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"MODELAJE ESPACIAL DE LA PERDIDA DE HABITAT Y AREAS RICAS EN  
ESPECIES EN DURANGO Y CHIHUAHUA, MEXICO"

T E S I S

Que para obtener el grado de  
Maestro en Ciencias en Ecología Básica

Presenta

Gustavo Manuel Cruz Bello



Universidad Nacional  
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CON TODO MI AMOR PARA LORE Y GUS

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## **RESUMEN**

El manejo de ecosistemas es un concepto que integra las actividades humanas y la conservación de la diversidad biológica. Es relevante para esta última ya que ahora se reconocen las incongruencias entre los límites administrativos y los límites biológicos de las áreas naturales protegidas (ANP), lo cual provoca que éstas no ofrezcan protección suficiente para de algunas especies, especialmente depredadores terciarios y animales migratorios.

La aplicación del esquema de manejo de ecosistemas está obstaculizada en México por la carencia de áreas naturales protegidas, las altas tasas de deforestación y la resultante pérdida de hábitats, y la falta de inventarios biológicos exhaustivos. Estos están sesgados hacia los sitios accesibles y se enfocan a un número reducido de taxa, lo cual ha resultado en que áreas biológicamente importantes permanezcan parcialmente exploradas. Tales condiciones y costo implícito de realizar evaluaciones en grandes extensiones obliga al uso de modelos espaciales para extrapolar los datos existentes hacia territorios no explorados. El propósito de este trabajo es establecer los elementos necesarios para el diseño de una estrategia para

resolución de conflictos entre la conservación de la biodiversidad y la extracción de recursos forestales en la Sierra Madre Occidental. Conforme a los principios del manejo de ecosistemas, se ubicaron las áreas críticas para la conservación de la diversidad biológica, ya que son éstas en donde más probablemente ocurran conflictos entre el sector conservación y el sector forestal.

El trabajo consistió de: (1) un análisis espacial para ubicar las áreas críticas para la conservación, con base en datos provenientes de inventarios biológicos; (2) el examen de la distribución de las áreas naturales protegidas en la región, para determinar el grado de protección que dan a las zonas ricas en especies; y (3) la evaluación del riesgo de transformación de áreas críticas, a través de un análisis del cambio de la cobertura vegetal.

El método consistió en una modificación al análisis de discrepancias para adecuarlo a las circunstancias de México. En esencia, el estudio se basó en un modelaje espacial desarrollado a través de bases de datos biológicos, sistemas de información geográfica (SIG), estadística multivariada, modelos lineales generalizados (GLIM) y la evaluación cuantitativa de la dinámica del uso del suelo. Esta última se realizó mediante la comparación bitemporal de la

cobertura vegetal y la simulación del cambio del uso del suelo por medio de cadenas de Markovianas.

A partir del CASEV, se conformaron 25 ensamblajes de especies con requerimientos similares en cuanto a las variables ambientales. Se obtuvieron 17 modelos lineales para delinear las distribuciones de los ensamblajes (los 8 restantes se determinaron considerando los valores observados de las variables ambientales) y, mediante técnicas de sobreposición de mapas, se delinearón las áreas ricas en especies -esto es, en donde coincidían varios ensamblajes de especies. Se detectaron con el análisis cambio de coberturas del suelo altas tasas de deforestación, fragmentación y wazzu pérdida de habitats durante el período de 1975-1992. La simulación de cadenas Markovianas mostró una pérdida de alrededor el 50% de la cobertura de vegetación en los próximos 100 años, de continuar las tendencias actuales. Por último, el análisis espacial demostró que la representación de las zonas ricas en especies dentro de las áreas naturales protegidas es mínima. Los resultados de este estudio ofrecen una base para el diseño de una estrategia regional de conservación y manejo de recursos, dentro de los principios del manejo de ecosistemas. En este sentido, los resultados demuestran que se requiere decretar nuevas reservas naturales para proteger

la mayoría de las áreas ricas en especies de la Sierra Madre Occidental. Además, se requiere de nuevos esquemas de desarrollo forestal, los cuales permitan modificar las tendencias de deforestación actuales y que la extracción de recursos sea compatible con los requerimientos de un sistema de áreas naturales protegidas en la región. Este estudio sirve de base para tal fin, ya que se ubican las distribuciones esperadas de los ensamblajes de especies.

Por otra parte, los resultados demuestran que las restricciones de los datos biológicos pueden ser superadas con el modelaje espacial. Estos métodos permiten realizar estudios predictivos para establecer las zonas potencialmente críticas para la conservación y que deban ser consideradas en los planes de desarrollo regional. Dichas áreas ricas en especies pueden ser validadas por medio de inventarios de campo y, de este modo, ser incorporadas a esquemas de manejo integrado de recursos naturales.

Por último, es importante mencionar que el formato de este trabajo es el de un artículo científico para publicación en una revista internacional. Es por esto que se empleó en su escritura el idioma inglés y que dentro de la descripción se usa el nosotros refiriéndose al alumno y a los miembros del comité tutorial.



**SPATIAL MODELING OF HABITAT LOSS AND SPECIES-RICH AREAS IN  
DURANGO AND CHIHUAHUA, MEXICO**

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Key words: GAP Analysis, Species distribution, Deforestation,  
Generalized linear models, Gradient analysis, GIS, GRASS

## **INTRODUCTION**

Ecosystem management has matured as a meaningful concept towards the integration of human activities and biodiversity conservation (Grumbine 1994). Its basic premise is that a holistic approach is needed to curtail current species extinction rates, since the effectiveness of reserve areas increases with sensible management of the semi-natural matrix. Furthermore, the concept acknowledges that the extensions of most natural reserves are insufficient to protect some species, especially top predators and migratory animals, since their ecological requirements exceed their legal limits (Newmark 1985). Thus, it assumes that resource extraction can be carried out in accordance with theoretical and empirical breakthroughs in conservation biology (Franklin 1993, Grumbine 1994, Noss and Harris 1986).

However, implementation of the ecosystem management scheme in most countries is prevented by the lack of natural protected areas and high deforestation rates, with resulting habitat loss. Another important factor is that most areas are deprived of adequate data for regional planning and decision making. Under such conditions, a strategy for ecosystem management has to address two fundamental issues: (1) The significant areas for biodiversity have to be located and protected, and (2) the risk

of losing important habitats has to be assessed, so that priorities can be established.

In the case of Mexico, biologically important areas remain partially explored (Ramamoorthy et al. 1993), and inventories are biased to a few taxa and accessible sites (Bojórquez-Tapia et al. 1994). Furthermore, natural protected areas are insufficient in number and size, and they are not a proper representation in terms of geography and ecosystem type (Flores-Villela and Gerez 1988). Extensive forest clearing threatens most vegetation types: from 1980 to 1992, the current annual deforestation rate was about 1,200,000 ha/yr (V. Sorani, personal communication). For instance, based on direct measurements of remote sensing materials, coupled with field surveys high annual rates of deforestation (4.3%) were determined from 1967 to 1986 in the Southeast Mexico (Dirzo and García 1992).

Such conditions and the implicit cost of surveys in large regions compels the use of models to extrapolate existing information to other unexplored territories. These models are needed to make sensible decisions concerning both the design of reserve networks (Vincent and Haworth 1983, Nicholls 1989, Austin et al. 1990) and regional development planning.

The tools to examine the above mentioned issues are gap analysis and quantitative evaluations of land-use dynamics. Gap analysis is an approach for designing a regional conservation strategy. The technique depicts species-rich areas and assess the representation of such areas in the natural protected networks by means of overlaying maps of species distributions and natural reserves (Caicco et al. 1995, Edwards et al. 1996, Scott et al. 1987, 1988, 1993, Wright et al. 1994).

A modification to the original approach has been used to conform Mexico's circumstances (Bojórquez-Tapia et al. 1995). In essence, the method consists of a spatial model carried out by means of biological computer databases, geographical information systems (GIS), multivariate statistics, and generalized linear models (GLIM).

Quantitative evaluations of land-use dynamics is of the utmost importance for designing future landscapes that meet a variety of ecological objectives. Therefore, it is necessary to develop a conceptual model and a set of indicator variables for modeling the effects of human activities over ecological systems (Pickup et al. 1994). An indicator is a measurable parameter of environmental change (Munn 1975). Changes in land cover has been used as an indicator for assessing the current state of a

landscape and the risk of losing critical elements at the temporal and spatial scales required for regional planning.

Such assessments can be achieved through multitemporal comparisons of vegetation cover by means of GIS analyses and remotely sensed data (Aspinall 1993, Paine 1981, Myers and Shelton 1980, Shreier et al. 1994, Spies et al. 1994). Since probabilities of change for each vegetation type can be derived from the multitemporal comparison, landscape dynamics can be simulated by a Markov chain, which iteratively generate transition states until a steady state is attained (Acevedo et al. 1995, Runkle 1981, Usher 1981, Wissel 1992).

The objective of this paper is to present a strategic framework towards ecosystems management in Mexico. Our study area was the Sierra Madre Occidental, which is considered as prominent in the biological diversity of Mexico (Bye 1993). We modeled the distribution areas of species assemblages to depict species-rich areas, and examined the deforestation process by means of a multitemporal analysis of land cover change. Deforestation rates were obtained for five land cover classes (pine, pine-oak, oak, grassland, and tropical deciduous forest), from which a Markovian model was derived to assess the risk of losing important habitats.

Our results depicted the critical areas for conservation, and allowed us to assess their priority for conservation. They also supported the assertion that successful biodiversity conservation compels the use of a large-scale landscape strategy to merge nature reserves and sensible management of the semi-natural landscape matrix (Franklin 1993, Grumbine 1994). These results are important because conflicts among forestry and biodiversity conservation have arisen since habitats in the Sierra Madre Occidental have been reduced and fragmented as a consequence of resource extraction.

## Study Area

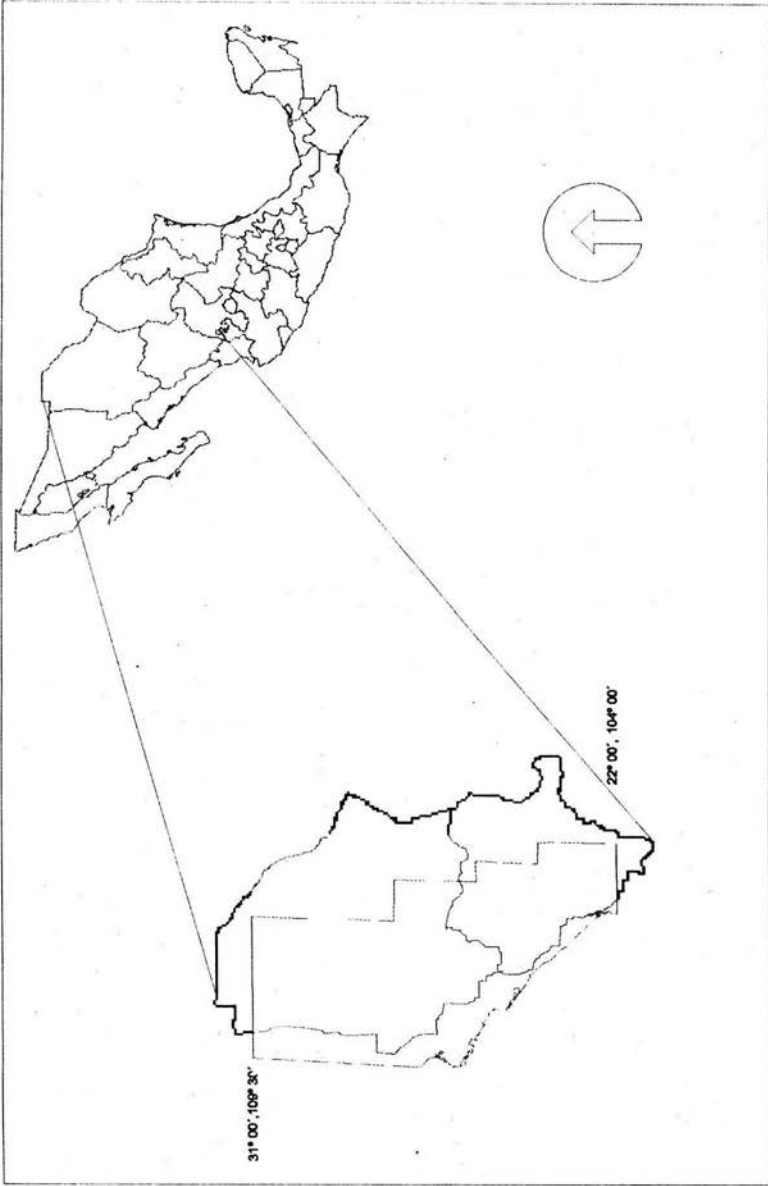
The study area is located in the Sierra Madre Occidental, in the states of Durango and Chihuahua (Fig. 1). The Sierra Madre is the largest morphotectonic province of Mexico. Because of its northwest-southeast orientation, the Sierra is both a longitudinal barrier and a latitudinal corridor for migrations (Bye 1993). Its altitude ranges between 2000 and 3,150 m a.s.l. The mean annual precipitation vary from 700 to 1,200 mm. Though rainfall is bimodal (summer and winter), most of it (60-80%) occurs from June to September. The mean annual temperature ranges between 22°C and 24 °C, in the lowlands, and from 6°C to 8 °C, in the mountains (INEGI 1982). In general, soils are poorly developed and correspond to Regosols, Lithosols, and Feozem (García y Falcón 1993).

Within our study area, the main vegetation types are the following (INEGI 1982, Rzedowski 1978):

Madrean coniferous forests. - It is located in the highest and coldest zones in the Sierra Madre, especially in northern aspects at 2,200 m a.s.l., although it can be found at higher elevations in southern aspects. The dominant species are Pseudosuga menziesii, Pinus ayacahuite, P. arizonica, P. strobiformis, P. tremuloides, Abies concolor, A. durangensis, A. acuminata.

Fig. 1. Study area





Relict and isolated populations of Picea chihuahuana, an endangered species, are located in northern aspects in restricted zones, such as Cerro Mohinora, and Cascada de Baseseachic.

Pine forests.- The pine forest distributes at elevation from 1,500 to 3,000 m a.s.l. Dominant species include Pinus reflexa, P. arizonica, P. lumbotzi, P. ayacahuite, and P. ponderosa. Microhabitats are important for the dominance of a particular species; for example, P. reflexa is dominant in the most xeric aspects, while P. ayacahuite prevails on more mesic slopes in canyons.

Pine-oak forests.- The similar ecological requirements of pines and oaks, their entangled successional relationships, and the diversity of microhabitats produce a mosaic of pines and oaks. Oak forest components often can be found above the lower limit of the pine forest, especially in xeric aspects. On disturbed sites, oaks are more abundant than pines. Common species are Quercus emoryi, Q. oblongifolia, Q. grisea, Q. santaclarensis, Q. durifolia, Q. arizonica, Q. albocincta, Q. coccolobifolia, Q. crassifolia, Q. hypoleucoides, Q. pennivenia, Q. sideroxyla, Pinus cembroides, P. emoryi, P. oocarpa, P. engelmannii, P. leiophylla, Cupressus arizonica, and Juniperus deppeana.

Oak woodlands.- Deciduous oaks dominate between 1,000 and 2,000 m a.s.l., in slopes and plateaus. The most abundant oak species are Q. chihuahuensis, Q. tuberculata, Q. sipuraca, Q. santaclarensis, and Q. fulva. Dominant understory genera are bunchy grasses, such as Bouteloa, Eragrostis, Muhlenbergia, and Schizachyrium.

Grasslands.- Grasslands locate in plateaus and valleys of moderately deep soils, between 200 and 2,000 m a.s.l. Important species are Bouteloa spp., Muhlenbergia spp., Bacharis spp., Schizachyrium spp., and Hilaria spp. In disturbed areas by fire, overgrazing, over-cutting, Aristida spp. are common.

Tropical deciduous forests.- Typical of subhumid hot climates, it extends along the lowest elevations until 29°N, due to the protection against northern winds of the Sierra Madre. Most of the individuals (75%-100%) loose their leaves after the summer rains and for long periods (6-8 months). The dominant trees lack of spines and the tallest are 15 m. The dominant species are: Lysiloma microphylla, L. watsoni, Ceiba acuminata, Bombax palmeri, Cochlospermum vitifolium, Lamiocereus spp., Caesalpinia atomaria, Tabeboua palmeri, Conzattia sericera, Bursera spp., Guazuma ulmifolia, and Ipomea arborescens. Representative understory species are: Hintonia latiflora, Schopfia parvifolia, Sebastiania pringlei, Agonandra racemosa, Wimmeria mexicana, Willardia mexicana, and Erythrina flabelliformis.

## **METHODS**

Our approach consisted of compilation of a data base, analysis of species distribution patterns, multitemporal comparisons of land cover, and simulation of deforestation trends. Compilation of the data base and analysis of distribution patterns followed the approach described in Bojórquez-Tapia et al. (1994) and Bojórquez-Tapia et al. (1995).

Individual locality records of vertebrates from the Sierra Madre were obtained from the literature and the scientific collections. Each record was georeferenced using topographic maps (scale 1:250,000; INEGI 1982) and compiled into a data base (CEUNAM 1992). The records were then transferred into the GIS to produce a presence/absence binary maps. The GIS software employed was Geographical Resources Analysis Support System, GRASS (USACERL 1993).

The following 1:1,000,000 maps (INEGI 1982) were digitized into the GIS: Soils, geology, vegetation and land-use, topography, mean annual precipitation, and mean annual temperature. A one km<sup>2</sup> cell size was used for each raster layer. Digitizing was carried out on two digitizing tables (Kurta IS/ONE and Numonics 2000) and by means of the programs AU2 (ICFA 1987) and Roots (Corson-Rickert 1990).

Following Bojórquez-Tapia et al. (1995), species distributions were depicted through correspondence analysis of species by environmental variable matrices (CASEV; Montaña and Greig-Smith 1990), and Generalized Linear Models (GLIM; Nicholls, 1989). CASEV generated a set of species assemblages, whose data on environmental variables were fitted into a GLIMs by means of a forward stepwise selection (significance level  $> 5\%$ ). The vegetation type layer was reclassified to reduce the number of categories to be considered into the CASEV, and was included into the models as a categorical variable as well as the soil layer; the other layers were not reclassified and were included as numerical variables. The best models were selected ( $r^2 > 0.25$ ;  $p < 0.001$ , for the linear term;  $p < 0.05$  for the squared term) and transferred to the GIS.

The response surface for each model was plotted and evaluated by visual examination (Ezcurra, et al. 1987). This allowed us to relate variable values and the predicted frequencies. Since the higher predicted frequencies never coincide for a single taxon, three scenarios of variable values ranges were analyzed: 100%, 80% and 50% of the maximum predicted frequencies. Thus, wider overlapping of species distributions were depicted. The corresponding variable values were transferred to the GIS to delineate the distributions of the species assemblages.

A multitemporal analysis of land cover was achieved by comparing the official vegetation and land-use map (INEGI 1982) and the National Forest Inventory of 1994 (NFI). However, the considered time laps was of 17 years because the baseline data for the INEGI's vegetation and land-use map were aerial photographs of 1975, while the NFI resulted from the interpretation of LANDSAT TM of 1992.

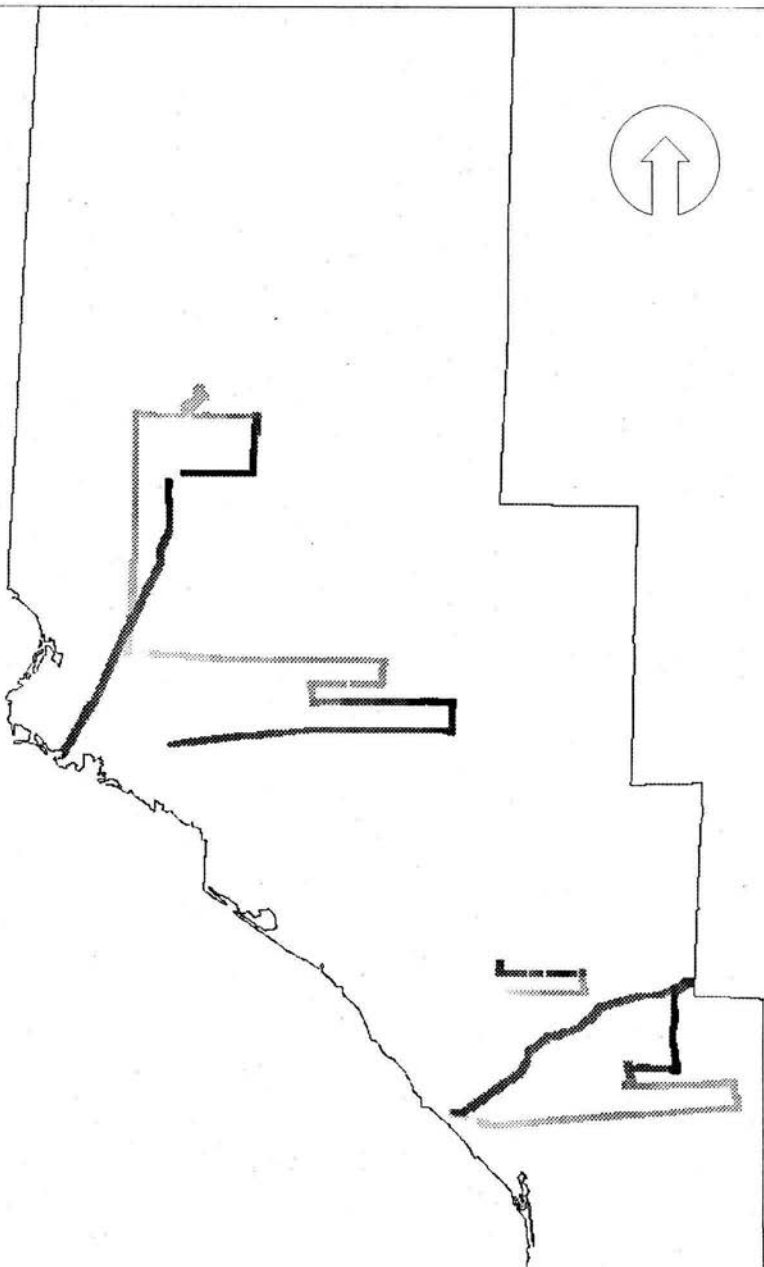
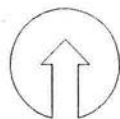
The results of the NFI were verified by means of a vertical aerial videography (Graham 1993, Slaymaker et al. in press). We flew four transects over altitudinal gradients (Fig. 2), for a total 2,000 km. The satellite image was reclassified to correspond INEGI; the categories were the following: Agriculture, grasslands, pine forests, pine-oak forests, oak woodlands, pinion-juniper forests, tropical semideciduous forests, tropical deciduous forests, mezquital, chaparral, scrub, desert scrub, halophyte vegetation, dunes vegetation, mangrove and savanna.

Deforestation rates and probabilities of change were estimated for those vegetation types that were included in the GLIMs. Deforestation process for each vegetation type was modeled (simulation time = 200 yr) through Markov chains (Acevedo 1995, Runkle 1981, Usher 1981, Wissel 1992). Also, the deforestation rates of different vegetation types were compared by means of the Barlett's test (Zar 1984).

Fig. 2. Videography fly routes

106° 30'  
31° 00'

106° 00'  
31° 00'



106° 30'  
29° 00'

106° 00'  
29° 00'



Finally, the species assemblages distribution maps were overlaid to the INEGI and NFI layers. Species-rich areas were ranked according to the number of species assemblages that coincide in the same tract of land. The individual patches of high ranking species-rich zones were measured, and the total extent of species-rich areas were compared to the size of the natural reserves in the region.

## RESULTS

The overlay operation of the seven environmental variables and the species localities records resulted in one matrix for each taxon. The total number of records by taxon was the following: Amphibians, 79; reptiles, 248; birds, 450; and mammals, 909. The following contingency tables were prepared (species x categories of environmental variables): Amphibians (10 x 36), reptiles (38 x 37), birds (292 x 34) and mammals (69x 46).

The two first axes of the CASEV explained percentages of variance that varied from low to moderate (Table 1). Nonetheless, the visual inspections of the ordination charts allowed us to separate 25 distinct groups or species assemblages (Figures 3-6, Table 2). The variables that explained the highest variance differed between orders: Amphibians, temperature, topography, and soils; reptiles, temperature, vegetation, and soils; birds, temperature, topography, soils, and vegetation; mammals, geology, soils, and vegetation. We decided to eliminate topography from further analysis because it was highly correlate with temperature ( $r^2 = -0.8$ ). Likewise, geology was also eliminated since it was significant for mammals only. And precipitation was included because its regional importance (Bojorquez-Tapia 1995).

Table 1. Explained variance of the first and second axes of the Correspondence Analysis.

<b>Orders</b>	<b>Axis 1</b> (%)	<b>Axis 2</b> (%)	<b>Axis 1+2</b> (%)	<b>Matrix</b>
Amphibians	37	22	59	10x29
Reptiles	30	19	49	38x33
Birds	26	16	42	292x26
Mammals	16	14	30	69x33

Fig. 3. CASEV analysis of 10 species of amphibians of Durango and Chihuahua, Mexico

Fig. 4. CASEV analysis of 292 species of birds of Durango and Chihuahua, Mexico

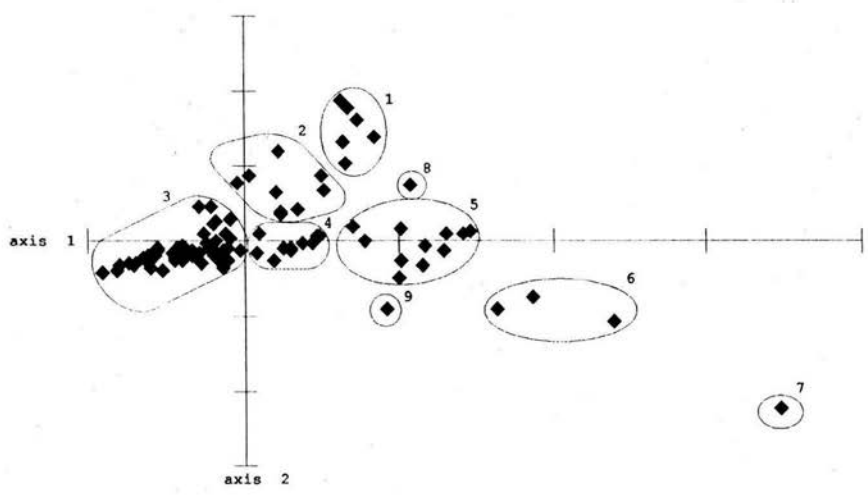
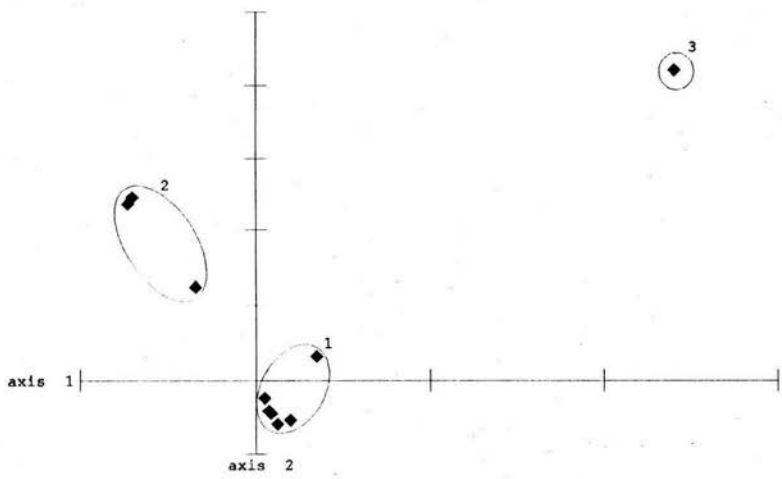


Fig. 5. CASEV analysis of 69 species of mammals of Durango and Chihuahua, Mexico

Fig. 6. CASEV analysis of 38 species of reptiles of Durango and Chihuahua, Mexico

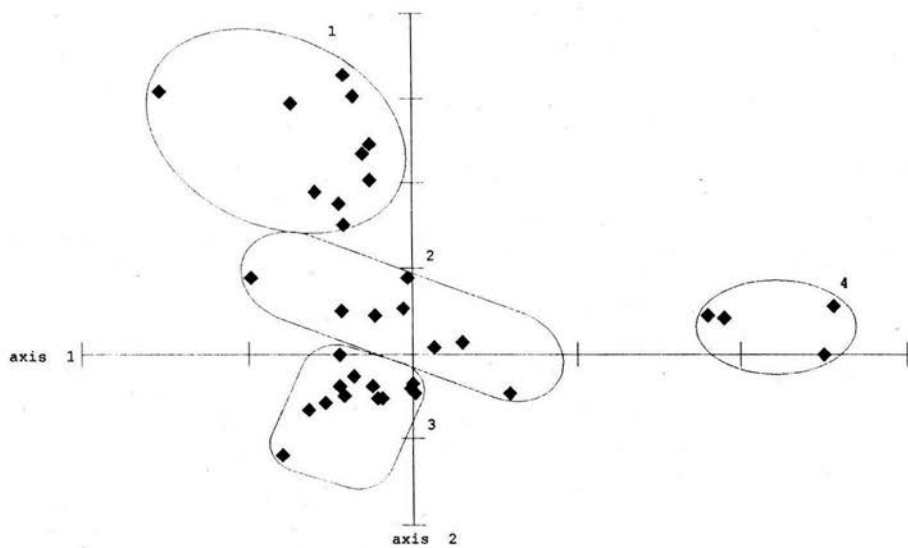
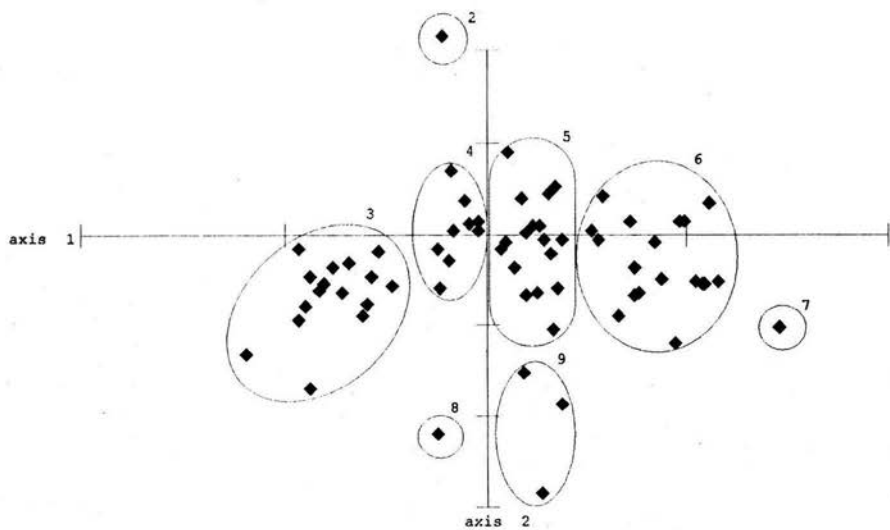


Table 2. Description of assemblages generated by CASEV for terrestrial vertebrates distributed in Chihuahua and Durango, Mexico.

Assemblage	Temperature (°C)	Precipitation (mm)	Soil type	Vegetation type
Amphibians				
1	11-19	550-1300	2, 7, 11	2, 3, 4, 5
2	19-25	450-1300	2, 7, 14	4, 5, 11
3	23	550	7	8
Reptiles				
1	15-21	650-1300	7,	4, 5, 8
2	11-19	350-1300	2, 6, 7	2, 3, 4
3	11-19	650-1300	2, 7, 11	2, 3, 4
4	15-19	250-900	6, 7, 11	2, 4
Birds				
1	11-13	900-1300	2	2, 3
2	11-19	450-1300	2, 6, 7	2, 4
3	15-17	450-1300	6, 7, 9, 11	2, 4, 5
4	13-19	450-1300	6, 7	2, 3, 5
5	9-23	650-1100	6, 7	3, 5
6	13-23	750-900	6, 7, 11	3, 8
7	21	750	11	8
8	11-13	750-1300	2, 6	3
9	17-21	450-1300	6, 11	2, 4, 8
Mammals				
1	11-17	450-650	6, 13	4, 10
2	11-17	450-900	6, 7, 11	3, 4, 5
3	11-21	650-1300	2, 7, 11	3, 4, 5
4	11-23	450-1300	2, 6, 7, 9, 11	2, 3, 4, 5
5	11-19	350-1300	2, 6, 7, 9,	2, 3, 4, 5
6	11-19	250-650	6, 7, 9, 11, 16	2, 4, 5, 11
7	17-19	350-450	6, 16	2, 11
8	13-23	650-1100	2, 6, 7,	3, 5, 8
9	15-23	450-1100	2, 7,	5, 8

SOIL TYPE: (2=Cambisol; 6=Phaeozem; 7=Lithosol; 9=Kastanozem; 11=Regosol; 13=Ranker; 14=Vertisol; 16=Xerosol)

VEGETATION TYPE: (2=Grassland; 3=Pine forest; 4=Pine-oak forest; 5=Oak forest; 8=Tropical deciduous forest; 10=Chaparral; 11=Scrub)



Thus, two continuous variables (temperature and precipitation) and two categorical variables (soils and vegetation) were used in GLIM. Significant fits were obtained for eight out of the 25 original species assemblages. The variable soils was eliminated because its low contribution to change in variance to the models.

GLIM analyses were repeated using temperature, precipitation and vegetation as independent variables, so possible variable combinations were reduced from 2,105 to 499. Then, significant models obtained for 17 species assemblages, for which the importance of equations' terms (represented by their positions in the equation) and goodness of fit varied (Table 3).

Response surfaces presented similar patterns for some species assemblages (Figs. 7-9). A species assemblage of amphibians (1) distributed along similar variable combinations as two species assemblages of reptiles (2 and 3), and three species assemblages of mammals (2, 3 and 4). Similarly, one species assemblages of reptiles (4) coincided with one species assemblages of birds (3), and two of mammals (6 and 7).

The outcome of both CASEV and GLIM proved that most of the land cover categories originally considered were not good indicators for the distributions of the species included in the study.

Table 3. Generalized linear models of the distribution of terrestrial vertebrates from Durango-Chihuahua, Mexico.

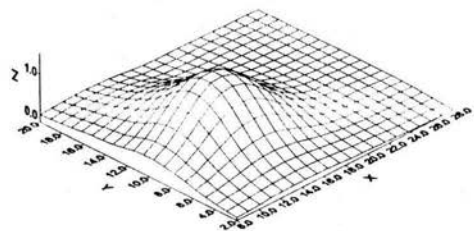
Assemblage	Model	$r^2*$
	Amphibians	
1	$y = e^{(a+v(i)+bt^2+cp^2)}$	0.38
	Reptiles	
1	$y = e^{(a+v(i)+bt^2+cp^2)}$	0.31
2	$y = e^{(a+v(i)+bt^2+cp^2)}$	0.28
3	$y = e^{(a+v(i)+bt^2+cp^2+dpt)}$	0.48
4	$y = e^{(a+bt^2+v(i)+ct^2+dp^2)}$	0.75
	Birds	
1	$y = e^{(a+bt^2+v(i)+cp^2)}$	0.72
3	$y = e^{(a+bt^2+v(i)+cp^2)}$	0.43
4	$y = e^{(a+v(i)+bt^2)}$	0.29
6	$y = e^{(a+v(i)+bp^2)}$	0.60
7	$y = e^{(a+v(i)+bt^2+cp^2)}$	0.99
	Mammals	
1	$y = e^{(a+bp^2+ct^2)}$	0.30
2	$y = e^{(a+bt^2+cp^2+dt^2)}$	0.26
3	$y = e^{(a+v(i)+bt^2+cp^2)}$	0.44
4	$y = e^{(a+bt^2+v(i)+cp^2)}$	0.30
5	$y = e^{(a+bt^2+v(i)+cp^2)}$	0.30
6	$y = e^{(a+bt^2+cp^2+v(i))}$	0.42
7	$y = e^{(a+bp^2+ct^2)}$	0.50

Where  $y$  is the predicted frequency of number of species,  $t$  is mean annual temperature,  $p$  is mean annual precipitation and  $v$  is vegetation.

\*  $r^2 = (\text{total deviance} - \text{residual deviance}) / (\text{total deviance})$  .

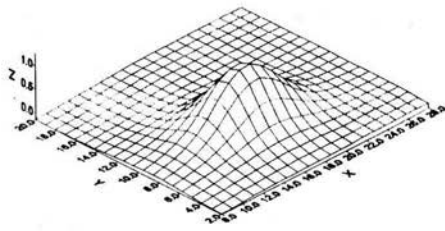
Fig. 7. Responce surfaces for amphibian and reptil assemblages of Durango and Chihuahua, Mexico. X=mean annual temperature ( $^{\circ}$ C); y=mean annual precipitation (mm/100); z=frequency

## AMPHIBIANS

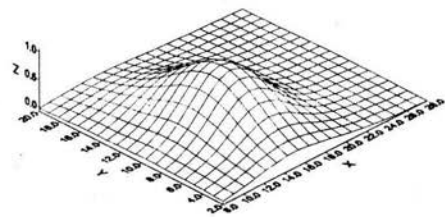


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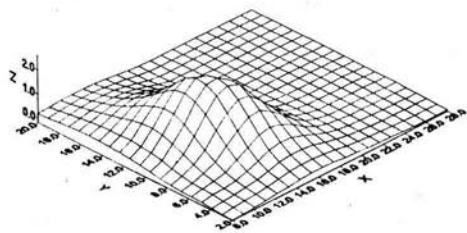
## REPTILES



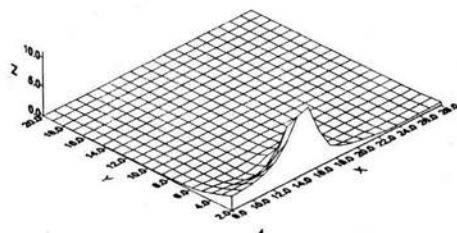
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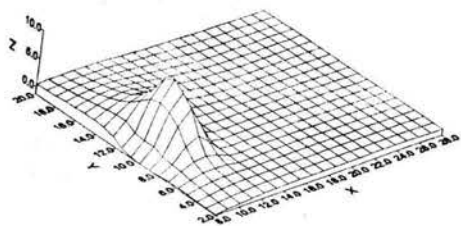
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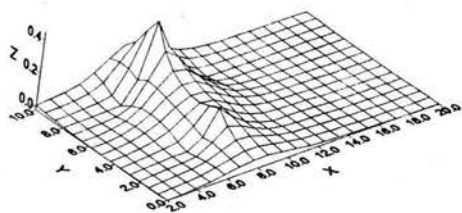
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Fig. 8. Responce surfaces for bird assemblages of Durango and Chihuahua, Mexico. X=mean annual temperature ( $^{\circ}$ C); y=mean annual precipitation(mm/100); z=frequency. For assemblage 4 x=mean annual temperature; y=vegetation types; z=frequency. For assemblage 6 x=mean annual precipitation; y=vegetation types; z=frequency  
Vegetation types: 1 agriculture, 2 grassland, 3 pine forest, 4 pine-oak forest, 5 oak forest, 6 Coniferous forest, 7 Tropical semideciduous forest, 8 Tropical deciduous forest, 9 Mezquital and 10 Chaparral

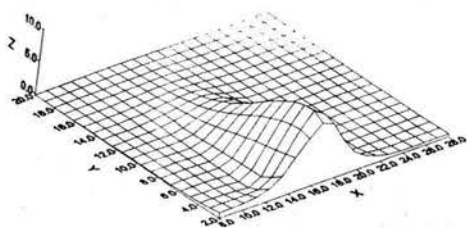
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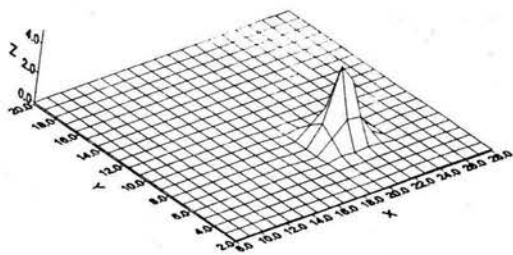
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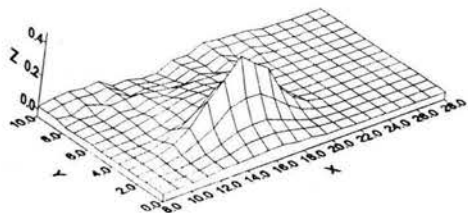
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3



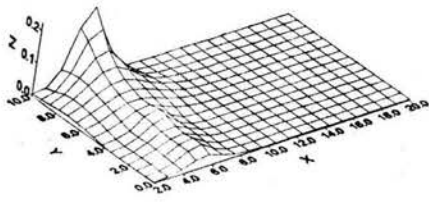
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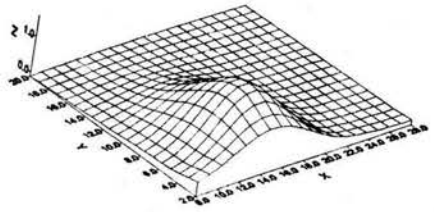
4

Fig. 9. Response surfaces for mammal assemblages of Durango and Chihuahua, Mexico. X=mean annual temperature ( $^{\circ}$ C); y=mean annual precipitation (mm/100); z=frequency. For assemblage 1 x=mean annual precipitation; y=vegetation types; z=frequency. Vegetation types: 1 agriculture, 2 grassland, 3 pine forest, 4 pine-oak forest, 5 oak forest, 6 Coniferous forest, 7 Tropical semideciduous forest, 8 Tropical deciduous forest, 9 Mezquital and 10 Chaparral.

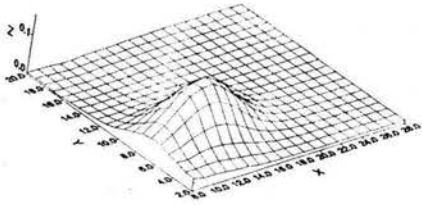
# MAMMALS



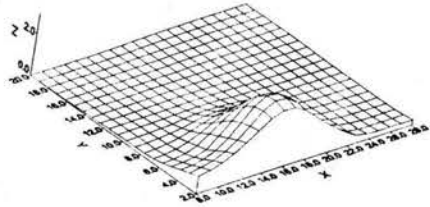
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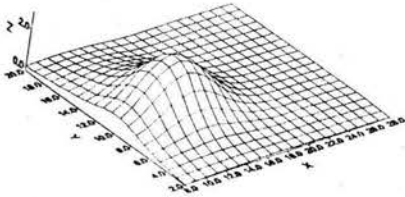
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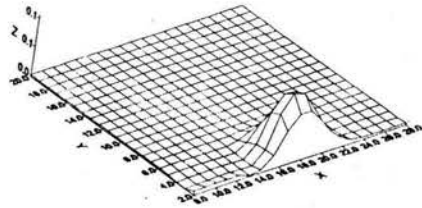
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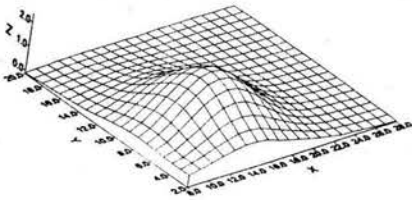
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3



7



4



Consequently, we limited the cover classes used in the examination of land cover change to pine forest, pine-oak forests, oak woodlands, and tropical deciduous forests, grasslands, agriculture, and disturbed cover.

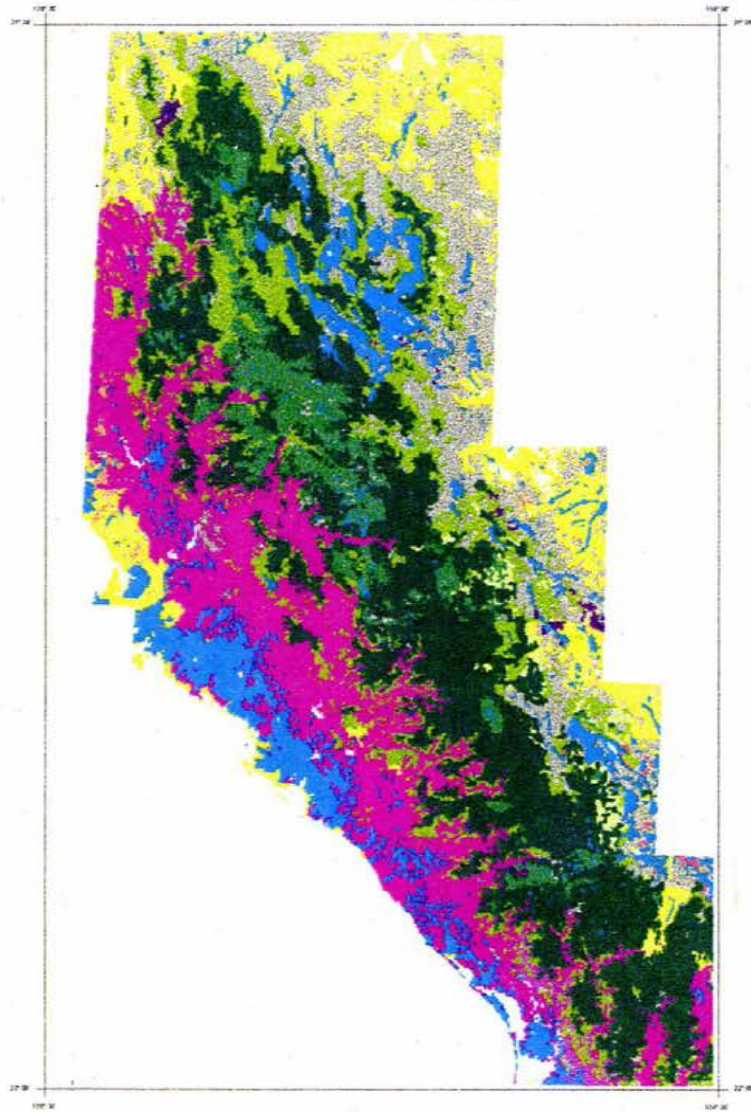
Land-use dynamics in the Sierra Madre Occidental showed extensive habitat loss, indicated by the transformation of the natural cover (Fig. 10). In the 17 years between INEGI and NFI, most of the cover change was from the original vegetation types to perturbed forests (33,368 km<sup>2</sup>), followed by conversions to agriculture (11,229 km<sup>2</sup>), and to vegetation types not included in our models. Likewise, Markov chains showed that, if prevalent trends continue, the habitats would be reduced to about one half of their current extension in 100 yr (Fig. 11). The deforestation rates were not significantly different between vegetation types (Bartlett's test  $F=0.043$ ,  $df=4,77$ ,  $p < 0.001$ ).

Habitat loss was similar for the three predicted frequencies scenarios (100%, 80%, and 50%), and equivalent to about one quarter of the initial vegetation cover (Table 4). For the majority of assemblages this loss was to perturbed areas, followed by agriculture, and other types of vegetation (Table 5).

Fig. 10. Vegetation change in Durango and Chihuahua,  
Mexico (1975-1992).



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E ECOLOGIA

-  Agriculture
-  Grassland
-  Pine
-  Pine-oak
-  Oak
-  Coniferous forest
-  Tropical semideciduous forest
-  Tropical deciduous forest
-  Mezquital
-  Chaparral
-  Scrub
-  Desert scrub
-  Halophyte vegetation
-  Dunes vegetation
-  Mangrove
-  Savanna

Change to:

-  Agriculture
-  Fragmented forest  
and perturbed zones
-  Other

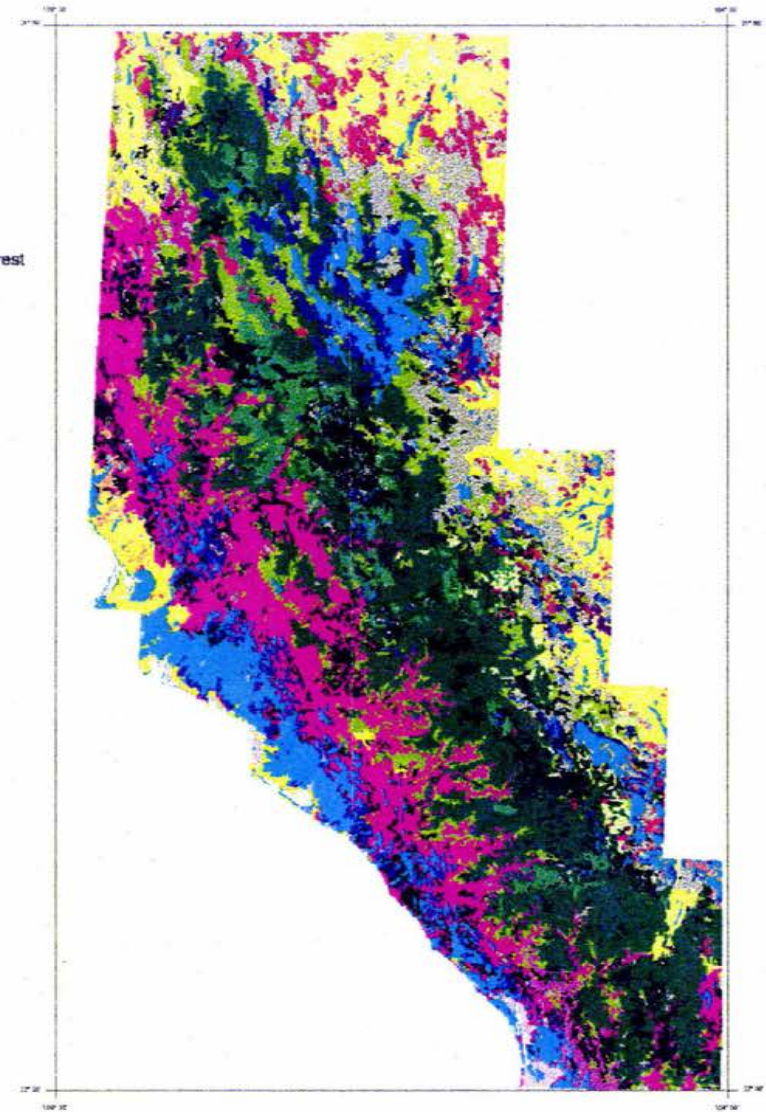


Fig. 11. Predicted deforestation in Durango and Chihuahua,  
Mexico through the use of Markov chains.

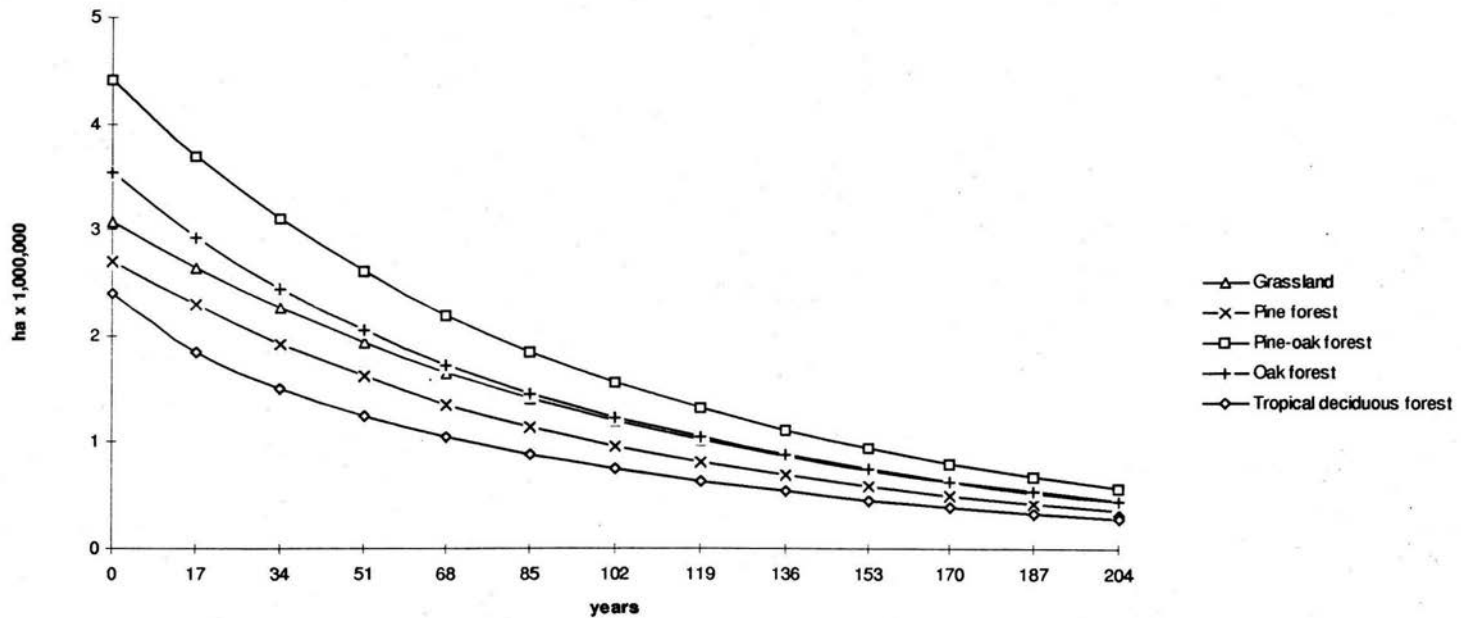


Table 4. Predicted vertebrate assemblages area in Durango and Chihuahua, Mexico.

Assemblage	Predicted frequency percentage											
	100 (%)				80 (%)				50 (%)			
	INEGI	NFI	LOSS	K	INEGI	NFI	LOSS	K	INEGI	NFI	LOSS	K
	<b>Amphibians</b>											
	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	ln(ha)/year	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	ln(ha)/year	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	ln(ha)/year
1	2,123	1,969	154	0.00	10,861	8,833	2,028	-0.01	40,936	33,637	7,299	-0.01
2	1,533	1,297	236	-0.01	1,533	1,297	236	-0.01	1,533	1,297	236	-0.01
3	1,951	1,442	509	-0.02	1,951	1,442	509	-0.02	1,951	1,442	509	-0.02
Total	5,607	4,708	899		14,345	11,572	2,773		44,420	36,376	8,044	
	<b>Birds</b>											
1	55	30	25	-0.04	120	85	35	-0.02	452	379	73	-0.01
2	65	55	10	-0.01	65	55	10	-0.01	65	55	10	-0.01
3	6,768	3,107	3,661	-0.05	24,563	15,245	9,318	-0.03	41,114	28,200	12,914	-0.02
4	2,521	2,115	406	-0.01	3,570	3,040	530	-0.01	7,252	5,751	1,501	-0.01
5	1,232	826	406	-0.02	1,232	826	406	-0.02	1,232	826	406	-0.02
6	11,062	8,850	2,212	-0.01	11,062	8,850	2,212	-0.01	17,788	13,145	4,643	-0.02
7	1,777	1,593	184	-0.01	1,777	1,593	184	-0.01	1,777	1,593	184	-0.01
8	1,371	960	411	-0.02	1,371	960	411	-0.02	1,371	960	411	-0.02
9	4,817	3,876	941	-0.01	4,817	3,876	941	-0.01	4,817	3,876	941	-0.01
Total	29,668	21,412	8,256		48,578	34,530	14,048		75,868	54,785	21,083	
	<b>Mammals</b>											
1	1,145	1,143	2	0.00	1,145	1,143	2	0.00	905	905	0	0.00
2	4,958	3,666	1,292	-0.02	30,118	22,436	7,682	-0.02	71,413	54,869	16,544	-0.02
3	2,209	1,790	419	-0.01	9,814	7,792	2,022	-0.01	30,796	24,492	6,304	-0.01
4	3,244	2,554	690	-0.01	26,344	20,158	6,186	-0.02	67,504	52,166	15,338	-0.02
5	2,354	1,521	833	-0.03	18,656	13,568	5,088	-0.02	81,665	60,647	21,018	-0.02
6	4,821	3,640	1,181	-0.02	32,978	21,189	11,789	-0.03	39,971	25,978	13,993	-0.03
7	7,593	5,766	1,827	-0.02	32,669	26,888	5,781	-0.01	60,461	50,413	10,048	-0.01
8	4,817	3,876	941	-0.01	4,817	3,876	941	-0.01	4,817	3,876	941	-0.01
9	2,856	2,365	491	-0.01	2,856	2,365	491	-0.01	2,856	2,365	491	-0.01
Total	33,997	26,321	7,676		159,397	119,415	39,982		360,388	275,711	84,677	
	<b>Reptiles</b>											
1	767	625	142	-0.01	767	625	142	-0.01	5,626	5,141	485	-0.01
2	2,913	2,514	399	-0.01	13,065	11,163	1,902	-0.01	40,685	32,676	8,009	-0.01
3	2,209	1,790	419	-0.01	15,414	12,475	2,939	-0.01	36,835	29,631	7,204	-0.01
4	966	685	281	-0.02	966	685	281	-0.02	5,787	4,325	1,462	-0.02
Total	6,855	5,614	1,241		30,212	24,948	5,264		88,933	71,773	17,160	

$K = \ln(x_2) - \ln(x_1) / t_2 - t_1$

Table 5. Habitat change from 1975 (INEGI) to 1992 (NFI),  
in Durango and Chihuahua, Mexico.

	<b>Assemblage</b>			<b>Predicted frequency percentage</b>					
	100(%)			80(%)			50(%)		
	Agriculture	Perturbed	Other	Agriculture	Perturbed	Other	Agriculture	Perturbed	Other
	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )
				<b>Amphibians</b>					
1	6	148	0	64	1,948	16	358	6,657	284
2	4	232	0	4	232	0	4	232	0
3	35	474	0	35	474	0	35	474	0
Total	45	854	0	103	2,654	2,757	397	7,363	7,760
				<b>Birds</b>					
1	9	16	0	9	26	0	36	37	0
2	0	10	0	0	10	0	0	10	0
3	62	0	3,599	1,525	1,053	6,740	2,285	1,958	8,671
4	25	381	0	25	505	0	47	1,454	0
5	5	401	0	5	401	0	5	401	0
6	874	1,338	0	874	1,338	0	959	3,684	0
7	10	174	0	10	174	0	10	174	0
8	5	406	0	5	406	0	5	406	0
9	192	749	0	192	749	0	192	749	0
Total	1,182	3,475	3,599	2,636	4,626	7,262	1,166	5,013	6,179
				<b>Mammals</b>					
1	2	0	0	2	0	0	0	0	0
2	52	1,213	27	835	6,501	346	3,235	12,532	777
3	24	394	1	66	1,941	15	253	5,956	95
4	51	604	35	546	5,173	467	2,152	12,360	826
5	53	633	147	997	3,166	925	3,946	10,918	6,154
6	168	6	1,007	2,011	1,272	8,506	2,831	2,143	9,019
7	190	5	1,632	282	5	5,494	1,506	1,239	7,303
8	192	749	0	192	749	0	192	749	0
9	187	304	0	187	304	0	187	304	0
Total	919	3,908	2,849	5,116	19,111	24,227	14,302	46,201	60,503
				<b>Reptiles</b>					
1	142	0	0	142	0	0	2	483	0
2	14	384	1	71	1,795	36	375	7,185	449
3	24	394	1	130	2,758	51	243	6,859	102
4	281	0	0	281	0	0	168	6	1,288
Total	461	778	2	482	4,553	87	788	14,533	1,839

However for assemblages birds 1 and mammals 6 and 7 the principal change was to other vegetation's types. Taking into account the habitat loss by order, the highest proportion corresponded to reptiles, and birds (27%), followed by mammals (22%), and amphibians (16%).

Considering all of the species assemblages and the three scenarios, the highest cover transformation rates were obtained for birds and mammals. Similarly, the highest cover change rates were obtained for the first scenario (100% predicted frequencies), particularly for birds (species assemblages 1, and 3), and mammals (species assemblage 5). In general, deforestation rates were alike for all the species assemblages in the three scenarios; although tended to decrease for the three above mentioned cases.

Representation of the species assemblages in the natural protected areas was minimal (Table 6a-b). Nonetheless, the scenario for 50% of the predicted frequencies showed that Cascada de Bassaseachic National Park included five species-rich areas (of one, two, four, five, and seven overlaying species assemblages, respectively), La Michilía Biosphere Reserve contained three species-rich areas (of two, three, and six overlaying species assemblages), and Cumbres de Majalca National Park encompassed one species-rich area (of two overlaying species



Table 6a. Area percentage under protection for each assemblage using INEGI vegetation.

Assemblage	Predicted frequency percentage								
	100%		80%			50%			
	National Park (ha)	Total Protected (%)	National Park (ha)	Biosphere Reserve (ha)	Total Protected (%)	National Park (ha)	Biosphere Reserve (ha)	Total Protected (%)	
	<b>Amphibians</b>								
1	0	0.00	1,085	0	0.10	1,579	6,771	0.20	
2	0	0.00	*	*	*	*	*	*	
3	0	0.00	*	*	*	*	*	*	
	<b>Birds</b>								
1	0	0.00	0	0	0.00	0	0	0.00	
2	0	0.00	*	*	*	*	*	*	
3	0	0.00	0	0	0.00	0	718	0.02	
4	99	0.04	99	0	0.03	400	0	0.06	
5	0	0.00	*	*	*	*	*	*	
6	2,468	0.22	*	*	*	2,500	0	0.14	
7	0	0.00	*	*	*	*	*	*	
8	0	0.00	*	*	*	*	*	*	
9	0	0.00	*	*	*	*	*	*	
	<b>Mammals</b>								
1	0	0.00	*	*	*	0	0	0.00	
2	0	0.00	0	0	0.00	4,900	6,600	0.16	
3	0	0.00	1,184	0	0.12	2,100	0	0.07	
4	0	0.00	1,085	6,771	0.30	3,500	17,300	0.31	
5	0	0.00	0	6,771	0.37	1,200	18,000	0.23	
6	0	0.00	0	0	0.00	0	0	0.00	
7	0	0.00	0	0	0.00	0	0	0.00	
8	0	0.00	*	*	*	*	*	*	
9	0	0.00	*	*	*	*	*	*	
	<b>Reptiles</b>								
1	494	0.64	*	*	*	3,300	0	0.60	
2	197	0.07	296	0	0.02	1,200	17,300	0.45	
3	0	0.00	1,184	0	0.08	1,600	6,600	0.22	
4	0	0.00	*	*	*	*	*	*	

\*=Not aplicable

Table 6b. Area percentage under protection for each assemblage using NFI vegetation.

Assemblage	Predicted frequency percentage								
	100%		80%			50%			
	National Park (ha)	Total Protected (%)	National Park (ha)	Biosphere Reserve (ha)	Total Protected (%)	National Park (ha)	Biosphere Reserve (ha)	Total Protected (%)	
<b>Amphibians</b>									
1	0	0.00	800	0	0.09	1,200	4,800	0.18	
2	0	0.00	*	*	*	*	*	*	
3	0	0.00	*	*	*	*	*	*	
<b>Birds</b>									
1	0	0.00	0	0	0.00	0	0	0.00	
2	0	0.00	*	*	*	*	*	*	
3	0	0.00	0	0	0.00	0	600	0.02	
4	99	0.04	99	0	0.03	0	0	0.00	
5	0	0.00	*	*	*	*	*	*	
6	2,500	0.28	*	*	*	0	0	0.00	
7	0	0.00	*	*	*	*	*	*	
8	0	0.00	*	*	*	*	*	*	
9	0	0.00	*	*	*	*	*	*	
<b>Mammals</b>									
1	0	0.00	*	*	*	0	0	0.00	
2	0	0.00	0	0	0.00	3,900	4,800	0.16	
3	0	0.00	900	0	0.11	1,700	0	0.07	
4	0	0.00	800	4,800	0.28	3,100	130,000	0.31	
5	0	0.00	0	4,800	0.35	900	136,000	0.23	
6	0	0.00	0	0	0.00	0	0	0.00	
7	0	0.00	0	0	0.00	0	0	0.00	
8	0	0.00	*	*	*	*	*	*	
9	0	0.00	*	*	*	*	*	*	
<b>Reptiles</b>									
1	500	0.80	*	*	*	2,900	0	0.56	
2	200	0.08	296	0	0.02	900	130,000	0.43	
3	0	0.00	900	0	0.72	1,300	4,800	0.20	
4	0	0.00	*	*	*	0	0	0.00	

\*=Not aplicable

assemblages). With respect to landscape dynamics, the vegetation cover has changed from natural vegetation to perturbed forest in a significant extension for both Cascada de Bassaseachic (17% out of 5,900 ha, SARH 1992), and La Michilía (10% out of 35,000 ha, SARH 1992). We did not detect any cover change for Cumbres de Majalca.

Maps of predicted distributions showed a consistent pattern: species-rich areas tended to be located at the highest elevations (Figs. 12-17). This result was congruent with the emphasis of the data on species distributed in forest lands. Considerable habitat fragmentation was detected for all of the species-rich areas and the three scenarios (Table 7). The trends were that the number of patches increased, both the average patch size and the standard deviation increased, the size of the largest patches diminished, and the size of the smallest areas persisted. The loss of species distribution areas with different number of species distribution overlays, depends upon the scenario considered. The loss for the areas with one assemblage varied between 10% to 16%, from 14% to 61% for areas with two assemblages, from 18% to 70% with three assemblages, from 20% to 30% with four assemblages, and from 20% to 33% for areas with five assemblages considering the three scenarios (Table 8). The loss was of about 20% for areas with 6, 7 and 10 assemblages only for the 50% predicted frequency scenario.

Fig. 12. Predicted assemblages distribution in Durango and Chihuahua. 100% of predicted frequency and INEGI vegetation.

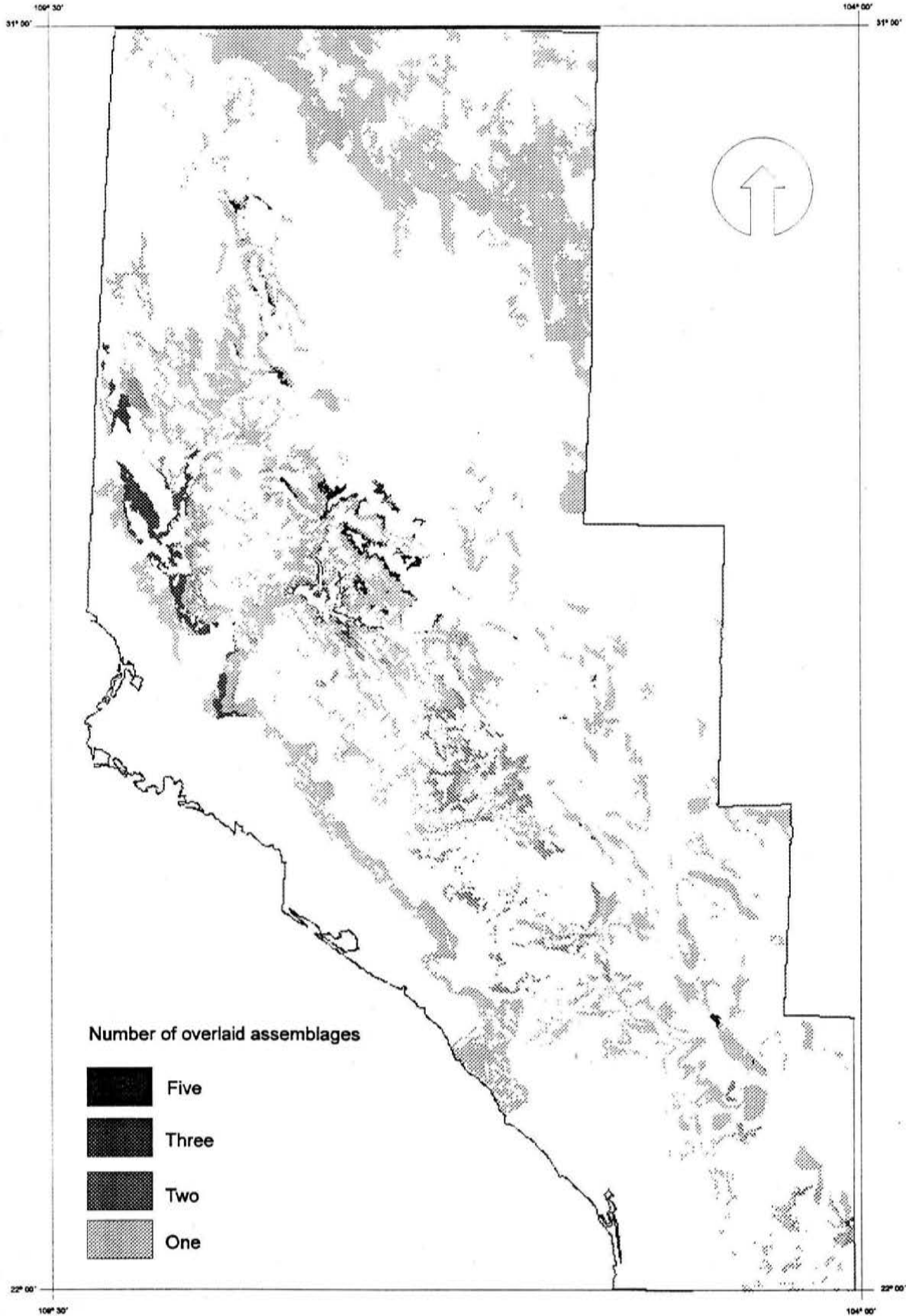


Fig. 13. Predicted assemblages distribution in Durango and Chihuahua. 80% of predicted frequency and INEGI vegetation.

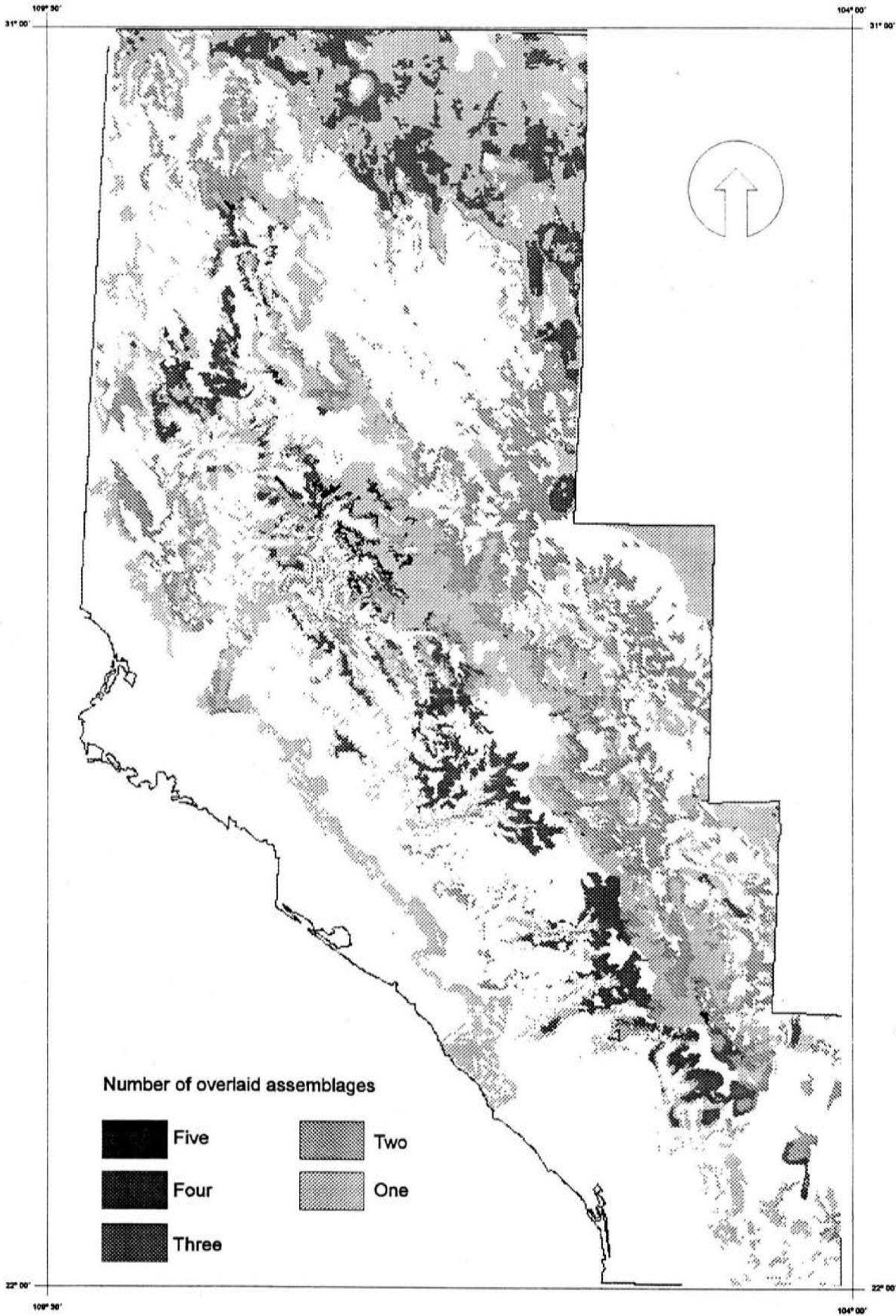


Fig. 14. Predicted assemblages distribution in Durango and Chihuahua. 50% of predicted frequency and INEGI vegetation.



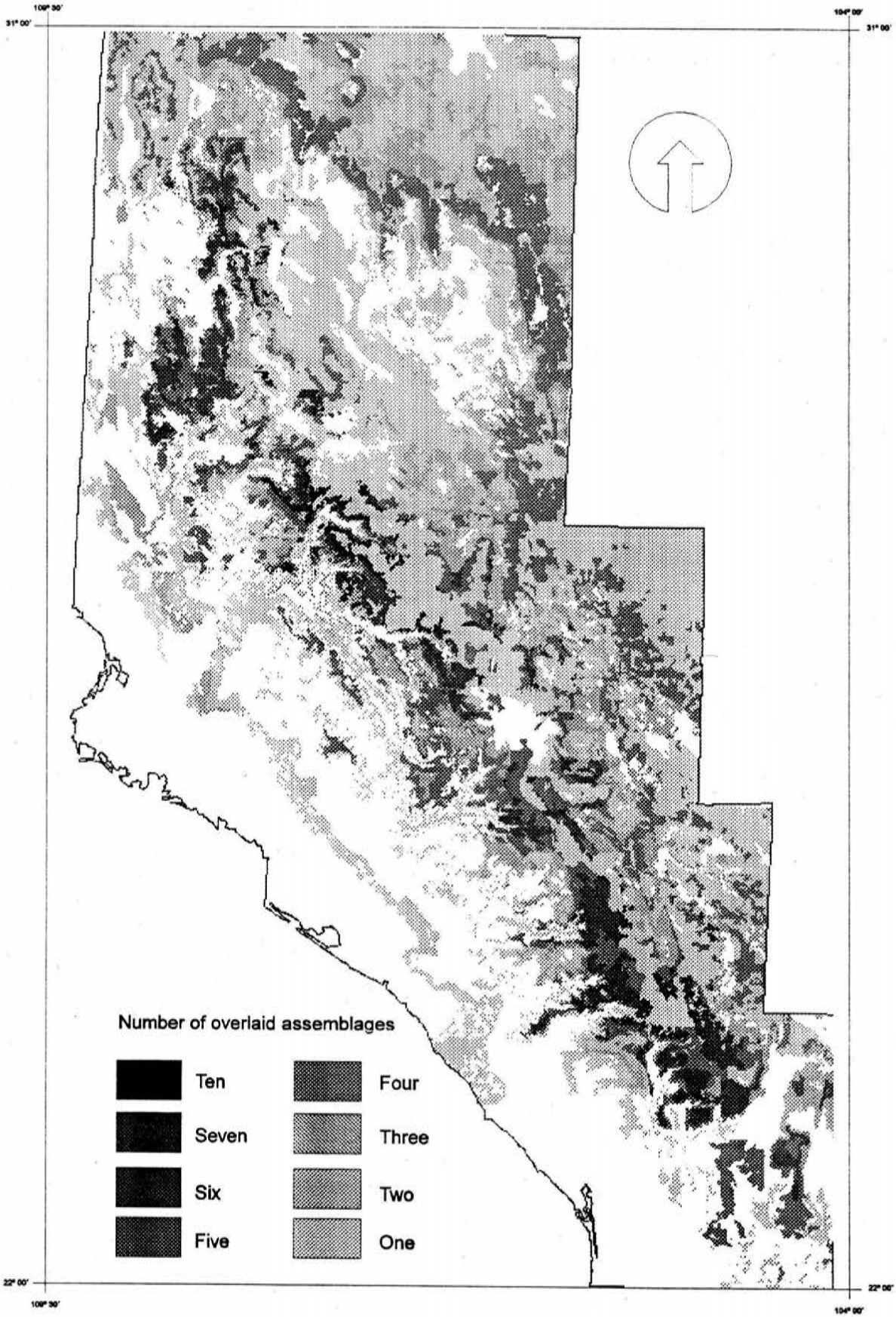


Fig. 15. Predicted assemblages distribution in Durango and Chihuahua. 100% of predicted frequency and NFI vegetation.

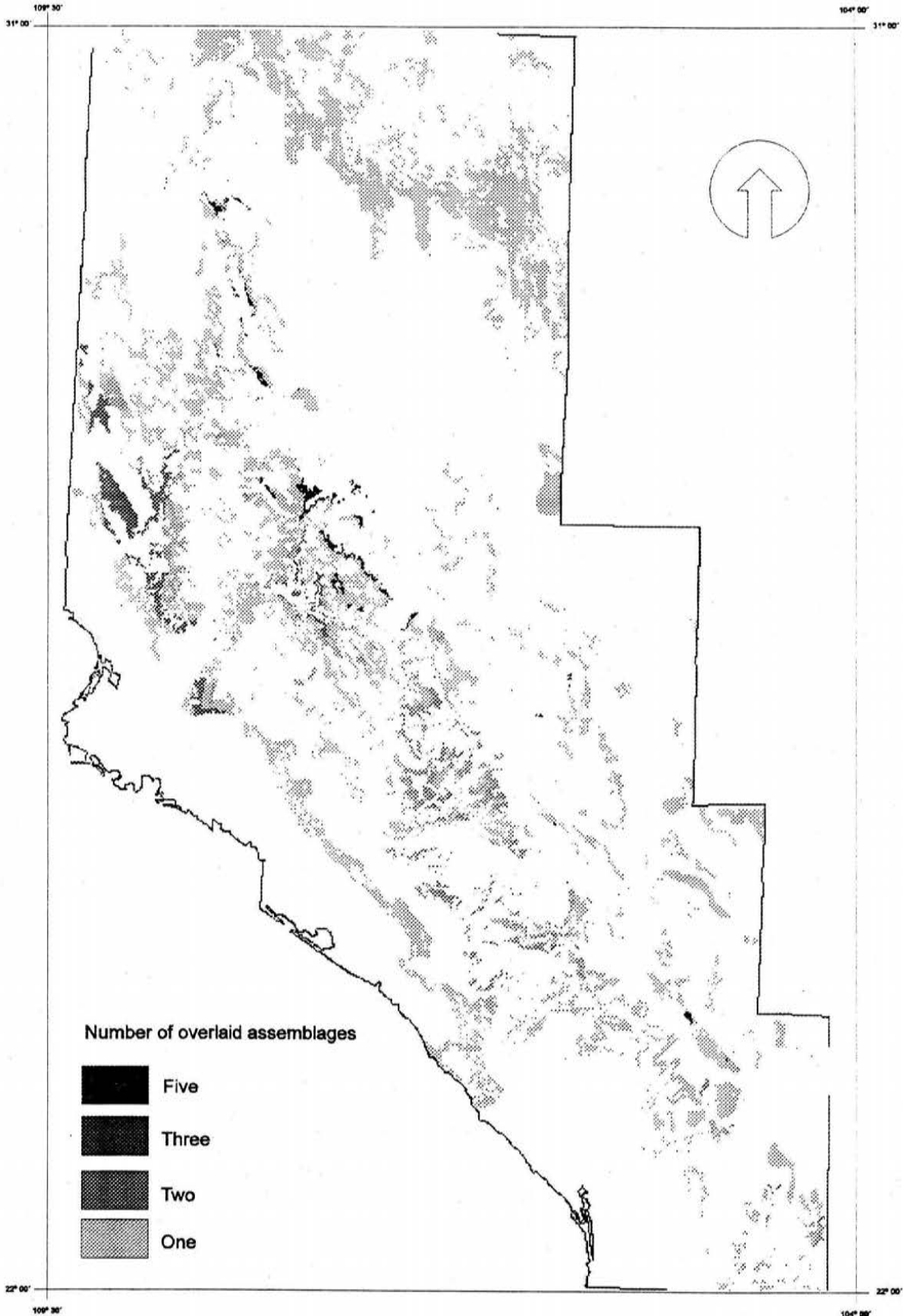


Fig. 16. Predicted assemblages distribution in Durango and Chihuahua. 80% of predicted frequency and NFI vegetation.

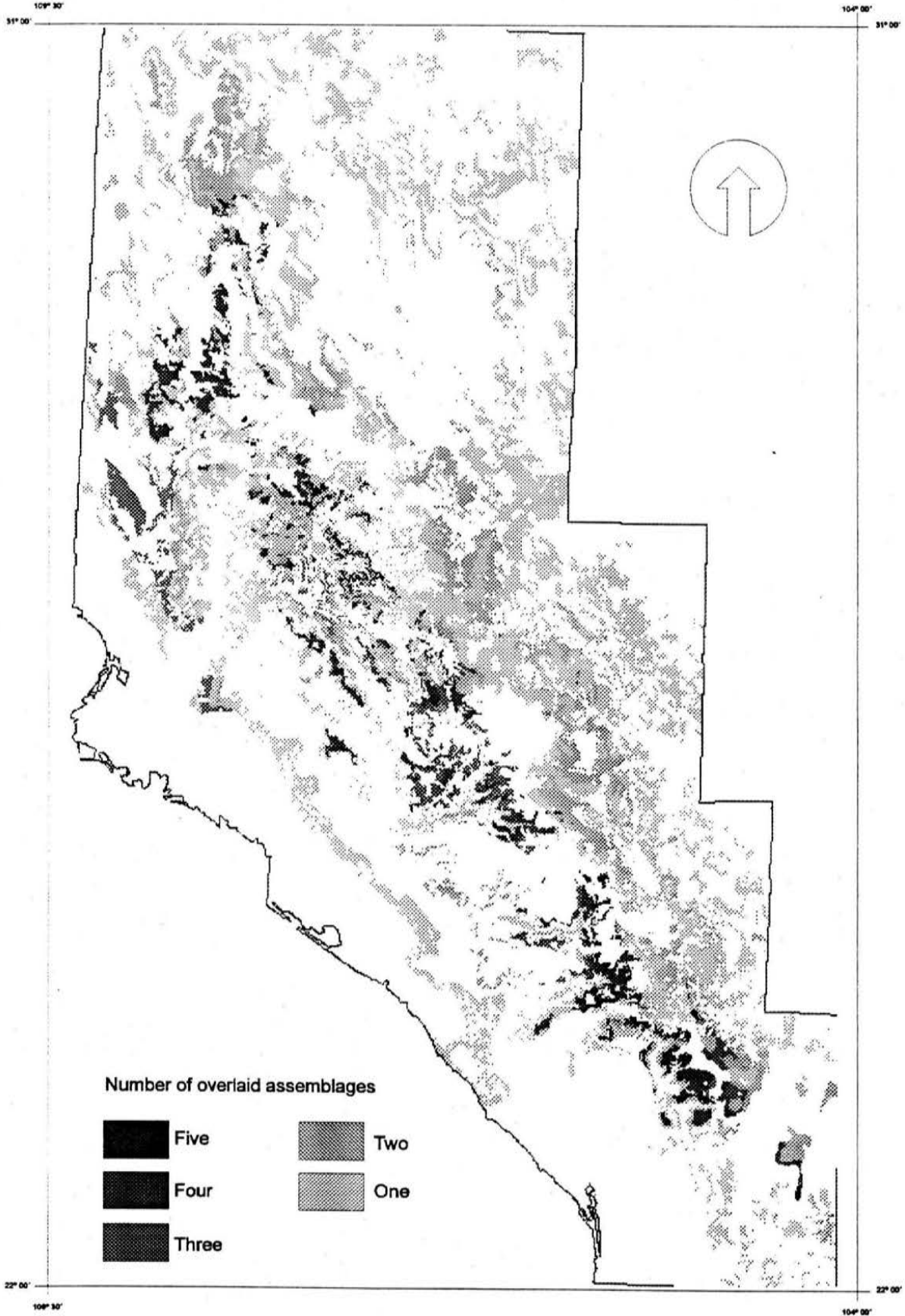


Fig. 17. Predicted assemblages distribution in Durango and Chihuahua. 50% of predicted frequency and NFI vegetation.

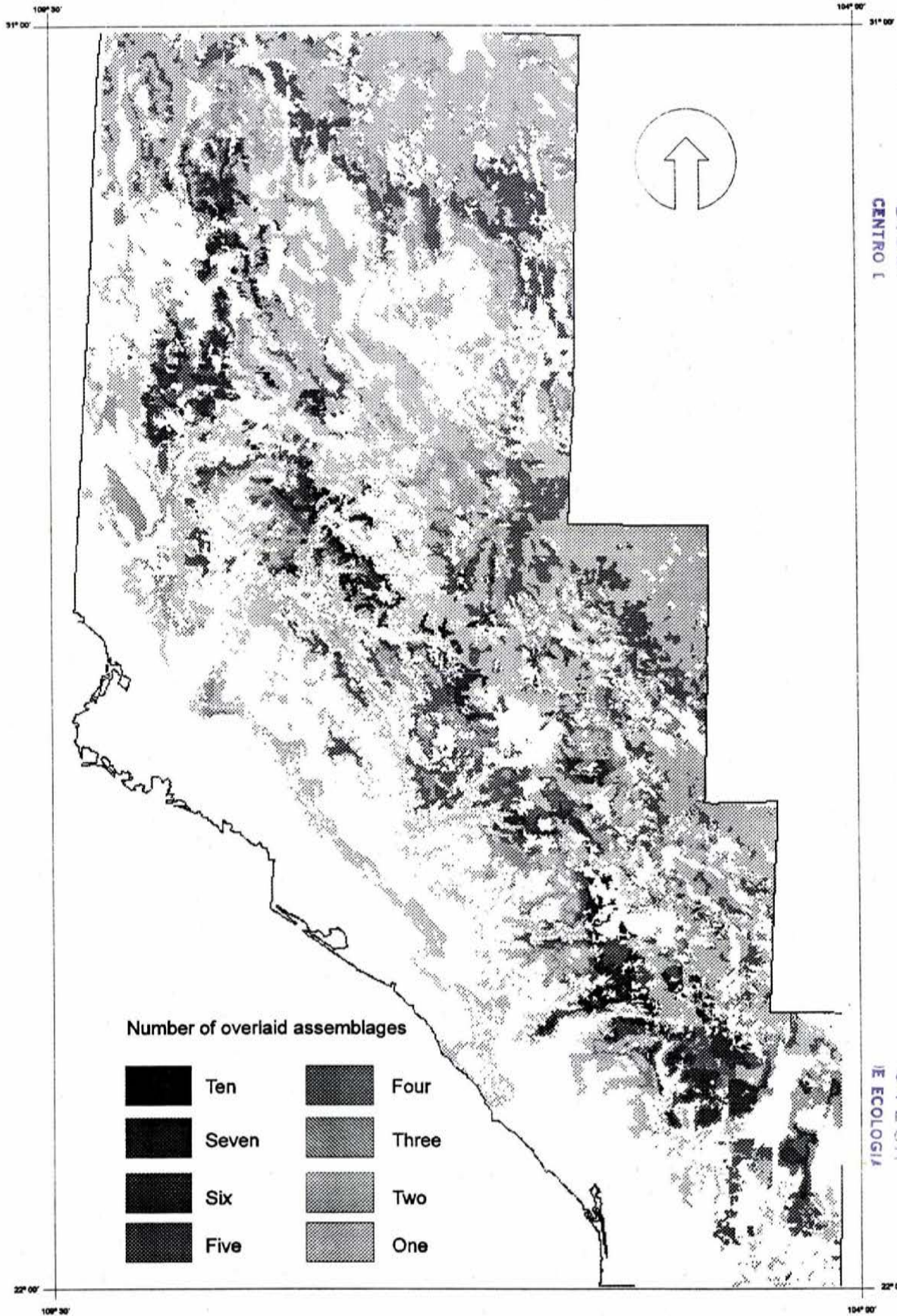


Table 7 . Habitat fragmentation in Durango and Chihuahua, Mexico.

Overlaid assemblages	Smallest area (ha)	Largest area (ha)	Average (ha)	S.D. (ha)	Number of polygons	Smallest area (ha)	Largest area (ha)	Average (ha)	S.D. (ha)	Number of polygons
<b>Predicted frequency 100 (%)</b>										
INEGI					NFI					
1	96	1,562,870	3,607	42,501	1,425	96	671,930	1,895	15,074	2,023
2	98	51,834	1,324	4,203	363	98	37,485	1,018	3,118	406
3	98	93,000	3,265	11,357	87	98	60,971	1,927	6,580	122
5	97	16,550	1,054	2,362	116	97	15,856	780	1,753	105
<b>Predicted frequency 80 (%)</b>										
INEGI					NFI					
1	96	1,403,630	3,969	45,661	1,843	96	389,609	1,979	12,273	2,789
2	96	539,782	3,696	23,107	1,081	96	107,887	1,646	7,015	969
3	96	204,962	6,127	22,274	217	98	60,971	1,732	5,421	240
4	97	166,316	3,240	13,910	369	97	87,242	2,044	7,235	472
5	97	16,550	1,054	2,362	116	97	15856	780	1753	105
<b>Predicted frequency 50 (%)</b>										
INEGI					NFI					
1	96	1,073,450	3,434	34,009	2,024	96	1,073,450	2,475	28,386	2,511
2	96	742,814	2,486	20,287	1,679	96	248,497	1,614	7,468	2,048
3	96	149,673	2,978	10,705	1,076	96	63,861	1,456	4,392	1,547
4	96	525,121	6,909	37,201	369	96	268,767	2,780	15,935	645
5	96	113,236	2,512	9,115	732	96	80,372	1,674	5,492	887
6	96	45,394	1,573	4,483	250	96	38,037	1,078	3,175	289
7	97	172,992	4,577	17,846	279	97	90,517	2,457	8,544	401
10	97	16,550	1,054	2,362	116	97	15,846	780	1,753	105



Table 8. Number and area of the overlaid species assemblages in Durango and Chihuahua, Mexico

**OVERLAID  
ASSEMBLAGES**

**Predicted frequency percentage**

	100 (%)		80 (%)		50 (%)	
	INEGI	NFI	INEGI	NFI	INEGI	NFI
	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )	(km <sup>2</sup> )
1	51,847	38,614	73,792	55,415	68,993	62,009
2	4,775	4,108	40,123	15,995	41,958	32,217
3	2,856	2,365	13,614	4,155	32,364	22,716
4	0	0	11,896	9,597	25,777	18,111
5	1,232	826	1,232	826	18,318	14,792
6	0	0	0	0	3,939	3,127
7	0	0	0	0	12,708	9,800
10	0	0	0	0	1,232	826
Total	60,710	45,913	140,657	85,988	205,289	163,598

## DISCUSSION AND CONCLUSIONS

Maintenance of all biodiversity levels (from genes to ecosystems) faces complex ecological and sociopolitical problems. As an aftermath, the concept of ecosystem management has arisen as an alternative to integrate conservation and resource extraction (Christensen et al. 1996, Grumbine 1994). Ecosystem management entails a holistic view for achieving its goal of integrating conservation of biological diversity strategies into regional land-use planning, by means of adaptive management (Holling 1978). In essence, such holistic view compels for a regional landscape design to harmonize resource extraction from the semi-natural matrix with the requirements natural protected areas administration (Conacher 1980, Harris 1984, Franklin 1993, Kushland 1979, Minta and Kareiva 1994, Naveh 1978, Noss and Harris 1986, Prins 1987).

Since it is based upon information and systems analysis (Holling 1978, Walters 1986), obstacles for achieving adaptive management -and thus true ecosystem management- can be summarized in three categories: Knowledge, practical constraints, and conservation planning. The first is related to the following: (1) inadequate information of the biological requirements of most species, (2) lack of understanding of the function and dynamics of ecosystem (Christensen et al. 1996), especially at a regional scale, (3)

lack of a regional conservation theory tested by observation and experiment (Golley and Bellot 1991), and (4) data on species distributions is biased biological to accessible sites and to a few taxa (Bojórquez-Tapia et al. 1994, Nelson et al. 1990). The second include, among others: (1) Presence of high rates of natural ecosystems degradation, generated by natural resource extraction schemes directed towards short term goals and yields (Christiansen et al 1996), and (2) high costs of surveys prevent regional biological inventories to be included as an integral part of land-use planning (Nicholls 1989). The third kind of obstacles denotes that (1) current conservation strategies fall short because of both lack of congruence of legal and biotic boundaries of natural reserves (Newmark 1985), and (2) representation of all levels of biological diversity in natural preserves networks is insufficient (Scott et al. 1987, 1988, 1993, Wright et al. 1994).

Experience indicates that the conditions listed above prevail in Mexico (Bojórquez-Tapia and Ongay-Delhumeau 1992, Bojórquez-Tapia et al. 1994). In particular, the Sierra Madre Occidental forestry project, located in our study area, is an example of a regional forest management plan that generated conflicts between conservation and timber production. In essence, environmental groups in Mexico and the United States perceived that biologically critical areas were at risk, since important

habitats would be fragmented or entirely wrecked by logging (Zahner 1992). Although the project was initially sponsored by the World Bank, the loan was eventually canceled to avoid further conflicts. Nonetheless, habitat loss continued at a high rate, as our assessment of vegetation dynamics suggests.

Given the conditions in our study area (which are typical of Mexico), a small-scale or regional strategy is the logical first step towards ecosystem management. This assertion is congruent with the notion of adaptive management as a process that increases our understanding of ecosystems processes, in order to assess the consequences of management interventions. In that sense, our results demonstrate that data constraints can be overcome, and a regional land-use and conservation plan can be devised through GIS modeling. Obviously, more detailed models are still required for resolving large-scale issues.

Distributions models by means of CASEV and GLIM allow us to find broad correlations between environmental variables and species assemblages. Thus, species distributions can be delineated in unexplored areas. The shape and the intensity of the hypothetical relationships are useful for evaluating the reliability on such predictions, and the degree of trust upon them to base conservation decisions. For example, eight of our model were

rejected because their goodness of fit were lower than 0.25, the rest (17 models) were accepted and incorporated into the GIS.

The results of the present study confirms previous findings (Bojórquez-Tapia et al. 1995), with respect that temperature, precipitation, and vegetation are the best predictors for species distributions at a small scale (1:1,000,000). Climatic data and vegetation type usually represent the only environmental data base available with sufficient geographic coverage for geographic modeling purposes (Box et al. 1993). Vegetation, on the other hand, is widely used as an indicator terrestrial plants and animal distributions (Austin 1991), and as a surrogate of habitat for conservation evaluations (Scott et al. 1993, Caicco et al. 1995, Edwards 1996). Soils and geology are poorer predictors because they are nominal and, therefore, could be omitted from spatial studies, with the concomitant reductions in analyses time and models' complexity.

In the Sierra Madre Occidental, severe fragmentation and loss for the predicted habitat areas occurred between 1975 to 1992. Significant extensions of pine forest, pine-oak forest, oak woodlands, grasslands, and tropical deciduous forest changed to agricultural or perturbed areas. At least in theory, such losses can be considered consequential biotic impoverishment at an

ecosystem level, since a major cause for species depletion is habitat loss (Botkin 1992, Stowe et al. 1993).

According to our models of species distributions and landscape dynamics, an additional 50% of the current habitats may be lost in the next 100 yr, if current trends persist. Since the deforestation rates among the vegetation types is not significantly different, conservation priorities are related to the reductions in species assemblages' predicted distributions. As table 4 shows, most species assemblages are at risk because of their high rates of habitat loss. However, species assemblages birds 1, 2, 5, and 8, and reptiles 1 and 4 can be considered as the most endangered because their small areas of distribution.

Likewise, the risk of losing a species-rich areas (those with the highest number of species distribution overlays) depends upon the scenario considered. Considering the total area for the three scenarios (Table 8), the loss may vary from 20% to 40%. Nonetheless, the species-rich area with the highest number of species assemblages shows a reduction of about 33% of its original extension in the three scenarios.

Notwithstanding, the use of vegetation cover to predict the presence of wildlife species has been criticized on the grounds that it is a poor predictor of species distributions because fine texture landscape features, such as a specific geology, soil, or biological interactions, determine the presence of an organism (Short and Herstbeck 1995). We acknowledge that small scale models, such the ones generated in this study, ignore relevant information about the dynamic interactions among populations and landscape change. However, we agree with Scott et al. (1995) on that limitations in mapping restricts the use of more detailed models, especially for a large number of species.

However we are frequently limited in our ability to use more detailed habitat features because they are not mapped across the entire range of a species (Scott et al. 1995). As stated by Levin (1992), useful models do not need to reproduce every detail of a biological system, but should produce results that are congruent with empirical observations at the appropriate scale. Digital map overlays in GIS are used to identify individual species, species-rich areas and vegetation types that are unrepresented or underrepresented in existing biodiversity management areas (Scott et al. 1993; Wright et al. 1994; Caicco et al.; Edwards et al. 1996).

Besides, current methodologies and available data preclude the design of more advanced models of species distributions at regional scales (Conroy and Noon 1996). For the case of the Sierra Madre Occidental, data on the effect of disturbance agents and the role of biotic relationships are not available. However, the change in vegetation cover can be quantified by remote sensing, and the species distribution models yield practical results for decision making. First, our results assess the risk of losing areas of potential habitats and species rich areas. Second, they show that the natural protected areas in the region are a poor representation of the biological diversity of the Sierra Madre Occidental, so additional preserves are needed for an adequate conservation strategy. And third, our results on fragmentation demonstrate that habitats are being destroyed at an alarming rate, especially those of where the species-rich areas occur.

Therefore, our study has to be taken as the first approximation towards an adaptive management of the forest lands in the study area. In that sense, the species-rich areas predicted by our models need to be validated through biological surveys. The creation of natural reserves in the Sierra Madre can be located by considering the predicted distribution areas. Other considerations include the altitudinal range, and the distribution of the conservation network (MacKinnon et al. 1990).



Since human demands for the goods and services has been increasing, ecosystems management is more compelling and important. In this context, Edwards (1996) states that errors in commission are preferred over omission in conservation planning. Accordingly, it is better to overpredict the species distributions, so preventive action can be implemented as part of a regional planning scheme. Our results provide a framework for establishing such actions before resource extraction take place.

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## APPENDIX

### Assamblages of vertebrate species from Durango-Chihuahua, Mexico

#### MAMALS

##### GROUP 1

#### CARNIVORA

##### URSIDAE

*Ursus americanus*

#### CHIROPTERA

*Myotis volans*

##### VESPERTILIONIDAE

##### GROUP 2

#### RODENTIA

##### SCIURIDAE

*Tamias dorsalis*

##### GROUP 3

#### CHIROPTERA

##### PHYLLOSTOMATIDAE

*Anoura geoffroyi*

*Choeronycteris mexicana*

##### VESPERTILIONIDAE

*Eptesicus fuscus*

#### EDENTATA

##### DASYPODIDAE

*Dasybus novemcinctus*

#### INSECTIVORA

##### SORICIDAE

*Sorex monticolus*

*Sorex saussurei*

#### RODENTIA

##### ARVICOLIDAE

*Microtus mexicanus*

##### CRECETIDAE

*Nelsonia neotomodoni*

*Peromyscus difficilis*

*Peromyscus melanotis*

*Sigmodon leucotis*

##### SCIURIDAE

*Tamias durangae*

*Sciurus aberti*

*Sciurus apache*

*Spermophilus madrensis*

##### GROUP 4

#### CARNIVORA

##### CANIDAE

*Urocyon cinereoargenteus*

##### PROCYONIDAE

*Bassariscus astutus*

*Canepatus mesoleucus*

*Procyon lotor*

#### CHIROPTERA

##### VESPERTILIONIDAE

*Plecotus mexicanus*

#### RODENTIA

##### CRICETIDAE

*Neotoma mexicana*

*Peromyscus boylii*

*Peromyscus polius*

*Peromyscus truei*

##### GEOMYIDAE

*Thomomys umbrinus*

##### LAGOMORPHA

##### LEPORIDAE

*Sylvilagus floridanus*

##### GROUP 5

#### ARTIODACTYLA

##### CERVIDAE

*Odocoileus virginianus*

*Reithrodontomys megalotis*

##### TAYASSUIDAE

*Tayassu tajacu*

#### CARNIVORA

##### CANIDAE

*Canis lupus*

##### FELIDAE

*Felis concolor*

*Lynx rufus*

##### MUSTELIDAE

*Lutra annectens*

*Mephitis macroura*

*Mephitis mephitis*

*Spilogale putorius*

#### CHIROPTERA

##### VESPERTILIONIDAE

*Myotis auriculus*

*Myotis leibii*

*Myotis lucifugus*

#### RODENTIA

##### SCIURIDAE

*Sciurus nayaritensis*

*Spermophilus variegatus*

##### CRICETIDAE

*Sigmodon ochrognathus*

#### INSECTIVORA

##### SORICIDAE

*Sorex oreopolus*

##### GROUP 6

#### ARTIODACTYLA

##### BOVIDAE

*Ovis canadensis*

#### CARNIVORA

##### CANIDAE

*Canis latrans*

*Cynomys ludovicianus*

##### MUSTELIDAE

*Mustela frenata*

##### URSIDAE

*Ursus arctos*

#### CHIROPTERA

##### VESPERTILIONIDAE

*Lasiurus borealis*

*Lasiurus cinereus*

*Myotis californicus*

*Myotis thysanodes*

*Myotis velifer*

*Myotis yumanensis*

*Plecotus phyllotis*

APPENDIX. Continued

RODENTIA

CRICETIDAE

Peromyscus eremicus  
Peromyscus leucopus  
Peromyscus maniculatus  
Peromyscus melanophrys  
Peromyscus pectoralis  
Reithrodontomys fulvescens

GROUP 7

Reithrodontomys montanus

GROUP 8

RODENTIA

SCIURIDAE

Sciurus colliaei

GROUP 9

CHIROPTERA

PHYLLOSTOMIDAE

Leptonycteris curazoe

CARNIVORA

PROCYONIDAE

Nasua nasua

MARSUPIALA

DIDELPHIDAE

Didelphis virginiana

AMPHIBIANS

GROUP 1

CAUDATA

AMBYSTOMATIDAE

Ambystoma rosaceum

ANURA

BUFONIDAE

Bufo compactilis

Bufo occidentalis

LEPTODACTYLIDAE

Hylactophryne tarahumaraensis

Tomodactylus nitidus

Tomodactylus saxatilis

GROUP 2

ANURA

BUFONIDAE

Bufo mazatlanensis

LEPTODACTYLIDAE

Eleutherodactylus vocalis

RANIDAE

Rana pustulosa

GROUP 3

ANURA

HYLIDAE

Hyla bistincta

REPTILES

GROUP 1

SQUAMATA

SAURIA

GEKKONIDAE

Phyllodactylus tuberculatus

IGUANIDAE

Ctenosaura hemilopha

Urosaurus bicarinatus

TEIIDAE

Cnemidophorus costatus

PHRYNOSOMATIDAE

Sceloporus horridus

Sceloporus nelsoni

SCINCIDAE

Eumeces costatus

Eumeces parviauriculatus

SERPENTES

COLUBRIDAE

Procinura aemula

Pseudoficimia frontalis

Sympholis lippiens

Trimorphodon tau

GROUP 2

SAURIA

ANGUIDAE

Barisia levicollis

Elgaria kingi

IGUANIDAE

Ctenosaura pectinata

PHRYNOSOMATIDAE

Sceloporus poinsetti

Sceloporus poinsettii

Sceloporus scalaris

Sceloporus virgatus

POLYCHRIDAE

Anolis nebulosus

SCINCIDAE

Eumeces lynxe

GROUP 3

SAURIA

ANGUIDAE

Barisia imbricata

Barisia laevicollis

Gerhonotus liocephalus

PHRYNOSOMATIDAE

Phrynosoma orbiculare

Sceloporus bulleri

Sceloporus grammicus

Sceloporus jarrovi

Sceloporus jarrovii

SCINCIDAE

Eumeces brevisrostris

Eumeces multilineatus

SERPENTES

COLUBRIDAE

Conopsis nasus

Pituophis deppei

Storeria storerioides

Tantilla bocourti

Thamnophis errans

APPENDIX. Continued  
GROUP 4

TESTUDINES  
KINOSTERNIDAE  
Kinosternon integrum  
SQUAMATA  
SAURIA  
PHRYNOSOMATIDAE  
Phrynosoma douglassi  
Phrynosoma douglassii  
Phrynosoma modestum  
Sceloporus undulatus

BIRDS

GROUP 1

PASSERIFORMES  
DENDROCOLAPTIDAE  
Lepidocolaptes leucogaster  
EMBERIZIDAE  
Atlapetes pileatus  
Melospiza melodia  
Peucedramus taeniatus  
Pheucticus melanocephalus  
Vermivora superciliosa  
FRINGILLIDAE  
Carduelis pinus  
Carpodacus cassinii  
PARIDAE  
Parus sclateri  
SITTIDAE  
Sitta carolinensis  
Sitta pygmaea  
TURDIDAE  
Catharus occidentalis  
Sialia mexicana  
Sialia sialis  
TYRANIDAE  
Empidonax affinis  
Empidonax albigularis  
VIREONIDAE  
Vireo huttoni

PICIFORMES  
PICIDAE  
Colaptes auratus  
Sphyrapicus thyroideus

TROGONIFORMES  
TROGONIDAE  
Euptilotis neoxenus

CERTHIDAE  
Certhia americana

GROUP 2

CHARADRIIFORMES  
SCOLOPACIDAE  
Actitis macularia

COLUMBIFORMES  
COLUMBIDAE  
Columba fasciata

PASSERIFORMES  
AEGITHALIDAE  
Psaltriparus minimus  
CORVIDAE  
Aphelocoma ultramarina

Cyanocitta stelleri  
EMBERIZIDAE  
Cardellina rubrifrons  
Dendroica coronata  
ICTERIDAE  
Agelaius phoeniceus  
Molothrus aeneus  
MIMIDAE  
Melanotis caerulescens  
REMIZIDAE  
Auriparus flaviceps  
SYLVIIDAE  
Regulus calendula

PICIFORMES  
PICIDAE  
Melanerpes formicivorus

PSITTACIFORMES  
PSITTACIDAE  
Aratinga holochlora

GROUP 3

ACCIPITRIDIFORMES  
ACCIPITRIDAE  
Buteo jamaicensis  
Buteo swainsoni  
FALCONIDAE  
Falco sparverius

ALCEDINI FORMES  
ALCEDINIDAE  
Chloroceryle americana

ANSERIFORMES  
ANATIDAE  
Anas cyanoptera  
Aythya collaris  
Aythya valisineria  
Bucephala albeola  
Oxyura jamaicensis

APODIFORMES  
TROCHILIDAE  
Archilochus alexandri  
Calothorax lucifer  
Eugenes fulgens  
Selasphorus platycercus  
Selasphorus rufus

CAPRIMULGIFORMES  
CAPRIMULGIDAE  
Caprimulgus vociferus  
Chordeiles acutipennis

CHARADRIIFORMES  
CHARADRIIDAE  
Charadrius vociferus  
SCOLOPACIDAE  
Calidris bairdii  
Calidris minutilla  
Catoptrophorus semipalmatus  
Gallinago gallinago  
Tringa melanoleuca

CICONIIFORMES  
ARDEIDAE  
Butorides striatus

COLUMBIFORMES  
COLUMBIDAE  
Columbina inca  
Zenaida asiatica  
Zenaida macroura

**APPENDIX. Continued**

CUCULIFORMES  
CUCULIDAE  
*Geococcyx californianus*

GALLIFORMES  
PHASIANIDAE  
*Callipepla squamata*

GRUIFORMES  
RALLIDAE  
*Fulica americana*  
*Rallus limnicola*  
PASSERIFORMES  
ALAUDIDAE  
*Eremophila alpestris*  
APODIDAE  
*Cypseloides niger*  
CORVIDAE  
*Corvus corax*  
*Corvus cryptoleucus*  
EMBERIZIDAE  
*Ammodramus bairdii*  
*Ammodramus savannarum*  
*Ammodramus sandwichensis*  
*Amphispiza bilineata*  
*Basileuterus rufifrons*  
*Calamospiza melanocorys*  
*Calcarius mccownii*  
*Calcarius ornatus*  
*Cardinalis sinuatus*  
*Chondestes grammacus*  
*Dendroica petechia*  
*Dendroica striata*  
*Dendroica townsendi*  
*Geothlypis trichas*  
*Icteria virens*  
*Junco hyemalis*  
*Junco phaeonotus*  
*Melospiza lincolni*  
*Mniotilta varia*  
*Oporornis tolmiei*  
*Oriturus superciliosus*  
*Passerina amoena*  
*Pipilo chlorurus*  
*Piranga flava*  
*Piranga rubra*  
*Poocetes gramineus*  
*Setophaga ruticilla*  
*Spiza americana*  
*Spizella breweri*  
*Spizella pallida*  
*Spizella passerina*  
*Vermivora celata*  
*Wilsonia pusilla*  
*Zonotrichia leucophrys*  
FRINGILLIDAE  
*Carduelis pinus*  
*Carduelis psaltria*  
*Loxia curvirostra*  
HIRUNDINIDAE  
*Hirundo fulva*  
*Progne subis*  
*Riparia riparia*  
*Stelgodypteryx serripennis*  
*Tachycineta thalassina*  
ICTERIDAE  
*Euphagus cyanocephalus*  
*Icterus galbula*  
*Icterus spurius*  
*Molothrus ater*  
*Quiscalus mexicanus*  
*Sturnella magna*  
*Sturnella neglecta*

LANNIDAE  
*Lanius ludovicianus*  
MIMIDAE  
*Mimus polyglottos*  
*Oreoscoptes montanus*  
*Toxostoma curvirostre*  
*Toxostoma crissale*  
MOTACILLIDAE  
*Anthus spinoletta*  
PARIDAE  
*Parus wollweberi*  
PTILOGONATIDAE  
*Phainopepla nitens*  
PHALACROCORACIDAE  
*Phalacrocorax brasilianus*  
REMIZIDAE  
*Auriparus flaviceps*  
SYLVIIDAE  
*Poliophtila melanura*  
*Poliophtila plumbea*  
TROGLODYTIDAE  
*Campylorhynchus brunneicapillus*  
*Cistothorus palustris*  
*Salpinctes obsoletus*  
*Thryomanes bewickii*  
*Thryothorus sinaloa*  
*Troglodytes aedon*  
TURDIDAE  
*Zoothera pinicola*  
TYRANNIDAE  
*Contopus pertinax*  
*Empidonax fulvifrons*  
*Empidonax traillii*  
*Empidonax wrightii*  
*Pyrocephalus rubinus*  
*Myiarchus cinerascens*  
*Sayornis nigricans*  
*Sayornis phoebe*  
*Sayornis saya*  
*Tyrannus vociferans*  
VIREONIDAE  
*Vireo bellii*  
*Vireo solitarius*  
*Vireo vicinior*

PICIFORMES  
PICIDAE  
*Centurus aurifrons*  
*Centurus uropygialis*  
*Melanerpes formicivorus*  
*Picoides scalaris*  
*Picoides villosus*  
*Sphyrapicus varius*

PSITTACIFORMES  
PSITTACIDAE  
*Rhynchopsitta pachyrhyncha*

STRIGIFORMES  
STRIGIDAE  
*Athene canicularia*  
*Otus kenicotti*  
*Otus trichopsis*

TROGONIFORMES  
TROGONIDAE  
*Trogon elegans*

## GROUP 4

ACCIPITRIFORMES  
CATHARTIDAE  
*Cathartes aura*

APPENDIX. Continued

PASSERIFORMES

EMBERIZIDAE

Pipilo fuscus  
Piranga ludoviciana

FRINGILLIDAE

Carpodacus mexicanus

PASSERIDAE

Passer domesticus

TURDIDAE

Catharus guttatus  
Turdus migratorius  
TYRANNIDAE  
Myiarchus tuberculifer

PICIFORMES

PICIDAE

Picoides stricklandi  
GROUP 5

ACCIPITRIFORMES

FALCONIDAE

Polyborus plancus

APODIFORMES

TROCHILIDAE

Amazilia beryllina  
Lampornis clemenciae

CORACIIFORMES

MOMOTIDAE

Momotus mexicanus

PASSERIFORMES

COTINGIDAE

Tityra semifasciata

EMBERIZIDAE

Aimophila ruficeps  
Cardinalis cardinalis  
Passerina caerulea  
Passerina versicolor  
Pipilo erythrophthalmus  
Piranga bidentata  
Spermagra erythrocephala  
Saltator coerulescens  
Vermivora ruficapilla  
Vermivora superciliosa

ICTERIDAE

Icterus wagleri

SILVIIDAE

Polioptila albiloris

TROGLODYTIDAE

Catherpes mexicanus

TURDIDAE

Turdus rufopalliatus

TYRANNIDAE

Myiarchus tyrannulus

Myiarchus nuttingi

VIREONIDAE

Vireo gilvus

STRIGIFORMES

STRIGIDAE

Glaucidium gnoma

TROGONIFORMES

TROGONIDAE

Trogon mexicanus

GROUP 6

ALCEDINIFORMES

ALCEDINIDAE

Ceryle alcyon

PASSERIFORMES

CORVIDAE

Calocitta formosa

EMBERIZIDAE

Aimophila ruficauda

Ergaticus ruber

TYRANNIDAE

Empidonax difficilis

PSITTACIFORMES

PSITTACIDAE

Ara militaris

GROUP 7

ACCIPITRIFORMES

ACCIPITRIDAE

Buteogallus anthracinus

PASSERIFORMES

TURDIDAE

Catharus aurantiirostris

Catharus ustulatus

PSITTACIFORMES

PSITTACIDAE

Amazona finschi

STRIGIFORMES

STRIGIDAE

Bubo virginianus

GROUP 8

PASSERIFORMES

TURDIDAE

Myadestes obscurus

GROUP 9

GALLIFORMES

PHASIANIDAE

Cyrtonyx montezumae