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Temporary analysis of land use changes in Pine and mixed forests in Mexico

Análisis temporal de cambios en el uso del suelo de bosques de pino y mixtos en México

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ABSTRACT

Objective: to evaluate the changes in land use that occurred in Pine and mixed forests, at the national level during the period 2001 to 2013.

Design/Methodology/Approach: layers of Land Use and Vegetation (Sp. equ. USV) of Series II (from 2001) and V (from 2013) of the Instituto Nacional de Estadística y Geografía, scale 1: 250,000 were used. Different categories of vegetation under study were reclassified and homogenized for both covers. Rates of change and indicators of transitions were estimated for the spatial-temporary analysis: surfaces of estimated losses and gains, indices of persistence, exchanges and net changes; also, indices of gain and loss to persistence.

Results: the rate of negative change for primary forests (Pine and mixed) ranges from 0.80 to 1.84. It was observed that 120 047 km^2 (57.72%) were stable surfaces. However, 36 986 km^2 (18.00%) were losses, 14 369 km^2 gains and 28 738 km^2 (14.00%) between categories. It was observed from 2001 to 2013 that 13.69% of the area corresponding to primary forests which existed in 2001 became part of secondary vegetation in 2013.

Study limitations/Implications: in order to observe the influence of other categories, it would be important to incorporate more classes throughout the study to be analyzed globally in the system throughout the country.

Findings/Conclusions: The persistence of the coverage of primary forests is important to design conservation policies.

Keywords: Oak forest, vegetation changes, conifers, Series II, Series V.

INTRODUCTION

Mexico is considered one of the megadiverse countries worldwide (Martínez *et al*., 2014). However, the accelerated transformation of natural vegetation in areas of agricultural and urban uses, to create infrastructure works have been the most common processes several regions of the country during the last 30 years (Velázquez *et al*., 2002a; Salazar *et al*., 2004). At a world level, land use change has been identified one of the greatest threats to biological diversity, since it involves not only the loss of plant cover but also the disruption of natural ecosystems in fragments of various sizes and, therefore, their discontinuity and isolation (Arriaga, 2009). This causes alterations in the region, such as the reduction of aquifers recharge, increase in the rate of erosion, modification of local climatic conditions and reduction of habitats (Martínez *et al*., 2014). Fragmentation is a key process to understand

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how land occupation dynamics intervene in the quality of forests (Granados *et al*., 2014). This implies an unfavorable outlook for the country forest masses and leads to a significant environmental imbalance (Gernandt and Pérez, 2014). The main factors contributing to landscape modification are agricultural intensification, population growth, infrastructure expansion, and economic policies (Sanderson *et al*., 2002).

Changes in land surface generate a reduction in vegetation cover, loss of habitats and reduction of biodiversity (Geist and Lambin, 2001; Gurrutxaga and Lozano, 2009; Reyes *et al*., 2006). The changes in forest cover induced by human action are considered as one of the main factors of global environmental modification, which presents diverse effects at different scales (Wang *et al*., 2012). These actions have repercussions at the local and regional level, modifying hydrological cycles, climatic regimes, accelerating soil degradation and leading to fragmentation processes. Gurrutxaga and Lozano (2006) considered that reduction and fragmentation are main causes of the current biodiversity crisis. This term is generally defined as a landscape-scale process involving both habitat loss and disruption (Fahrig, 2003). In recent years, emphasis has been placed on evaluating the extent of forest cover and landscape fragmentation that directly impacts the functionality of the ecosystem (Saura *et al*., 2011). Likewise, studies on processes related to land cover and use are at the center of the attention of environmental research (Bocco *et al*., 2001), due to the implications that these entail in relation to the loss of habitat.

The analysis of change in land cover and use represents a means to understand the mechanisms of this deterioration process and constitutes a useful guide for making reasonable decisions about land use (Chen and Yang, 2008), as a strategy for the identification of priority areas for conservation and restoration (González *et al*., 2016). Based on the above, land cover changes in the Pine, Pine-oak and Oak-pine forest in Mexico were evaluated, during the period 2001 to 2013.

MATERIALS AND METHODS

The study area comprised the temperate coniferous forests throughout Mexico (Figure 1). Temperate Mexican forests represent around 13% of the Mexican territory (SEMARNAT, 2010) and are mainly composed of the genus *Pinus* (Rzedowski, 2006; Colditz *et al*., 2010) but also include firs, cedars and junipers and are characterized by their particular climatic and topographic conditions (Gebhardt *et al*., 2014). In this study, the focus was on the Pine forest communities and their mixed associations. In Mexico, Pine forests are found in three types of communities: pure Pine forests, mixed Pine-oak and Oak-pine forests that grow at different elevations, climates and aspects (Rzedowski, 2006). They are representative of the high ecological diversity of the Mexican landscape. Temperate Mexican forests are found mainly at high altitudes over mountainous areas caused by volcanoes (Gebhardt *et al*., 2014). The most typical mountain ranges in Mexico are the Trans-Mexico Volcanic Belt, located in the central part of the country, the Sierra Madre Occidental and the Sierra Madre Oriental.

Homogenization of vegetation categories

A homogenization of terms of the information contained between the two digital coverages, Land Use and Vegetation of Series II (from 2001) and Series V (from 2013) of INEGI was carried out, similar to the work by Gebhardt *et al*. (2014). In order to debug the information that is outside the objective of the study, and regrouping the categories to be analyzed, reclassification resulted as shown in Table 1.

Subsequently, in the ArcGis™ 10.5 geographic information system, editing procedures were performed in the Editor Toolbar to rename the categories of digital

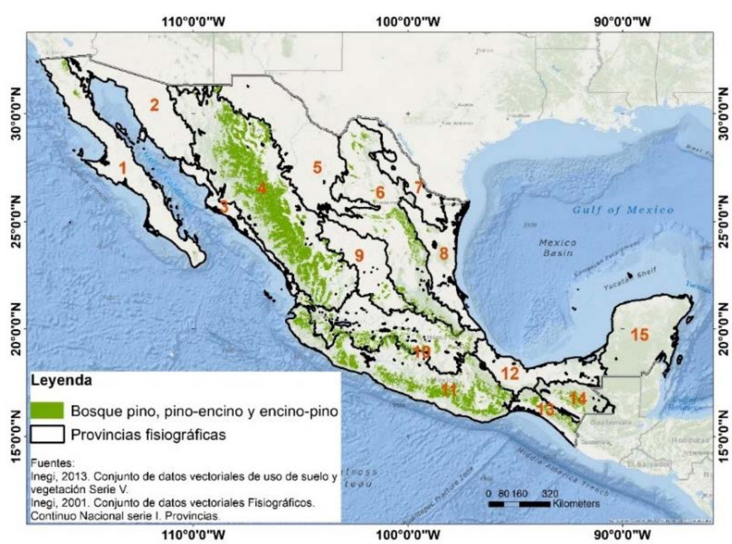

Figure 1. Study area: 1) Baja California Peninsula, 2) Sonoran Plain, 3) Pacific Coastal Plain, 4) Western Sierra Madre, 5) Northern Sierras and Plains, 6) Eastern Sierra Madre, 7) Great Plains of North America, 8) Coastal Plain del Golfo Norte, 9) Mesa del Centro, 10) Neovolcanic Axis, 11) Sierra Madre del Sur, 12) Coastal Plain of the Southern Gulf, 13) Central American Cordillera, 14) Sierras de Chiapas and Guatemala, 15) Yucatan Peninsula.

Table 1. Reclassified and homogenized categories.

Homogenized categories	Reclassified categories
Oak-pine forest (Bep)	Oak-pine forest
Pine forest (Bp)	Pine forest
Pine-oak forest (Bep)	Pine-oak forest
Secondary vegetation of Oak-pine forest (Vsbep)	Tree Secondary vegetation of Oak-pine forest Shrub Secondary vegetation of Oak-pine forest Herbaceous Secondary vegetation of Oak-pine forest
Secondary vegetation of Pine forest (Vsbp)	Tree Secondary vegetation of Pine forest Shrub Secondary vegetation of Pine forest Herbaceous Secondary vegetation of Pine forest.
Secondary vegetation of Pine-oak forest (Vsbep)	Tree Secondary vegetation of Pine-oak forest. Shrub Secondary vegetation of Pine-oak forest. Herbaceous Secondary vegetation of Pine-oak forest.

layers. Afterwards, the geoprocessing of the layers was carried out using the Intersect module to determine changes.

Annual exchange rates

The evaluation of the exchange rates was estimated with the equation (Velázquez *et al*., 2002a):

$$Tc=(S_2/S_1)^{1/n}-1 \quad (1)$$

Where: S_1=Land use area in the initial time; S_2=Land use area at time 2; n=number of years between the two dates.

Dynamics and processes of change

For the analysis of the spatial-temporary dynamics, the transitions in vegetation under study that occurred in the period were determined according to Pontius *et al*. (2004), using the following formulas:

$$\text{Estimated losses: } P=Stc_1-Pc \quad (2)$$

$$\text{Estimated earnings: } G=Stc_2-Pc \quad (3)$$

Where: Stc_1=Area of the category in year 1; Stc_2=Area of the category in year 2; Pc=Category persistence.

To determine the persistence indices, those proposed by Braimoh (2006) were used to evaluate the characteristics of the stable zones in relation to gains, losses, exchanges and net changes by category.

The persistence gain index (G_p) was calculated as:

$$G_p=G_{ij}/P_{jj} \quad (4)$$

Where: G_{ij}=Area gained for categories i in year 2; P_{jj}=Persistence of category i between dates.

The index of losses to persistence (L_p) was estimated as:

$$L_p=L_{ij}/P_{jj} \quad (5)$$

Where: L_{ij}=Lost area of category i in year 1; P_{jj}=Persistence of category i between dates.

The resulting values of the indices greater than 1 indicate that a category has a high tendency to present a transition towards another class, rather than to persist.

The exchange of surfaces between categories was calculated by:

$$Int=2{*}m_{pg} \quad (6)$$

Where: m_{pg}=The minimum value between the losses and the gains occurred in the category.

The net change was estimated:

$$CN=G-P \quad (7)$$

Where: G_{ij}=Gains; L_{ij}=Losses.

Spatial analysis and procedures were carried out in ArcGis ™ 10.5 geographic information system.

RESULTS AND DISCUSSION

Change of land use and vegetation

Figure 2 presents the spatial distribution of Pine forests (including mixed forests and secondary vegetation of the same forests) of the years 2001 and 2013, main changes occurred in the Sierra Madre Occidental and in the Northwest and Northeast of Mexico. The forest cover (Pine, Pine-oak and Oak-pine forests and secondary vegetation of Pine, Pine-oak and Oak-pine forest) in 2001 covers about 11%, results very similar to those of Velázquez *et al*. (2002a).

Figure 3 shows the total area distributed in the different categories of Pine forest in 2001.

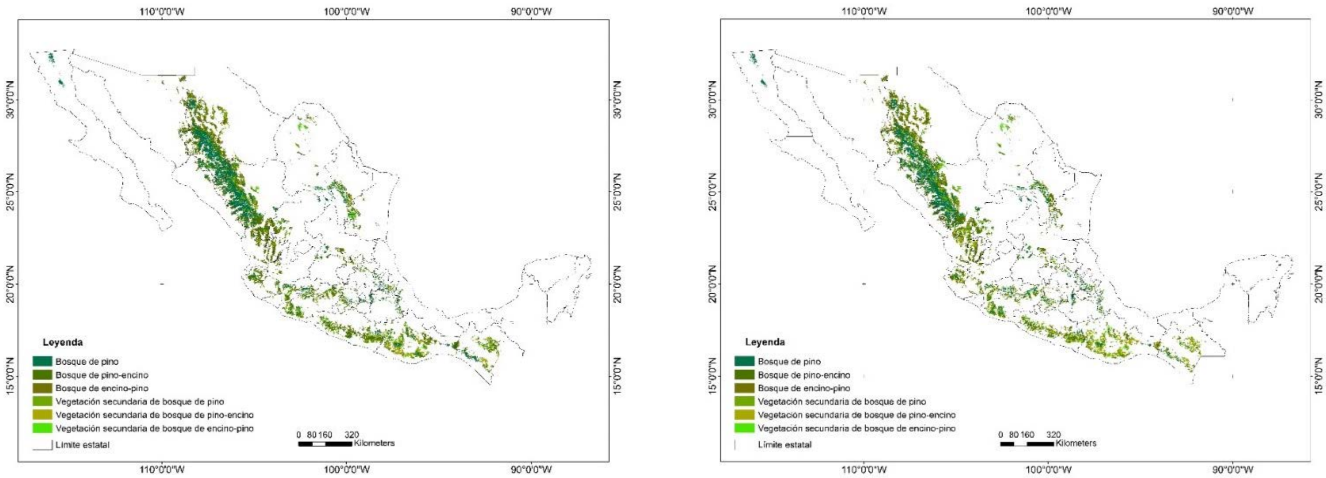

Figure 2. Maps of pine and mixed forest and secondary vegetation: a) 2001 and b) 2013.

Regarding the coverage of 2013, the surfaces are similar to 2001. The surface occupied by forest species represented about 10% of the national territory, this is composed of Pine, Pine-oak and Oak-pine forests, and their secondary vegetation (Figure 4).

When performing an analysis of land use changes in Mexico during the period 2001 to 2013 (Table 2), it is observed that it is mainly related to the decrease and loss of natural vegetation. During the 12-year period, the rates of change in forest cover showed a decrease, Pine-oak forests are those that obtained the highest losses, less than −1.83% per year, followed by Pine forests (−0.96%) and by lastly, Oak-pine forests (−0.80%). These results are expressed for Mexico by FAO (2010) with the same trend than that according to the World Forest Resources Assessment; just from 2005 to 2010, 775 thousand hectares of temperate and tropical forests were lost.

Table 2. Areas and rates of change in land use and vegetation (2001-2013).

Category	2001		2013		Exchange rate
	Area (km^2)	%	Area (km^2)	%	
Bep	32,736.38	15.74	29,713.62	14.46	−0.80
Bp	57,614.94	27.70	51,310.42	24.97	−0.96
Bpe	66,681.50	32.06	53,391.31	25.99	−1.84
Vsbep	10,484.95	5.04	13,328.38	6.49	2.02
Vsbp	17,765.40	8.54	24,709.03	12.03	2.79
Vsbpe	22,710.51	10.92	33,010.21	16.07	3.17

Table 3 shows the results of the change indicators, where it can be seen that 160 471 km^2 (77.15%) remained stable. However, 92 515 km^2 presented total change, where 20.78% (42 705 km^2) corresponds to net changes and 24.44% (49 811 km^2) to exchanges among different categories.

Figure 3. Percentage of forest area and secondary vegetation of Pine and mixed forests in Mexico, in 2001.

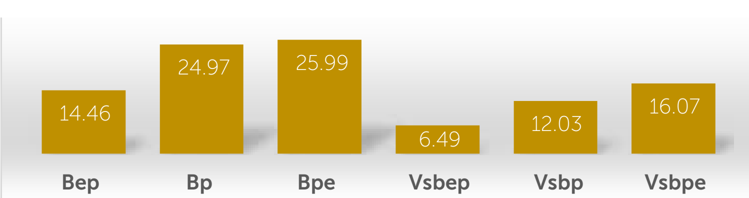

Figure 4. Percentage of Pine and mixed forest and secondary vegetation areas in Mexico, 2013.

Regarding the reductions in surface, the Oak-pine forest was the one that lost the most with 9.60%, then the Pine forest with 5.12%. On the contrary, the class that obtained the most increase in surface area was the secondary vegetation of Oak-pine with 7.20%, and then the secondary vegetation of Pine forest with 4.96%.

The analysis of the persistence index allows to know the vulnerability of the categories to a transition of loss or gain during the study period. Of the total area of the period under

Table 3. Persistence indices.

Category	Persistence (km^2)	%	Losses (km^2)	%	Gains (km^2)	%	Exchanges (km^2)	%	Net gain (km^2)	%	Net change (km^2)	%	G_p	L_p
Bep	25,989	12.50	6,748	3.28	3,725	1.81	7,450	3.63	3,023	1.47	10,472	5.10	6.98	0.26
Bp	47,093	22.64	10,522	5.12	4,218	2.05	8,435	4.11	6,305	3.07	14,740	7.17	11.17	0.22
Bpe	46,965	22.58	19,716	9.60	6,426	3.13	12,853	6.26	13,290	6.47	26,143	12.72	7.31	0.42
Vsbep	7,683	3.69	2,802	1.36	5,645	2.75	5,604	2.73	2,843	1.38	8,447	4.11	1.36	0.36
Vsbp	14,526	6.98	3,239	1.58	10,183	4.96	6,478	3.15	6,944	3.38	13,422	6.53	1.43	0.22
Vsbpe	18,215	8.76	4,496	2.19	14,795	7.20	8,991	4.38	10,300	5.01	19,291	9.39	1.23	0.25
Gross total	160,471	77.15	47,523	23.13	44,992	21.90	49,811	24.24	42,705	20.78	92,515	45.03	-	-

study, 77.15% was persistent, that is, without changes; in particular, Pine and mixed forests (BPM) as pure stands together was 57.72%. In the same way, for this BPM group the total losses were 18%; gains, 6.99%; exchanges between categories, 28.73% and net change 11.01%. The highest index of gain to persistence greater than ten units was that of the Pine forest (11.17) and together the BPM added up to 25.45. On the contrary, the highest index of loss to persistence were the Pine-oak forests (0.42) and the BPM as a whole totaled 0.90.

Table 4 presents the matrix of real changes among the different categories for the period 2001 to 2013. The values of the diagonal to the upper left and lower right directions show those of the areas that have remained stable during the period studied, this means that they are surfaces of the categories that were not modified. Those that are outside the diagonal are areas in transition, or that changed to another land use. The most representative changes were recorded in primary forests, which passed to secondary vegetation. For example, 9672 km^2 became secondary vegetation of Pine-oak forest, 6283 km^2 to secondary vegetation of Pine forest, and 2431 km^2 ha, to secondary vegetation of Oak-pine forest.

Table 5 shows dynamics of the primary and secondary coniferous forests under study to other classes. In this context, important changes stand out, such as the 10 917 km^2 of primary forests that became secondary vegetation of Pine-oak forest, 8110 km^2 changed to secondary vegetation of Pine forest, 2866 km^2 to

Table 4. Transition matrix between categories of Pine forest, mixed and secondary vegetation from 2001 to 2013 (km^2).

		2013						
		Bep	Bp	Bpe	Vsbep	Vsbp	Vsbpe	Gross Total
2001	Bep	25,989	0	0	2,431	114	817	29,351
	Bp	0	47,093	0	41	6,283	428	53,845
	Bpe	0	0	46,965	394	1,713	9,672	58,744
	Vsbep	0	0	0	7,683	0	0	7,683
	Vsbp	0	0	0	0	14,526	0	14,526
	Vsbpe	0	0	0	0	0	18,215	18,215
	Gross total	25,989	47,093	46,965	10,549	22,636	29,132	1,342,740

Table 5. Transition areas of Pine forest categories, mixed and secondary vegetation and other classes, from 2001 to 2013 (km^2).

		2013							
		Agri	Mat	Pcul	Pnat	Vsbep	Vsbp	Vsbpe	Zu
2001	Agri	257,222	2,106	9,154	670	0	0	0	3,895
	Bep	523	14	565	51	2,431	114	817	12
	Bp	1,393	19	988	32	41	6,283	428	16
	Bpe	1,242	11	944	24	394	1,713	9,672	16
	Vsbep	356	1	431	9	7,683	0	0	4
	Vsbp	702	11	669	10	0	14,526	0	6
	Vsbpe	939	1	990	1	0	0	18,215	15

secondary vegetation of Oak-pine forest, 3158 km^2 to agriculture and 2497 km^2 to cultivated pasture. Without ignoring that there were also changes to scrubland, natural grassland and urban area.

According to the above information, it can be inferred that primary Pine forests, and mixed, are threatened by other types of land uses of anthropogenic origin, such as agriculture, cultivated pasture and urban areas, mainly. If this trend continues, the consequences for ecosystems are diverse, highlighting soil erosion, reduction of aquifers, silt of streams and rivers, climate change, losses in biodiversity, droughts and fires, among others. The projections are negative for society if it is observed that, in a short period of time, this study reports that there were important changes in the forests.

CONCLUSIONS

In the span of 12 years, 36 986 km^2 of vegetation were lost, which corresponds to 18% of Pine forests, primary forests (Pine and mixed). The main replacements were to secondary vegetation of Pine and mixed forests, agriculture, cultivated grasslands, and scrublands. Of all types of vegetation, 77.15% remains unchanged, and of this, only 57.72% corresponded to Pine and mixed forests, which are important to design management and conservation policies.

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