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Land use and deforestation in northeast Mexico (1985–2020): A multi-temporal analysis in the Tamaulipas Biotic Province

Uso del suelo y deforestación en el noreste de México (1985-2020): un análisis multitemporal en la Provincia Biótica de Tamaulipas

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Abstract

Remote sensing time-series analysis can allow planning and policy development to ensure the conservation, restoration, and the sustainable use of terrestrial ecosystems. We analyzed land use change and deforestation over 35 years (1985-2020) in the Tamaulipas Biotic Province of Mexico by using multi-spectral satellite imagery. In addition, the annual rate of forest change was calculated for each land cover type. Between 1985 and 2020, the Tamaulipas Biotic Province lost 391 772 ha of natural vegetation and experienced the highest annual rate of forest change in the Tamaulipas Biotic Province in grassland and deciduous forest, with -3.1% and -2.9% annually, respectively. Xerophytic scrub is the principal natural vegetation in the Tamaulipas Biotic Province, occupying approximately 2 000 000 ha (21%), dominated by Tamaulipan thornscrub (51.1%) and submontane scrubland (32.6%). In conclusion, according to our results, the Tamaulipas Biotic Province has suffered a continuous process of deforestation that has led to the loss of more than 14.5% of native vegetation in the last 35 years. Xerophytic scrub is the natural cover that has lost the greatest area, but due to their higher representation, grasslands and deciduous forest have shown the highest deforestation rate. These results could be used to promote the sustainable use and conservation of natural resources.

Keywords: Biodiversity conservation, land cover change, mapping, remote sensing, xerophytic scrub.

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Resumen

El análisis de series temporales de teledetección puede permitir la planificación y el desarrollo de políticas para garantizar la conservación, restauración y uso sostenible de los ecosistemas terrestres. Analizamos el cambio de uso del suelo y la deforestación durante 35 años (1985-2020) en la Provincia Biótica de Tamaulipas en México, mediante el uso de imágenes satelitales multiespectrales. Además, se calculó la tasa anual de cambio forestal para cada tipo de cobertura terrestre. Entre 1985 y 2020, la Provincia Biótica de Tamaulipas perdió 391 772 ha de vegetación natural y experimentó la tasa anual más alta de cambio forestal en la Provincia Biótica de Tamaulipas en pastizales y bosques caducifolios, con -3,1 % y -2,9 % anual, respectivamente. La principal vegetación natural de la Provincia Biótica de Tamaulipas es el matorral xerófilo, que ocupa aproximadamente 2 000 000 ha (21 %), que a su vez está dominado por matorral espinoso tamaulipeco (51.1 %) y matorral submontano (32,6 %). Según nuestros resultados, la Provincia Biótica de Tamaulipas ha sufrido un proceso continuo de deforestación que ha llevado a la pérdida de más del 14,5 % de la vegetación nativa en los últimos 35 años. El matorral xerófilo es la cobertura natural que más superficie ha perdido, pero debido a su mayor representación, los pastizales y bosques caducifolios han mostrado la mayor tasa de deforestación. Estos resultados podrían utilizarse para promover el uso sostenible y la conservación de los recursos naturales.

Palabras clave: Cambio de cobertura terrestre, cartografía, conservación de la biodiversidad, matorral xerófilo, teledetección.

Introduction

Scientific evidence indicates that we are in a state of planetary emergency that should compel us to take political and economic action on emissions [1]. Several planetary boundaries have already been crossed, for example, climate change, biosphere integrity and land-system change [2]. These three planetary boundaries are closely linked to landscape structure. For example, although the increase in carbon dioxide (CO_2) in the atmosphere, one of the main greenhouse gases, comes primarily from fossil fuel burning, land use change, mainly deforestation, also contributes a significant amount of CO_2 to the atmosphere [3]. Thus, the amount of carbon stored in terrestrial vegetation is a key component of the global carbon cycle [4]. Conserving and, where appropriate, improving terrestrial vegetation carbon stocks, as well as monitoring changes in biomass stocks, are therefore key to ensuring progress towards the commitment to halt climate change. For this reason, one of the Sustainable Development Goals (SDGs) of the United Nations is to protect, restore and promote the sustainable use of terrestrial ecosystems (SDG15 [5]) Likewise, the United Nations declared 2021-2030 to be the United Nations Decade on Ecosystem Restoration.

In this context, to ensure the conservation, restoration and sustainable use of terrestrial ecosystems, knowledge about land cover is required for both planning and policy development. Furthermore, information about land cover is essential for monitoring vegetation cover and modeling environmental changes [6]. Earth Observation data, i.e., big data about our built and natural environment, have proven to be a useful tool to further help stakeholders take relevant actions to respond to environmental problems [7]. Remote sensing data, for example, have effectively assessed long-term changes in vegetation cover [8], [9], [10], [11].

Earth Observation data, through methods such as remote sensing time-series analysis, can allow the design and implementation of well-informed policies, land planning and resource management based on evidence [12]. This technique has been used in northeastern Mexico, but on small areas and for very specific cases, for example, in the Cumbres de Monterrey National Park [13], the Potosi Basin [14], or to identify habitat use patterns of ocelots (Leopardus pardalis Linnaeus; [15]). However, for remote sensing time-series to have a true management and conservation impact, it is necessary to work at a landscape level. Thus, this study analyzes land use change and deforestation over the 35 years from 1985 to 2020 in the Tamaulipas Biotic Province of Mexico by using multi-spectral satellite imagery from Landsat.

Materials and Methods

The study was conducted in the Tamaulipas Biotic Province, located in southern Texas, United States and northeast Mexico, between 23°45'-29°10' N and 97°10'-101°50' W (Figure 1). In Mexico, the Tamaulipas Biotic Province comprises the lowland plains and a few isolated of low mountains in eastern Coahuila, northern Nuevo Leon, and Tamaulipas, except the southwestern part [16], the total land area covers approximately 93,000 km². The climate is broadly arid or semiarid, warm, with mean annual temperature above 22°C and little rain all year (Köppen Climate Zone BS); and tropical, semi-warm, with mean annual temperature between 18 and 22°C and rain mainly during the summer (Köppen Climate Zone A).

The sources used for data extraction were Landsat 5 TM (bands 5, 4 and 1) for the periods of 1985 and 1990, Landsat 7 ETM (bands 6, 5 and 2) for the periods of 2000 and 2010, and Landsat 8 OLI (bands 6, 5 and 2) for 2020

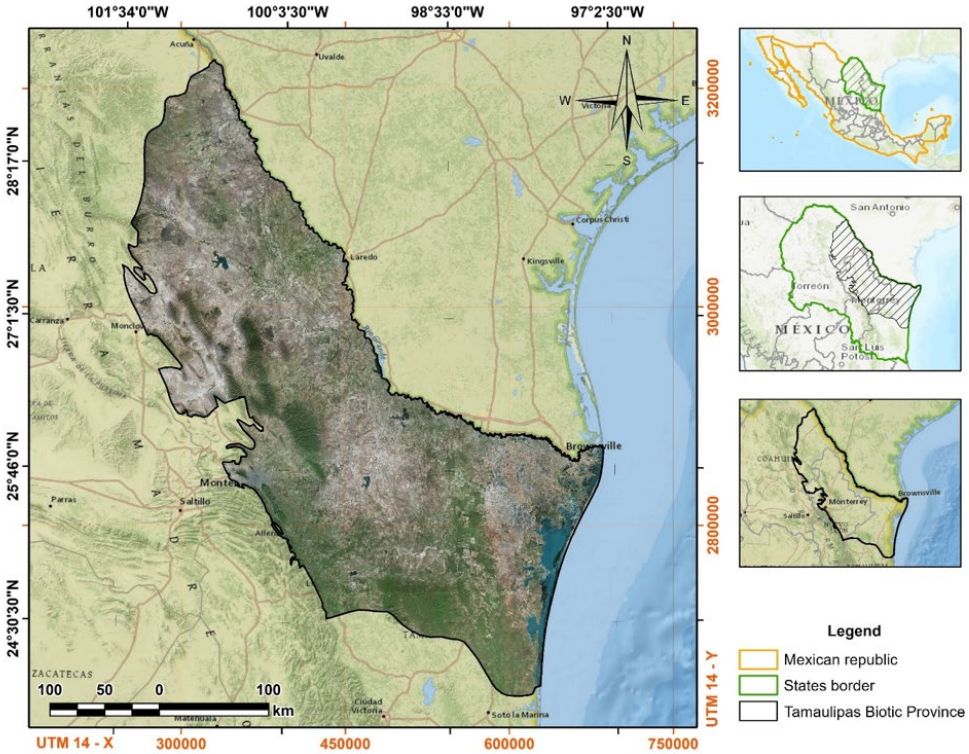

Figure 1. Tamaulipas Biotic Province-study area.

Figura 1. Provincia Biótica de Tamaulipas-área de estudio.

(Figure 2), obtained from Earth Explorer of the United States Geological Survey (USGS; https://earthexplorer.usgs.gov/). Were created five mosaics composed of 10 cloud-free satellite images each, with a resolution of 30m/pixel. Initially, an unsupervised classification process with the K-means cluster analysis module was applied using QGIS software (version 3.20.3 Odense). Subsequently, outputs from the unsupervised classification were converted from raster to vector format for subsequent supervised classification, by integrating datasets from the National Forestry Commission [17] and the National Institute of Statistics and Geography [18]. To validate the agreement and accuracy of the classification results, an error matrix and kappa parameter was calculated using the r.kappa module in the QGIS software with GRASS 7.6.0. Kappa values < 0 indicate no agreement, 0–0.2 slight, 0.0–0.41 poor, 0.41–0.60 moderate, 0.60–0.80 substantial, and 0.81–1.0 almost perfect agreement [19].

We used cross-tabulation to calculate land cover changes between five different time periods: 1985 to 1990, 1990 to 2000, 2000 to 2010, 2010 to 2020 and 1985 to 2020 and at two geographic scales: Tamaulipas Biotic Province level and Xerophytic scrub level. Percentage changes, net change, rate of change and relative change for each land cover type over time were calculated. In addition, the annual rate of forest change was calculated for each land cover type according to Puyravaud [20] using a formula derived from the compound interest law:

$$r = \frac{1}{t_2 - t_1} \times \ln\left(\frac{A_2}{A_1}\right) \times 100 \qquad (1)$$

where A_1 and A_2 are the land cover at time t_1 and t_2 (per year or percentage per year). A positive “r” value indicates that the specific land cover type is expanding, while negative demonstrates a diminishing pattern.

Our results showed a Kappa coefficient of 0.63 for the Landsat-derived classified images (1985-2020). The accuracy could meet the needs of further research. Figure 3 shows the results of land cover classification of Tamaulipas Biotic Province for the years 1985, 1990, 2000, 2010, and 2020. Additionally, quantitative details about the land cover are presented in Table 1.

Since 1985, agriculture, xerophilous scrub and verdureless areas have represented more than 90% of the Tamaulipas Biotic Province surface area. In 2020, agriculture was the largest, with an area of 4 768 889 ha that represents 51% of the area; followed by verdureless and xerophytic scrub with approximately 2 213 873 ha (24%) and 1 945 326 ha (21%), respectively (Table 1).

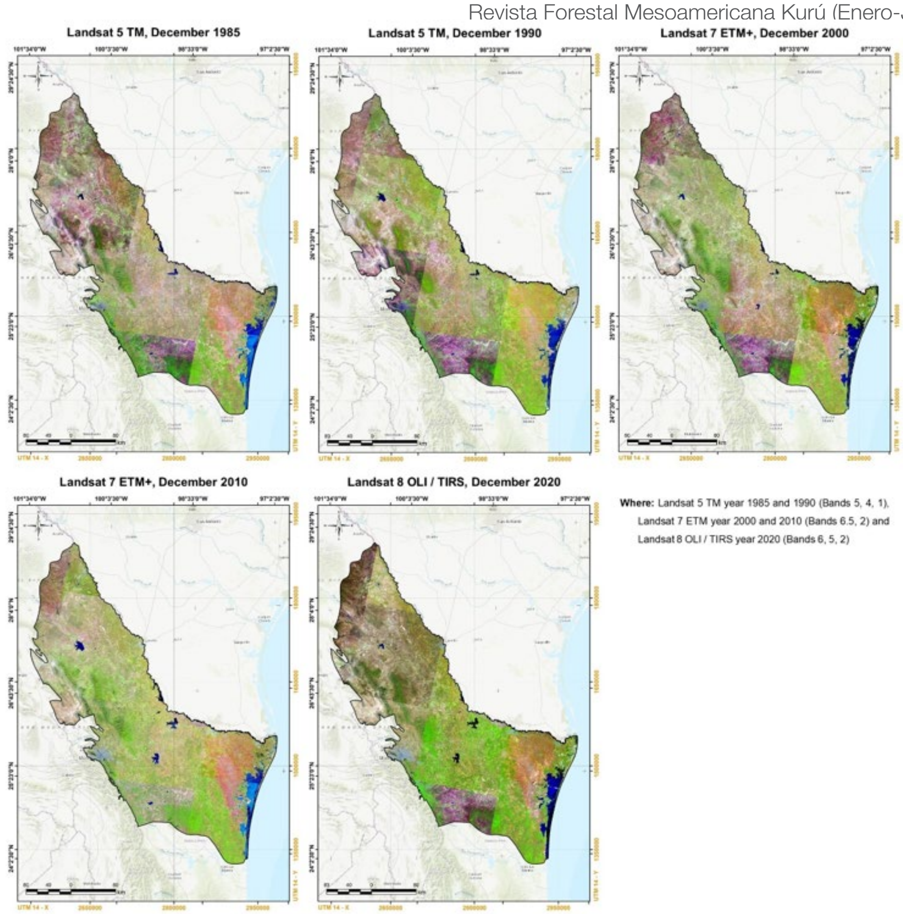

Figure 2. Landsat 7 ETM+ and Landsat 8 OLI images of the Tamaulipas Biotic Province, for 1985, 1990, 2000, 2010 and 2020.
Figura 2. Imágenes Landsat 7 ETM+ y Landsat 8 OLI de la Provincia Biótica de Tamaulipas, para 1985, 1990, 2000, 2010 y 2020.

The results of land cover change analysis are evidence that the study area was affected by substantial fluctuations in the last 35 years. Since 1985, the Tamaulipas Biotic Province has lost 391 772 ha of natural vegetation (Table 2), which signifies a loss of 14.5% of the original surface area, and an annual rate of forest change of -0.4%. Agriculture and verdureless terrain increased by 247 987 ha (2.7%) and 143 750 ha (1.5%), respectively. On the other hand, xerophytic scrub, grassland, hydrophilic vegetation, and deciduous forest decreased by 206 039 ha (2.2%), 189 526 ha (2.0%), 4 295 (< 0.1%), and 12 ha (< 0.01%), respectively (Table 2). However, the relative change rate of grassland and deciduous forest between 1985 and 2020 was -66.6% and -63.2%, respectively, indicating important change in both vegetation types (Figure 4). Likewise, the analysis showed that the highest annual rate of forest change in the Tamaulipas Biotic Province occurred in grassland and deciduous forest, at -3.1% and -2.9%, respectively, in the last 35 years (Table 3).

Xerophytic scrub is the principal natural vegetation in the Tamaulipas Biotic Province, occupying approximately 2 000 000 ha (21%), predominantly Tamaulipan thornscrub (51.1%) and submontane scrubland (32.6%), followed by rosetophilous desert scrubland and xerophile mesquital (7.6% and 6.1%, respectively; Table 4). The Tamaulipan thornscrub is distributed in two main zones, one to the east, in the Gulf Coastal Plain; and the other in the northeast part of the state of Coahuila and northwest of the state of Nuevo León (Figure 5). Furthermore, submontane scrubland is distributed in the southwest of the Tamaulipas Biotic Province, in the central part of the states of Nuevo León and Coahuila, where the altitude begins to increase, and on the eastern slope of the Eastern Sierra Madre (Figure 5).

The Table 5 shows the land cover changes during the whole observation period from 1985 to 2020 in xerophytic scrub. Moreover, it highlights the rate of the changes of land cover for the periods from 1985 to 1990, 1990 to 2000, 2000 to 2010, and 2010 to 2020. These results provide evidence that just two vegetation types, rosetophilous desert scrub and chaparral, have increased since 1985, by approximately 31 400 ha (1.6%) and 323 ha (< 0.1), respectively (Table 5). In contrast,

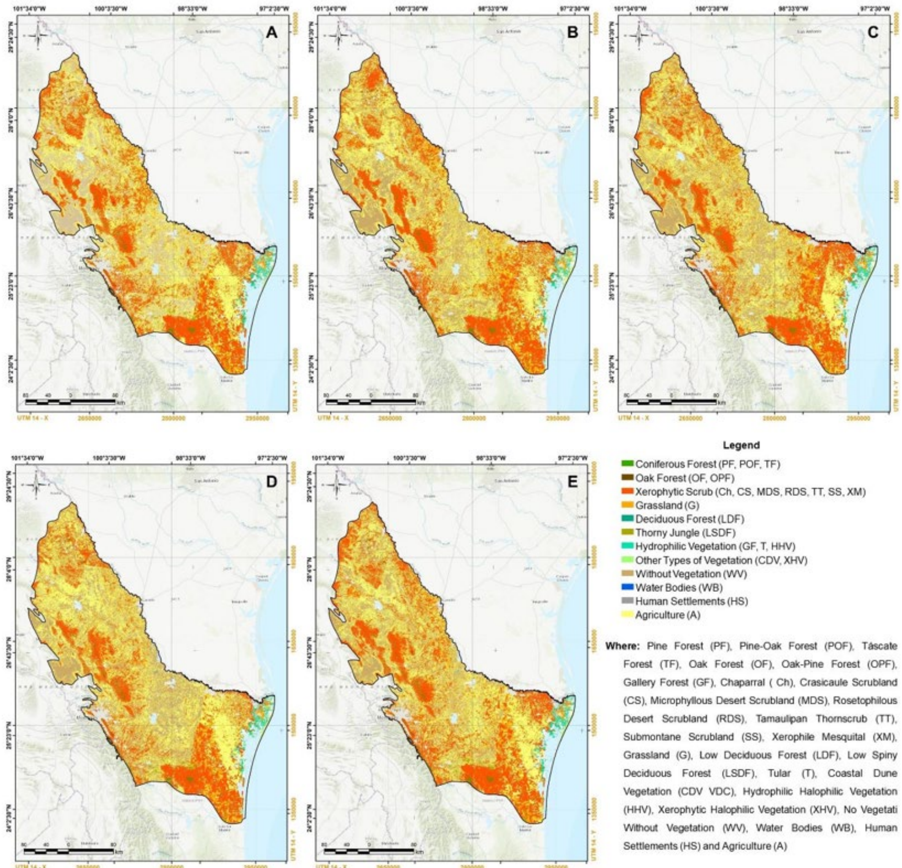

Figura 3. Land cover maps of Tamaulipas Biotic Province for (A) 1985, (B) 1990, (C) 2000, (D) 2010, and (E) 2020.

Figura 3. Mapas de cobertura del suelo de la Provincia Biótica de Tamaulipas para (A) 1985, (B) 1990, (C) 2000, (D) 2010 y (E) 2020.

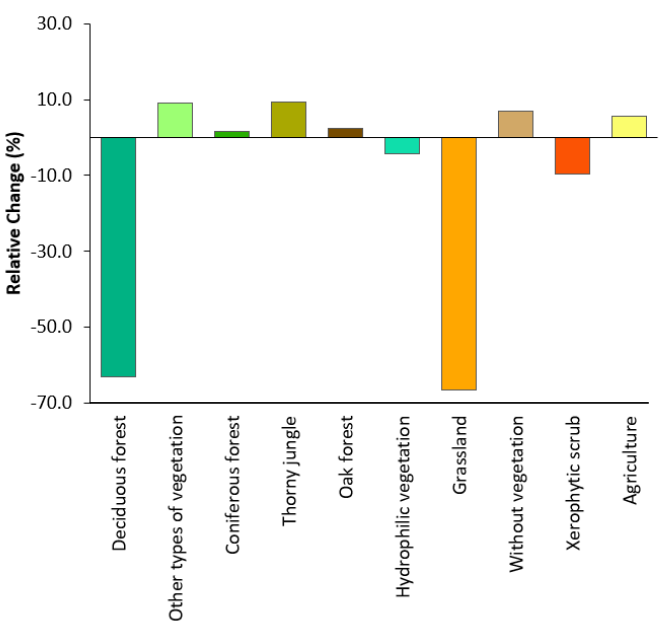

Figura 4. Land cover change of the Tamaulipas Biotic Province over study period (1985-2020).

Figura 4. Cambio de cobertura del suelo de la Provincia Biótica de Tamaulipas durante el periodo de estudio (1985-2020).

microphyll desert scrub shows the most important change during 1985-2020, with a relative change of -46.4% (Figure 6), and -1.78% annually (Table 6).

Discussion

To our knowledge, this is the first study to analyze the multi-temporal trend in deforestation and land cover in the Tamaulipas Biotic Province. We examined the 35 years from 1985 to 2020 using historical Landsat imagery. Our results show that 391 772 ha of natural vegetation have been converted to other land uses since 1985, which represents a net loss of 14.5% and an annual rate of forest change of -0.4%. This deforested area of natural vegetation has been transformed into agricultural and verdureless land (Table 2). This matches the results of Mendoza-Ponce et al. [21] who found that more than 70% of land use/cover change in Mexico, is caused particularly by the expansion of pasture for cattle ranching and rain-fed agriculture.

The annual rate of forest change found in this study for xerophytic scrub (-0.3%) was similar to the rate established

Table 1. Total area coverage between the years 1985, 1990, 2000, 2010, and 2020 for the classified landcover categories in the Tamaulipas Biotic Province.

Cuadro 1. Cobertura total del área entre los años 1985, 1990, 2000, 2010 y 2020 para las categorías de cobertura del suelo clasificadas en la Provincia Biótica de Tamaulipas.

Vegetation type	1985		1990		2000		2010		2020	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Deciduous forest	19	<0.01	18	<0.01	18	<0.01	20	<0.01	7	<0.01
Other types of vegetation	11 826	0.1	10 433	0.1	13 457	0.1	8 343	0.1	12 914	0.1
Coniferous forest	13 101	0.1	13 282	0.1	13 252	0.1	12 653	0.1	13 305	0.1
Thorny jungle	50 623	0.6	47 526	0.5	48 127	0.5	50 355	0.5	55 413	0.6
Oak forest	84 247	0.9	88 577	1.0	87 655	0.9	80 768	0.9	86 265	0.9
Hydrophilic vegetation	99 382	1.1	79 748	0.9	87 196	0.9	89 023	1.0	95 087	1.0
Grassland	284 758	3.1	257 994	2.8	280 509	3.0	149 034	1.6	95 232	1.0
Verdureless	2 070 123	22.3	2 158 682	23.3	2 097 167	22.6	2 613 650	28.2	2 213 873	23.8
Xerophytic scrub	2 151 365	23.2	2 222 267	23.9	2 263 250	24.4	1 989 055	21.4	1 945 326	21.0
Agriculture	4 520 902	48.7	4 407 813	47.5	4 395 701	47.3	4 293 421	46.2	4 768 889	51.4

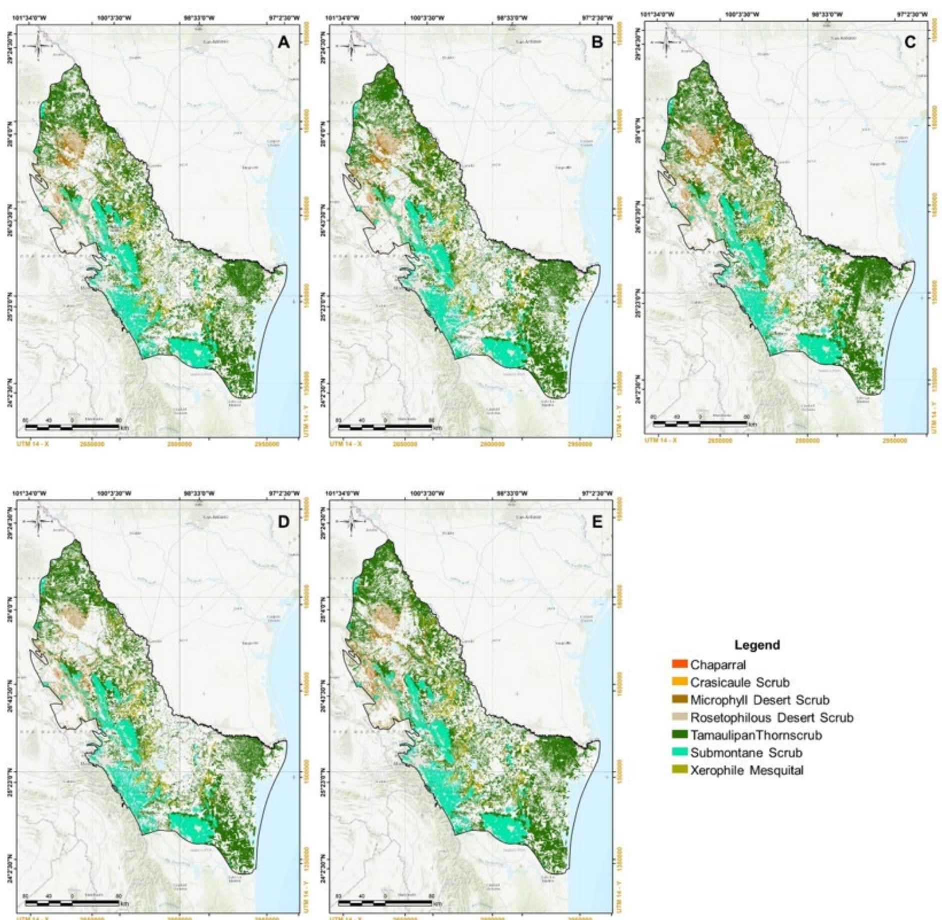

Figure 5. Land cover maps of Xerophytic scrub for (A) 1985, (B) 1990, (C) 2000, (D) 2010, and (E) 2020.

Figura 5. Mapas de cobertura terrestre del matorral xerófilo para (A) 1985, (B) 1990, (C) 2000, (D) 2010 y (E) 2020.

Table 2. Net change, percentage change, and rate of change occurring between the years 1985, 1990, 2000, 2010, and 2020 in classified land cover categories in the Tamaulipas Biotic Province.

Cuadro 2. Cambio neto, cambio porcentual y tasa de cambio ocurridos entre los años 1985, 1990, 2000, 2010 y 2020 en las categorías de cobertura del suelo clasificadas en la Provincia Biótica de Tamaulipas.

Vegetation type	Net Change in hectares (Percentage change)					Rate of Change (ha/Year)				
	1985-1990	1990-2000	2000-2010	2010-2020	1985-2020	1985-1990	1990-2000	2000-2010	2010-2020	1985-2020
Deciduous forest	-1 (<0.01)	0 (<0.01)	2 (<0.01)	-13 (<0.01)	-12 (<0.01)	-0.2	0	0.2	-1.3	-0.3
Other types of vegetation	-1 393 (<0.01)	3 024 (<0.01)	-5 114 (-0.1)	4 571 (<0.01)	1 088 (<0.01)	-278.6	302.4	-511.4	457.1	31.1
Coniferous forest	181 (<0.01)	-30 (<0.01)	-599 (<0.01)	652 (<0.01)	204 (<0.01)	36.2	-3	-59.9	65.2	5.8
Thorny jungle	-3 097 (<0.01)	601 (<0.01)	2 228 (<0.01)	5 058 (0.1)	4 790 (0.1)	-619.4	60.1	222.8	505.8	136.9
Oak forest	4 330 (<0.01)	-922 (<0.01)	-6 887 (-0.1)	5 497 (0.1)	2,018 (<0.01)	866	-92.2	-688.7	549.7	57.7
Hydrophilic vegetation	-19 634 (-0.2)	7 448 (0.1)	1 827 (<0.01)	6 064 (0.1)	-4 295 (<0.01)	-3 926.8	744.8	182.7	606.4	-122.7
Grassland	-26 764 (-0.3)	22,515 (0.2)	-131 475 (-1.4)	-53 802 (-0.6)	-189 526 (-2.0)	-5 352.8	2 251.5	-13 147.5	-5 380.2	-5 415.0
Verdureless	88 559 (1.0)	-61 515 (-0.7)	516 483 (5.6)	-399 777 (-4.3)	143 750 (1.5)	17 711.8	-6 151.5	51 648.3	-39 977.7	4 107.1
Xerophytic scrub	70 902 (0.8)	40,983 (0.4)	-274 195 (-3.0)	-43 729 (-0.5)	-206 039 (-2.2)	14 180.4	4 098.3	-27 419.5	-4 372.9	-5 886.8
Agriculture	-113 089 (-1.2)	-12 112 (-0.1)	-102 280 (-1.1)	475 468 (5.1)	247 987 (2.7)	-22 617.8	-1 211.2	-10 228	47 546.8	7 085.3

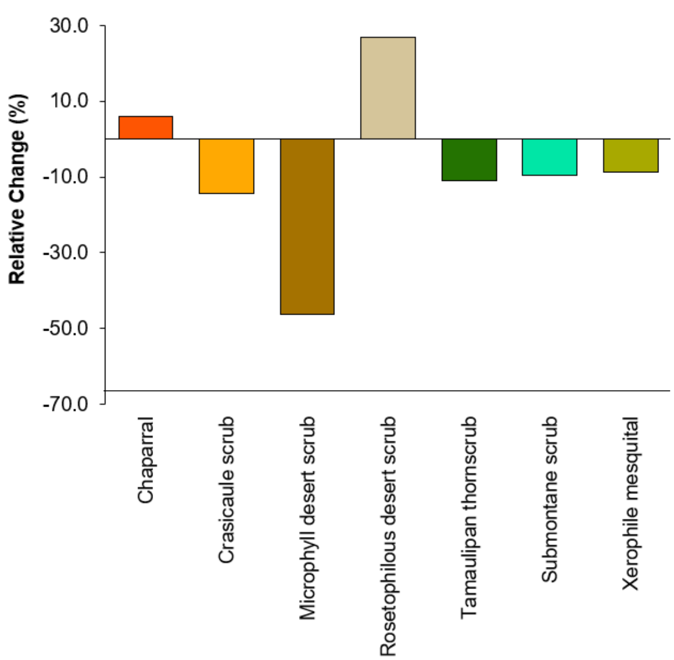

Figure 6. Land cover change of the Xerophytic scrub over study period (1985-2020).

Figura 6. Cambio de cobertura del suelo del matorral xerófilo durante el período de estudio (1985-2020).

by Mas et al. [22] for Mexico in scrubland between 1976 and 2000, with -0.33%, but lower than the -0.53% found by Rosete-Vergés et al. [23] for the same period. However, some authors report a recuperation of scrubland and mesquital in Mexico for the period between 2000 and 2007 with an annual rate of forest change of 0.23% [23], while we found an important loss of xerophytic scrub from 2000 to 2010 (annual change rate of -1.29%; Table 3). This agrees with the results of other authors who reported loss of Tamaulipan thornscrub of northeastern Mexico (see [24]). On the other hand, coniferous forest, thorny jungle, and oak forest, have shown an increase in cover since 1985, however, the consequences are negligible, since they represent only 0.2% of the surface area.

Furthermore, we observed a severe level of deforestation in two vegetation types: deciduous forest and grasslands. According to our results, deciduous forest and grasslands underwent a relative change rate greater than 60% from 1985 to 2020, signifying with annual rate of -2.9% and -3.1%, respectively. Our results concur with those found by Mendoza-Ponce et al. [21], who projected that the loss of deciduous forest and grasslands will keep decreasing, in the coming decades, despite the influence

Table 3. Annual deforestation rate in the Tamaulipas Biotic Province.

Cuadro 3. Tasa anual de deforestación en la Provincia Biótica de Tamaulipas.

Vegetation type	1985-1990	1990-2000	2000-2010	2010-2020	1985-2020
Deciduous forest	-1.08	0.00	1.05	-10.50	-2.9
Other types of vegetation	-2.51	2.55	-4.78	4.37	0.3
Coniferous forest	0.27	-0.02	-0.46	0.50	0.0
Thorny jungle	-1.26	0.13	0.45	0.96	0.3
Oak forest	1.00	-0.10	-0.82	0.66	0.1
Hydrophilic veg-etation	-4.40	0.89	0.21	0.66	-0.1
Grassland	-1.97	0.84	-6.32	-4.48	-3.1
Verdureless	0.84	-0.29	2.20	-1.66	0.2
Xerophytic scrub	0.65	0.18	-1.29	-0.22	-0.3
Agriculture	-0.51	-0.03	-0.24	1.05	0.2

Table 4. Total area coverage between the years 1985, 1990, 2000, 2010, and 2020 for the classified landcover categories in the Xerophytic scrub.

Cuadro 4. Cobertura total del área entre los años 1985, 1990, 2000, 2010 y 2020 para las categorías de cobertura terrestre clasificadas en el matorral xerófilo.

Vegetation type	1985		1990		2000		2010		2020	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Chaparral	5 314.9	0.2	6 991.5	0.3	6 260.7	0.3	6 019.8	0.3	5 637.8	0.3
Crasicaule scrub	1 141.1	0.1	1 581.8	0.1	1 540.3	0.1	1 211.5	0.1	978.4	0.1
Microphyll desert scrub	78 443.3	3.6	77 876.3	3.5	38 353.3	1.7	46 758.6	2.4	42 072.4	2.2
Rosetophilous desert scrub	117 020.8	5.4	103 595.5	4.7	135 804.4	6.0	100 277.2	5.0	148 420.1	7.6
Tamaulipan thornscrub	1 116 523.1	51.9	1 273 888.9	57.3	1 284 066.9	56.7	1 086 479.7	54.6	994 303.7	51.1
Submontane scrub	702 786.4	32.7	650 583.3	29.3	651 347.4	28.8	631 995.0	31.8	635 052.0	32.6
Xerophile mesquital	130 135.3	6.0	107 750.1	4.8	145 876.8	6.4	116 313.3	5.8	118 862.0	6.1

of climate change due to the land use cover change. Consequently, management actions directed towards the ecological restoration of grasslands are essential and urgent, especially in arid zones, where the natural recovery rate is very slow: Recovery can take from tens to hundreds of years [25], and in some cases up to 700 years [26] to return to their natural state. For this reason, grasslands have become one of the most endangered ecosystems in the world and face significant threats from multiple anthropogenic activities [27], which have caused the disappearance of the original, pristine grasslands and altered species composition [28], impacting both ecosystem services and biodiversity. For example, the prairie dog (*Cynomys mexicanus* Merriam) is a keystone ecosystem species [29], however, it is at risk of extinction and its populations have been declining for decades due to the loss of its natural habitat, i.e., grasslands [30], [31].

According to our results, xerophytic scrub suffered a net loss of 206,039 ha from 1985 to 2020 which, being the predominant type of vegetation, represents a threat to the conservation of flora and fauna that inhabit these ecosystems. For example, one of the most critical areas for Cactaceae diversity is associated with xerophytic

Table 5. Net change, percentage change, and rate of change occurring between the years 1985, 1990, 2000, 2010, and 2020 in classified land cover categories in the Xerophytic scrub.

Cuadro 5. Cambio neto, cambio porcentual y tasa de cambio ocurridos entre los años 1985, 1990, 2000, 2010 y 2020 en las categorías de cobertura terrestre clasificadas en el matorral xerófilo.

Vegetation type	Net Change in hectares (Percentage change)					Rate of Change (ha/Year)				
	1985-1990	1990-2000	2000-2010	2010-2020	1985-2020	1985-1990	1990-2000	2000-2010	2010-2020	1985-2020
Chaparral	1 677 (0.1)	-731 (<0.1)	-241 (<0.1)	-382 (<0.1)	323 (<0.1)	335.3	-73.1	-24.1	-38.2	9.2
Crasicaule scrub	441 (<0.1)	-42 (<0.1)	-329 (<0.1)	-233 (<0.1)	-163 (<0.1)	88.1	-4.2	-32.9	-23.3	-4.6
Microphyll desert scrub	-567 (<0.1)	-39 523 (-1.8)	8 405 (0.4)	-4 686 (-0.2)	-36 371 (-1.9)	-113.4	-3 952.3	840.5	-468.6	-1 039.2
Rosetophilous desert scrub	-13 425 (-0.6)	32 209 (1.4)	-35 527 (-1.6)	48 143 (2.4)	31 399 (1.6)	-2 685.1	3 220.9	-3 552.7	4 814.3	897.1
Tamaulipan thornscrub	157 366 (7.3)	10 178 (0.5)	-197 587 (-8.7)	-92 176 (-4.6)	-122 219 (-6.3)	31 473.2	1 017.8	-19 758.7	-9 217.6	-3 492.0
Submontane scrub	-52 203 (-2.4)	764 (<0.1)	-19 352 (-0.9)	3 057 (0.2)	-67 734 (-3.5)	-10 440.6	76.4	-1 935.2	305.7	-1 935.3
Xerophile mesquital	-22 385 (-1.0)	38 127 (1.7)	-29 564 (-1.3)	2 549 (0.1)	-11 273 (-0.6)	-4 477.0	3 812.7	-2 956.4	254.9	-322.1
Verdureless	88 559 (1.0)	-61 515 (-0.7)	516 483 (5.6)	-399 777 (-4.3)	143 750 (1.5)	17 711.8	-6 151.5	51 648.3	-39 977.7	4 107.1
Xerophytic scrub	70 902 (0.8)	40,983 (0.4)	-274 195 (-3.0)	-43 729 (-0.5)	-206 039 (-2.2)	14 180.4	4 098.3	-27 419.5	-4 372.9	-5 886.8
Agriculture	-113 089 (-1.2)	-12 112 (-0.1)	-102 280 (-1.1)	475 468 (5.1)	247 987 (2.7)	-22 617.8	-1 211.2	-10 228	47 546.8	7 085.3

Table 6. Annual deforestation rate in the Xerophytic scrub.

Cuadro 6. Tasa anual de deforestación en el matorral xerófilo.

Vegetation type	1985-1990	1990-2000	2000-2010	2010-2020	1985-2020
Chaparral	5.48	-1.10	-0.39	-0.66	0.17
Crasicaule scrub	6.53	-0.27	-2.40	-2.14	-0.44
Microphyll desert scrub	-0.15	-7.08	1.98	-1.06	-1.78
Rosetophilous desert scrub	-2.44	2.71	-3.03	3.92	0.68
Tamaulipan thornscrub	2.64	0.08	-1.67	-0.89	-0.33
Submontane scrub	-1.54	0.01	-0.30	0.05	-0.29
Xerophile mesquital	-3.78	3.03	-2.26	0.22	-0.26

vegetation, where several species are included in National and International lists in different conservation risk categories. For example, *Ariocarpus trigonus* (Weber) Schumann, *Coryphantha nickelsiae* (K. Brand.) Britton & Rose and *Thelocactus bicolor* Galeotti ex Pfeiff.) Britton & Rose are classified as threatened in the NOM-059-SEMARNAT-2010, while Astrophytum caput-medusae (Velazco & Nevárez) D. Hunt is in the critically endangered category in the Red List of the IUCN [32]. Moreover, although some species of xerophytic scrub have been associated with high forest potential as timber species [33], the exploitation of non-timber forest products is the main source of livelihood of rural communities (e.g., food, medicines and as raw materials for houses, tools and equipment; [34]). One of the main non-timber forest products in the xerophytic scrub is game, both subsistence and sport hunting. In northern Mexico, the economic value of sport hunting, particularly of white-tailed deer (*Odocoileus virginianus* Zimm.) has led to the recovery of wildlife habitat, providing countless benefits to both game and non-game species [35], [36]. Xerophytic scrub loss would probably be greater without the wildlife management programs that promote the recovery, conservation, and sustainable managementw of flora and fauna resources (see [35]).

Conclusions

According to our results, the Tamaulipas Biotic Province has suffered a continuous process of deforestation that has led to the loss of more than 390 000 ha (14.5%) of native vegetation over the 35-year period studied. Xerophytic scrub has lost most surface area, but due to their high representation, grasslands and deciduous forest have shown the highest deforestation rate. Thus, if effective protection is not provided or conservation actions are not applied, grasslands and deciduous forest, even xerophytic scrub, are at severe risk of disappearing altogether. Biodiversity is a critical component in sustainable development; therefore, federal and state governments are responsible for promoting the sustainable use and conservation of natural resources. Correct and integrated approaches to implementing land resource management policies and strategies must be considered.

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To the project CONTEX 2019-24b Cooperative Database on Biodiversity in the Endangered and Cross-Border Tamaulipan Biotic Province.