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Analysis of Land Use and Land Cover Changes and Evaluation of Natural Generation and Potential Restoration Areas in the Mexican Huasteca Region

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This study aims to analyze temporal changes in land use and land cover change (LUCC) as well as identify areas for natural regeneration and potential areas for forest restoration in the Huasteca region for the period from 1976 to 2007. Changes were quantified in numbers and, additionally, cartography was used to identify and map the main affected areas. Different models based on Geographic Information Systems (GIS) demonstrated that LUCC have occurred on an area of 11718.82 km^2, representing 17.84% of the region's surface. Agriculture and the growth of pasture could be identified as the main human-induced activities that have led to landscape modification. In addition, forest cover is affected by a deforestation rate which is higher than the national average. Further important changes include a change from natural land cover to non-original land cover, affecting an area of 4911.88 km^2 in the period from 1976-1993, and an area of 1892.5 km^2 in the period from 1993-2002. Smaller changes could be observed for the period from 1993-2002 with an affected area of 1029.78 km^2. At the same time, a natural regeneration from non-original to original land cover took place from 1976-1993 on an area of 1318.68 km^2, and also on an area of 974.18 km^2 between 1993 an 2002. The surface that underwent a natural regeneration of forest cover made up 1932.07 km^2. At the same time, an area of 5739.29 km^2 for potential forest restoration was identified. Drawing on GIS methods and techniques, the development of thematic maps for land use, land use and land cover changes for the years of analysis (1976-1993-2002-2007) proved to be very adequate for the evaluation and analysis of the land cover and land use change, in particular with regard to the decrease of natural vegetation cover.

Keywords: Land User; Land Cover; Natural Regeneration; Forest Restoration; LUCC; GIS; Temporal Analysis; Huasteca

Introduction

In the twentieth century, human-induced activities substantially changed the biophysical surface of the earth (Ramankutty et al., 2006), due to the fact that the human population gained possession of between 20% and 40% of primary net productivity of the planet. At the same time, changed consumption patterns based on the development of economic activities had a direct influence on the transformation of ecosystems (Vitouseck et al., 1986; Bassols, 1993; Oliva et al., 2010). This has provoked the generation of differentiated spatial patterns of land use change which, generally, are reflected in the loss of areas with natural vegetation such as temperate or tropical forests (López-Blanco, 2005).

This ambition to convert forests and rain forests in grounds for livestock production and agriculture has caused annual deforestation rates of up to 2% in the world's rain forests (Dirzo & García, 1995; Castillo-Santiago et al., 2007; Pacheco et al., 2009). In the case of the Mexican Republic, 52% of the country's total surface of 1,945,748 km^2 was covered by forests, rainforests and large areas of scrublands with tree vegetation that reached a height of up to 3 meters.

The National Forest Inventory for the year 2000 registered a loss of 36% with regard to forest and rainforest ecosystems (Ricker, 2010). According to Velazquéz et al., (2002), deforestation rates in Mexico vary between −0.25% and −1.02% for the period from 1976 to 2000, indicating a loss of 0.25% and 1.02% of forest cover per year. Land use mapping data from the National Institute for Statistics and Geography until the year 2007 indicates that in the year 2007, forest areas in Mexico

were only made up approximately 64,785,000 hectares of forest and 20,128,000 hectares of other forest areas (FAO/FRA, 2010).

Especially in the Huasteca Region in Mexico, forest cover has been modified in various ways as a result of human-induced activities. The most important alteration can be observed with regard to rainforests and forest (Quinteros, 2012). Capitalist modernization has accelerated and deepened these changes since the age of industrialization provoked the increase of livestock herding, the demand for wood and the need for wood-derived products (Aguilar-Robledo, 2001).

Despite this loss of forest cover in the past, there is little quantifiable information on the deforestation rate and other changes in land use and land cover that have occurred in this important Mexican region, which has traditionally been famous for great natural potential due to forest resources.

Hence, the timely and precise evaluation of patterns pertaining to land use and land use change allows understanding how regeneration, succession and degradation processes work in woodland ecosystem (Márquez-Linares et al., 2005). At the same time, this study will contribute to the development of forest management, conservation and restoration strategies in an area affected by human-induced activities (Zepeda et al., 2012b).

Based on the previous discussion, this study aims to evaluate the changes in land use and land cover in the Huasteca region in order to quantify and map the main affected areas as well as generate information on forest resources and decision-making for a sound forest management and the restoration of forest cover.

Study Area

The Huasteca region is divided into different political and administrative entities, each of which is named according to the state of the Mexican Republic to which it belongs. This is how the Huasteca is constituted by the Huasteca "hidalguense, potosina, tamaulipeca, veracruzana, poblana y queretana" (**Figure 1**). The region is located between 22˚16'00" Northern Latitude and 98˚30'00" Western Longitude; covering approximatelty 65675.85 km^2 with a population of about 3,064,711 habitants (CONABIO, 2012).

Within the region, different biophysical climate and vegetation factors come together with human-induced activities such as agriculture and livestock production, which may have an important impact on the transformation of ecosystems (Algara, 2009).

Methodology

Preparation of the Data Base

The methodological approach was based on the use of a Geographical Information System, which allowed analyzing changes in land use and land cover with a reasonable degree of effectiveness (Treitz & Rogan, 2004; Berberoglu & Akin, 2009). This method made it possible to collect, to structure and to analyze important spatial information for the management of tropical areas such as the Huasteca region (Green et al., 1996; Klemas, 2001).

Many research projects on large areas use cartography from official sources (Velázquez et al., 2002; Rosete-Vergés et al., 2009; Miranda-Aragón et al., 2013), being also the case of the Huasteca Region. Accordingly, the data base for land use and vegetation was used corresponding to series I (t_1) (1976), series II (t_2) (1993), series III (t_3) (2002), and series IV (t_4) (2007) on a scale of 1:250,000, provided by the National Institute for Statistics and Geography (INEGI) which had generated and carried out a process of data validation. In order to obtain the data base for the study area, maps on land use and vegetation were merged and projected on the coordinate system UTM WGS-84 of the area 14 North, in order to guarantee a better overlap of polygons, and finally be able to be able to extract the study area.

Finally, classes of land cover and land use were standardized, and the following classes were established: agriculture, water, urban areas, forest, scrubland, other types of vegetation, grassland, rainforest, without vegetation and secondary vegetation (**Figure 2**) (**Appendix 1**).

Likewise, the different standardized classes were reclassified as natural covers, non original covers, water and urban areas with the aim to analyze the effect of human-induced activities on the land use and land cover in the region (Weckmüller et al., 2011; Peralta et al., 2013) (**Figure 2**) (**Appendix 1**).

Analysis of Processes of Land Use and Land Cover Changes, Natural Regeneration and Restoration Areas

In order to obtain statistical data and maps on land use and-land cover changes standardized and cartography sources were superimposed with reclassified cartography sources from the series t_1, t_2, t_3 and t_4.

This part of the analysis allowed generating a reliable mapping tool which expressed the magnitude as well as the spatial distribution of land cover and land use change dynamics in the Huasteca region.

In order to describe the dynamics of change in the forest cover, a "deforestation process" model was developed, based on which change rates were calculated according to the equation introduced by the FAO (1996) (Equation (1)). This rate expresses change in terms of the percentage of the surface at the beginning of each year. For each of the other standardized classes, the same procedure was used, in a way that the results reflect all transitions regarding land cover and land use.

$$\delta_n = \left(\frac{S_2}{S_1}\right)^{1/n} - 1 \qquad (1)$$

where δ is the change rate (in order to express percentage, it has to be multiplied by 100);

S_1 is the surface on the first date 1;

S_2 is the surface on the second date 2;

n is the number of years between the two points of time.

Covers that were affected by systematic transitions were distinguished from those where change happened randomly. Dominant marks of change and indications for change were identified as well as gross gains and losses, with the aim to obtain the total change in the respective categories (Pontius et al., 2004). To this end, a cross-tabulation or change matrix was developed by crossing the maps created at a specific time (time 1 and time 2). In the said matrix, the rows represent the categories of the map in time 1 ($T1$) and the columns represent the categories of the map in time 2 ($T2$). In addition, another column is added in order to represent the deforestation rate or land use and land

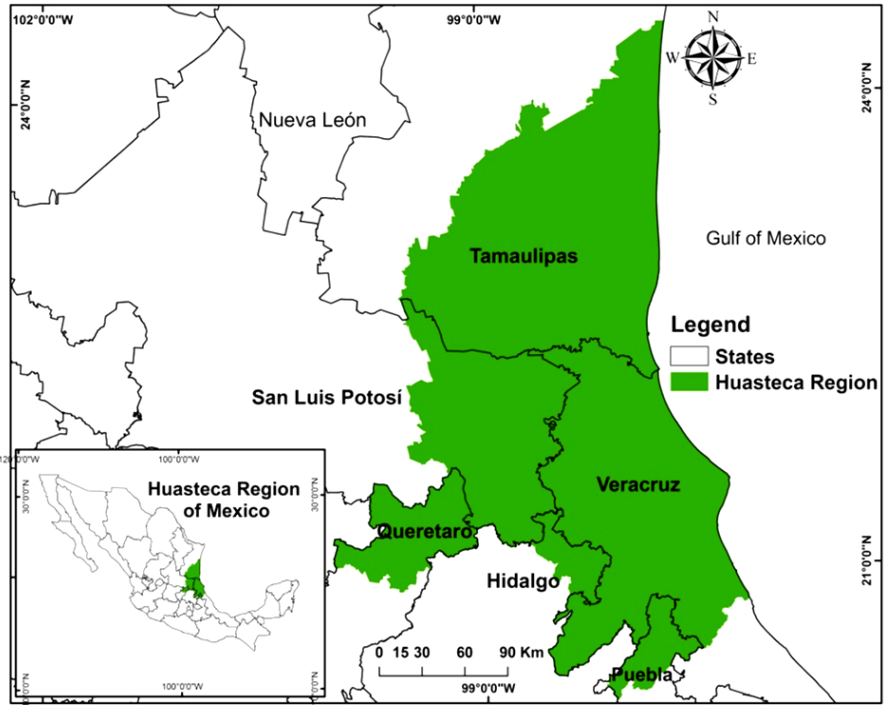

Figure 1.
Map of the study area.

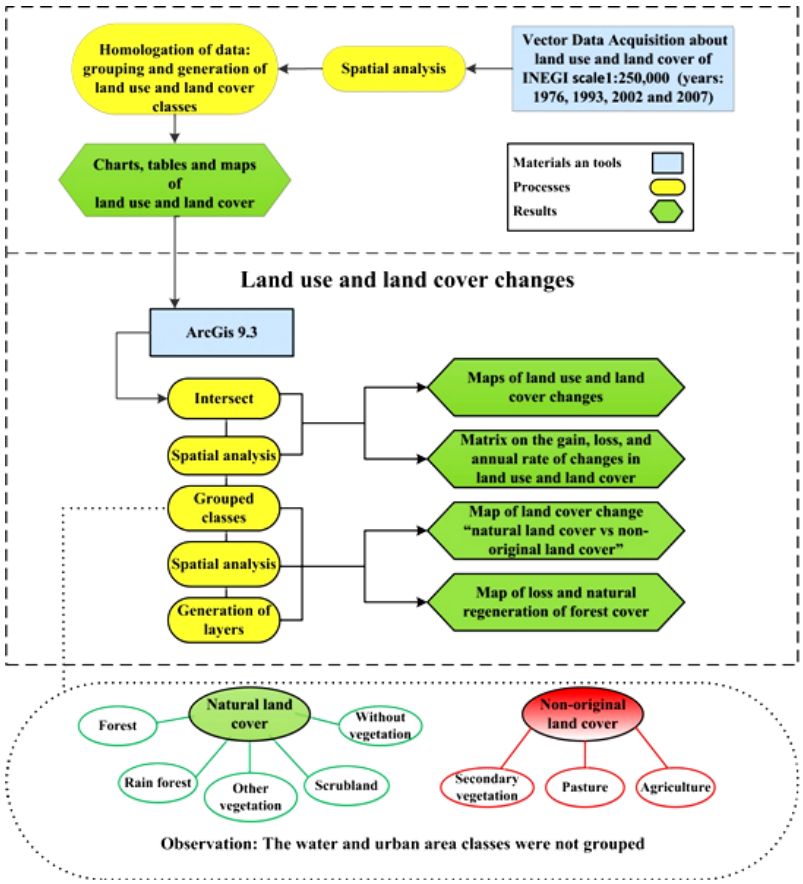

Figure 2.
Flowchart of the stages developed in the analysis of land cover and land use change.

cover change for the different classes (Table 1).

Finally, to estimate the areas that were subject to the natural regeneration of vegetation, those covers were quantified and mapped which had reached a primary forest stratum. To identify restoration areas were recognized forest areas changed to other land uses (1976-2007) and which had a restoration potential.

Results and Discussion

Land Use and Land Cover

The dynamics of land use and land cover in the Huasteca region can be reconstructed for a timeframe of 31 years (Table 2) (Figure 3), based on the analysis of the obtained information.

Table 2 indicates that the biggest areas that were mapped and quantified correspond to agriculture and pasture, representing approximately 60% of the surface of the Huasteca region in the year 2007. It can be observed that the share of agricultural land has increased by 50% over the past 31 years. This shows that agricultural modernization and industrialization, the increase of livestock, and the demand for wood and wood-derived products have an important stake in the considerable increase of land cover types that were induced by humans (Aguilar-Robledo, 2001).

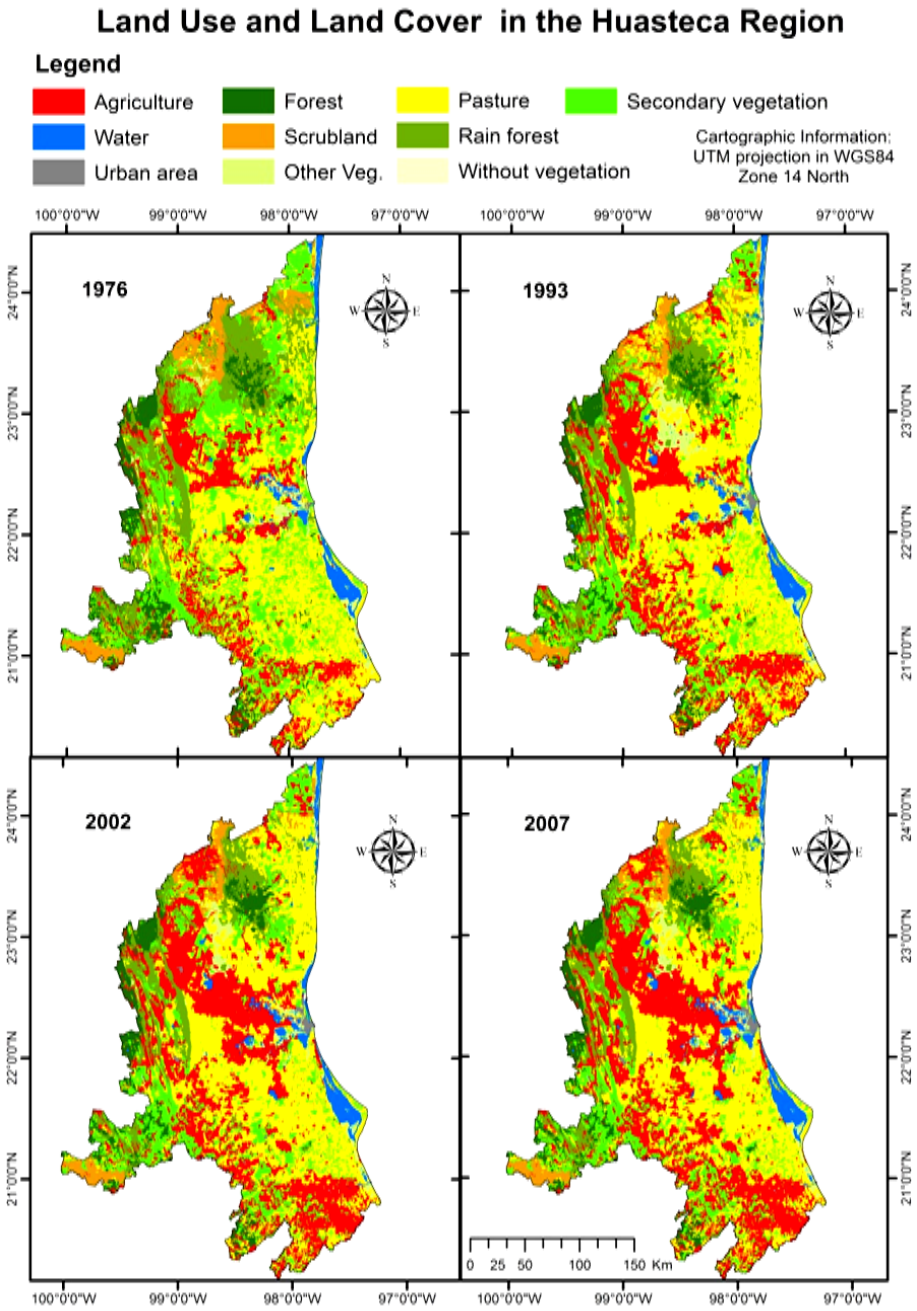

Figure 3.
Land use and land cover in the Huasteca region (1976-2007).

Table 1.
Cross-tabulation matrix for two maps from different dates.

		Time 2						
Time 1	1	2	3	4	5	6	7	8
1		*Class* 1	*Class* 2	……	*Class n*	*Total* T_1	*Loss* (L_{ij})	*Lossrate*
2	*Class* 1	P_{11}	P_{12}	……	P_{1n}	P_{1+}	$P_{1+} - P_{11}$	%
3	*Class* 2	P_{21}	P_{22}	……	P_{2n}	P_{2+}	$P_{2+} - P_{22}$	%
4	……	……	……	……	……	……	……	%
5	*Class n*	P_{n1}	P_{n2}	……	P_{nn}	P_{n+}	$P_{n+} - P_{nn}$	%
6	*Total* T_2	P_{+1}	P_{+2}	……	P_{+n}	P		
7	*Gain* (G_{ij})	$P_{+1} - P_{11}$	$P_{+2} - P_{22}$	……	$P_{+n} - P_{nn}$			

Source: Pontius et al., 2004 y FAO, 1996.

Table 2.
Sistematization of the areas according to class and year of classification.

	1976	**1993**	**2002**	**2007**	**1976**	**1993**	**2002**	**2007**
Classes	**km²**	**km²**	**km²**	**km²**	**%**	**%**	**%**	**%**
Agriculture	10206.76	14265.25	17701.80	18477.82	15.54	21.72	26.95	28.13
Water	1911.56	2245.01	2242.83	2313.97	2.91	3.42	3.42	3.52
Urban area	51.39	351.03	438.64	508.87	0.08	0.53	0.67	0.77
Forest	4165.14	3598.73	3553.75	3548.43	6.34	5.48	5.41	5.40
Scrubland	3064.50	2360.94	2177.06	2148.29	4.67	3.59	3.31	3.27
Other vegetation	1726.66	2385.14	1686.28	1713.34	2.63	3.63	2.57	2.61
Pasture	18067.40	22169.03	20882.93	20148.85	27.51	33.76	31.80	30.68
Rain forest	9410.23	6665.79	6088.87	6102.92	14.33	10.15	9.27	9.29
Without vegetation	25.51	72.36	71.24	71.90	0.04	0.11	0.11	0.11
Secondary vegetation	17046.70	11562.57	10832.44	10641.45	25.96	17.61	16.49	16.20

Obtained data demonstrates that for the studied years, forest cover (rain forest, forest and scrubland) in particular has been reduced, as affirmed by Quinteros (2012).

Land Use and Land Cover Changes

The most reliable statistical data for the analysis of land use and land cover changes use for the years of study correspond to data on the vegetal cover, while the least reliable data refers to water and urban areas. Data of land use and land cover shows slight imprecision with regard to the transition, which has also occurred in other analysis on land cover and land use change in Mexico (Velázquez et al., 2002). Nonetheless, reasonable evidence of LUCC was found when crossing t_1-t_2, t_2-t_3 and t_3-t_4, while also taking account of the particular dynamics of the ecosystems that had been analyzed.

Of the changes that occurred between t_1-t_2, the increase in agriculture (1.99%) as well as a change in the deforestation rate of rain forests −2.01% must be noted, the latter being higher than the general national deforestation rate for Mexico,(−0.25 and −1.02%) according to Velázquez et al., 2002, and (−0.76%) according to Mas et al., (2009). In comparison, only the state of Veracruz has a higher deforestation rate (−2.2%), and the deforestation rate is generally lower in all other states of the Mexican Republic (Céspedes-Flores & Moreno-Sánchez, 2010). Furthermore, urban areas increased by 500% over the same time period, while areas without vegetation, despite the fact that their growth rate is merely 6.33%, have increased by 56.03 km^2 (**Table 3**).

Between 1993 and 2002 (t_2-t_3), most classes of land cover and land use suffered from losses, except for agriculture, water and urban areas. The greatest loss of forest cover was registered for the categories “other types of vegetation” (−3.78%) and “rain forest” (−1.41%), again at a higher rate than the rate calculated by Velázquez et al., (2002). For other types of land cover and land use the loss was less amounting to 0.9% (**Table 4**).

Between 2002 and 2007 (t_3-t_4), the loss and gain rates of land use and land cover were much smaller than for the previous periods. A gain could be observed for the category rain forest and other vegetation with 249.55 km^2 and 236.55 km^2 respectively. Also, urban areas increased annually by 3.01%, and agriculture by 0.86%, as reported by Algara (2009), which had an important impact on the transformation of ecosystems (**Table 5**).

General Changes in Land Use and Land Cover

By crossing data from four years (1976, 1993, 2002 and 2007) it can be observed that the pressure of human-induced activities on natural land cover (forest, rain forest, other vegetation, scrubland and no vegetation) has increased exponentially, which translates into an increase of non-original cover (secondary vegetation, pasture and agriculture). Despite this, in 2007

Table 3.
Cross-tabulation matrix or change matrix between t_1 and t_2 (data in km^2).

	1993												
1976	Agriculture	Water	Urban area	Forest	Scrubland	Other vegetation	Pasture	Rain forest	Without vegetation	Secondary vegetation	Total 1976	Loss	Lossrate (%)
Agriculture	**7901.13**	98.60	103.12	94.48	30.49	362.92	761.07	136.26	3.65	715.04	10206.76	2305.63	1.99
Water	37.85	**1602.29**	0.00	0.14	6.30	154.86	70.37	4.82	22.76	12.17	1911.57	309.28	0.97
Urban area	0.58	1.28	**48.33**	0	0	0.31	0.87	0	0.01	0	51.39	3.06	11.82
Forest	168.69	0.71	1.23	**2968.13**	27.54	9.57	166.44	138.25	0	684.60	4165.14	1197.01	−0.86
Scrubland	136.14	7.37	1.71	5.43	**2077.65**	13.28	634.57	49.94	0	138.40	3064.50	986.85	−1.52
Other vegetation	166.78	259.82	8.02	5.11	24.93	**843.03**	311.93	41.69	14.41	50.94	1726.67	883.63	1.92
Pasture	2238.15	149.35	106.30	58.48	18.91	236.94	**13259.08**	155.47	5.11	1839.61	18067.40	4808.32	1.21
Rain forest	684.77	25.30	9.30	187.12	62.40	50.51	1774.82	**5874.45**	2.02	739.55	9410.23	3535.78	−2.01
Without vegetation	0	2.61	0.22	0	0	3.49	0.68	0	**16.34**	2.16	25.51	9.17	6.33
Secondary vegetation	2931.15	105.61	64.87	279.85	112.72	710.22	5189.22	264.90	8.07	**7380.08**	17046.69	9666.61	−2.26
Total 1993	14265.25	2252.95	343.09	3598.73	2360.94	2385.14	22169.03	6665.79	72.37	11562.56			
Gain	6364.12	650.66	294.76	630.60	283.28	1542.11	8909.96	791.34	56.03	4182.48			

Table 4.
Cross-tabulation matrix or change matrix between t_2 and t_3 (data in km^2).

	2002												
1993	Agriculture	Water	Urban area	Forest	Scrubland	Other vegetation	Pasture	Rain forest	Without vegetation	Secondary vegetation	Total 1993	Loss	Lossrate (%)
Agriculture	**12579.24**	49.44	45.32	67.39	41.76	81.43	807.98	154.83	0.03	437.85	14265.25	1686.01	2.43
Water	60.94	**2071.78**	0.00	0.81	2.85	77.61	0.00	0.00	10.26	20.78	2245.01	173.24	0.45
Urban area	43.30	6.81	**295.17**	0.00	0.42	2.36	0.00	0.00	0.00	2.96	351.03	55.85	2.85
Forest	70.40	0.80	1.32	**3088.95**	5.91	2.75	114.60	77.81	0.00	236.19	3598.73	509.78	−0.14
Scrubland	140.56	8.35	0.51	4.35	**1959.26**	24.84	136.88	53.92	0.00	32.27	2360.94	401.68	−0.90
Other vegetation	132.94	74.12	9.72	1.42	16.85	**1374.88**	555.19	66.76	2.80	150.46	2385.14	1010.27	−3.78
Pasture	3547.92	94.99	60.44	68.45	84.87	81.43	**17436.16**	0.00	0.96	793.81	22169.03	4732.87	−0.60
Rain forest	232.08	9.66	13.17	199.76	35.59	14.17	420.05	**5382.64**	1.15	357.51	6665.79	1283.15	−1.41
Without vegetation	0.00	3.43	2.05	0.00	0.00	4.72	2.43	0.00	**54.40**	5.34	72.36	17.96	−0.12
Secondary vegetation	894.40	17.94	24.27	122.08	29.56	22.11	1523.69	131.24	2.02	**8795.27**	11562.57	2767.31	−0.72
Total 2002	17701.79	2337.30	451.98	3553.21	2177.06	1686.29	20996.98	5867.19	71.61	10832.44			
Gain	5122.55	265.53	156.80	464.26	217.80	311.41	3560.82	484.55	17.21	2037.17			

the Huasteca region still conserved approximately 10602.59 km^2 of original land cover representing 16.4% of the surface (Table 6).

Furthermore, the development of total changes in land cover and land use amount to 17.84%, or 11718.82 km^2 of the Huasteca region (Table 7), as shown in detail in (Table 8).

Table 5.
Cross-tabulation matrix or change matrix between t_3 and t_4 (data in km^2).

	2007												
2002	Agriculture	Water	Urban area	Forest	Scrubland	Other vegetation	Pasture	Rain forest	Without vegetation	Secondary vegetation	Total 2002	Loss	Lossrate (%)
Agriculture	**16829.65**	19.07	32.79	9.47	0.85	24.18	351.08	77.46	0.55	356.71	17701.80	872.15	0.86
Water	1.16	**2184.40**	0.00	0.00	2.22	46.30	5.81	1.55	0.14	1.26	2242.84	58.44	0.63
Urban area	0.70	0.12	**437.41**	0.02	0.00	0.00	0.36	0.00	0.00	0.03	438.64	1.23	3.01
Forest	14.91	0.00	0.00	**3496.50**	0.57	3.43	19.01	4.08	0.00	15.24	3553.75	57.25	−0.03
Scrubland	12.60	0.11	0.45	0.53	**2128.25**	0.82	30.71	0.03	0.00	3.56	2177.06	48.82	−0.27
Other vegetation	77.09	71.71	3.02	0.00	0.11	**1476.80**	25.51	3.83	0.68	27.54	1686.29	209.49	0.32
Pasture	757.71	37.04	26.80	13.74	15.46	143.84	**19306.69**	55.46	1.49	524.69	20882.93	1576.24	−0.71
Rain forest	64.79	0.91	0.00	22.36	0.00	0.06	58.45	**5853.37**	0.61	88.34	6088.87	235.51	0.05
Without vegetation	0.11	0.00	0.00	0.00	0.00	2.80	0.07	0.46	**67.16**	0.64	71.24	4.08	0.18
Secondary vegetation	719.22	0.51	8.39	5.82	0.83	15.12	351.16	106.68	1.28	**9623.43**	10832.44	1209.00	−0.36
Total 2007	18477.93	2313.87	508.87	3548.43	2148.29	1713.35	20148.85	6102.92	71.90	10641.45			
Gain	1648.28	129.47	71.46	51.93	20.04	236.55	842.16	249.55	4.74	1018.02			

Table 6.
Evolution of the status and changes in all the grouped and maintained covers in the years 1976, 1993, 2002 and 2007.

Covers that maintained the same state	km^2	%
Natural cover maintained until 2007	10602.59	16.14
Non-original cover maintained until 2007	41158.59	62.67
Urban area maintained until 2007	46.97	0.07
Water maintained until 2007	1478.60	2.25
Cover changes	11718.82	17.84
Error	670.29	1.02

Table 7.
General evolution of land cover change for the Huasteca region from 1976 until 2007.

Development of changes in land cover and land use	km^2	%
Cover maintained until 2007	53,286.74	81.14
Changes in cover until 2007	11,718.82	17.84
Error	670.29	1.02

Table 8 indicates that the main changes occurred with regard to natural covers which transformed into non-original covers, mostly in the period of time between 1976 and 1993 with 4911.88 km^2, followed by 1892.5 km^2 for the period of time between 2002 and 2007, and finally 1029.78 km^2 for the period of time between 1993 and 2002.

In spite of this loss of natural cover, 1318.68 km^2 were recovered between 1976 and 1993, 974.18 km^2 between 1993 and 2002 as well as 468.43 km^2 between 2002 and 2007. The total change in land cover (17.84%) for the Huasteca region, equaling 11,718.82 km^2, can be observed in 100% (Figure 4).

Natural Regeneration and Potential Areas for Restoration

Areas of land cover and land use that regenerated naturally to forest cover between the years 1976 and 2007 are approximately 721.25 km^2 of forest area and 1210.82 km^2 of rain forests, without taking into account changes between other forest covers. The greatest natural regeneration took place between 1976 and 1993 for both forest types. At the same time, the greatest loss of these ecosystems falls also into this timeframe (1021.66 km^2 of forest area and 3235.75 km^2 of rain forest). In

Table 8.
Changes in land use and land cover of reclassified classes in the Huasteca region, years 1976, 1993, 2002 and 2007.

Cambios en las Coberturas	km^2	%
Water that changed to non-original land cover between 1976-1993	79.32	0.12
Water that changed to natural land cover between 1976-1993	92.66	0.14
Water that changed to natural land cover between 1993-2002	83.09	0.13
Water bodies mantained between 1976 and 2007*	1478.60	2.25
Urban area maintained between 1976 and 2007*	46.97	0.07
Non-original land cover that changed to water between 1976-1993	243.15	0.37
Non-original land cover that changed to urban area between 1976-1993	210.42	0.32
Non-original land cover that changed to natural land cover 1976-1993	1318.68	2.01
Non-original land cover that changed to natural land cover 1993-2002	974.18	1.48
Non-original land cover that changed to natural land cover 2002-2007	468.43	0.71
Natural land cover that changed to water between 1976-1993	211.39	0.32
Natural land cover that changed to water between 1993-2002	90.38	0.14
Natural land cover that changed to water between 2002-2007	73.02	0.11
Natural land cover that changed to urban area between 1976-1993	14.44	0.02
Natural land cover that changed to urban area between 1993-2002	25.51	0.04
Natural land cover that changed to non-original land cover 1976-1993	4911.88	7.48
Natural land cover that changed to non-original land cover 1993-2002	1029.78	1.57
Natural land cover that changed to non-original land cover 2002-2007	1892.50	2.88
Non-original land cover maintained between 1976-2007*	41158.59	62.67
Natural land cover maintained between 1976-2007*	10602.59	16.14
Error or other changes of land use and land cover**	670.29	1.02
Total	65675.85	100

*Covers without a change in land use or land cover from 1976 until the year 2007. **The margin of error refers to possible inconsistencies with regard to classification; inconsistent changes in land use and land cover take into account the individual dynamics of ecosystems and problems of overlap.

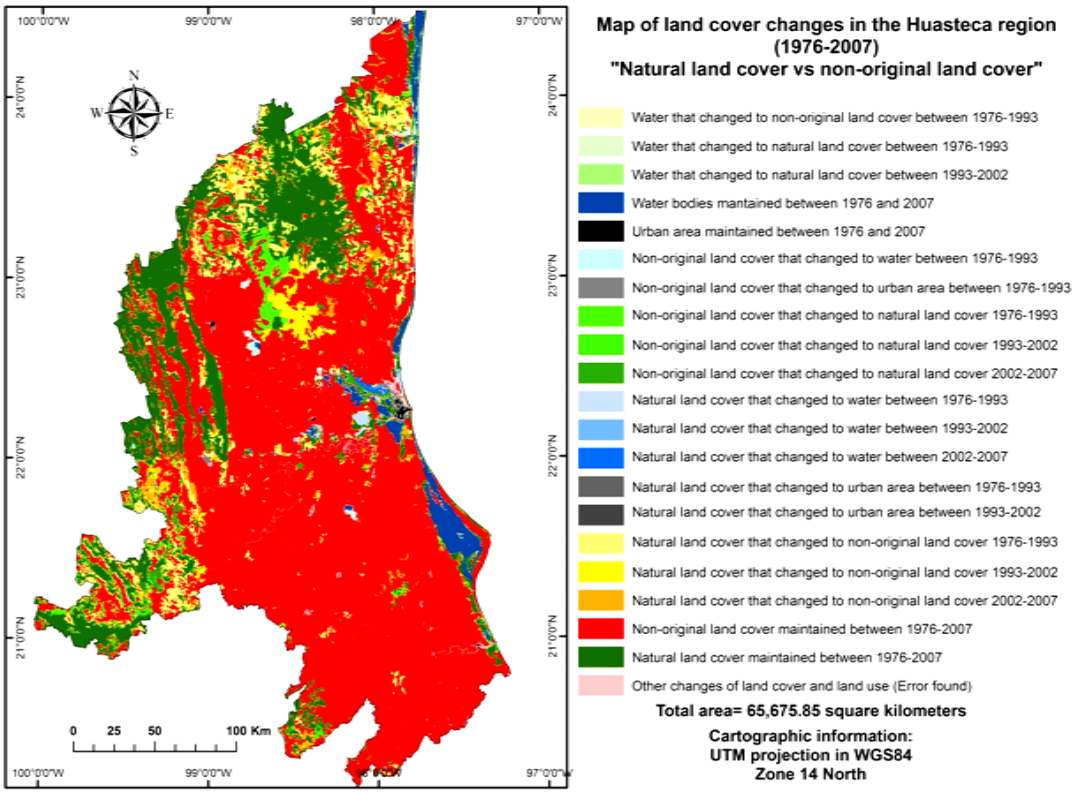

Figure 4.
Land covers dynamics of the grouped classes for the Huasteca región, for the periods 1976-1993, 1993-2002 and 2002-2007.

total, 1310.82 km^2 of forest and 4482.47 km^2 of rain forest were lost or deforested between 1976 and 2007, without accounting for the change towards other types of forest cover (Figure 5). Hence, the areas that had been deforested or put to other use are an indicator of the main potential areas which should be restored in the region in order to restore the forest cover (Figure 5).

Conclusion

It can be concluded that the thematic maps illustrating changes in land cover and land use for the period of study (1976-2007), and that were created based on GIS methods and techniques, are adequate for the evaluation and the analysis of the changes that have occurred in the Huasteca region.

In the analysis of land use and land cover changes, more reliable statistical results correspond to vegetation cover, while the least reliable appear to be the water and urban area classes, the same categories that presents small inaccuracies in the transitions of changes.

Analysis carried out based on a cross-tabulation matrix demonstrated that agriculture and pasture in particular have modified the biophysical landscape of the Huasteca over the period of time from 1976 until 1993.

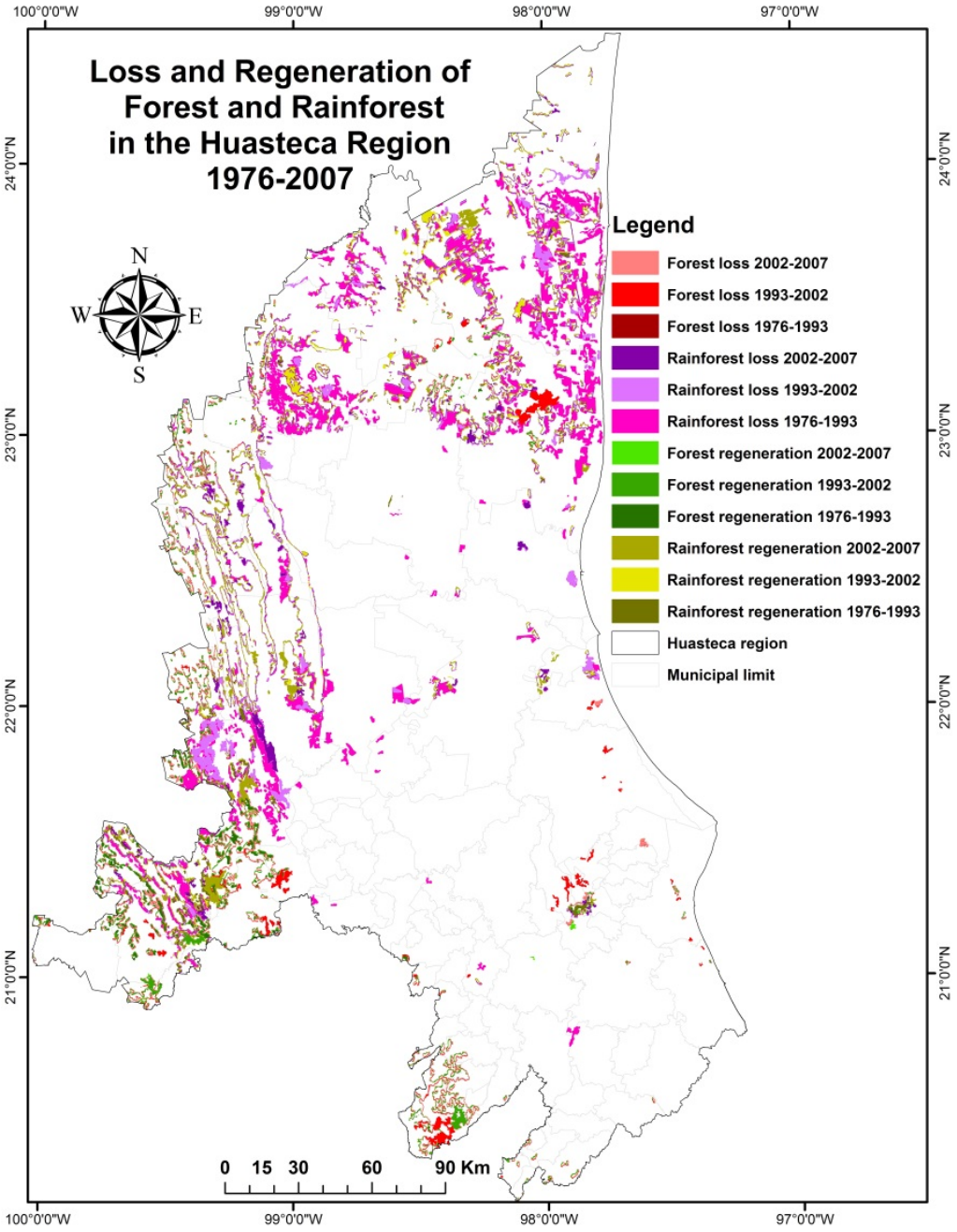

Figure 5.
Deforestation and natural regeneration of forest cover in the Huasteca region, 1976-2007.

Deforestation rates for rain forests, forests, scrublands and other types of vegetation were also higher than the national deforestation rates reported for México by other authors, even though for the period of time between 2002 and 2007 a backward trend could be observed.

The analysis which measured the land cover change (natural land cover and non-original land cover), we envisioned that non-original coverage increased by 7834.16 km^2, and natural land cover only recovered 2761.29 km^2 in the same period of 31 years. Furthermore, this method showed that 62.67% of the surface of the Huasteca region had been modified by human activities before the year 1976, and from 1976 until 2007 changes affected 17.84% of the studied area.

It was also demonstrated that the greatest loss of forest cover in the Huasteca between 1976 and 2007 amounted to 1310.82 km^2 for forests and 4482.47 km^2 for rain forests, while the natural regeneration of non-forest covers to forest covers made up 721.25 km^2 for forests and 1210.82 km^2 for rain forests.

Between the years 1976 and 2007 an area of approximately 1932.07 km^2 regenerated naturally to forest cover (forests and rainforests), and 5739.29 km^2 were identified as potential areas for forest restoration.

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Appendix 1. Classification and Reclassification of Land Use and Land Cover Classes Employed in the Analysis of Land Use and Land Cover Changes for the Huasteca Region

Land use and land cover classes	Reclassification of classes	Grouped classes
Water bodies	Water	Water
Aquaculture		Non-original land cover
Moisture agriculture	Agriculture	Non-original land cover
Irrigated agriculture		
Seasonal agriculture		
Oak forest	Forest	Natural land cover
Oak-pine forest		
Pine forest		
Pine-oak forest		
Tascate forest		
Cloud forest		
Crasicaule scrubland	Scrubland	Natural land cover
Microphyll scrubland		
Short xerophitic scrunland		
Tamaulipan thornscrub		
Submontane scrubland		
Cultivated pasture	Pasture	Non-original land cover
Halophytic pasture		Natural land cover
Induced pasture		Non-original land cover
High moist evergreen forest	Rain forest	Natural land cover
High semi-evergreen forest		
Low dry forest		
Low thorny dry forest		
Semi-deciduous low dry forest		
Medium semi-deciduous forest		
Medium semi-evergreen forest		
No vegetation apparent	Without vegetation	Natural land cover
Cultivated forest		Non-original land cover
Induced palmar		Non-original land cover
Arboreal secondary vegetation of oak forest	Secondary vegetation	Non-original land cover
Arboreal secondary vegetation of oak-pine forest		
Arboreal secondary vegetation of pine forest		
Arboreal secondary vegetation of pine-oak forest		
Arboreal secondary vegetation of tascate forest		
Arboreal secondary vegetation of cloud forest		
Shrubby secondary vegetation of oak forest		
Shrubby secondary vegetation of oak-pine forest		
Shrubby secondary vegetation of pine forest		
Shrubby secondary vegetation of pine-oak forest		
Shrubby secondary vegetation of tascate forest		
Shrubby secondary vegetation of cloud forest		
Herbaceous secondary vegetation of oak forest		
Herbaceous secondary vegetation of pine-oak forest		
Herbaceous secondary vegetation of cloud forest		
Arboreal secondary vegetation of high moist evergreen forest		
Arboreal secondary vegetation of high semi-evergreen forest		
Arboreal secondary vegetation of low dry forest		

Continued

Arboreal secondary vegetation of low thorny dry forest		
Arboreal secondary vegetation of low thorny semi-evergreen forest		
Arboreal secondary vegetation of medium semi-evergreen forest		
Arboreal secondary vegetation of low thorny forest		
Arboreal secondary vegetation of medium semi-deciduous forest		
Shrubby secondary vegetation of high evergreen forest		
Shrubby secondary vegetation of high semi-evergreen forest		
Shrubby secondary vegetation of low dry forest		
Shrubby secondary vegetation of low thorny dry forest		
Shrubby secondary vegetation of low semi-deciduous forest		
Shrubby secondary vegetation of medium semi-deciduous forest		
Shrubby secondary vegetation of medium semi-evergreen forest		
Shrubby secondary vegetation of low thorny forest		
Shrubby secondary vegetation of low semi-evergreen forest		
Herbaceous secondary vegetation of high evergreen forest		
Herbaceous secondary vegetation of low thorny forest		
Herbaceous secondary vegetation of high semi-evergreen forest		
Herbaceous secondary vegetation of low dry forest		
Herbaceous secondary vegetation of medium semi-evergreen forest		
Shrubby secondary vegetation of microphyll scrubland		
Shrubby secondary vegetation of crasicaule scrubland		
Shrubby secondary vegetation of conifer scrubland		
Shrubby secondary vegetation of submontane scrubland		
Shrubby secondary vegetation of tamaulipan thornscrub		
Shrubby secondary vegetation of chaparral		
Shrubby secondary vegetation of mezquital		
Herbaceous secondary vegetation of submontane scrubland		
Chaparral		
Mezquital		
Palmar		
Costal dunes vegetation		Natural land cover
Gallery vegetation		
Mesquite forest		
Native palmar	Other vegetation	
Mangroves		
Gallery rain forest		
Gallery forest		Natural land cover
Floodable		
Halophilous vegetation		
Reed beds		
Urban zone	Urban area	Urban area
Human settlements		