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Artículos

Changes in the deforestation dynamics of a river sub-basin of Mexico: non-recovery of primary habitats following cessation of deforestation[1]

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ABSTRACT

In the Neotropical area of the Río Apatlaco sub-basin (central Mexico), high deforestation can be attributed to urban development, as this area concentrates the highest human population density in Morelos state. The objective of this study was to analyze changes in land use and vegetation in this sub-basin from 2002 to 2012 using geographic information systems. The results show that, over the period of analysis, the main changes occurred in the grassland and coniferous forest. However, in the tropical dry forest (TDF) the annual rate of deforestation (0.13%) was much lower than previously estimated (1.4%), but no recovery took place. It is possible that deforestation of the TDF was halted because the remaining areas with forest remnants were unsuitable for agricultural activities and/or abandonment of such activities has taken place. It is therefore a priority to protect these areas of secondary vegetation that serve as a buffer for conserved areas, allowing their recovery and contributing to their interconnectivity.

Key words: Land cover change, Rio Apatlaco, Geographic Information Systems.

RESUMEN

En la zona Neotropical de la sub-cuenca del río Apatlaco (centro de México), la alta deforestación puede ser atribuida al desarrollo urbano, ya que esta zona concentra la mayor densidad de población del Estado de Morelos. El objetivo de este estudio es analizar los cambios en el uso del suelo y de la vegetación en esta subcuenca entre 2002 y 2012, utilizando Sistemas de Información Geográfica. Los resultados muestran que, durante el período de análisis, los principales cambios ocurrieron en los pastizales y bosques de coníferas. Sin embargo, el bosque tropical caducifolio (BTC) sufrió una tasa anual de deforestación (0,13%) mucho más baja que la estimada previamente (1,4%), pero no ocurrió una recuperación. Es posible que la deforestación del BTC se haya detenido, debido a que las áreas con remanentes de bosque, son inadecuados para la agricultura u otras actividades. Es una prioridad proteger las áreas de vegetación secundaria, pues sirven como un amortiguador para las áreas fragmentadas, lo que permitiría su recuperación y contribuir a su interconectividad.

Palabras clave: Cambio de cobertura del suelo, río Apatlaco, Sistemas de Información Geográfica.

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Estimation and monitoring of the magnitude, dynamics and causality of deforestation in terrestrial ecosystems is a primary goal of conservation (Goetz *et al*., 2009; Whitehurst *et al*., 2009), since knowledge of the rates of change enables measurement of the condition of natural resources and an understanding of the trends presented by degradation/recovery processes. Deforestation rates have also been used to estimate extinction, although this has produced largely inaccurate results (He & Hubbell, 2011).

Over the period 1990 to 2000, the tropical forests of Mexico suffered a loss of 5.5 million hectares (1.1 %) per year (FAO, 2006). Among these forests, the tropical dry forest (TDF) is one of the most important in Mexico, since it occupies the third largest area (Flores and Gerez, 1994., Palacios-Prieto *et al*., 2000). It has been calculated that the TDF hosts 33.0% (824 species) of the terrestrial vertebrates of Mexico and 6000 species of vascular plants (Ceballos & García, 1995., Rzedowski, 1991a), of which 40.0% are endemic (Rzedowski, 1991b).

Flores and Gerez (1994) estimated that the coverage of TDF in Mexico in 1981 was 12.4% but that only 8.9% presented no evidence of disturbance. In 1990, the national coverage of unaltered TDF was 7.0%, while in 1992 the area lost to deforestation was estimated to be 163,000 hectares per year (Rincón and Huante, 1993). More recent estimates indicate that the tropical dry forests of Mesoamerican and Mexico are the most threatened worldwide, because of high deforestation, high fragmentation, isolation and exposure to high pressures of human population density. Moreover, current TDF distribution is under threat from the effects of climate change and is poorly protected (Miles *et al.,* 2006).

In the state of Morelos (Central Mexico), TDF is the most extensive vegetation type (Contreras-MacBeath *et al*., 2004), but an annual loss of 1.4% was calculated for the period 1973 to 1989 (Trejo & Dirzo, 2000). This rate of deforestation was suggested as one of the highest among the tropical ecosystems of Mexico (Trejo & Dirzo, 2000). In areas of Morelos, such as the Río Apatlaco sub-basin, high deforestation can be attributed to urban development, since this is the area of highest human population density in the state (INEGI, 2005). Urban development has taken place in this area because the TDF zone combines a warm, dry climate with an abundance of rivers and water bodies that originate in the upper zones. These climatic and hydrological factors have favoured the establishment of agriculture, as well as urban and touristic development (Contreras-MacBeath *et al*., 2004).

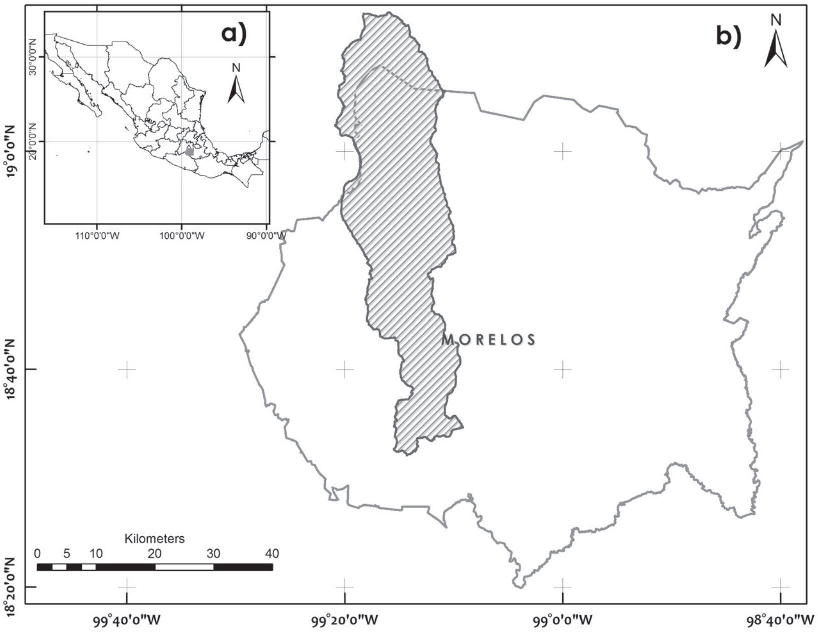
Deforestation is a dynamic phenomenon; it can accelerate, halt or reverse depending on the particular period under analysis (Ernst *et al*., 2013). Monitoring deforestation rates provides a parameter with which to measure the degree of threat faced by terrestrial ecosystems (Miles *et al*., 2006). However, large-scale (*e.g*. global) measurement of land use change can impede the detection of finer-scale causes (Miles *et al*., 2006). For this reason, it is necessary to conduct continuous studies of these spatial changes at the regional scale, in order to determine both the causes and rhythm of deforestation.

The objective of the present study was to measure the rate of land use cover change over the period 2002-2012 in the Apatlaco River sub-basin (central Mexico). This area features a continuum of temperate forest to TDF. The rate of deforestation in the former is unknown, but there is one previous deforestation rate estimate for the TDF (1.4% in the period 1973 to 1989; Trejo & Dirzo, 2000) and this forest accounted for more than 70.0% of the coverage of Morelos state (Trejo & Dirzo, 2000). For the TDF, we also compared our rate of change with this previous estimate and we estimated its potential distribution within the sub-basin. The general hypothesis is that the annual rate of deforestation of TDF of this area would remain at least at 1.4% (Trejo & Dirzo, 2000) but may increase, since this area has not been subject to any particular conservation measures and suffers pressure from increases in the urban zone. The temperate forests, located within a protected zone, should present deforestation rates close to zero, or even recovery.

Method

The Río Apatlaco hydrological sub-basin is located in central Mexico, and is shared between the states of Morelos, Mexico and Distrito Federal (Figure N° 1). The sub-basin

Figure Nº 1
Map of the study area. (a) Mexico and the state of Morelos in gray, (b) state of Morelos and Apatlaco River sub-basin highlighted in grey diagonal lines



Source: Own elaboration.

has an area of 85,312 ha, 90 % of which lies in the state of Morelos, comprising 13% of the area of that state (SAGARPA, 2006). The upper areas of the sub-basin are located at around 2550 m a.s.l. and are characterized by a semi-cold climate (monthly mean temperature of the coldest month is < 16°C) and precipitation of 1500 mm per year, while the low zone (around 890 m a.s.l.) of the sub-basin has a semi-warm climate (the monthly mean temperature of the hottest month is > 23°C) and lower annual precipitation (850 mm).

The main primary vegetation types are coniferous forest, pine-oak forest, oak forest, lower montane forest, TDF and shrubland (Table Nº 1) (Ernst *et al.,* 2005). It is estimated that 51% of the human population of Morelos live in the Río Apatlaco sub-basin, which

Table Nº 1
Main primary vegetation types present in the Río Apatlaco sub-basin

Vegetation type	Altitudinal range (m.a.s.l.)	Characteristic species and traits
Coniferous forest	2100 – 2800	*Pinus pseudostrobus, P. patula* and *Abies religiosa*.
Pine-Oak forest	1900 – 2100	*P. pseudostrobus, P. patula* and *A. religiosa*, mixed with *Quercus crassipes* and *Q. oleoides*.
Oak forest	1700 – 1900	*Quercus crassipes* and *Q. oleoides*
Lower montane forest		*Clethra mexicana, Symplocos prionophylla* and *Q. rugosa*.

Continuation Table N° 1

Vegetation type	Altitudinal range (m.a.s.l.)	Characteristic species and traits
Tropical dry forest	<1700	*Conzattia multiflora* and *Bursera* spp. Low stature forest with an open canopy, vines are common.
Scrubland		*Agave horrida* and *Hechtia chichinautzensis*. Open areas in lava flows.

Source: Own elaboration.

presents a mean density of 1171 habitants/km² (CNA, 2010).

Cartography of the vegetation and land use cover

Cartographic information generated by the National Microbasins Program (SAGARPA, 2006) was used to delimit the study area. Unpublished maps on land-use and vegetation from the years 2000 and 2010 were consulted in order to define the vegetation types.

For the 2012 map and the potential distribution of TDF, SPOT5 images with a spatial resolution of 10 x 10 m per pixel were used. From these sources, a composite image was generated using version 9.0 of the ERDAS software (Fueyo, 2008), highlighting the natural vegetation and its status in terms of conservation or stress. Bands 4 (1.58-1.75 μm), 3 (0.78-0.89 μm) and 2 (0.61-0.68 μm) of each image were combined in order to generate this image (Mas *et al*., 1996).

Using the INEGI digital model of terrain (DMT), each image used was orthorectified, assigning the projection of the UTM Zone 14, Datum WGS84 and the same classification of vegetation types was used throughout. The 2012 map was generated by photointerpretation of a composite image at a scale of 1:10000 with the software ArcGis 10.1. For the 2002 map, we used orthophotographs with 8.0 m resolution. To interpret the TDF distribution in the 2012 map, TDF was divided into three categories. The first was primary TDF, which corresponded to areas with a dense cover of vegetation. The arboreal elements appeared clumped in the images and conservation indicator species, such as *Conzattia multiflora* and species of the genus *Bursera*, were detected during field surveys. In addition, there were herbaceous, shrub and arboreal strata, as well as vines and epiphytes. The second category was disturbed TDF (TDFd), which included zones where the arboreal coverage did not appear dense in the images and disturbance indicator species, such as *Acacia angustissima*, *A. cochliacantha, Ipomoea* sp. and/or *Guazuma ulmifolia* (Contreras-Macbeath, 2004), were observed during field surveys. Nevertheless, it was still possible to observe herbaceous, shrub and arboreal strata, as well as vines. The third category was secondary vegetation derived from TDF (TDFs). It was possible to distinguish this vegetation type in the images because it occupied zones of potential TDF, but where recent images displayed few arboreal elements. It was observed during the field surveys that this vegetation was dominated by herbaceous plants or by scrub or dwarf forests that could feature monospecific stands of *Acacia cochliacantha* or *A. angustissima*, or multispecific stands, where the most frequent species were *A. angustissima*, *A. cochliacantha*, *Ipomoea* spp. and/or *Guazuma ulmifolia*. The strata were basically herbaceous and shrub, with few arboreal elements. Finally, thematic maps were presented at a scale of 1:10,000 and rates of change were calculated for each vegetation type using the exponential model (Trejo & Dirzo, 2000).

Potential distribution of TDF in the sub-basin was estimated with an aptitude model (SEMARNAT, 2012), using the cartographic attributes of pedology, lithology, precipitation and digital model of elevation. This model weighed the zones that presented characteristics suitable for the development of TDF (SEMARNAT, 2012).

Reliability analysis

The classification-evaluation was subjected to a reliability analysis in order to deter-

Table N° 2
Error matrix to measure the reliability of the classification

Categories	CF	CFd	PO	POd	Oak	Oakd	LMF	TDF	TDFd	TDFs	RF	Sh	G	IC	RA	Soil	R	UR	UA	W	*Accuracy (%)*
Coniferous forest (CF)	**4**																				*100*
Disturbed coniferous forest (CFd)	1	**5**																			*83*
Pine-Oak forest (PO)		1	**4**			1															*67*
Disturbed Pine-Oak forest (POd)				**3**	1	1															*60*
Oak forest (Oak)		1			**4**																*80*
Disturbed oak forest (Oakd)						4															*100*
Lower montane forest (LMF)							3														*100*
Tropical dry forest (TDF)								8													*100*
Disturbed TDF (TDFd)								1	**11**		2										79
TDF-derived secondary vegetation (TDFs)										11			1		1	1					*79*

Continuation Table N° 2

Riparian forest (RF)											8										*100*
Shrubland (Sh)												2									100
Grassland (G)													8								*100*
Irrigated crops (IC)														11							*100*
Rain-fed agriculture (RA)															6						*100*
Apparently bare soil (Soil)																4					100
Roads (R)																	3				*100*
Unpaved roads (UR)																	1	**2**			*67*
Urban area (UA)																			12		*100*
Water body (W)																				**3**	*100*
Reliability (%)	80	71	100	100	80	67	100	89	100	100	80	100	89	100	86	80	75	100	100	100	91

The principal diagonal indicates the number of areas that were classified correctly for each category. Numbers outside the diagonal, but in the same row, are errors of assignation corrected during field verification. The accuracy is the percentage of points correctly classified by the system for each row; this percentage declines as more areas are incorrectly assigned to a vegetation type. The reliability is the number of points of verification classified correctly by the system for each column; this percentage is reduced when many areas of that particular vegetation type were not originally detected.
Source: Own elaboration.

mine the precision of the results of this process (Johnson and Wichern, 2002). An error matrix was generated in which a comparison was made between the points of verification in the field and those derived from interpretation of the digital aerial photographs. The generated cartography (2012) was compared with 129 verification points. In turn, the overall accuracy was calculated (Anderson *et al* 1976).

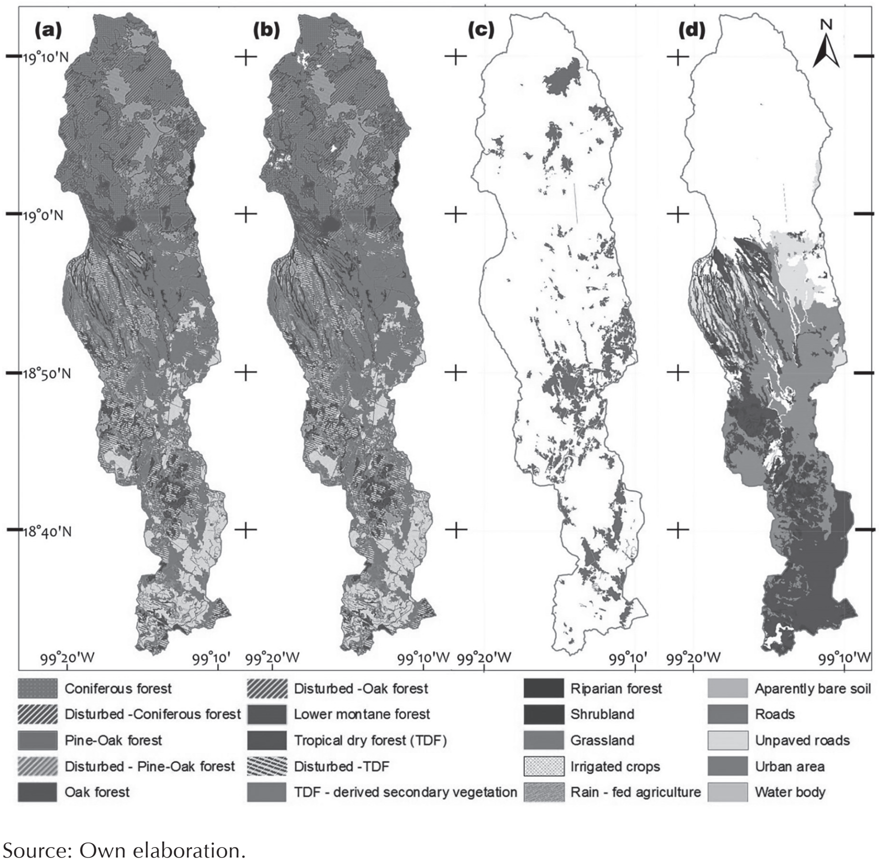
Interviews

In order to determine the causes of land use change in the TDF and to explore the perception of the landowners to such changes, 25 semi-structured interviews (Bernard, 1994) were conducted with inhabitants of the sub-basin. The interviewees were chosen from people who had previously sold their land. Interviews were conducted during the months of October and December of 2013, the age of the respondents was 35-70 years and 100% were men. This sex bias was a result of the fact that in the studied area >90% of landowners were male.

Results

Overall a exactness of the photointerpretation was 90%, while reliability was 90% and precision was 91%. The lowest values of reliability were estimated for disturbed coniferous and oak forests (Table Nº 2). The potential vegetation map suggests that TDF covered 63,320 ha (73.0% of the study area) (Figure Nº 2).

Figure Nº 2
Land use and vegetation maps 2002 (a), 2012 (b) and the area that changed between these years (c) in the Río Apatlaco sub-basin, central Mexico. The map of the potential distribution of TDF (d) is also shown, in different intensities directly corresponding to the probability of TDF presence.



Source: Own elaboration.

Among the different vegetation and land cover classes, only three did not change over the course of the analysed period (disturbed oak-forest, primary scrubland and water bodies/rivers), (Table Nº 3, Figure Nº 2). The categories that lost the least area (less than 50 ha) were oak forest, riparian forest, and disturbed pine-oak forest (Table Nº 3).

Table Nº 3
Area covered with different vegetation and land-cover types in the Río Apatlaco sub-basin in central Mexico. For each category, the area presented in 2002 and in 2012 is shown, along with the net change and the rate of change over this ten-year period

Vegetation/ land-cover type	2002		2012		Net change	Rate of change (%/year)
	(ha)	%	(ha)	%		
Coniferous forest	13,479.2	15	11,441.2	13	-2038	-1.41
Disturbed coniferous forest	7316.5	8	8573.2	10	1 256.8	1.86
Pine-Oak forest	2208	3	2266	3	58	0.26
Disturbed Pine-Oak forest	643	1	629	1	-14	-0.21
Oak forest	1053	1	1052	1	-1	0.00
Disturbed oak forest	2127.7	2	2127.7	2	0	0,00
Lower montane forest	151,5	0	151.8	0	0.3	0.02
Tropical dry forest (TDF)	4381.5	5	4321.5	5	-60	-0.13
Disturbed TDF	6355	7	5975	7	-380	-0.58
TDF-derived secondary vegetation	5287	6	4280	5	-1007	-1.75
Riparian forest	1172.2	1	1171.8	1	-0.4	0.00
Shrubland	225.1	0	225.2	0	0.1	0.00
Grassland	9647.8	11	6619	8	-3028.8	-2.76
Irrigated crops	1099.1	13	9256	11	-1735	-1.47
Rain-fed agriculture	9.650.7	11	9537	11	-113.7	-0.11
Apparently bare soil	1400.9	2	1416.8	2	16	0.11
Roads	517.9	1	516.9	1	-1	-0.02
Unpaved roads	416.6	0	402.6	0	-14	-0.33
Urban area	10078	12	1714.0	20	7062	11.36
Water body	209	0	209	0	0	0.00

Source: Own elaboration.

TDFd, TDF and rain-fed agriculture lost between 50 ha and 400 ha over the period of analysis, presenting negative rates of change of below 1% per year (Table Nº 3 and Figure Nº 2). Zones of grassland, irrigated crops, secondary vegetation derived from TDF and coniferous forest lost more than 400 ha in area and presented negative rates of change above 1% per year (Table Nº 3 and Figure Nº 2). Among these categories, grassland and secondary vegetation derived from TDF pre-

Table Nº 4
Transition matrix showing the area (ha) of distribution of the vegetation and land cover types of the Río Apatlaco sub-basin in central Mexico.

Categories	CF	CFd	P0	TDF	TDFd	TDFs	G	IC	RA	U A
Coniferous forest (CF)	1138 (83%)	2119 (16%)	10 (0.7 %)				208 (1.5%)	4 (0.3%)		
Disturbed coniferous forest (CFd)	295 (4%)	6430 (88%)	48 (1%)				521 (7%)			22 (0.4 %)
Pine-Oak forest (PO)			2208 (100 %)							
Tropical dry forest (TDF)				4321 (99%)	60 (1%)					
Disturbed TDF (TDFd)					5838 (92%)	154 (2%)	100 (2%)			263 (4%)
TDF-derived secondary vegetation (TDFs)						4080 (77%)	595 (11%)			612 (12%)
Grassland (G)	8 (0.08%)	23 (0.20%)				24 (0.20%)	4794 (50%)			4796 (50%)
Irrigated crops (IC)		1 (0.09%)			77 (0.70%)	22 (0.20%)	378 (3%)	9252 (84%)		1261 (12%)
Rain-fed agriculture (RA)									9537 (99%)	93 (1%)
Urban area (UA)										100078 (100%)

Each row shows the area of each vegetation/land cover type in the year 2002 that remained the same (bold in the diagonal) or transformed into another type. Each column shows the area that remained or was gained by each vegetation/land cover type by 2012. Numbers in parentheses are the percentage of area that remained the same (diagonal) or changed, relative to the 2002 area distribution. This matrix shows only those vegetation/land cover types that changed by more than 50 ha over the ten-year period (see Table Nº 3).
Source: Own elaboration.

sented the greatest negative rates of change (Table Nº 3).

Five categories increased in area (Table Nº 3, Figure Nº 2): the lower montane forest, bare soil and pine-oak forest gained less than 60 ha; their rate of change was positive, but less than 1% per year. The disturbed coniferous forest and urban areas, however, gained more than 1000 ha and presented the highest positive rates of change (greater than 1.5% per year).

The transition matrix (Table Nº 4) suggests three different dynamics of change; one in the upper zone of the sub-basin, another in the TDF zone and another in the zones of urban development, grassland and agricultural land. In the upper zone of the sub-basin, the transformations observed suggest processes of both natural recovery and human impact.

The primary coniferous forest presented probabilities of persistence greater than 80% (Table Nº 4). The coniferous forest and its disturbed vegetation presented a dynamic where 4% of the disturbed zones recovered to become conserved areas; however, 16% of the primary coniferous forest became disturbed, while 7% of the area of disturbed coniferous forest transformed into grassland, along with 1.5% of the primary coniferous forest.

The dynamic of the TDF and TDFs showed that deforestation had ceased, but no recovery had taken place in the areas of TDFs. The areas of TDF remained at more than 98% of their initial value (Table Nº 4); however, the areas of TDFd and of TDFs did not become conserved forest; instead, these areas deteriorated into grassland or urban zones. Among the forests of the sub-basin, TDF is the most fragmented (Table Nº 5, Figure Nº 3). In 2012, it consisted of 246 fragments in primary condition, 418 disturbed and 711 fragments of secondary vegetation derived from TDF.

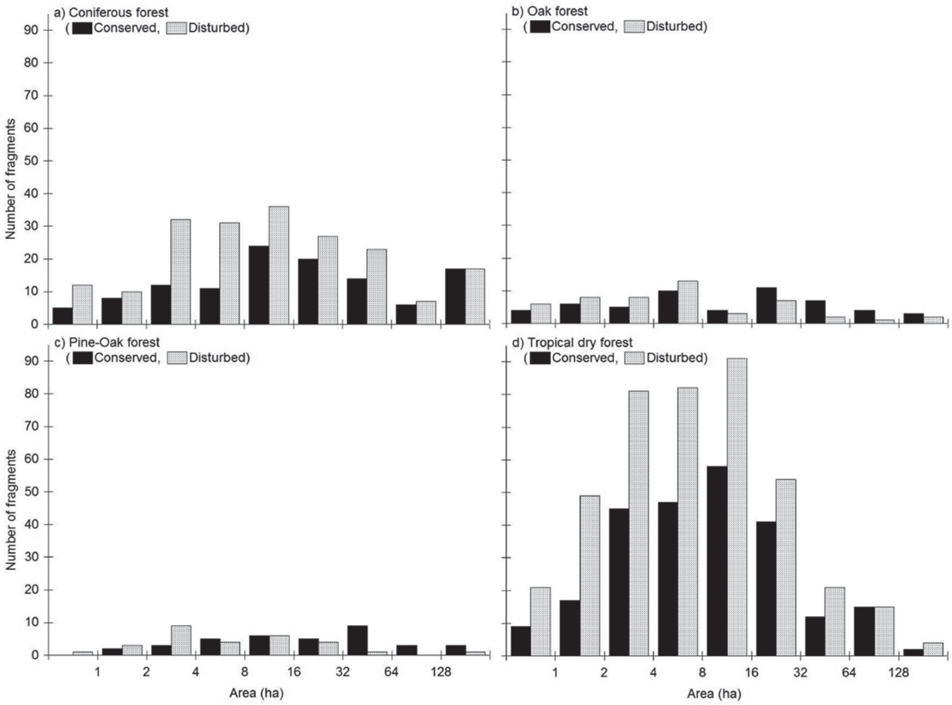
Table Nº 5
Number and size of forest fragments found in the 2012 vegetation/land cover map of the Río Apatlaco sub-basin, central Mexico. Information regarding the most abundant forest types and the derived disturbed or secondary vegetation is shown.

Vegetation type	Number of fragments	Area (ha)				
		Mean (± S.D.)	Quartile			Maximum
			25th	50th	75th	
Coniferous forest	117	94 ± 263	5	16	49	2006
Disturbed coniferous forest	195	43 ± 114	4	10	31	888
Oak forest	54	35 ± 73	4	12	34	486
Disturbed oak forest	50	16 ± 35	2	4	15	183
Pine-Oak forest	36	56 ± 112	6	21	55	580
Disturbed Pine-Oak forest	29	13 ± 27	3	5	13	144
Tropical dry forest (TDF)	246	18 ± 30	4	9	17	276
Disturbed TDF	418	14 ± 26	3	7	15	315
TDF-derived secondary vegetation	711	6 ± 11	1	3	6	109

Source: Own elaboration.

The dynamic of the period analysed shows that the urban zones grew mainly at the expense of the grasslands, agricultural zones and secondary vegetation. Despite the fact that new areas of grassland were created by the conversion of primary forest and secondary

Figure Nº 3
Size distribution of the forest fragments presented in the 2012 vegetation/land cover map of the Río Apatlaco sub-basin, central Mexico. Only the fragment size distribution of the most abundant conserved/disturbed forest types are shown.



Source: Own elaboration.

vegetation, and half of the areas recorded as grassland in 2002 remained unmodified, the grasslands derived from TDF transformed into urban zones, while those that had developed from the temperate forest remained intact. As a result, grassland was the land cover that lost most area (Table Nº 4); half of the area that was grassland in 2002 was transformed into urban zones (Table Nº 4). More than 10% of the zones with irrigated crops were transformed into urban zones. The urban zone was the land use category that presented the largest increase in size (>7000 ha).

In the TDF zone, 78% of the landowners interviewed had sold all or part of their land, while 42% had had no prior interest in selling, but received offerts that induced them to sell and another 36% sold because their descendants no longer worked the land. This was either because they were studying or had migrated to the United States. The remainder sold their land because they needed money. Prior to sale, the lands had been abandoned for between three and 12 years, and were covered by secondary vegetation. Once sold, 67% of these lands became urban areas, while 22% became agricultural land and 11 % remained abandoned.

Discussion

Land use change is a process that determines the quantity of conserved terrestrial ecosystems and their spatial disposition (Whitehurst *et al.*, 2009). This study in the Río Apatlaco sub-basin found that, at the regional scale, processes of recovery and deterioration simultaneously exist in terrestrial ecosystems and that these processes are altitudinally stratified. The majority of changes in area corresponded to growth of the urban zone at the expense of TDF, TDFd and TDFs, mainly in areas that were no longer cultivated and already had secondary vegetation (TDFs). This pattern would have remained undetected in large-scale studies (Miles *et al*., 2006).

In the elevated zone of the sub-basin (>2550 m.a.s.l.), recovery of the coniferous forest was slight and smaller than the change of this forest into disturbed zones, as has been noted in other reserves (Whitehurst *et al*., 2009). The recovery of coniferous forest from disturbed zones corresponds to succession within the protected area and is an indicator of the success of conservation policies. However, two processes were more extensive than recovery; conversion of coniferous forest into grassland and increase in area of disturbed forest. The increase in area of disturbed cold forests may be the result of small-scale tree harvesting in the zone. In a zone of coniferous and oak forest located close to the study area, recent research found that the frequency of zones with evidence of small-scale tree harvesting is 67.7% and is similar to that found in Neotropical cold forests (Cruz-Fernandez *et al*., 2011). The data from our study suggest that timber extraction may affect the density of trees to such an extent that it becomes evident at the resolution of the images used for the purposes of the present study, as has been noted for tropical dry forest (Whitehurst *et al*., 2009).

According to the results of this study, the hypothesis was rejected for the TDF, since the annual rate of change found was less than a tenth (0.1%), whereas previous studies have reported an annual rate of 1.4% (Trejo and Dirzo, 2000). This shows that, over the period 2002-2012, deceleration took place in the TDF deforestation in the zone of study. The difference between this and the estimate for the period 1973-1989 could be related to policies applied during 1970-1976, when land and credits for elimination of vegetation were distributed (Merino-Pérez, 2004). As a result of these policies, livestock production grew and the area dedicated to this activity increased by more than 100% (Word Bank, 1995). The observed deceleration of deforestation, rather than being the result of efficient conservation policies, could be the product of a lack of resources for agricultural exploitation or that the areas of conserved forest are located in zones that are unsuitable for the development of agricultural activities.

Halting deforestation is a primary goal of conservation. The evidence provided by this study shows that, even when deforestation is halted and coverage of secondary vegetation diminished, no increase was recorded in the coverage of primary ecosystems. This occurred because land use change produced an increased area of urban zones, in a process driven by two factors: poverty and a modification to the Mexican constitution in 1992 that eliminated prior restrictions regarding the sale of communal land (Secretaría de Gobernación, 1992). The interviews revealed that the majority of the agricultural areas of TDF sold had been previously abandoned because owners lacked the financial resources to work their land. As a consequence, some owners migrated to the United States and the abandoned land became covered by secondary vegetation. While forest deforestation is restricted, agricultural land and land covered with secondary vegetation can be sold freely, allowing a direct relationship between the sale of communal lands and the conversion to urban zones of land under active agricultural use and/or abandonment with secondary vegetation.

The results of this study suggest that TDF covered more than 70% of the Río Apatlaco sub-basin but is currently reduced to less than 20% and dominated by fragments of TDFd and TDFs. The data shows that TDFd has not recovered, since the secondary vegetation and grasslands derived from TDF have become urban zones, instead of returning to TDF. The 246 fragments of TDF in primary condition and 418 disturbed fragments are chronically reduced and isolated and cannot increase in area. The matrix that surrounds them could act to impede the movement of organisms, especially where it is dominated by urban areas and roads.

The TDF is the most fragmented forest in the sub-basin, a finding that agrees with a prior evaluation of the status of this forest on the Mexican Pacific coast (Miles *et al*., 2006). The number of fragments of TDF is twice that of the coniferous forest, four times that of the oak forest and six times that of the pine-oak forest (Table 5). In addition to this high fragmentation, only three fragments of TDF are greater than 100 ha. Of these, two are greater than 128 ha (Figure Nº 2), but the majority of fragments are between 2 and 16 ha. In the coniferous, oak and pine-oak forests, there is at least one fragment greater than 500 ha.

The decline and high fragmentation of the TDF in its different states of conservation are a direct threat to biodiversity, since some species of flora and fauna may require continuous TDF in order to sustain their populations (Henle *et al*., 2004; Raghubanshi and Tripathi, 2009). Further reduction and fragmentation of the TDF could increase the threat to the survival of many species of plants and animals. Raghubanshi and Tripathi (2009) found that the TDF plant communities of least area are also those with lower species richness and diversity.

Continuous monitoring of changes in vegetal coverage at the regional scale is important in order to obtain updated information, evaluate trends and to understand the behaviour of these trends over time (Ernst *et al*.,2013; Miles *et al*., 2006; Whitehurst *et al*., 2009), but also for urban planning and prioritization of restoration actions in key zones or vegetation types. Regional scale monitoring can prompt actions to correct trends of change; for example, at the global scale, only population density is perceived as a factor that affects TDF (Miles *et al.,* 2006) but, at regional scale, urban development is identified as the mechanism that impedes recovery of TDF, but not the demand for expanding agricultural areas. Conserving forest resources in the face of increasing human pressure is a challenging task, as urbanization does nothing to allow ecosystem recovery (Whitehurst *et al.*, 2009). In accordance with other areas of TDF (Whitehurst *et al*., 2009), in those of the studied region it is necessary to protect secondary and disturbed areas that serve as a buffer for the remaining fragments and could allow the TDF to recover. In the studied sub-basin, natural protected areas do not include TDF and urban expansion into secondary vegetation is allowed. Creation of protected areas in areas of TDF will help to conserve the primary vegetation but also to protect TDFd and TDFs vegetation, which can act as buffers or as areas for TDF recovery. Studies of the effects of chronic reduction and isolation of the TDF on organisms are also a priority.

Bibliographic References

ANDERSON, J.R.; HARDY, E.E.; ROACH, J.T. & WITMER, R.E. A *land use and land cover classification system for use with remote sensor data*. Washington: Geological Survey Professional Paper No. 964, U.S. Government Printing Office, 1976.

BERNARD, R. Structured interviewing. In: BERNARD, R. (editor). *Research methods in cultural anthropology: qualitative and quantitative approaches*. London: Altamira Press, 1994, p.237-255.

CEBALLOS, G. & GARCÍA, A. Conserving neotropical biodiversity: the role of dry forest in western México. *Conservation Biology*.1995, Vol. 9, Nº 6, p.1349–1353.

CONTRERAS-MACBEAT, T.; JARAMILLO, F.; MONROY, R. y BOYÁS-DELGADO, J.C. *La diversidad biológica en Morelos. Estudio de Estado*. México: CONABIO/Universidad Autónoma del Estado de Morelos, 2004.

COMISIÓN NACIONAL DEL AGUA (CNA). *Programa Hídrico Visión 2030 del Estado de Morelos*. México: Secretaría del Medio Ambiente y Recursos Naturales, 2010.

CRUZ-FERNÁNDEZ, Q.T.; ALQUICIRA-ARTEAGA M.L. & FLORES-PALACIOS, A. Is orchid species richness and abundance related to the conservation status of oak forest? *Plant Ecology*, 2011, Vol. 212, Nº 7 p.1091–1099.

ERNST,C.; MAYAUX, P.;VERHEGGHEN, A.; BODART, C.; CHRISTOPHE, M. & DEFAURNY, P. National forest cover change in Congo Basin: Deforestation, reforestation, degradation and regeneration for years 1990, 2000 and 2005. *Global Change Biology,* 2013, Vol. 19, Nº 4 p. 1173–1187.

FLORES, O. y GEREZ, P. *Conservación en México: Síntesis sobre vertebrados terrestres, vegetación y uso de suelo*. México: Instituto Nacional de Investigaciones sobre recursos bioticos/Conservación internacional, 1994.

FUEYO, L. *Manglares de México*. México: Comisión Nacional para el Conocimiento y uso de la Biodiversidad, 2008.

GOETZ, S.J.; BACCINI, A.; LAPORTE, N.T.; JOHNS, T.; WALKER, W.; KELLNDORFER, J.; HOUGHTON, R.A. & SUN, M. Mapping and monitoring carbon stocks with satellite observations: a comparison of methods. *Carbon Balance and Monitoring*, 2009, Vol. 4, Nº 2, p. 1-7.

HE, F. & HUBBELL, P. Species–area relationships always overestimate extinction rates from habitat loss. *Nature,* 2011, Vol. 473**,** p. 368–371.

HENLE, K.; DAVIES, K.F.; KLEYER, M.; MARGULES, C. & SETTELE, J. Predictors of species sensitivity to fragmentation. *Biodiversity and Conservation*, 2004, Vol.13, Nº 1, p. 207–251.

INSTITUTO NACIONAL DE ESTADÍSTICA, GEOGRAFIA E INFORMATICA (INEGI). *Anuario estadístico 2005*. Cuernavaca: INEGI, 2005.

JOHNSON, R.A. & WICHERN, D.W. Applied Multivariate Statistical Analysis. *Upper Saddle River*, New York: Prentice-Hall, 2002.

MAS, J.F.; SORANI, V. y ÁLVAREZ, R. Elaboración de un modelo de simulación del proceso de deforestación. *Investigaciones Geográficas*, 1996, Nº 5, p.43-47.

MERINO-PÉREZ, L. *Conservación o deterioro. El impacto de las políticas en las instituciones comunitarias y en las prácticas de usos de los recursos forestales en México.* México: Instituto Nacional de Ecología, 2004.

MILES, L.; NEWTON, A.C.; DEFRIES, R.S.;RAVILIOUS, C.; MAY, I.; BLYTH, S.; KAPOS, V. & GORDON, J.E. A global overview of the conservation status of tropical dry forest. *Journal of Biogeogaphy*, 2006, Vol. 33, p. 491–505.

ORGANIZACIÓN DE LAS NACIONES UNIDAS PARA LA ALIMENTACIÓN Y LA AGRICULTURA (FAO). *Evaluación de los recursos forestales mundiales 2005 - hacia la ordenación forestal sostenible*. Roma: Estudio FAO, Montes N° 47, 2006.

PALACIOS-PRIETO, J.L.; BOCCO, G.; VELÁZQUEZ, A.; MAS. J.F, TAKAKI-TAKAKI, F.; VICTORIA, A.; LUNA-GONZÁLEZ, L.; GÓMEZ-RODRÍGUEZ, G.; LÓPEZ-GARCÍA, J.; PALMA-MUÑOZ, M.; TREJO-VÁZQUEZ, I.; PERALTA HIGUERA, A.; PRADO-MOLINA, J.; RODRÍGUEZ- AGUILAR, A.; MAYORGA-SAUCEDO, R. y GONZÁLEZ-MEDRANO, F. La condición actual de los recursos forestales en México: resultados del Inventario Forestal Nacional. *Investigaciones Geográficas*, 2000, Nº 43 p. 183–203.

SAGARPA. *Programa Nacional de Microcuencas.* México: Secretaría de Agricultura, Ganadería, Desarrollo rural, Pesca y Alimentación, 2006.

SECRETARIA DE GOBERNACIÓN. Decreto por el que se Reforma el artículo 27 de la Constitución política de los Estados Unidos Mexicanos. *Diario Oficial de la Federación*, Vol. CDLX, 1992, N° 3, Enero 6.

SEMARNAT. *Manual del Proceso de Ordenamiento Ecológico. Anexo 5. Análisis de aptitud con técnicas multicriterio*. México: Secretaría de Medio Ambiente, Recursos Naturales y Pesca, 2012.

RAGHUBANSHI, A.S. & TRIPATHI, A. Effect of disturbance, habitat fragmentation and alien invasive plants on floral diversity in dry tropical forests of Vindhyan highland: a review. *Tropical Ecology*, 2009, Vol. 50, Nº 1, p. 57-69.

RINCÓN, E. & HUANTE, P. Growth responses of tropical deciduous tree seedlings to contrasting light conditions. *Trees,* 1993, Nº 7, p. 202–207.

RZEDOWSKI, J. Diversidad y orígenes de la flora fanerogámica de México. *Acta Botánica Mexicana*, 1991a, Nº 14, p. 3–21.

RZEDOWSKI, J. El endemismo en la flora fanerogámica mexicana: una apreciación analítica preliminar. *Acta Botánica Mexicana*, 1991b, Nº 15, p. 47-64.

TREJO, I. & DIRZO, R. Deforestation of seasonally dry tropical forests: a national and local analysis in Mexico. *Biological Conservation*, 2000, Vol. 94, Nº 2 p. 133-142.

WHITEHURST, A.S.; SEXTON, J,O. & DOLLAR, L. Land cover change in western Madagascar's dry deciduous forests: A comparison of forest changes in and around Kirindy Mite National Park. *Oryx*, 2009, Vol 43, Nº 2, p. 275–283.

WORLD BANK *Estudio de revisión del sector forestal y conservación de recursos. Report 13114-ME*. México: Oficina Regional de América Latina y el Caribe, 1995.