under severe deforestation pressure as well (Wilson, 1988; Laurance and Bierregaard, 1997; Mittermeier et al., 1998; Rodrigues et al., 2004).

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Mexico is a megadiverse country, but annual rates of deforestation over 1% nationwide pose threats to biodiversity conservation (Arriaga et al., 2001; FAO, 2001; Mas et al., 2004). An estimated 90% of the original humid tropical forest has been converted into agrosystems or urban settlements, presumably resulting in drastic biodiversity loss (Toledo et al., 1989; Mittermeier et al., 1998; Dirzo and García, 1992; Arriaga et al., 2001). Other dominant vegetation types identified as hotspots of species richness and endemicity also show increasing deforestation, ranging from 20% in tropical deciduous forests to 30% in cloud forests (Challenger, 1998; Arriaga et al., 2001; Velázquez et al., 2001; Mas et al., 2004). Although these measures of deforestation of main vegetation types provide general ideas of trends, little can be inferred for effects on individual species.

Recently developed methodologies for modeling species' ecological niches are based on a "Grinnellian" niche concept – the suite of environmental conditions within which a species can maintain populations without immigrational input (Grinnell, 1917; MacArthur, 1972). Primary occurrence data usually exist as museum voucher specimens with georeferenced coordinates of collecting localities. Environmental datasets are typically derived from digitized maps based on remote-sensed data and climatic models. These coarse-grained niche models can identify geographic areas suitable in principle for each species (Peterson et al., 1999; Stockwell and Peters, 1999; Peterson, 2001; Anderson et al., 2003). We believe that such geographic projections of niches can provide a framework for understanding how habitat loss impacts distributions of individual species (Sánchez-Cordero et al., 2001, 2004). Our aims were to (1) estimate range loss due to deforestation by determining the remnant untransformed habitats within species' distributions, and (2) identify regions of potentially high species endangerment and extinction risk.

2. Materials and methods

2.1. Study area and data set

We used the Inventario Nacional Forestal (INF) 2000 (Secretaría del Medio Ambiente, Recursos Naturales y Pesca, et al., 2001; Velázquez et al., 2001; Mas et al., 2004) as the base for current land use and vegetation types for Mexico. INF 2000 is based on LandSat satellite imagery interpretation, as well as ground field validation of main vegetation types and land use in Mexico scaled at 1:250,000. It is jointly produced by the Instituto de Geografía of the Universidad Nacional Autónoma de México (www.igeograf.unam.mx), and the government agency, Instituto Nacional de Geografía, Estadística e Informática (www.inegi.gob.mx). Detailed information on INF 2000 interpretation and field validation methodologies are available in the literature (Secretaría del Medio Ambiente, Recursos Naturales y Pesca et al., 2001; Velázquez et al., 2001; Mas et al., 2004; www.igeograf.unam.mx).

We modeled ecological niches for the 85 continental endemic mammal species of Mexico (Hall, 1981). Point occurrence distributional data for each endemic species were compiled from national and international scientific collections (see Acknowledgments), and from the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO; www.conabio.gob.mx). We included point occurrence data for all endemics only from collecting localities prior to 1970, which likely occurred in untransformed habitats, before major deforestation practices started nationwide (Toledo et al., 1989). Point occurrence data were georeferenced to the nearest 0.01° of longitude and latitude for each locality using 1:250,000 topographic maps (CONABIO, 1998; www.conabio.gob.mx).

To characterize species' ecological niches, we used 10 environmental data layers ($0.04 \times 0.04°$ pixel resolution), including potential vegetation type (Rzedowski, 1986); elevation, slope, and aspect (from the US Geological Survey's Hydro-1K data set; www.usgs.gov); and climatic parameters including mean annual precipitation, mean daily precipitation, maximum daily precipitation, minimum and maximum daily temperature, and mean annual temperature (CONABIO, 1998; www.conabio.gob.mx).

2.2. Modeling species' distributions

We used the Genetic Algorithm for Rule-set Prediction (GARP; Stockwell and Peters, 1999), available for download at www.lifemapper.org/desktopgarp, for modeling species' ecological niches calculated as potential distributions. GARP has proven a robust tool for correctly predicting species' distributions in diverse faunistic groups, including mammals (Peterson et al., 1999; Peterson and Cohoon, 1999; Stockwell and Peterson, 2002a,b; Peterson, 2003; Peterson and Kluza, 2003; Illoldi-Rangel et al., 2004). GARP relates ecological-environmental biotic and abiotic variables of known occurrence points to those of points randomly sampled from the rest of the study region, seeking to develop a series of decision rules that best summarize factors associated with the species' presence. In GARP, occurrence points are divided evenly into training and testing data sets. The algorithm uses an iterative process of rule selection, evaluation, testing, and incorporation or rejection. The training data are used to develop or evolve a rule. Predictive accuracy is evaluated using the testing data. Change in predictive accuracy between iterations is used to evaluate whether particular rules should be retained; the algorithm runs 1000 iterations or until convergence (Stockwell and Peters, 1999).

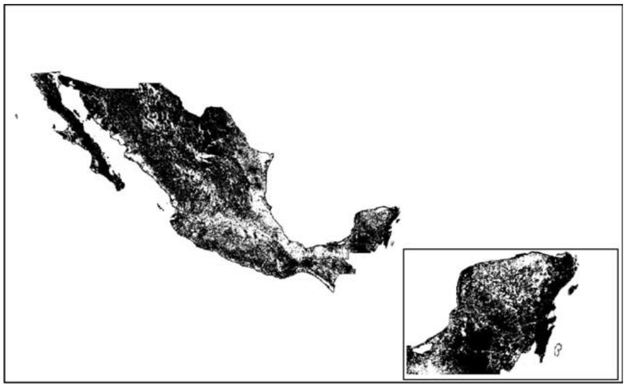

Fig. 1. Transformed habitat (white areas) and untransformed habitat (black areas) projected nationwide, based on the Inventario Nacional Forestal 2000; transition of untransformed areas to transformed ones is due mainly to primary habitat conversion to agrosystem and rural and urban settlements. A detailed map of habitat transformation for the Yucatan peninsula is depicted at the lower corner.

Because GARP does not produce unique solutions (i.e., each model produced is slightly different; Stockwell and Peters, 1999), we followed recommendation of Anderson et al. (2003) for identifying an optimal subset of replicate models. For each analysis, we developed 100 replicate models; of these models, we retained the 20 models with lowest omission error. Finally, we retained the 10 models with moderate commission error (i.e., we discarded the 10 models with areas predicted as "present" showing greatest deviations from the overall median areas predicted as present across all models). This 'best subset' of models was summed to produce final predictions of potential distributions.

Species' extant distributional areas were then identified provisionally by overlaying the potential distributions with the INF 2000, and retaining only those areas holding untransformed natural habitats (Fig. 1). We assumed that habitat transformed into agrosystems and rural or urban settlements constitutes unsuitable habitat for the species included in this study (see below). Finally, we contrasted species' extinction risk based on percentage of untransformed habitat within distributional predictions with assigned conservation status of Mexican mammals published by the government (Norma Oficial Mexicana, NOM; see www.conabio.gob.mx, and www.ine.gob.mx); the NOM list, unlike the IUCN list, includes a comprehensive analyses assigning conservation status categories for the Mexican mammals.

3. Results

More than one-fourth of the endemics (23 out of 85) lost >50% of untransformed habitat within their potential distributions. Two endemics showed a particularly drastic distributional loss of >90%, and another two showed losses of >80%. Only 10 endemics retained >80% of untransformed habitat within their distributional areas (Table 1; Figs. 2 and 3). An estimated 34.5% of untransformed habitat has been transformed nationwide, with major losses occurring mostly in tropical habitats (Fig. 1). Most endemics (61 of 85, 72%) showed a higher proportion of transformed habitat within their potential distributions compared to the overall proportion of transformed habitat at the national level (Figs. 1–3); potential distributions of all endemics were modeled before such wide habitat transformations occurred.

No significant correlation existed between the proportion of untransformed area and the original distributional area ($r = 0.07$, $P > 0.1$), but residuals decreased with increased species' potential distributional area (Fig. 4). The proportional area of untransformed habitat appeared more dependent on geographic location. For example, 25 out of 37 (68%) endemic species retaining <60% of untransformed habitat in their distributions occurred in eastern Mexico (in the state of Veracruz) or in the Transvolcanic Belt of central Mexico. Conversely, 45 out of 48 (94%) endemic species retaining >60% of untransformed habitat in their potential distributions occurred in other regions (Table 1).

Less than half of the endemic species (34 out of 85, 40%) included in our study are listed in the NOM. Nonetheless, some of the species not listed lost >50% of their potential distribution in our reconstructions: *Chaetodipus artus*, *Cratogeomys gymnurus*, *Cratogeomys zinseri*, *Pappogeomys tylorhinus*, *Dasyprocta mexicana*, *Habromys simulatus*, *Neotomodon alstoni*, *Peromyscus furvus*, and *Reithrodontomys cryophilus* (Table 1).

We found no significant correlation between proportion of untransformed area and assigned conservation status ($r^s = 0.11$, $P > 0.1$; Fig. 5). For example, *Myotis vivesi*, *Romerolagus diazi*, and *Musonycteris harrisoni*, with <50% of habitat untransformed, and *Dipodomys gravipes* with close to 75% of habitat untransformed, are all officially listed as endangered species. The microendemic species, *Orthogeomys cuniculus* (<5%), *Spermophilus perotensis* (<30%), and *Peromyscus mekisturus* (<50%) are all listed as threatened species. However, *Peromyscus bullatus* (<5%), *Sorex macrodon* (<20%), and *Nelsonia neotomodon*, *Dipodomys phillipsi*, *Sylvilagus insonus*, *Neotoma phenax*, *Sciurus oculatus*, and *Peromyscus zarhynchus* (all <50%) are listed as "protected," a lower category of threat (Table 1).

4. Discussion

Traditional approaches have, for the most part, linked transformation of dominant vegetation types with general biodiversity loss (Dirzo and García, 1992; Laurance and Bierregaard, 1997; Heaney et al., 1999). These approaches are limited in that they do not assess

Table 1
Continental endemic mammal species of Mexico included in the study, with proportion of remaining habitat retained in untransformed state

Endemic species	% remnant untransformed habitat	Conservation status	Distribution by state or region
Orthogeomys cuniculus	2.32	T	Guerrero, Oaxaca
Peromyscus bullatus	3.24	E	Veracruz
Pappogeomys tylorhinus	11.25	NL	Transvolcanic belt
Sorex macrodon	15.95	E	Veracruz
Habromys simulatus	25.00	NL	Veracruz
Chaetodipus artus	25.35	NL	Sinaloa
Spermophilus perotensis	29.22	T	Veracruz
Dasyprocta mexicana	34.66	NL	Veracruz
Nelsonia neotomodon	35.82	E	Transvolcanic belt
Myotis vivesi	36.27	P	Sonora
Cratogeomys zinseri	36.36	NL	Transvolcanic belt
Dipodomys phillipsii	38.80	E	Central plateau, transvolcanic belt
Reithtrodontomys cryophilus	38.84	NL	Transvolcanic belt
Peromyscus furvus	39.38	NL	Veracruz
Neotomodon alstoni	39.90	NL	Transvolcanic belt
Peromyscus mekisturus	41.66	T	Transvolcanic belt
Sylvilagus insonus	42.85	E	Guerrero
Neotoma phenax	43.11	E	Sonora, Sinaloa
Sciurus oculatus	43.55	E	Sierra madre occidental
Romerolagus diazi	45.11	P	Transvolcanic belt
Musonycteris harrisoni	46.60	P	Transvolcanic belt, Oaxaca
Cratogeomys gymnurus	47.58	NL	Transvolcanic belt
Peromyscus zarhyncus	48.49	E	Chiapas
Liomys spectabilis	50.72	E	Transvolcanic belt
Xenomys nelson	51.67	T	Jalisco
Rhogoessa allen	52.43	NL	Transvolcanic belt, Oaxaca
Sigmodon leucotis	52.59	NL	Transvolcanic belt
Reithrodontomys burti	52.61	NL	Sonora, Sinaloa
Habromys chinanteco	52.80	NL	Oaxaca
Microtus quasiater	54.30	E	Veracruz
Spermophilus annulatus	54.37	NL	Transvolcanic belt
Spermophilus adocetus	55.42	NL	Transvolcanic belt, Guerrero, Michoacán
Sigmodon mascotensis	55.60	NL	Transvolcanic belt, Southwest
Cryptotis mexicana	57.57	E	Sierra madre oriental, Oaxaca
Rhogoessa gracilis	57.80	NL	Transvolcanic belt, Sierra Madre Occidental
Pappogeomys bullatus	58.85	NL	Transvolcanic belt
Peromyscus perfulvus	59.53	NL	Jalisco
Marmosa canescens	60.37	NL	Neotropical region
Plecotus mexicanus	60.81	NL	Sierra Madre Occidental
Peromyscus aztecus	60.92	NL	Transvolcanic belt, Oaxaca
Lepus flavigularis	61.63	E	Oaxaca
Osgoodomys banderanus	63.43	NL	Sierra Madre del Sur
Neotoma angustapalata	63.67	NL	Tamaulipas, San Luis Potosí
Neotoma palatina	64.06	NL	Zacatecas, Guanajuato, Aguascalientes
Rheomys mexicanus	64.11	E	Oaxaca
Peromyscus melanotis	64.74	NL	Transvolcanic belt
Reithrodontomys hirsutus	64.76	NL	Transvolcanic belt
Spilogale pygmea	65.41	T	Sierra Madre Occidental
Megadontomys thomasi	65.60	T	Guerrero, Oaxaca
Artibeus hirsutus	65.79	NL	Sierra Madre Occidental
Peromyscus simulus	66.03	NL	Sierra Madre Occidental
Tamias bullatus	66.26	NL	North
Hodomys alleni	66.39	NL	Sierra Madre Occidental, Sierra Madre del Sur
Peromyscus melanophrys	66.80	NL	Central Plateau to Oaxaca
Peromyscus yucatanicus	66.96	NL	Yucatán
Megasorex giga	67.59	NL	Oaxaca
Sciurus colliaei	67.67	NL	Sierra Madre Occidental
Crateogeomys fumosus	67.81	T	Jalisco, Colima
Peromyscus merriami	67.97	NL	Sierra Madre Occidental
Sigmodon allen	68.61	NL	Sierra Madre del Sur
Sciurus allen	69.16	NL	Nuevo León, Tamaulipas, San Luis Potosí
Peromyscus melanurus	69.96	NL	Oaxaca
Peromyscus megalops	71.55	NL	Guerrero, Oaxaca

Table 1 (*continued*)

Endemic species	% remnant untransformed habitat	Conservation status	Distribution by state or region
Cryptotis magna	72.48	E	Oaxaca
Cynomys mexicanus	73.08	T	Central plateau
Neotoma goldmani	73.66	NL	Central plateau
Dipodomys gravipes	74.45	P	Baja California
Sorex veraepacis	75.84	E	Guerrero, Oaxaca
Chaetodipus arenarius	76.30	T	Baja Península
Peromyscus eva	76.84	T	Baja Península
Chaetodipus pennicillatus	77.01	T	Baja California, Sonora
Habromys lepturus	78.47	NL	Oaxaca
Megadontomys cryophilus	79.52	NL	Oaxaca
Peromyscus ochraventer	79.54	NL	San Luis Potosí, Querétaro, Tamaulipas
Peromsycus melanocarpus	79.60	NL	Oaxaca
Peromyscus polius	80.62	NL	Chihuahua, Durango
Rhogoessa aeneus	80.93	NL	Yucatán
Microtus umbrosus	81.25	E	Oaxaca
Peromyscus spicilegus	82.14	NL	Sierra Madre Occidental
Dipodomys nelson	82.19	NL	Chihuahua, Coahuila, Durango
Myotis penninsularis	82.51	NL	Baja California Sur
Sorex milleri	82.70	E	Coahuila, Tamaulipas, Nuevo León
Peromyscus winkelmanni	82.85	E	Transvolcanic belt
Spermophilus madrensis	83.41	E	Chihuahua, Durango
Microtus oaxacensis	83.64	NL	Oaxaca

Conservation status is drawn from the Norma Oficial Mexicana: E = endangered; T = threatened; P = protected; NL = not listed in the NOM.

the status of individual species. The methods explored herein, in contrast, using point occurrence data, digitized environmental GIS layers, and niche modeling, provide a framework for assessing impacts of deforestation on individual species' distributions, and hence, their conservation status. Moreover, by modeling ecological niches of the continental endemic Mexican mammals, we were able to produce testable predictions of species' extant distributions.

Our final models are based on the assumption that coarse-scale conversion of natural habitats into agrosystems or human habitation (rural or urban settlements) results in non-viable conditions for species (Egbert et al., 1999; Peterson et al., 2000; Ortega-Huerta and Peterson, 2004; Sánchez-Cordero et al., 2004). Ecological support for this idea comes from the hypothesis of general niche conservatism which has been tested for a diverse range of fauna in Mexico and elsewhere (Peterson et al., 1999; Peterson and Vieglais, 2001; Peterson and Holt, 2003). Theoretically, rapid adaptation to new environments produced by anthropogenic habitat transformation is unlikely. Moreover, populations of these species are unlikely to persist without significant immigration from adjacent natural habitats (Peterson and Holt, 2003). These effects reinforce the idea of the importance of conserving untransformed habitats. All of these factors are likely to hold for locally-adapted endemic species. According to our model, endemics are assumed to persist chiefly in untransformed habitat, although this assumption requires some relaxation since some species may be able to use agrosystems as source food and shelter, and even convert into pests, such as *Pappogeomys tylorhinus* and *Spermophilus adocetus* (Sánchez-Cordero and Martínez-Meyer, 2000; Sánchez-Cordero and García-Zepeda, 2003). Our model does not specifically predict which endemics may be tolerant to transformed habitat, as is known to be the case for some mammals (see Fisher et al., 2003; Isaac and Cowlishaw, 2004). Moreover, a coarse forest pixel resolution assumed as suitable habitat can include portions of transformed habitat thus underestimating range loss for species particularly sensitive to anthropogenic disturbance. Other factors not included in our model can contribute to population extirpation, such as illegal hunting, and biological attributes of species' home range, fecundity rate, and rarity in fragmented habitats (Mace et al., 1998).

However, these methodological limitations do not affect our conclusions which are based on the observed patterns of reductions in species' suitable niches due to anthropogenic habitat transformation. From the perspective of biodiversity conservation, our approach satisfies the precautionary principle: even where it require subsequent refinement and modification, it is conservative about what constitutes viable habitat for species; as such, it will have done no harm to conservation aims (Sarakinos et al., 2001). If areas are selected for conservation, but other areas also allow the persistence of species, the use of our model will not result in detriment of potential suitable habitat for conserving species (Sarkar, 2004).

Our predictions of species' remaining distributional areas can be readily tested via field surveys, testing presence and absence of endemics on remnant untransformed habitat fragments versus converted habitats (Sánchez-Cordero et al., 2004, 2005). We have previously

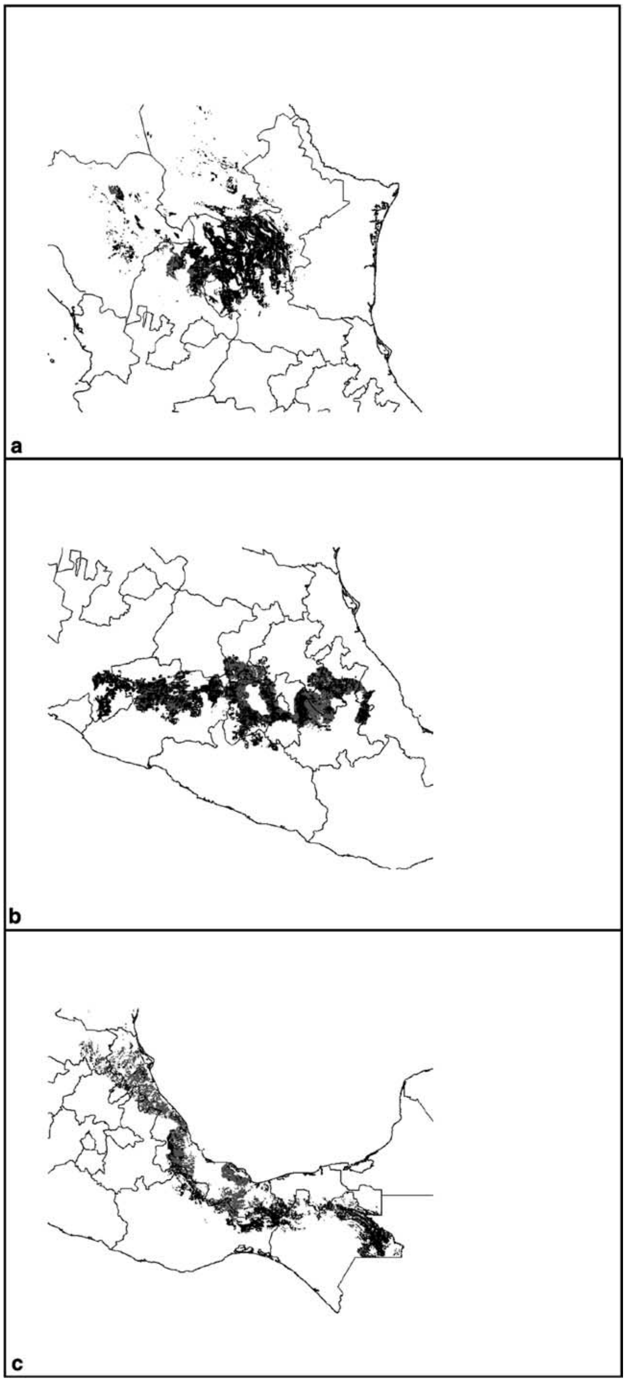

Fig. 2. Impact of deforestation on continental endemic mammals. (a) *Cynomys mexicanus* showing moderate niche loss, and (b) *Reithrodontomys crysopsis*, and (c) *Dasyprocta mexicana*, showing significant niche loss. Light gray indicates the species' computed potential distribution; black indicates areas with remnant untransformed habitat which are interpreted as the species' extant distribution.

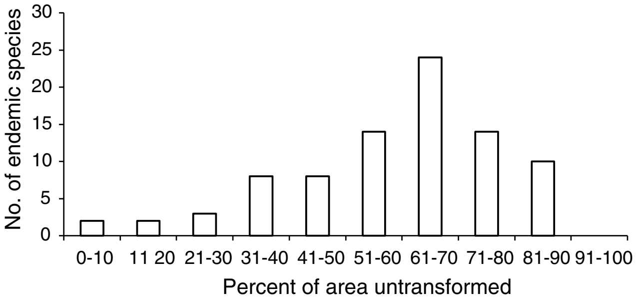

Fig. 3. Frequency distribution of remnant untransformed habitat within potential geographic distributions of Mexican continental endemic mammals.

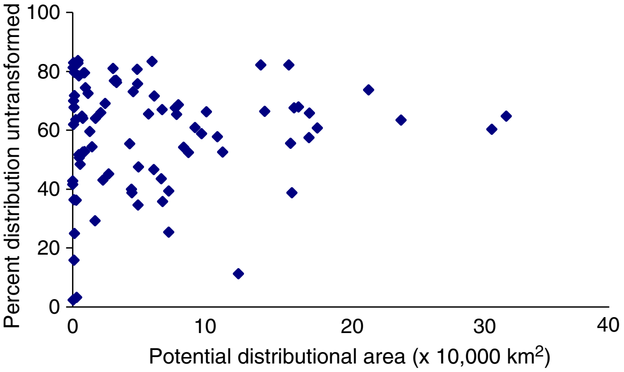

Fig. 4. Percentage of untransformed habitat within species' distributions as function of original potential distributional area.

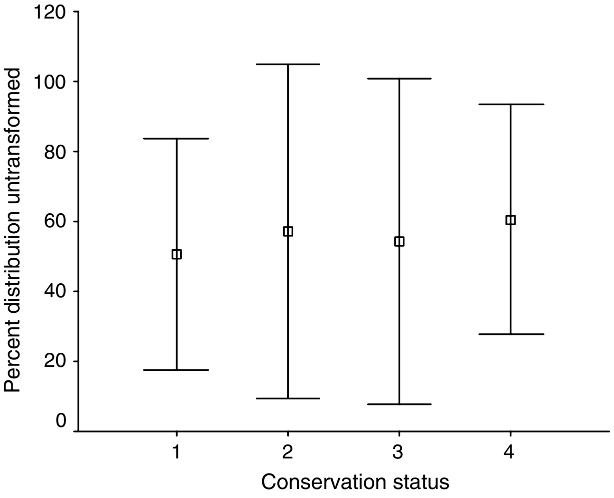

Fig. 5. Percentage (mean and standard deviation) of untransformed habitat within species' distributions as a function of the conservation status assigned by the NOM (Norma Oficial Mexicana). 1, endangered; 2, threatened, and 3, protected; 4, endemics not listed in the NOM.

carried out such tests regarding the presence of endemic species on remnant untransformed habitats in Oaxaca, Mexico and found – at least in a preliminary test – good agreement with predictions; for all 11 tested species with adequate number of localities, distributional predictions were significantly more coincident with independent test points than random expectations (Illoldi-Rangel et al., 2004).

Most endemic species showed significant areal reductions with low remnant untransformed habitat coverage within their potential distributions, which can be interpreted as posing an extinction threat. For example, *C. tylorhinus*, *H. simulatus*, *O. cuniculus*, *P. bullatus*, *Sorex macrodon* all showed drastic areal losses retaining <25% of their potential distributions. Conversely, *Dipodomys nelsoni*, *Microtus umbrosus*, *Microtus oaxacensis*, *Myotis peninsularis*, *Peromyscus spicilegus*, *Peromyscus winkelmanni*, *Peromysus polius*, *Rhogoessa aeneus*, *Sorex milleri*, and *Spermophilus madrensis* all retained >80% of their potential distributions as untransformed habitat (Table 1).

Nearly all endemics with large ranges lost a large proportion of their potential habitats, whereas species with small ranges showed both high and low loss, indicating that a broad distribution does not preclude a high extinction risk (Figs. 2, 4 and 5). Niche loss appeared related to geographic locations of species' ranges rather than to distributional area per se (Table 1; Fig. 1). Some microendemic species showed drastic niche loss, retaining only marginal fragments of remnant untransformed habitat (e.g., *O. cuniculus*, *P. bullatus*, and *H. simulatus*), whereas others showed broad areas of remnant untransformed habitat within their (small) distributions (e.g., *P. winkelmanni* and *M. umbrosus*; Table 1). Furthermore, endemic species can be particularly prone to extirpation in certain areas of their ranges, in which only small fragments of untransformed habitat remain. For example, *Dasyprocta mexicana* occurs mostly in tropical rainforest in eastern and southern Mexico (Hall, 1981; Fig. 2). Conversion of tropical humid forests to agroecosystems in the northern part of *D. mexicana*'s range left only small remnant fragments. Large areas of tropical humid forest, however, still remain in the southern part of its distribution (Fig. 2). Although this species is not listed in the NOM, our models show that the species faces a high risk of extirpation across approximately half of its range (Table 1).

Our results suggest that populations face different extirpation risks according to geographic location, thus providing a geographic context towards designing regional and local conservation plans. This criterion can be extrapolated generally to other faunistic groups as a useful tool for defining conservation priorities (Ceballos and Rodríguez, 1993; Mace et al., 1998; Hilton-Taylor, 2000; Colyvan et al., 2002; Fuller et al., 2003; Kinnaird et al., 2003; Sánchez-Cordero et al., 2004, 2005). In our example, we found no correlation between species' untransformed distributions and the conservation status assigned by the NOM (Fig. 5). While habitat loss is recognized as a critical factor for extinction risk, the NOM includes other factors, such as hunting pressure, and species' biological attributes when assigning conservation status (see www.conabio.gob.mx and www.ine.gob.mx).

Most endemic species occurring in eastern and central Mexico suffered disproportionate habitat loss compared with endemics occurring elsewhere. Historically, Veracruz and the Transvolcanic Belt have seen deforestation and urbanization increases since the 1960s, converting 70% of untransformed habitat into agrosystems and rural or urban settlements (Toledo et al., 1989; Challenger, 1998; Arriaga et al., 2001). Veracruz ranks as one of the states with the highest prevalence of agriculture in Mexico, and the Transvolcanic Belt has extensive agricultural areas besides the highest level of urbanization in the country (Toledo et al., 1989; Egbert et al., 1999; Peterson et al., 2000). Extinction risk for endemics in these regions appears higher compared with other regions in the country. Nearly 40% of Mexican endemics are restricted to these regions (Hall, 1981; Table 1). If habitat loss across landscapes is assumed to occur random, we expect more variability in the loss rates of potential habitat for species with small rather than large distributional ranges. Interestingly, most endemics restricted to these regions have small distributions (Hall, 1981), showing high variability in their proportion of untransformed distribution (Fig. 4).

Such analyses should be expanded more broadly taxonomically to identify areas of potential high broad-spectrum extinction risk, where conservation investment or habitat restoration can have a strong impact in preventing biodiversity loss. A clear result of these analyses is that a regional, rather than taxonomic or areal, focus should guide conservation assessment and planning in Mexico (Egbert et al., 1999; Peterson et al., 2000; Andelman and Willig, 2003; Sarkar et al., 2002; Sánchez-Cordero et al., 2005).

On a broader scale, our approach can be incorporated into current methodologies for assigning species' conservation status worldwide (Hilton-Taylor, 2000), providing quantitative estimates of likely range loss across the geographic distributions of individual species. Increasing efforts supported by universities and governmental agencies are leading to compilation of large databases of georeferenced species' point occurrences. These developments will facilitate conducting analyses similar to ours for a wide range of biotic groups anywhere in the world.

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