Modeling land use/cover change and biodiversity conservation in Mexico

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Abstract

A nationwide multidate GIS database was generated in order to carry out the quantification and spatial characterization of land use/cover changes (LUCC) in Mexico during the last decades. Digital maps from three different dates (1993, 2002 and 2007) were revised and integrated into a GIS database along with ancillary data (Road network, settlements, slope and socio-economical parameters at the municipality level). Land cover maps were overlaid in order to generate LUCC maps and calculate two indices de LUCC: 1) a simple rate of deforestation and 2) a rate of degradation which takes into account the degradation and recovery processes. An analysis of causes and drivers of LUCC was conducted, at the municipality level, computing the Spearman coefficient between these two rates and biophysical and socio-economic factors. Change trends were also compared with biodiversity distribution. Preliminary results show that although rates of deforestation have decreased during the most recent period, LUCC still represents a serious threat to biodiversity conservation in Mexico.

Keywords:land use/cover change, modeling, drivers, biodiversity

1. Introduction

Mexico is a megadiverse country, but biodiversity is threatened by the loss of native vegetation due to the high rates of deforestation (FAO, 2001). Various studies have attempted to assess land use/ cover change (LUCC) over the last decades (Mas et al., 2004). Fuller et al. (2007) examined the effect of LUCC on the distributions of 86 endemic mammal species in 1970, 1976, 1993, and 2000 in Mexico. They showed that this fauna could have been protected considerably more economically if a conservation plan had been implemented in 1970 than is possible today due to extensive conversion of primary habitats. At each time step, optimal conservation area networks were selected to represent all species. These authors found that 90% more land must be protected after 2000 to protect adequate mammal habitat than would have been required in 1970. The goals of this study are to 1) delineate maps of LUCC in Mexico for different periods, 2) identify variables and drivers that influence the LUCC rates and 3) compare LUCC trends with a biodiversity map to evaluate the possible effects of LUCC on biodiversity conservation. In this paper, we present the preliminary results.

2. Methodology

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2.1. Material

The following data were used:

- Maps of land use/cover (LUC) at 1:250,000 scale from the National Institute of Geography, Statistics and Informatics (INEGI) for 1993, 2002 and 2007. These maps are compatible with regards to scale and classification scheme. The classification scheme distinguishes primary covers and 3 categories of secondary land covers (with herbaceous, scrub and tree secondary vegetation respectively). According to INEGI, primary vegetation is defined as relatively undisturbed vegetation that preserves, in large part, its condition of density, coverage, and species composition from its original, primary, ecosystem. Secondary vegetation is defined as the vegetation which substitutes totally or partially the original (primary) vegetation as a result of secondary succession.

- Map of species richness: To generate this map, Sánchez-Cordero et al. (2005) modeled ecological niches for the 459 continental mammal species of Mexico using point occurrence distribution from national and international scientific collections and environmental data layers, including potential vegetation type, elevation, topography and climatic parameters using the Genetic Algorithm for Rule-set Prediction (Stockwell et al. 1999; Anderson et al. 2003). Then maps of each species were overlain in order to calculate the species richness.

- Maps of ancillary data (digital elevation model, roads maps, human settlements, municipal boundaries).

- Socio-economic data from the INEGI organized by municipality (Population census for 2000 and 2005).

GIS operations were carried out with the program ArcGIS (ESRI, Redlands, CA) and statistical analysis and graphs were created using R (R Development Core Team 2009).

2.2. LUCC Monitoring

Mapping of LUCC was done by overlaying the LUC maps of different dates. Based upon LUCC maps, areas of change were tabulated and rates of change, including the rate of deforestation, were computed. As the rate of deforestation is sensitive to the change from forest areas (primary and secondary covers altogether) to non forest area only, we also applied an “index of conservation” which takes into account forest degradation and recovery (e.g. transitions between secondary categories). Land cover categories were associated to a weight value ranging from 0 to 4 for anthropogenic, herbaceous secondary, scrub secondary, tree secondary and primary forest forest respectively. Mean values of this index was calculated for 2004 and 2007 for each municipality.

3.2. Relationship between LUCC and socioeconomic features

To determine which socioeconomic factors are most likely to be indirect drivers of deforestation we calculated the rate of deforestation and the variation of the conservation index for each municipality for 2004-2007 and compared them with various indices describing population density, education, poverty and accessibility to resources. These indices were: a) Population density in 2000 and 2005 (people per km^2) and the variation of density between these two dates; b) settlements density (number of settlements per km^2); c) proportion of the population older than 12 years without primary education; d) proportion of the population speaking an indigenous language; e) proportion of the population living in small settlements (with less than 100 and 2500 inhabitants); f) proportion of population between 20 and 39 years (%), which is expected to be inversely correlated with migration; g) proportion of houses with a cement roof as an index of social welfare; h) the Gini index which measures inequality and ranges theoretically from 0 to 100, where 0 is perfect equality and 100 perfect inequality; i) the mean salary (expressed as the number of minimum wage salaries) and the proportion of the population with less than one and two minimum wage salaries; j) the natural cover area (ha) and the proportion of total area covered by natural cover; k) the mean slope (degrees); and l) the road density (km of road per km^2).

3. Result

3.1. LUCC Monitoring

Figure 1 and table 1 shows a significant decrease of forest area (except secondary temperate forest) and an increase of crop and pasture lands during both periods. However, rates of change are lower during the more recent period.

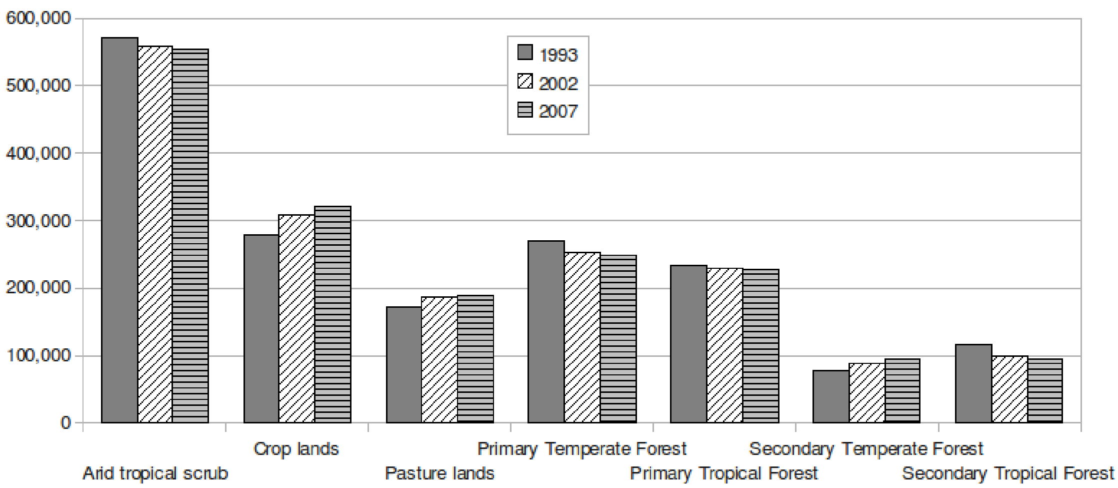

Figure 1: Areas of the main land cover types in 1993, 2002 and 2007 (km^2)

Table 1: Rates of changes for the main land cover types

Land cover category	Area (km^2)			Change (km^2/yr)		Rate of change (%/yr)	
	1993	**2002**	**2007**	**1993-2002**	**2002-07**	**1993-2002**	**2002-07**
Arid tropical scrub	571383	558297	554661	-1454	-727	-0.26	-0.13
Crop lands	278424	308592	321597	3352	2601	1.15	0.83
Pasture lands	172278	187587	188964	1701	275	0.95	0.15
Primary Temperate Forest	270432	252891	247707	-1949	-1037	-0.74	-0.41
Primary Tropical Forest	233388	229815	227205	-397	-522	-0.17	-0.23
Secondary Temperate Forest	78021	89028	93987	1223	992	1.48	1.09
Secondary Tropical Forest	116316	99333	93726	-1887	-1121	-1.74	-1.16

3.2. Analysis of drivers

For the statistical analysis we use only the municipalities with a scrublands or forest area covering at least 500 ha and 30% of the municipality. 2314 municipalities (of a total of 2443) fulfilled this condition and represent more than 96% of the forest and scrub area of the country. Figure 2 shows the rate of deforestation per municipality.

Table 2 shows that rate of deforestation and the variation of the conservation index are strongly associated ($R = 0.77$, $p < 0.01$) and that both indices are weakly, but significantly, related to some of the indices describing the socio-economic and environmental characteristics of the municipalities. Unexpectedly, population density is negatively correlated with degradation and deforestation during 2002-2007 although the increase of density is related with an increase of deforestation. Indices related with poverty present a positive correlation with deforestation and degradation. No significant correlation was found with the Gini index. Higher slopes and unexpectedly road density tend to reduce the deforestation/degradation.

Table 2: Spearman correlation between change and municipality characteristics

Index	Rate of deforestation*		Degradation (Variation of conservation index) *	
	R	p	R	p
Population density 2000 (people per km^2)	-0.04	0.14	-0.05	0.03
Population density 2005 (people per km^2)	-0.02	0.34	-0.05	0.06
Population density variation 2000-2005	0.11	0.00	0.05	0.05
Settlements density (settlements per km^2)	-0.07	0.01	-0.06	0.02
Population older than 12 years without primary education (%)	-0.10	0.00	-0.05	0.06
Population speaking an indigenous language (%)	-0.04	0.07	-0.06	0.02
Population living in settlement of less than 100 inhabitants (%)	-0.02	0.37	0.00	0.97
Population living in settlement of less than 2500 inhabitants (%)	-0.09	0.00	-0.05	0.03
Population between 20 and 39 years (%)	0.17	0.00	0.06	0.02
Houses with cement roof (%)	0.06	0.01	0.03	0.21
Gini index	0.00	0.95	0.00	1.00
Mean salary (number of minimum salary)	0.13	0.00	0.13	0.00
Population with less than one minimum salary (%)	-0.11	0.00	-0.12	0.00
Population with less than 2 minimum salary (%)	-0.13	0.00	-0.13	0.00
Natural cover area (ha)	0.23	0.00	0.23	0.00
Natural cover area (%)	0.09	0.00	0.11	0.00
Mean slope (degrees)	-0.24	0.00	-0.15	0.00
Road density (km/km^2)	-0.13	0.00	-0.11	0.00
Rate of deforestation	-	-	0.77	0.00

* A negative value for the rate of deforestation and degradation indicates recovery

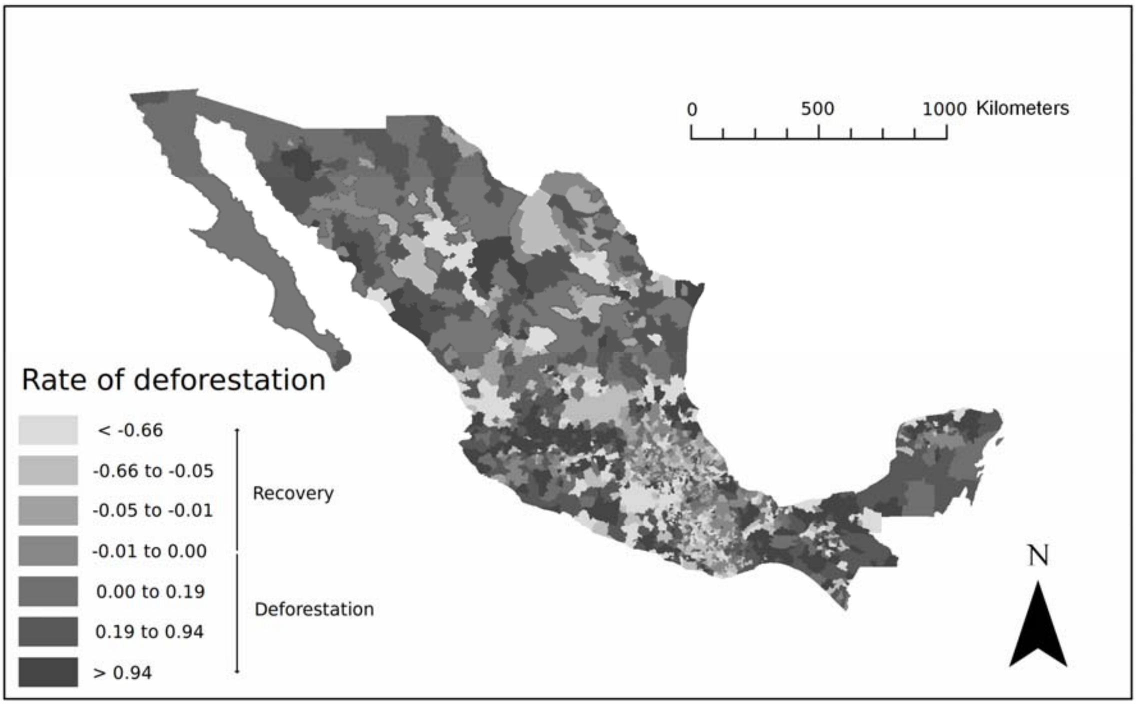

Figure 2: Rates of deforestation by municipality (2002-2007)

Spearman's coefficient of rank correlation between the rate of deforestation and the average species richness per municipality is 0.06 ($p < 0.01$). The coefficient between the rate of degradation and the average species richness is 0.11 ($p < 0.01$) which indicates that most threatened areas tend to present more biodiversity.

4. Discussion

According to INEGI maps, the patterns of change observed during 1993-2002 remain similar in 2002-2007: Crop and pasture area is increasing and forest area, expect secondary temperate forest, is decreasing. However, the rates of deforestation are lower during the second period except for primary tropical forest, which presented an increase of the rate of deforestation. Rates of deforestation and degradation tend to be higher in biodiverse areas and, therefore, LUCC still represents a serious threat to biodiversity conservation in Mexico.

The results of the analysis of the drivers must be taken with caution for various reasons: 1) Analysis was based upon average characteristics of the municipality, yet their size is very variable (125 to more than 5,000,000 ha) and they are often heterogeneous; 2) the causes of LUCC in a given municipality are not necessarily reflected in the characteristics of this municipality (spatial lag); 3) LUCC are likely due to different processes over the entire territory, which can obscure meaningful explanatory variables in a nationwide study; 4) only recent LUCC are observed, in many settled regions, with high population and road density, rates of deforestation are low because few forests remain. Moreover, due to multicollinearity, a variable correlated with rates of LUCC may actually have no influence and be correlated with the true causal variables. In further research, method such as hierarchical partitioning will be used in order to deal with these limitations (MacNally 2000; 2002).

However, the results obtained which indicate that marginal poor areas present lower rates of deforestation and degradation are not surprising. Many previous studies reported that most conserved natural areas in Mexico are often located in poor rural areas and/or community lands where people have demonstrated for centuries that they have the ingenuity to cope with major environmental and social threats to their live-hoods (Klooster 2000; Alix-Garcia et al. 2005; Merino 2007, Figueroa et al. 2009, García-Barrios et al. 2009).

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