Article

Impact of agricultural and oil activities on the natural covers of the Samaria oil field, Tabasco

Rodimiro Ramos-Reyes[1]
Miguel Á. Palomeque-De la Cruz[2]
Joel Zavala Cruz[3§]

[1]The College of the Southern Border-Villahermosa Unit. Highway to Reforma km 15.5, s/n, Ra. Guineo 2nd. Downtown Section, Tabasco, Mexico. CP. 86280. (rramos@ecosur.mx). [2]Juárez Autonomous University of Tabasco-Academic Division of Biological Sciences. Villahermosa-Cárdenas highway km 0.5, s/n, junction to Bosques de Saloya, Villahermosa, Tabasco. CP. 86150. (migueldacbiol@hotmail.com). [3]Postgraduate College-*Campus* Tabasco. Peripheral Carlos A. Molina s/n, H. Cárdenas, Tabasco. CP. 86500. Tel. 937 3722386.

[§]Corresponding author: zavala_cruz@colpos.mx.

Abstract

In the tropical regions of southeast Mexico, subsistence productive activities, the growth of cities and the oil industry are occupying original covers of jungle vegetation, hydrophytic vegetation and bodies of water. The objective of the study was to assess the effect caused by the growth of primary and oil extraction activities on natural covers by modeling the change of land use in the Samaria oil field in the municipalities of Cunduacán and Centro, Tabasco, Mexico. A spatial analysis was performed with land occupation maps by means of Land Change Modeler and gains, losses, contributions, net change and transitions of each category were determined. From the beginning of oil extraction in 1965 until 2019, in the SOF, with an area of 8 052 ha, 647 ha of wetlands and 436 ha of arboreal vegetation disappeared, as a result of the expansion of primary activities and the oil industry, which occupied 1 287 ha of agricultural use, 1 598 ha of livestock use, 269 ha of oil infrastructure and 775 ha of urban area. It is concluded that the application of Land Change Modeler was novel for the evaluation of the degradation of ecosystems and the estimation of the distribution of the change of natural covers and artificial uses in the Santamaria oil field, state of Tabasco.

Keywords: agricultural activities, land use change, Mexican oils.

Reception date: August 2021
Acceptance date: October 2021

Introduction

Due to the growing demand for goods such as food, housing, drinking water and other services, anthropogenic activities generate constant pressure on natural resources at wide geographical scales, which affects their structure, functioning and distribution (Vitousek *et al*., 1997; Challenger and Dirzo, 2009). These activities cause land use change that transforms the original vegetation cover to other uses and degrades the quality of vegetation, which modifies the density and composition of plant species. Among the most important consequences of land use change is the loss of biodiversity and environmental services (Balvanera, 2012).

Land use change, in its broadest sense, refers to the different ways in which a land is used and its vegetation or aquatic cover (Trucíos-Caciano *et al*., 2013). Use change because of agricultural activities induces loss of biodiversity by fragmenting and destroying the different habitats, decreases the capacity for water purification, soil regeneration, nutrient recycling (Zavala-Cruz and Castillo-Acosta, 2007) and generates greenhouse gas emissions that represent a quarter of current global emissions (Tubiello *et al*., 2015).

The conversion of tropical forests to agricultural and livestock areas stands out among the major sources of deforestation and environmental degradation (Davidson *et al*., 2012). In Mexico, in addition to agricultural use, urban growth has led to the depredation of natural resources (Sánchez and Batres, 2006), the loss of tropical and temperate forests, desert vegetation and wetlands (Torres-Vera *et al*., 2009; Zepeda-Gómez *et al*., 2012), with a negative annual change rate (-0.08% to -0.41%) for forests, jungles, shrublands and mesquite forests (Rosete-Vergés *et al*., 2014).

These indicators are consistent with the deforestation rate of 0.3% of temperate and tropical forests between 1990-2015 in Mexico (FAO, 2015). Wetlands face environmental deterioration due to the desiccation for the expansion of urban, agricultural, aquaculture, livestock areas (Brena, 2016) and the increase in oil extraction infrastructure (Tudela, 1992; Tubiello *et al*., 2015). One of the biggest impacts of land use change has been the degradation of 45% of Mexico's soils (Ortiz-Solorio *et al*., 2011). In the Southeast of Mexico, Tabasco became the largest producer of hydrocarbons in the country in the seventies (Capdepont-Ballina and Marín-Olán, 2014), which generated a social and economic boost that had an impact on the growth of cities, mostly Villahermosa (Bazant, 2010).

In 1978, three quarters of the state's GDP came from hydrocarbon production, but the agricultural sector decreased by more than half (Lezama, 1987). The oil boom accelerated the growth of urban areas and increased the environmental deterioration of adjacent ecosystems by locating on lagoons fillings and flood zones (Sánchez-Munguía, 2005). In this context is the SOF that produces, together with the Luna field, 127 thousand barrels of oil day^{-1}, being the most productive in the terrestrial zone of Mexico (PEMEX, 2016).

The analysis of changes in urbanized, rural and natural territories requires the modeling of land use change to predict environmental and socioeconomic scenarios and establish territorial planning policies considering the interaction of socioeconomic and biophysical factors in a geographical space (Paegelow *et al*., 2003; Pineda-Jaimes *et al*., 2009). The application of one or more models of land use change allows understanding its scope, causal factors and consequences, this information contributes to generating proposals for territorial planning (Jiménez-Moreno *et al*., 2011).

In that sense, Land Change Modeler (LCM) is an innovative system that supports land planning decision-making, with an automated and easy-to-use workflow, simplifies the complexities of change analysis, allows the quick analysis of land cover change, empirically modeling relationships with explanatory variables and simulating future land change scenarios (Eastman, 2012).

This system is aimed at evaluating problems of accelerated land conversion and contributes to solving the analytical needs of biodiversity conservation, also integrates data analysis, the notion of land use changes and scenario prediction (Camacho-Olmedo *et al*., 2010; Eastman, 2012). The objective of the study was to analyze the change of land use on wetland ecosystems and arboreal vegetation because of oil, agricultural and urban activities in the SOF, state of Tabasco.

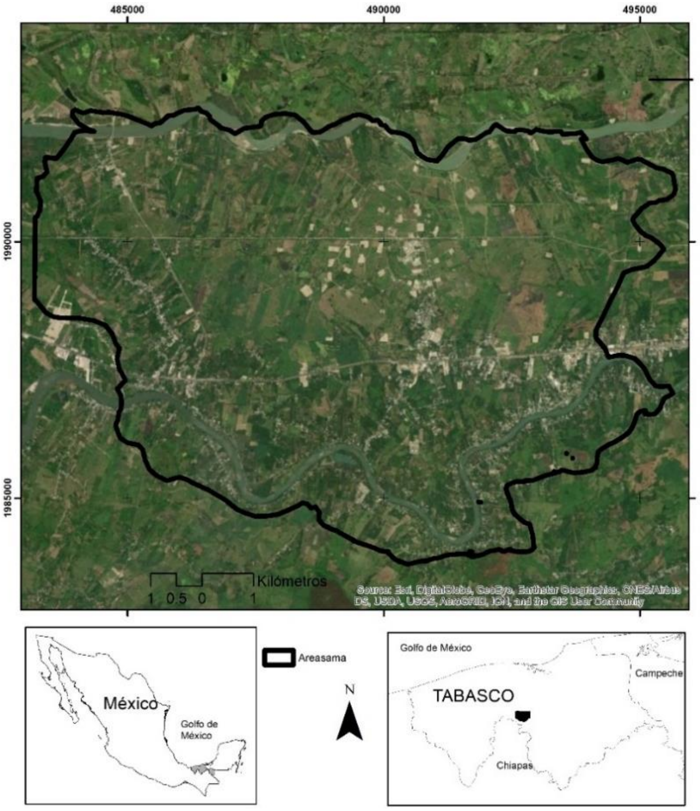
Materials and methods

Study area

The Samaria oil field (SOF) is located in the center-south of Tabasco, on an area of 8 052 ha, in the municipalities of Cunduacán and Centro (Figure 1). It has a hot humid climate with abundant rainfall in summer, average annual temperature of 25 °C and annual rainfall of 2 000 mm. It is part of the Gulf Coastal Plain physiographic region and the geomorphological landscape of fluvial plain, the rivers Samaria to the north and Carrizal to the south have modeled natural dikes, floodplains and settling basins, on alluvial sediments of the Holocene Quaternary, with heights of 4 to 10 masl. Uses of grassland, banana, cocoa and corn crops, secondary vegetation, oil infrastructure and human settlements prevail (Zavala-Cruz *et al*., 2003).

Preparation of the geographic database

Aerial photographs of 1 965 scale 1:30 000 from INEGI and a Sentinel-2 satellite image of 2019 at a resolution of 10 m provided by the European Space Agency, from the platform (https://scihub.copernicus.eu/dhus/#/home), were used. These two periods were used because 1965 is when oil activity began in the Samaria field and 2019 because it is somewhat more recent. Land uses and natural covers were identified by photointerpretation and digitization of vector polygons at the on-screen observation scale 1:15 000, applying the criteria of tone, shape, size and texture (Ramos-Reyes *et al*., 2016).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1. Location of the Samaria oil field, Tabasco.

A Datum WGS84-UTM Projection zone 15N was used and the digitization process was carried out with the Arc GIS 10.5® program. The digitization of the vector of 1965 was corroborated with historical information from the Samaria field (Zavala-Cruz *et al*., 2003) and that of the vector of 2019 was supported with field supervision and comparison with cartographic sources of other studies carried out in Samaria and studies on soils of Tabasco (Zavala-Cruz *et al*., 2003; Zavala-Cruz *et al*., 2007) and the location of sites with GPS equipment.

It is essential to note that to ensure that the crossing of the categories of land use and covers with the images in Land Change Modeler and the crossing of tables with CrossTab was equivalent, it was decided to unify the classification methodology with a reclassification with the Reclassify command of Arc GIS 10.5®, obtaining: 1) wetlands (rivers, lagoons and marshes); 2) arboreal (medium rainforest and riparian vegetation); 3) agricultural (crops); 4) livestock (grasslands with different levels of management and in association with shrublands and brambles subject to temporary flooding); and 5) oil infrastructure.

The reclassified vectors (1965 and 2019) were transformed to raster format with a pixel size of 20 meters including 370 columns and 252 rows with the Polygon to Raster command of ArcToolbox, within the Arc Gis 10.5® program, this reduction of pixels facilitates that the models of spatial analysis of the IDRISI TerrSet® program can be executed more quickly without affecting the spatial values obtained in the digitization of vectors in Arc Gis. Subsequently, the two raster files (1965 and 2019) were exported to TIF format to facilitate the export of the two files to the IDRISI TerrSet® program using the GeoTIFF/Tiff to Idrisi command and later be used for the crossing of images with Land Change Modeler and for the crossing of tables with CrossTab.

Land use change modelling 1965-2019 (LCM)

The analysis of land use change was carried out with Land Change Modeler (LCM) from IDRISI Selva®. This module is based on the analysis of two dates by means of a cross-tabulation matrix consisting of a table with symmetrical arrangements (CrossTab Command) (Table 1), which allows finding for each category of land use and cover, the gains and losses, the net change and contributions between categories experienced between two temporal moments (Table 1).

Table 1. Cross-tabulation matrix for two maps of different dates (Pontius *et al*., 2004).

	Time 2							
	1	2	3	4	5	6	7	
1	Time 1		Class 1	Class 2		Class n	T 1 sum	Losses
2	Class 1	P11	P12		P 1n	P 1+	P 1+ - pjj	
3	Class 2	P21	P12		P2n	P 2+	P 2+ - pjj	
4								
5	Class n	P n1	Pn2		Pnn	Pn+	Pn+ - pjj	
6	Total T2	P+1	P+2		P+n	P	P	
7	Gains		P+1 - Pjj	P+2 - Pjj		P+n	Pjj	

Likewise, it facilitates assessing the total change taking as a reference the persistence and thus evaluating what the transitions from one state of the land surface to another were (Pineda-Jaimes *et al*., 2009; Pontius *et al*., 2012). In this matrix, the rows represent the categories of the map at time 1 (T1) and the columns the categories of the map at time 2 (T2). Likewise, the main diagonal shows the persistence between T1 and T2, while the elements outside the main diagonal represent the transitions that occurred between T1 and T2 for each category.

Row 6 shows the total occupied by each category in T2 (P+j), while column 6 shows the total of each category in time T1 (Pi+). Row 7 shows the gain that each category had between T1 and T2 and column 7 the loss that each category had between T1 and T2 (Pontius *et al*., 2004; Pineda-Jaimes *et al*., 2009). Once the cross-tabulation matrix was obtained, the following parameters were calculated for the analysis of land occupation changes (Pontius *et al*., 2004; Pineda-Jaimes *et al*., 2009): the gains, expressed as the difference of the total sum of row 6 and the values of the main diagonal; i.e., Gij = P+j – Pjj; the losses, expressed as the difference of the total sum of column 6 and the values of the main diagonal; ie., Lij = Pj+ – Pjj.

The net change, expressed as the absolute value of the gain and loss difference of each category Dj= |Lij - Gij|; transitions, expressed as twice the minimum value of gains or losses; ie., Sj= 2 x MIN (Pj+ - Pjj, Pj+ - Pjj). With the land change modeler (LCM) module, the cross-tabulation matrix between the land use and cover maps of 1965 and 2019 was generated (Figure 2). The images of 1965 and 2019 were crossed with the LCM module and Crosstab to obtain a validated change probability matrix.

The CrosstaB module generated the probabilities of Cramer’s V= 0.99, and Overall Kappa: 0.99 (Table 2), demonstrating that both images represent an accurate spatiotemporal analysis that is in accordance with the reality of the territory. The results (1965-2019) include a cartographic, tabular and graphical summary showing the area of each category, compared to others, in terms of persistence, gains, losses, contributions and transitions.

Table 2. Cross-tabulation matrix in pixels 1965 *vs* 2019.

Category	Wetlands	Arboreal	Agricultural	Livestock	Oil infrastructure	Total
Wetlands	7 728	1 264	349	2703	13	12 057
Arboreal	599	970	1691	1 623	0	4 883
Agricultural	1 671	2 375	8850	6 714	1	19 611
Livestock	6 219	3 430	3618	8 240	25	21 532
Oil infrastructure	879	194	263	913	53	2 302
Urban	369	294	4154	1 663	2	6 482
Total	17 484	8 532	18943	21 899	94	93 240

Chi-squared= 465472.2188; df= 25; *p*-Level= 0; Cramer’s V= 0.9992; Overall Kappa: 0.9988. Note: Rows 2019, columns 1964.

Land use change rate

The land use change rate identifies the type and magnitude of pressure on natural resources and indicates as a percentage the annual change in a category of use at the beginning of each year of analysis (Mas *et al*., 2002; Palacio-Prieto *et al*., 2004). The land use and cover maps of 1965 and 2019 were used (Figure 2) and the formula $d = [(S2/S1)^{1/n} - 1]100$ was used for their calculation. Where: *S*1 is the area covered by a given land use at the beginning of the period; *S*2 is the area covered by a given land use at the end of the period and *T* is the number of years of the analysis period (Palacio-Prieto *et al*., 2004).

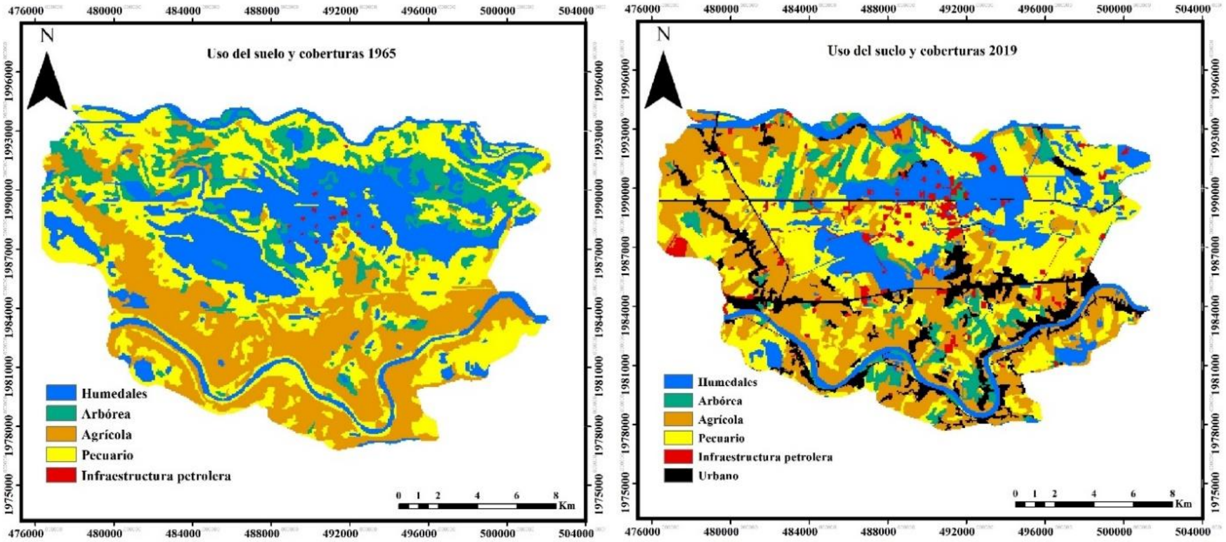


Figure 2. Land use and covers in the Samaria oil field, Tabasco (1965 and 2019).

Results and discussion

Land use change (1965-2019)

In 1965, 26.1% of the area of the SOF corresponded to wetlands, and 12% was represented by arboreal vegetation; the agricultural and livestock areas occupied the largest areas (28.3 and 32.7%, respectively), and the infrastructure for the extraction of oil barely represented 0.1% of the territory (Figure 2 and Table 2). In 2019, it was detected that wetland and arboreal vegetation covers occupied 18% and 7.3%, agricultural and livestock areas maintained the largest area (29.3 and 32.2%), oil infrastructure increased its area (3.4%) and urban use appeared (9.7%) (Figure 2 and Table 2). It should be noted that in the calculation of gains and losses (Table 2) and in the map of losses, persistence and gains for each of the categories (Figure 3).

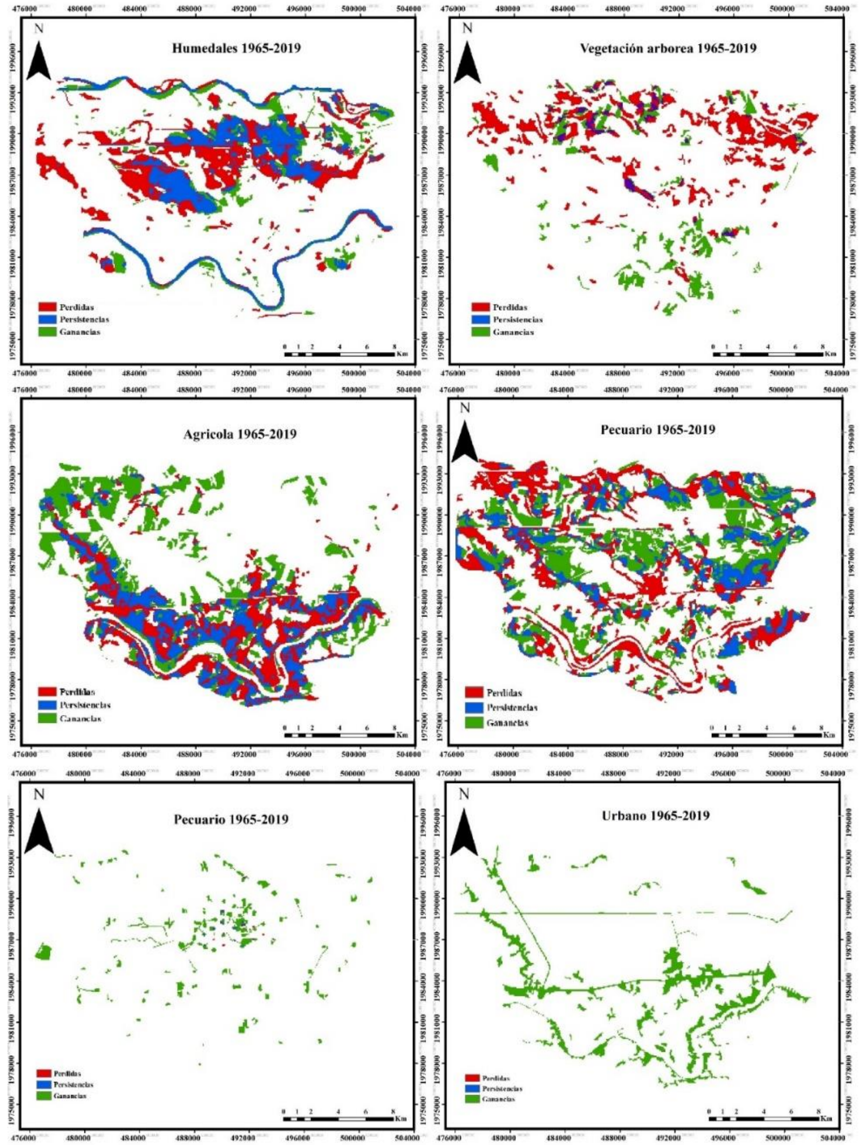


Figure 3. Maps of losses, persistence and gains in the Samaria oil field, Tabasco (1965-2019). Wetlands and arboreal vegetation.

The analysis of the contributions between the categories shows that the loss of wetland covers during the five decades was related to the increase of 158 ha in agricultural area, 480 ha in livestock area and 104 ha in oil infrastructure (Figure 4). The degradation of this vegetation coincides with the decrease in wetlands in the environment of Villahermosa, which was related to the modification of its hydraulic interconnection through the construction of canals, urban infrastructure and roads, as well as the regulation of riverbeds for water retention or diversion, the dredging of wetlands for flood control and the extraction of water for agricultural uses (Hettiarachchi *et al*., 2014; Sánchez *et al*., 2015).

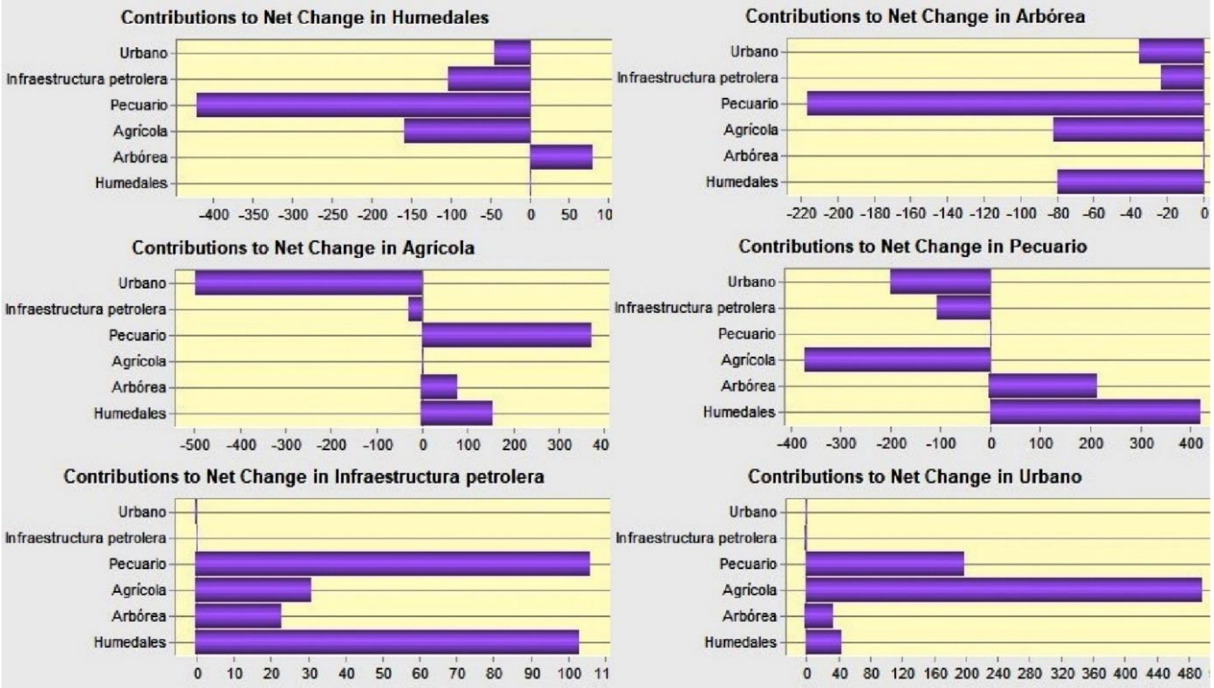


Figure 4. Contributions of areas (ha) for natural covers in the Samaria oil field, Tabasco (1965-2019).

In other wetlands such as the Pantanos de Centla Biosphere Reserve, located in the delta of the Usumacinta and Grijalva rivers, the loss of wetlands has also been attributed to the opening of communication routes to activities of the oil industry, the overexploitation of natural resources and the livestock and agriculture expansion (Guerra-Martínez and Ochoa-Gaona, 2006). Similarly, the losses of arboreal vegetation in the SOF were caused by the establishment of 216 ha of livestock use and 82 ha of agricultural use (Figure 4).

The rate of change of arboreal vegetation registered in the SOF was 1%, being lower than that of Villahermosa, which was 4.63% in the period 1984-2008, because it lost 4 008 ha, causing one of the major impacts in the last three decades in Tabasco (Palomeque-De la Cruz *et al*., 2017a). The rates of loss of arboreal vegetation and wetlands lead to the disappearance of environmental services such as the provision of water and food, the maintenance of flora and fauna biodiversity and the regulation of climate and floods (Balvanera, 2012).

Agricultural area increased by 3.5% while livestock use showed a slight percentage decrease of 1.5% (Table 2). The growth of agricultural use occurred on the livestock area (370 ha) and to a lesser extent on wetlands and arboreal vegetation (240 ha); however, 497 ha of agricultural use were displaced by urban use (Figure 4). The increase in the agricultural area in the SOF coincides with the agricultural boom in Tabasco that began in the sixties, with the promotion of extensive livestock farming to supply the national market through the Chontalpa Plan (1965-1976) and the Integrated Rural Development Program for the Humid Tropics (Flores-Santiago, 1987; Capdepont-Ballina and Marín-Olán, 2014).

In the nineties, policies to support the countryside influenced the dynamics of land use in Tabasco (Murillo and Martínez, 2010). The Program of direct support to the countryside, PROCAMPO (for its acronym in Spanish), led to the transformation of wetland areas and grasslands to agricultural areas, accelerating the processes of land use change (Klepeis and Vance, 2003; Schmook and Vance, 2009; Zarazúa-Escobar *et al*., 2011). In addition, in the state of Tabasco, drainage works were promoted to reduce flooding in areas surrounding wetlands and promote agriculture. In the SOF, at the end of the eighties, drainage works were carried out by the State Government and PEMEX, in response to *ejidatarios* (shareholders of common lan) who demanded water retention because of oil infrastructure and dirt roads on the flow of water, which increased agricultural uses (Zavala-Cruz *et al*., 2003; Zavala-Cruz and Castillo-Acosta, 2007).

As for livestock use, it grew on 480 ha of wetland covers and on 216 ha of arboreal vegetation and lost 305 ha due to expansion of agricultural, oil infrastructure and urban uses (Figure 4). The increase in livestock use in the SOF is consistent with the increase in the area with grasslands for livestock farming in the state of Tabasco, as a result of support programs such as the improvement of meadows with more nutritious grass species in the period 1965-2019 (Zavala-Cruz and Castillo-Acosta, 2007), the implementation of credits to producers for the establishment of grasslands and improvement of facilities for cattle, through the Program of Sustainable Livestock Production and Livestock and Beekeeping Management (PROGAN, for its acronym in Spanish), at the end of the 20th century and the execution of the Program of Direct Support to the Countryside (PROCAMPO, for its acronym in Spanish) (Kolb *et al*., 2013).

Urban use in the SOF expanded 100% from 1965 to date (Table 2), this was due to the phenomenon of peri-urbanization of Villahermosa on agricultural and livestock areas (Palomeque-De la Cruz *et al*., 2017a). This oil field has favorable characteristics for urbanization, such as: a) the geographical position, being a link point between the cities of Villahermosa (7 km), Cárdenas, Cunduacán and Reforma and two petrochemical plants, through highway 180 that facilitates connectivity; b) Fluvisols free from fluvial floods, being located on geoforms of natural dikes of the Carrizal River with the highest topography in the plain; and c) the protection of the area with dikes against floods (Zavala-Cruz *et al*., 2003; Zavala-Cruz *et al*., 2016).

However, the change to urban use induces degradation of Fluvisoles by sealing, although they are the most fertile and suitable for food production (Palma-López *et al*., 2017), going from uses with natural or cultivated vegetation to uses of homes, offices, roads and oil industry, which reduce agricultural fitness and the ability to infiltrate water into the aquifer (Franco-Idarraga, 2010; García-Rodríguez and Pérez-González, 2011). The oil infrastructure of the SOF increased 95.9%

(Table 2) and grew on 104 ha of wetlands and 106 ha of livestock area (Figure 4). The impulse of this industry coincided with the oil boom in Tabasco, based on the exploitation of new hydrocarbon deposits in southeast Mexico between 1973 and 1980, which produced a radical change in the economy of Villahermosa and accelerated deforestation in the state (Allub and Michel, 1979; Sánchez-Munguía, 2005).

The SOF and most of the oil fields in Tabasco were in floodplains, and the construction of roads through the wetlands to access the oil wells modified the patterns of natural water circulation, biogeochemical cycles and the biodiversity of aquatic fauna, because of the lack of efficient water passages (Zavala-Cruz *et al*., 2003; Capdepont-Ballina and Marin-Olan, 2014; Sánchez *et al*., 2015). In addition, water and soil contamination was generated by oil spills and toxic waste discharge (Gutiérrez-Castorena and Zavala-Cruz, 2001; Zavala-Cruz *et al*., 2003; Olguín *et al*., 2007).

The environmental impact in the SOF is also evidenced by the cartographic and quantitative detection of the most outstanding transitions during the period 1965-2019, where agricultural and livestock activities had the greatest influence (Figure 5). First, the replacement of 807 ha of livestock area by agricultural areas was detected, followed by the loss of 747.8 ha of wetlands that were transformed into livestock use (Figure 6). Other transitions that contributed to environmental deterioration were the growth of 499.6 ha in urban area on agricultural use and the deforestation of 400 ha of arboreal vegetation for the establishment of livestock use (Figure 6).

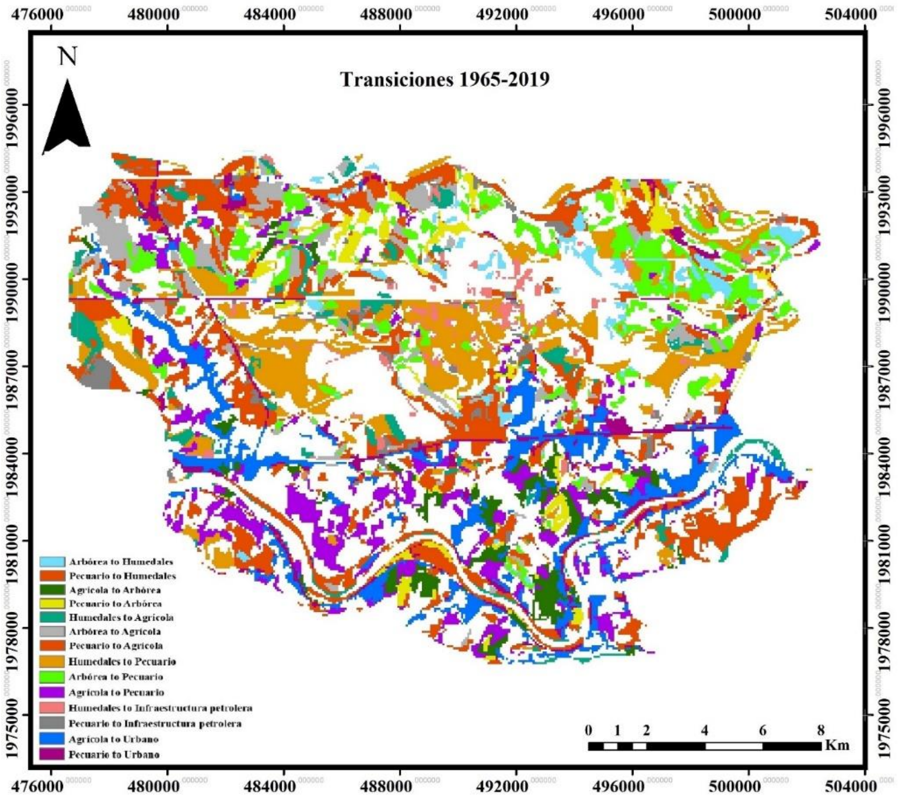


Figure 5. Map of transitions of land use and covers in the Samaria oil field, Tabasco (1965-2019).

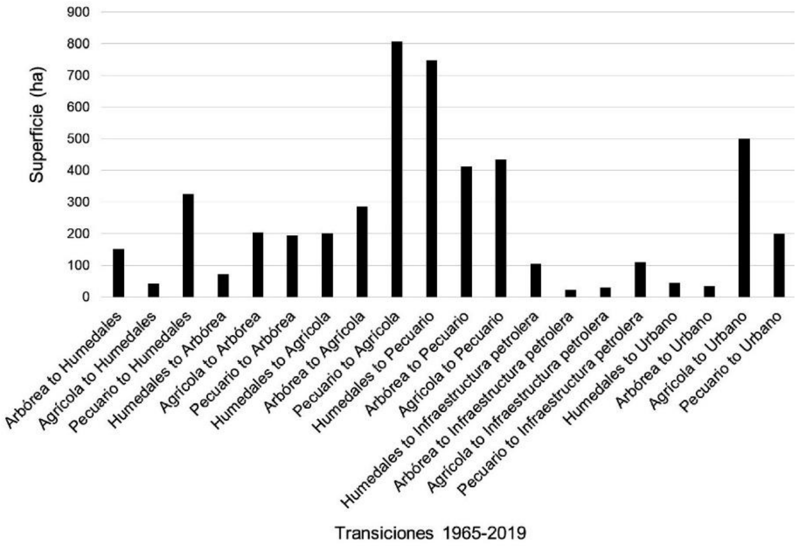


Figure 6. Graph of transitions of land use and covers in the Samaria oil field, Tabasco (1965-2019).

The analysis of land use change during 1965-2019 indicates that, if the trend of loss of wetlands and vegetation continues in the coming decades due to the effect of agricultural and urban use, plus the possible impacts associated with the reactivation of the oil industry in Tabasco in new oil fields and the new refinery in Dos Bocas, the last relicts of these ecosystems could disappear, increasing the loss of the habitat of wild flora and fauna, the degradation of agricultural soils, the loss of spaces for human recreation, and the deterioration of environmental services.

The lands of the SOF are an example of the process of change towards livestock farming and together with the oil industry have caused degradation of natural vegetation and wetlands, by not considering the capacity of use and agroecological potential of the lands; so, it is advisable to stop the disorderly advance of these uses. The activities of the oil industry and the construction of roads must be planned based on environmental impact and ecological management studies and prioritize the use of land for agricultural and forestry production (Zavala-Cruz and Castillo-Acosta, 2007).

This study demonstrates that geomatic models of land use change for the evaluation of ecosystem degradation because of land use change are accurate in estimating the distribution of the change in natural covers and artificial uses and identifies the covers that have the greatest environmental impacts (Velázquez *et al*., 2002). It is pertinent to combine geomatic models for the study of land use change, and to simulate future scenarios and the driving variables of the transition potential (Palomeque-De la Cruz *et al*., 2017b).

Conclusions

The study of land use change in the Samaria Oil Field (SOF), Tabasco, shows that in the period 1964-2019, the establishment of grasslands for livestock farming dominated the territory, followed by agricultural crops and oil infrastructure, together they caused degradation of wetland ecosystems and arboreal vegetation. Currently, agricultural uses tend to decrease because of urbanization promoted from the city of Villahermosa. Modeling using land change modeler reveals that it is an appropriate tool to evaluate land use changes and estimate the distribution of the change in natural covers and artificial uses, in areas with agricultural, urban and oil industry use.

Cited literature

Allub, L. y Michel, M. A. 1979. La formación socioeconómica de Tabasco y el petróleo. Investigación Económica. 38(148/149):327-355. http://www.jstor.org/stable/42777039.

Balvanera, P. 2012. Los servicios ecosistémicos que ofrecen los bosques tropicales. Ecosistemas. 21(1-2):136-147.

Bazant, J. 2010. Expansión urbana incontrolada y paradigmas de la planeación urbana. Espacio Abierto. 19(3):475-503.

Brena, J.; Castillo, C. y Wagner, A. 2016. Metodología para la delimitación y caracterización de humedales en escalas 1:50,000 y 1:20,000. Tecnología y Ciencias del Agua. 7(2):85-98.

Camacho-Olmedo, M. T.; Molero-Melgarejo, E. y Paegelow, M. 2010. Modelos geomáticos aplicados a la simulación de cambios de usos del suelo. Evaluación del potencial de cambio. *In*: Ojeda, J.; Pita, M. F. y Vallejo, I. (Ed.). Tecnologías de la información geográfica: la información geográfica al servicio de los ciudadanos. Secretariado de publicaciones de la Universidad de Sevilla. Sevilla, España. 658-678 pp.

Capdepont-Ballina, J. L. y Marín-Olán, P. 2014. La economía de Tabasco y su impacto en el crecimiento urbano de la ciudad de Villahermosa (1960-2010). LiminaR. 12(1):144-160. https://doi.org/10.29043/liminar.v12i1.330.

Challenger, A. y Dirzo, R. 2009. Tendencias de cambio de la biodiversidad. *In*: capital natural de México vol. II: Estado de conservación y tendencias de cambio. Comisión Nacional de la Biodiversidad (CONABIO). México, DF. 37-73 pp.

Davidson, E. A.; de Araújo, A. C.; Artaxo, P.; Balch, J. K.; Brown, I. F.; Bustamante, M. M. C.; Coe, M. T. C.; DeFries, R. S.; Keller, M.; Longo, M.; Munger, J. W.; Schroeder, W.; Soares-Filho, B. S.; Souza Jr., C. M. and Wofsy, S. C. 2012. The Amazon Basin in transition. Nature. 481:321-328. http://www.nature.com/doifinder/10.1038/nature10717.

Eastman, J. R. 2012. IDRISI Selva GIS and image processing software version 17.0. Clark Labs. Massachusetts, USA. 321 p. https://clarklabs.org/wp-content/uploads/2016/10/IDRISI-Selva-Spanish-Manual.pdf.

FAO. 2015. Organización de las Naciones Unidas para la Alimentación y la Agricultura. Evaluación de los recursos forestales mundiales 2015 compendio de datos. Roma, Italia. 245 p. http://www.fao.org/3/a-i4808s.pdf.

Flores-Santiago, A. 1987. La modernización de la agricultura en el trópico húmedo mexicano: veinte años de experiencia en la Chontalpa, Tabasco. Rev. Geogr. Agríc. 13-14(2):105-114.

Franco-Idarraga, F. L. 2010. Respuestas y propuestas ante el riesgo de inundación de las ciudades colombianas. Rev. Ing. 31:97-108. https://doi:10.16924/riua.v0i31.216.

García-Rodríguez, M. y Pérez-González, M. E. 2011. Sellado de fluvisoles en la comunidad de Madrid. Análisis a partir de imágenes Landsat. Anales de Geografía de la Universidad Complutense. 31(2):125-137. https://doi.org/10.5209/rev_AGUC.2011.v31.n2.37021.

Guerra-Martínez, V. y Ochoa-Gaona, S. 2006. Evaluación espacio-temporal de la vegetación y uso del suelo en la Reserva de la Biosfera Pantanos de Centla, Tabasco (1990-2000). Investigaciones Geogr. 59:7-25. http://www.investigacionesgeograficas.unam.mx/index.php/rig/article/viewFile/30018/27897.

Gutiérrez-Castorena, M. C. y Zavala-Cruz, J. 2001. Rasgos hidromórficos de suelos tropicales contaminados con hidrocarburos. Terrra Latinoam. 20(2):101-111.

Hettiarachchi, M.; Morrison, T. H.; Wickramsinghe, D.; Mapa, R.; De Alwis, A. and McAlpine, C. A. 2014. The eco-social transformation of urban wetlands: a case study of Colombo, Sri Lanka. Landscape and Urban Planning. 132:55-68. https://doi.org/10.1016/j.landurbplan.2014.08.006.

Jiménez-Moreno, M. J.; González-Guillen, M. D. J. Escalona-Maurice, M.; Valdez-Lazalde, J. R. y Aguirre-Salado, C. A. 2011. Comparación de métodos espaciales para detectar cambios en el uso del suelo urbano. Rev. Chapingo Ser. Cienc. Forest. Amb. 17(3):389-406. doi: 10.5154./r.rchscfa.2010.04.020.

Klepeis, P. and Vance, C. 2003. Neoliberal policy and deforestation in southeastern Mexico: an assessment of the Procampo program. Econ. Geography. 79(3):221-240. https://www.jstor.org/stable/30032931.

Kolb, M.; Mas, J. F. and Galicia, L. 2013. Evaluating drivers of land-use change and transition potential models in a complex landscape in Southern Mexico. Int. J. Geogr Inf. Sci. 27(9):1804-1827. doi:10.1080/13658816.2013.770517.

Lezama, J. L. 1987. Migración y petróleo en Tabasco. Estudios demográficos y urbanos. 2(2):231-256. https:// doi.org/10.24201/edu.v2i2.627.

Murillo, L. D. y Martínez, R. J. 2010. Comunicación para el desarrollo en México: reflexiones sobre una experiencia en el trópico húmedo. Estudios sobre las Culturas Contemporáneas. 16(31):201-225. https://www.redalyc.org/pdf/316/31613952008.pdf.

Olguín, E. J.; Hernández, M. E. y Sánchez-Galván, G. 2007. Contaminación de manglares por hidrocarburos y estrategias de biorremediación, fitorremediación y restauración. Rev. Int. Cont. Amb. 23(3):139-154. https://www.redalyc.org/pdf/370/37023304.pdf.

Ortiz-Solorio, C. A.; Gutiérrez-Castorena M. del C.; Sánchez-Guzmán, P. y Gutiérrez-Castorena, E. V. 2011. Cartografía de la degradación de suelos en la República Mexicana: evolución y perspectivas. *In*: Krasilnikov, P.; Jiménez-Nava, F. J.; Reyna-Trujillo, T. y García-Calderón, N. E. (Ed.). Geografía de suelos de México. Facultad de Ciencias-Universidad Nacional Autónoma de México (UNAM). México, D F. 173-210 pp.

Paegelow, M.; Camacho, M. y Menor, J. 2003. Cadenas de Markov, evaluación multicriterio y evaluación multiobjetivo para la modelización prospectiva del paisaje. GeoFocus. 3:22-44. http://www.geofocus.org/index.php/geofocus/article/view/21.

Palacio-Prieto, J. L; Sánchez-Salazar, M. T.; Casado, I. J. M.; Propin, F. E.; Delgado, C. J.; Velázquez, M. A.; Chías, B. L.; Ortiz, A. M. I.; González, S. J.; Negrete, F. G.; Gabriel, M. J. y Márquez, H. R. 2004. Indicadores para la caracterización y el ordenamiento territorial. Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT)-Instituto Federal Electoral (INE)-Universidad Nacional Autónoma de México (UNAM). Instituto de Geografía y SEDESOL. México, DF. 161 p.

Palma-López, D. J.; Jiménez-Ramírez, R.; Zavala-Cruz, J.; Bautista-Zúñiga, F.; Gavi-Reyes, F. y Palma-Cancino, D. Y. 2017. Actualización de la clasificación de suelos de Tabasco. Agroproductividad. 10(12):29-35.

Palomeque-De la Cruz, M. A.; Galindo-Alcántara, A.; Sánchez, A. J. y Escalona-Maurice, M. J. 2017a. Pérdida de humedales y vegetación por urbanización en la cuenca del río Grijalva, México. Investigaciones Geográficas. 68:151-162. https://www.redalyc.org/pdf/176/17653923009.pdf.

Palomeque-De la Cruz, M. A.; Galindo-Alcántara, A.; Pérez-Sánchez, E.; Sánchez, A. D. J. y Escalona-Maurice, M. J. 2017b. Modelos geomáticos con base en transición para el análisis espacial en Villahermosa, Tabasco. Rev. Mex. Cienc. Agríc. 8(2):253-267. http://www.scielo.org.mx/pdf/remexca/v8n2/2007-0934-remexca-8-02-253-en.pdf.

PEMEX. 2016. Petróleos Mexicanos. Anuario estadístico 2016. Ciudad de México. 122 p. https://www.pemex.com/ri/Publicaciones/Anuario%20Estadistico%20Archivos/anuario-estadistico-2016.pdf.

Pineda-Jaimes, N. B.; Bosque-Sendra, J.; Gómez-Delgado, M. y Plata-Rocha, W. 2009. Análisis de cambio del uso del suelo en el Estado de México mediante sistemas de información geográfica y técnicas de regresión multivariantes. Una aproximación a los procesos de deforestación. Investigaciones Geogr. 69:33-52. https://www.redalyc.org/pdf/569/56912295004.pdf.

Pontius Jr. R. G.; Huffaker, D. and Denman, K. 2004. Useful techniques of validation for spatially explicit land-change models. Ecological Modelling. 179:445-461. https://doi.org/10.1016/j.ecolmodel.2004.05.010.

Ramos-Reyes, R.; Sánchez-Hernández, R. y Gama-Campillo, L. M. 2016. Análisis de cambios de uso del suelo en el municipio costero de Comalcalco, Tabasco, México. Ecosistemas y Recursos Agropecuarios. 3(8):151-160.

Rosete-Vergés, F. A.; Pérez-Damián, J. L.; Villalobos-Delgado, M.; Navarro-Salas, E. N.; Salinas-Chávez, E. y Remond-Noa, R. 2014. El avance de la deforestación en México 1976-2007. Madera y Bosques. 20(1):21-35. https://doi.org/10.21829/myb.2014.201173.

Sánchez, A.J.; Salcedo, M.A.; Florido, R.; Mendoza, J.D.; Ruiz-Carrera, V. y Álvarez-Pliego, N. 2015. Ciclos de inundación y conservación de servicios ambientales en la cuenca baja de los ríos Grijalva-Usumacinta. Contactos. 97:5-14. http://www2.izt.uam.mx/newpage/contactos/revista/97/pdfs/inundacion.pdf.

Sánchez-Munguía, A. 2005. Uso del suelo agropecuario y desforestación en Tabasco 1950-2000. Universidad Juárez Autónoma de Tabasco. Villahermosa, Tabasco, México. 123 p.

Schmook, B. and Vance, C. 2009. Agricultural policy, market barriers, and deforestation: the case of Mexico’s southern Yucatán. World Development. 37(5):1015-1025.

Torres-Vera, M. A.; Prol-Ledesma, R. M. and García-López, D. 2009. Three decades of land use variations in Mexico City. Int. J. Remote Sens. 30(1):117-138. https://doi.org/10.1080/01431160802261163.

Trucíos-Caciano, R.; Rivera-González, M.; Delgado-Ramírez, G.; Estrada-Ávalos, J. y Cerano-Paredes, J. 2013. Análisis sobre cambio de uso de suelo en dos escalas de trabajo. Terra Latinoam. 31(4):339-346.

Tubiello, F. N.; Salvatore, M.; Ferrara, A. F.; House, J.; Federici, S.; Rossi, S.; Biancalani, R.; Condor, G. R. D.; Jacobs, H.; Flammini, A.; Prosperi, P.; Cardenas-Galindo, P.; Schmidhuber, J.; Sanz, S. M. J.; Srivastava, N. and Smith, P. 2015. The contribution of agriculture, forestry and other land use activities to global warming, 1990-2012. Global Change Biol. 21(7):2655-2660.

Tudela, F. 1992. La modernización forzada del trópico: El caso de Tabasco. Proyecto integrado del golfo. 2ª (Ed.). El Colegio de México, CINVESTAV, INFIAS y UNRISD. México, DF. 474 p.

Velázquez, A.; Mas, J. F.; Gallegos, J. R. D.; Mayorga-Saucedo, R.; Alcántara, P. C.; Castro, R. y Palacio, J. L. 2002. Patrones y tasas de cambio de uso del suelo en México. Gaceta Ecológica. 62:21-37. https://www.redalyc.org/pdf/539/53906202.pdf.

Vitousek, P. M.; Mooney, H. A.; Lubchenco, J. and Melillo, J. M. 1997. Human domination of Earth’s ecosystems. Science. 277(5325):494-499. Doi: 10.1126/science.277.5325.494.

Zarazúa-Escobar, J. A.; Almaguer-Vargas, G. y Ocampo-Ledesma, J. G. 2011. El programa de apoyos directos al campo (PROCAMPO) y su impacto sobre la gestión del conocimiento productivo y comercial de la agricultura del Estado de México. Agric. Soc. Des. 8(1):89-105.

Zavala-Cruz, J.; Gutiérrez-Castorena, M. del C. y Palma-López, D. J. 2003. Impacto ambiental en las tierras del campo petrolero Samaria, Tabasco. Colegio de postgraduados. CCYTET-CONACYT. Villahermosa, Tabasco. 131 p.

Zavala-Cruz, J. y Castillo-Acosta, O. 2007. Cambio de uso de la tierra en el estado de Tabasco. *In*: Palma D. J. y Triano, A. (Ed.). Plan de uso sustentable de los suelos del estado de Tabasco (vol, II). Colegio de Posgraduados, ISPROTAB. Villahermosa, México. 38-56 pp.

Zavala-Cruz, J.; Morales-Garduza, M. A.; Vargas-Villamil, L. M.; Palma-López, D. J. y Ortiz-Solorio, C. A. 2016. Capacidad de uso del suelo urbano en planicies fluviales costeras: el caso de Villahermosa, Tabasco, México. Interciencia. 41(5):296-304.

Zepeda-Gómez, C.; Nemiga, X. A.; Lot-Helgueras, A. y Madrigal-Uribe, D. 2012. Análisis del cambio del uso del suelo en las Ciénegas de Lerma (1973-2008) y su impacto en la vegetación acuática. Investigaciones Geográficas. 78:48-61. https://www.redalyc.org/articulo.oa?id=569/56924410005.