Article

Modeling of changes in cover and land use in Nacajuca, Tabasco

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Abstract

The urban growth of Nacajuca, Tabasco, has transformed the natural system, being necessary to know the current spatial configuration of natural covers and artificial uses in order to provide information on spatial dynamics for ecological planning. The objective of the study was to model changes in covers and land use (2000, 2008 and 2017), through a multitemporal analysis using the Land Change Modeler for ecological sustainability of IDRISI. The results indicate that in the period 2000-2008, there was a decrease in wetlands (1 796 ha) and a slight increase in tree vegetation (689 ha), contrary to urban growth (796 ha) and a large increase in grassland (2 168 ha). In the second period (2008-2017), the greatest loss of wetlands (3 995 ha) and tree vegetation (1 233 ha) was detected, while the urban area and grassland had the greatest increases (1 365 and 4 378 ha). The main transitions were first, the change from large wetland covers to grassland and secondly the transformation from grassland to urban area. The disturbance relates to the dynamics of the metropolitan area of Villahermosa and coincides with the loss of large wetland areas in the areas analyzed. In view of this, the alternatives to reduce the effects of land use change are the elaboration of the territorial ecological planning and the urban development program in which the use of Geographic Information Systems, environmental remote sensing and the implementation of geomatic models for spatial analysis are involved.

Keywords: environmental disturbance, geographic information systems, land use change modeler, territorial ecological planning.

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Introduction

Land use change and urbanization are transforming ecosystems into metropolitan areas as they have experienced considerable growth in recent decades (Dadashpoor and Alidadi, 2017; Salvati *et al*., 2018; Dadashpoor *et al*., 2019) and represent the dominant environmental disturbance in the world (Vitousek *et al*., 1997). At the local level, the dynamics of the territory influence the deterioration and degradation of soils, changes in ecological niches and the resilience of ecological components (Najera Gonzalez *et al*., 2010). Dynamics are determined by factors such as relief, socioeconomics, land management, land tenure and sectoral policies (Delgado *et al*., 2017).

The study of space-time dynamics is one of the most important aspects of physical-biotic analysis for territorial ecological planning (Aguayo *et al*., 2009). It provides the basis for identifying the trends in patterns of deforestation, degradation, desertification and loss of biodiversity (Lambin *et al*., 2001).

For the elaboration of territorial planning in urban areas, it is necessary to know the patterns of land use change that help to implement strategies and actions aimed at sustainable use to reduce the problems of the deterioration of urban ecosystems (Duch *et al*., 2019).

The Land Change Modeler (LCM) for ecological sustainability of IDRISI (Eastman and Toledano, 2018) is designed for land use planning, because it simplifies the complexities of land cover change analysis (Camacho-Olmedo *et al*., 2010; Eastman, 2012). It is aimed at assessing the constant problem of accelerated soil conversion and the analytical needs of biodiversity conservation (Camacho-Olmedo *et al*., 2010; Eastman, 2012).

In Tabasco, more than 90% of state cover was degraded as a result of the economic impulse of the twentieth century (Sánchez, 2005; Navarro and Toledo, 2008; Zavala, 2009; Pinkus-Rendón and Contreras-Sánchez, 2012). In this regard, the following stands out, the plantations of banana and cocoa oriented to the international market that spread since the late nineteenth century, until the 1940s, extensive livestock directed to the national market known as the Chontalpa Plan (1965-1976), the Integrated Rural Development Program for the Humid Tropic, and the oil boom that remained booming between the 1970s and 1980s (Allub and Michel, 1979; Flores-Santiago, 1987; Capdepont-Ballina; Marín-Olán, 2014).

These programs exploited jungle lands and gained space of wetlands with irreversible disruption of natural resources (Lara and Vera, 2017). During 1940-1996 the major disruption of ecosystems was the loss of 95% of the jungle covers of Tabasco (Zavala *et al*., 2009).

Nacajuca is part of the metropolitan area of Villahermosa and is influenced by accelerated urban growth with occupation of roads, housing developments, shopping centers and other services that have transformed the natural system, specifically the impacts have focused on the transformation of tree vegetation, as well as lake, swamp and riverine wetlands (Capdepont-Ballina and Marín-Olán, 2014; Diaz, 2014; Palomeque-De la Cruz *et al*., 2017).

During the sixties and seventies, cattle farming received an extraordinary boost in southeastern Mexico and particularly in the state of Tabasco, which transformed more than 1 200 ha from jungle into grasslands (Morales, 1990, Galindo, 2006). By the eighties, the discovery and exploitation of large oil mantle in the region caused several alterations to ecosystems. In this way, frequent oil spills, deforestation and road construction to build and maintain oil facilities (Lara and Vera, 2017) not only contributed to environmental impact, but have also changed surface runoff patterns, meaning an environmental impact not yet quantified.

Because of this, it is necessary to use the geomatic models of land use change with a GIS platform to know the current spatial configuration of natural covers and artificial uses in order to provide accurate and up-to-date information on spatial dynamics for territorial ecological planning. The objective of this paper was to model changes in cover and use of land in the municipality of Nacajuca, Tabasco, Mexico (2000, 2008 and 2017), through a multitemporal analysis using the Land Change Modeler for ecological sustainability of the IDRISI program (Eastman and Toledano, 2018).

Materials and methods

Study area

The municipality of Nacajuca is in the Central subregion, located in the northwest of the city of Villahermosa in the state of Tabasco. It is bordered to the north by the municipalities of Jalpa de Méndez, Centla and Centro; to the east by Centro, to the south by Cunduacán and Centro; finally, to the west borders Cunduacán and Jalpa de Méndez (Ayuntamiento de Nacajuca Tabasco, 2018; Gobierno del Estado de Tabasco, 2018). It is located between coordinates 18° 09’ 05’’ north latitude and 93° 01’ 06’’ west longitude.

The average altitude of the territory is 10 masl and has an area of 52 457 hectares (Figure 1). The soils are coastal plain with numerous swamps and lagoon systems and with alluvial soil, so much of its territory is floodable (Lara and Vera, 2017; Ayuntamiento de Nacajuca Tabasco, 2018).

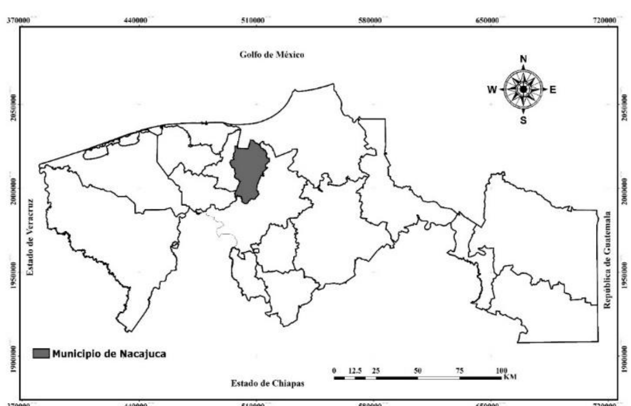

Figure 1. Map of the study area: Nacajuca, Tabasco, Mexico.

Two orthophotos of 2000 (1:20 000) and 2008 (1:10 000) downloaded from the INEGI database (INEGI, 2008) were used. An image of the Sentinel satellite (1:10,000) from 2017 was also obtained (ESA, 2017). The information presented a UTM coordinate and projection system, zone 15 N and datum WGS84. Vector scanning was then performed with the software Arc GIS® 10.2 (ESRI, 2017).

Digitization was supported by field monitoring and comparison with cartographic sources. The categories used were: 1) wetlands; 2) tree vegetation; 3) urban area; 4) wasteland; 5) industrial zone; and 6) grassland. The vectors were later transformed into raster format with the command RasterVector of the software Idrisi Terrset (Eastman, 2016).

Modelling the change in land use (2000, 2008 and 2017)

Land Change Modeler of IDRISI Terrset software generates a land use change matrix with images that vary in the number of collection dates; that is, in more than two periods (Pontius *et al*., 2004; Pineda *et al*., 2009). In that matrix the rows represent the categories of the map at time one (T_1) and the columns the categories of the map at time two (T_2) (Table 1).

Table 1. Model of cross-tabulation matrix for two maps of different dates (Pontius *et al*., 2004). T1 and T2 are the periods to be analyzed; class are the different categories of analysis; and n is the number of categories in the analysis.

Time 1	Time 2				Total T1	Loss
	Class 1	Class 2	Class 3	Class n		
Class 1	P11	P12	P13	P1n	P1+	P1+ - P1n
Class 2	P21	P22	P23	P2n	P2+	P2+ -P2n
Class 3	P31	P32	P33	P3n	P3+	P3+ -P3
Class n	Pn1	Pn2	Pn3	Pn,n	Pn+	Pn+ - Pn, n
Total T2	P+1	P+2	P+3	P+n		
Gain	P+1-Pn1	P+2-Pn2	P+3-Pn3	P+n- Pn, n		

Also, the main diagonal shows the persistence between the categories of T_1 and T_2, while the elements outside the main diagonal account for the transitions that occurred between the two periods for each category (Table 1). The subtotal with the summation of each category is in the penultimate row and in the penultimate column both represent the total changes for each category in each period.

The last row and last column collect the total variations for each category. Table 1 shows a generic model of the matrix, which is a by-product of the analysis, and its results are used to construct Table 2, where the totals of each category per year are expressed, as well as the losses and gains of each of these.

Table 2. Quantification of the change in land use in Nacajuca, Tabasco 2000-2008, 2008-2017.

Categories	2000		2008		Losses (ha)	Gains (ha)	Net change (ha)	Tc (%)
	(ha)	(%)	(ha)	(%)				
Wetlands	29 608	56.4	28 097	53.6	-1 796	285	-1 511	-0.7
Tree vegetation	7 826	14.9	7 866	15	-640	680	40	0.1
Urban area	769	1.5	1565	3	-1	796	796	9.3
Wasteland	15	0	136	0.3	0	122	122	32
Grassland	14 239	27.1	14 792	28.2	-1 614	2 168	554	0.5
Categories	2008 (ha)	(%)	2017 (ha)	(%)	Losses (ha)	Gains (ha)	Net change (ha)	Tc (ha)
Wetlands	28 097	53.6	25 187	48	-3 995	1 085	-2 910	-1.4
Tree vegetation	7 866	15	7 262	13.8	-1 322	718	-604	-1
Urban area	1 565	3	2 889	5.5	-40	1 365	1 325	8
Wasteland	136	0.3	115	0.2	-41	19	-22	-2.1
Grassland	14 792	28.2	17 004	32.4	-2 167	4 378	2 212	1.8

The cross of the 2000 and 2008 covers and land-use images (Figure 2) generated a matrix with a Kappa statistic= 0.9349; while the 2008 and 2017 images (Figure 2) generated a matrix with a Kappa statistic= 0.8802. These statistics close to 1.000 are reliable for the analysis of the dynamics of the territory in the two time periods (Eastman and Toledano, 2018).

The results included the summary of the matrices that shows the surface of each category, compared to others, in terms of gains, losses, net changes, transitions, and contributions between categories.

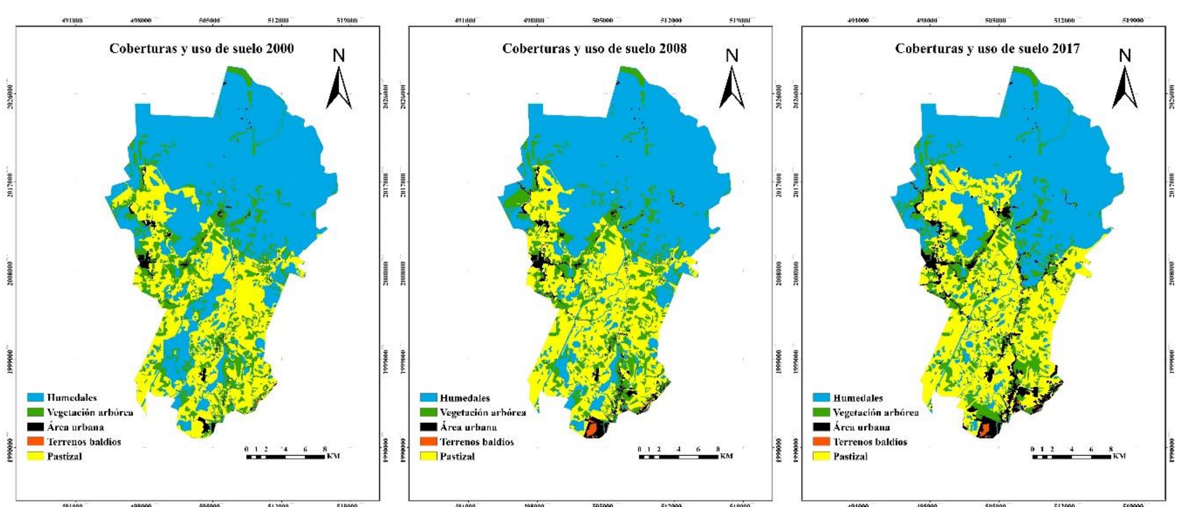

Figure 2. Map of covers and land use in Nacajuca, Tabasco (2000, 2008 and 2017).

Rates of change

Rates of change of land-use for the two study periods were calculated using the formula (Palacio-Prieto, 2004): Td= [(S2 / S1) (1 / n) -1] ∗ 100. Where: Td= annual rate of change (%); S1= covered area at the beginning of the period (ha); S2= covered area at the end of the period (ha); and n= the number of years of the period.

Results and discussion

Change analysis 2000-2008-2017

Table 2 reports land-use areas and rate of change per period analyzed. In 2000; 56.4% of Nacajuca consisted of wetlands (Table 2), in which swamps with a variety of flora and fauna stand out. Other dominant wetlands are the lagoons, where the called chontal ridges were established in the 1970s, whose objective was to combine soils for vegetable crops and the development of fish farming (Ayuntamiento de Nacajuca Tabasco, 2015).

In wetlands there is presence of floating hydrophilic vegetation inside and on the shores such as black mimosa (*Mimosa pigra*), alligator flag (*Thalia geniculata*), common reed (*Phragmites australls*) and Southern cattail (*Typha domingensis*) (Cálix *et al*., 1991; Pérez Sánchez, 2007). In the territory there is the presence of acahuales at different levels of conservation and small portions of jungles that in 2000 occupied 14.9% (Table 2).

Forest wealth has been displaced by irrational exploitation, timber smuggling, retaining small portions of cedar, pink poui, ceiba and on a smaller scale mahogany (Ayuntamiento de Nacajuca Tabasco, 2015). Urban area and grassland occupied smaller areas (1.5% and 27.1%) compared to natural covers (Table 2). In the grasslands there are also agricultural areas that have a diversity of crops varying from grains to fruits, edible plants among which maize, bean and pumpkin stand out (Pérez, 2007).

As shown in Table 2 and Figure 3, during the first analysis period (2000-2008), wetlands were found to have decreased by 1 796 ha with a negative rate of change of 0.7%, while tree vegetation showed a slight increase (680 ha) with a rate of change of 0.1% (Table 2). At the same time, the urban area occupied remarkable growth of 796 ha with a rate of change of 9.3% and the grassland had increases of 2 168 ha with a rate of change of 0.5% (Table 2).

These data indicate that in the first period of analysis, Nacajuca exhibited land-use change patterns like those recorded in the city of Villahermosa (2000-2008), in which losses of natural vegetation and wetlands were detected (1 624 and 2 013 ha) with high rates of change (-7.45 and -1.13%) while grassland and urban area increased (540 and 1 334 ha) with rates of change of 0.62 and 1.46% (Palomeque-De la Cruz *et al*., 2017).

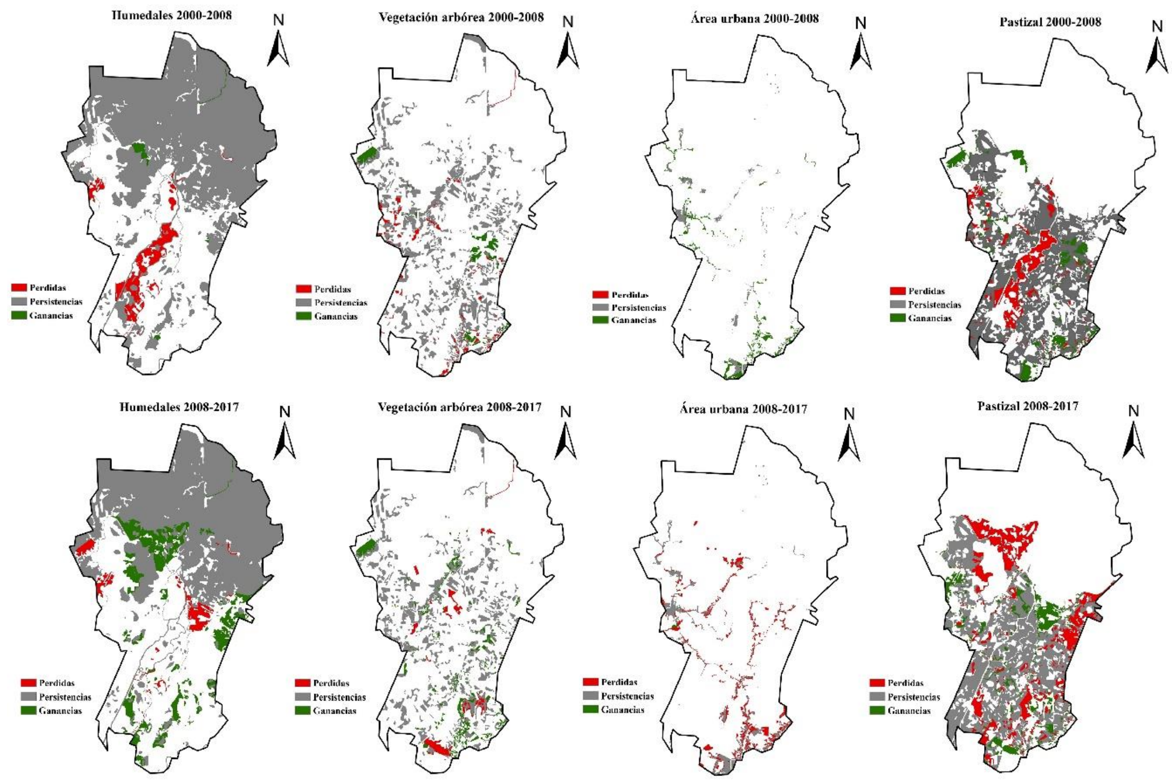

Figure 3. Map of losses and gains in Nacajuca, Tabasco, 2000-2008 and 2008-2017 (ha).

Despite the influence of the spatial dynamics of the metropolitan area of Villahermosa, in Nacajuca rates of change for wetlands, tree vegetation and grasslands were less than 1% for both the loss of wetlands and for the increase of the urban area and grasslands (Table 2). However, these rates more similar to the average deforestation in the Grijalva-Usumacinta basin (0.90%) during 1993-2007 (Kolb and Galicia, 2012).

In the period 2008-2017, the greatest disruption of ecosystems was detected because losses of wetlands (3 995 ha) and tree vegetation (1 322 ha) increased by comparison with the previous period (2000-2008) with high negative rates of change (1.4% and 1%), while the urban area continued to occupy areas with gains of 1 365 ha, and with rates of change of 8% (Table 2).

Grassland was also found to have the highest gains increases of 4 378 ha and a rate of change of 1.8% (Table 2). This was the period of greatest spatial dynamics and coincides with the speed of deforestation (-0.3%) nationally recorded during 1999-2015, according to the annual report of the Food and Agriculture Organization of United Nations (FAO, 2015).

In the land use map for 2017, the greatest growth of the municipal seat of Nacajuca and the town of Guatacalca to the West, the dense urban core of the Pomoca housing development in the Southeast and the conurbation area of Bosques de Saloya to the South stand out (Figure 2).

Despite their constant dynamics, wetlands are the covers with the greatest dominance in the subbasin Grijalva-Villahermosa, their great persistence relates to increases in their distribution area due to higher percentages of moisture in the soil and because they are subject to flood processes as they are in low-lying areas and by the influence of water pond systems (Neiser *et al*., 2019).

Soils also influence with flood vulnerability because the Northwest and Southwest region that occupies half the municipal area are classified as Gleysols, which are clayey or loamy textured soils, which have problems of excess moisture due to poor drainage. While in the Central and South part, there are soils classified as Fluvisols, whose presence is associated with the existence of rivers in the area. To the North, bordering the municipality of Centla, there are soils classified as Solonchak, which are saline soils due to the proximity of the Gulf of Mexico (Ayuntamiento de Nacajuca Tabasco, 2015).

Nacajuca is in conurbation with Villahermosa from urban growth to the South and West of the state capital. The urbanization rate of the municipality of Nacajuca (63.1%) it is above the state average in terms of agglomeration (59.7%), with the municipality currently absorbing the population and metropolitan growth suffered by Villahermosa (Ayuntamiento de Nacajuca Tabasco, 2015). Regarding the role played by Nacajuca with the metropolization of Villahermosa, it is observed that the urban poles that by 2000 were linked by primary roads, in 2017 are visualized connected by urban corridors and scattered human settlements (Figure 2).

The consolidation of the corridors was based on the construction of housing developments and shopping centers (Ayuntamiento de Nacajuca Tabasco, 2018). Spatial analysis shows that Nacajuca is expanding uncontrollably, decreasing its tree vegetation covers and increasing its grassland areas, with a domain of low and flood land (Figure 2). Artificial infrastructure acts as a barrier, so the filling of areas for the expansion of new urban areas adjacent to roads has favored the occupation of flood zones, which contributes to increasing the high risk of flooding (Zamora *et al*., 2019).

In the map for 2017, Nacajuca is observed with landscape fragmentation (Figure 2), a process caused by anthropogenic factors and is considered to be one of the main causes of biodiversity loss, due to its biological effects such as loss of genetic variability of populations; ecological effects such as habitat loss, public health such as the transmission of zoonotic diseases , and socioeconomic effects such as the loss of natural resource sources for the social development of human populations, being a problem of global interest very common in Latin American urban areas (Santos and Telleria, 2006; Bähr and Borsdorf, 2011).

The spatial dynamics of the Nacajuca ecosystems were also determined by cartographic and quantitative detection of transitions 2000-2008. It shows that the most outstanding transformations were the high conversion of wetland covers to grassland, although changes from grassland to tree vegetation were also found due to natural or induced reversal processes. Likewise, grassland to urban transitions were detected and despite vegetation reversal, the replacement of tree vegetation to grassland for the growth of agricultural activities was found (Figure 4).

Transitions 2008-2017 showed the replacement of wetlands with grassland and important displacements of tree vegetation for the expansion of the urban area and for the increase of grassland. There were also reversal dynamics, although on smaller areas such as grassland conversions to wetlands and grassland to tree vegetation (Figure4).

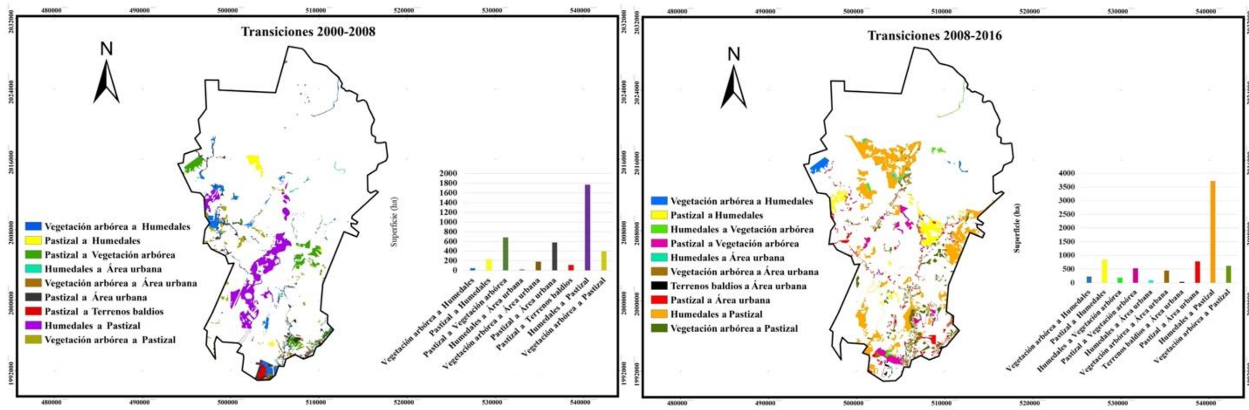

Figure 4. Maps of transitions in Nacajuca, Tabasco, 2000-2008 and 2008-2017 (ha).

Contributions of areas between the five categories in the analysis period 2000-2008 indicate that wetland loss was directly related to the increase of 1 531 ha of grassland and 29 ha of urban area (Figure 5). In contrast, tree vegetation losses were caused by the growth of 186 ha in the urban area (Figure 5). However, there was a reversal of vegetation on 279 ha of space previously occupied by grassland (Figure 5).

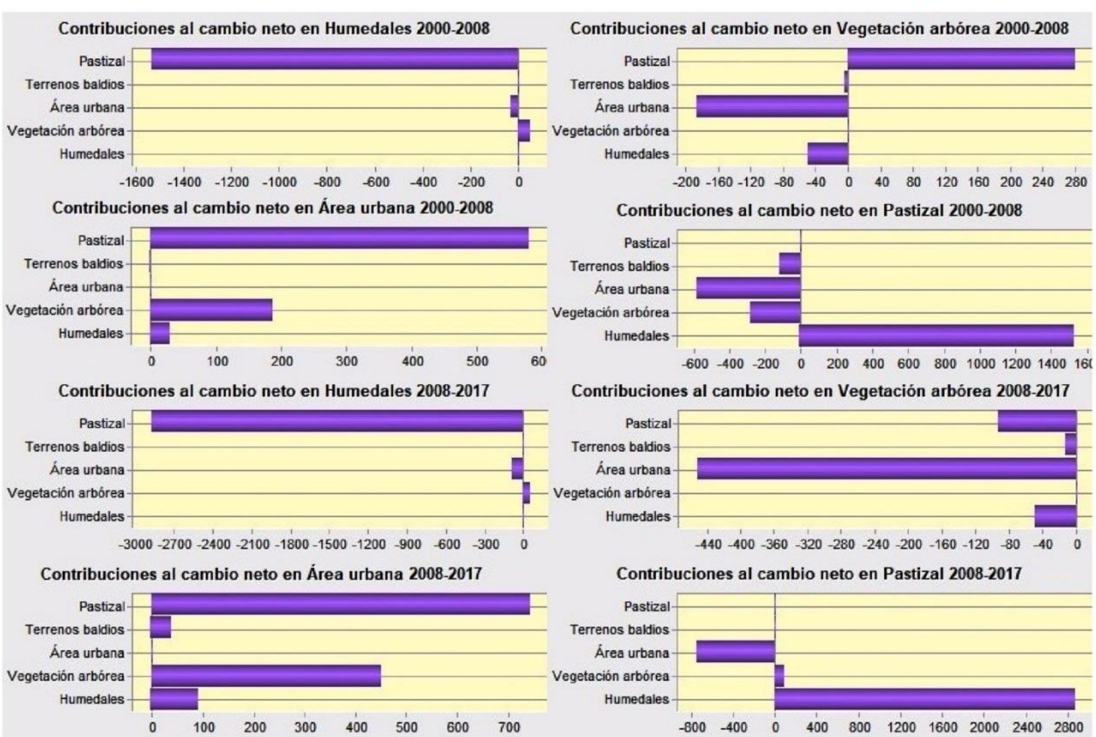

Figure 5. Contributions of areas between categories 2000-2008 and 2008-2017 (ha).

The regeneration of tree covers in this period coincides with reforestation actions in the ejidos of Tabasco due to increasing reforestation programs for forest use and payments for environmental services such as carbon capture (Alejandro-Montiel *et al*., 2010). Similarly, the grassland grew on 118 ha of wasteland and lost 580 ha to urban area growth (Figure 5). Contributions of the period 2008-2017 indicated that 2 866 ha of wetlands were converted to grassland, while another 29 ha of wetlands were transformed into urban areas (Figure 5).

The losses of tree vegetation were caused by increases of 93 ha of grassland, 12 ha of wasteland, 49 ha due to the increase in wetlands and 450 ha by the growth of the urban area (Figure 5). Grassland was the space for the growth of 743 ha in the urban area (Figure5).

In this way, it becomes clear that the patterns of change in land use during 2000, 2008 and 2017 were first, the transition from large wetland covers to grassland and secondly the transformation of grassland into urban areas. These transitions coincide with the degradation of the ecosystems of the urban area of Villahermosa (1984-2000-2008) that were caused first by the transition to grassland for agricultural use and second by urbanization (Zavala-Cruz *et al*., 2011; Palomeque de la Cruz *et al*., 2017).

In addition, in Tabasco, large wetland covers have disappeared due to grassland growth, followed by urban growth, consolidation of industrial and road infrastructure (Estrada *et al*., 2013). Loss of wetland covers is a national priority problem because they are suppliers of ecosystem services such as the maintenance of biodiversity of flora and fauna, environmental regulation, nutrient retention, water purification, flood control, carbon sequestration and water for agricultural activities and human consumption (Henny and Meutia, 2014; Moreno-Casasola and Infante, 2016; López-Jiménez, 2019).

It is claimed that transitions from wetlands to grassland are of great influence in the territory, so they can be used in the Land Change Modeler for the construction of submodels of transition potential that aim to find the rules that influence the dynamics of space-time change, and identify the variables that condition them (Eastman, 2012; Diaz-Pacheco and Hewitt, 2013). Transitions can also help simulate forward-looking scenarios by combining with the determining variables and with a Markov Chain (Mishra *et al*., 2011; Diaz-Pacheco and Hewitt, 2013).

The change in land use in Nacajuca was also induced by oil activities, mainly the construction of wells and access roads to them, which led to the filling of wetlands; but also due to spills and explosions in the wells (Pinkus-Rendón and Contreras-Sánchez, 2012; Lara and Vera, 2017). The environmental impact on wetlands also affected indigenous communities such as those in the village of Tucta, where the construction of ridges to obtain spaces for agricultural production required the filling of flood zones, thus contributing to the vulnerability of the territory to the increase of more flood events in 2000, 2001, 2007, 2008 and 2010 that resulted in the reduction of crop production and even the disappearance of local species (Lara and Vera, 2017).

According to space-time analysis and literature review, alternatives to reduce the effects of land use change should be focused on the objectives of territorial ecological planning and urban development for sustainable development. In this, it is necessary the diagnosis and sustainable management of the territory to improve the quality of life, to protect and conserve natural resources, as well as integrate the provisions and rules to order and regulate the zoning of reserve areas, ecological restoration, uses and destinations of land that allow to design processes of social action, problem solving and conflicts between society and the environment that guarantee a better standard of living for the population (Ayuntamiento de Nacajuca Tabasco, 2015; Castillo and Moreno, 2015).

In this sense, GIS, remote sensing and the various geomatic models for the analysis of land use change are tools that must be integrated into environmental, social and economic diagnosis, prior to the territorial planning model. With these, space-time dynamics can be analyzed on a larger spatial scale and constitute a more accurate classification method. It allows to visualize the main transitions between the categories of uses and covers to understand, prevent and reverse the destructive impacts of economic activities and urbanization patterns, as well as the simulation of future projections of spatial dynamics (Camacho-Olmedo *et al*., 2010; Eastman, 2012; Eastman and Toledano, 2018).

Conclusions

The change in land use in Nacajuca, Tabasco, during 2000-2008-2017, has been characterized by the total development of 8 707 ha of urbanized areas and the occupation of soil for agricultural activities. The disruption of ecosystems increased by 7 753 ha with the modification of much of the municipality, putting at risk the carrying capacity of the natural system, increasing the risk of flooding on land for housing use, as well as use for productive activities with impacts on the economy of families mainly of rural origin.

The main changes occur due to the transformation of wetlands into grassland caused by the choking of water bodies, to later be transformed from grasslands to urban areas with the consequent risks that this originates to both environmental services and the safety of the population that ends up residing in those spaces.

The change in use of Nacajuca has contributed to the conurbation with Villahermosa from urban growth to the South and West of the state capital. The modelling of spatial dynamics with the Land Change Modeler of IDRISI showed that the main transitions were first, the change from large wetland coves to grassland and secondly the transformation of grassland into urban areas and that this relates to the current dynamics of the metropolitan area of the city of Villahermosa. It also coincides with the loss of large wetland covers in much of the territory of Tabasco, due to the growth of grasslands, followed by urban growth and road consolidation.

The results indicate that to avoid possible scenarios of environmental deterioration for at least the next two decades, 'if a substantive change in development policies is not achieved', alternatives should be implemented to reduce the effects of land use change, aligned with the objectives of territorial ecological planning and urban development for sustainable development. So, this study helps provide accurate, truthful and up-to-date information on spatial dynamics in the study area for future programs.

It highlights the importance of the use of Geographic Information Systems (GIS), environmental remote sensing and geomatic models as tools to study the territory more accurately, which allows to work a larger scale and with better classification methods for the current and future diagnosis of environmental, social and economic dynamics in territorial ecological planning.

Cited literature

Aguayo, M.; Pauchard, A.; Azócar, G. y Parra, O. 2009. Cambio del uso del suelo en el centro sur de Chile a fines del siglo XX. Entendiendo la dinámica espacial y temporal del paisaje. Rev. Chilena Hist. Natur. 82(3):361-374. https://doi.org/10.4067/s0716-078x2009000300004.

Alejandro-Montiel, C.; Galmiche-Tejeda, A.; Dominguez-Dominguez, M. y Rincón-Ramírez, A. 2010. Cambios en la cubierta forestal del área ecoturística de la reserva ecológica de agua selva, México. cambios en la cubierta forestal del área ecoturística de la reserva ecológica de agua selva, México, DF. Tropical and Subtropical Agroecosystems. 12(3):605-617.

Allub, L. y Michel, M. A. 1979. La formación socioeconómica de Tabasco y el petróleo. Investigación Económica. 148/149(38):327-355. https://doi.org/10.2307/42777039.

Ayuntamiento de Nacajuca Tabasco. 2015. Plan municipal de desarrollo. 2-76 pp.

Ayuntamiento de Nacajuca Tabasco. 2018. Plan municipal de desarrollo. 200 p.

Bähr, J. y Borsdorf, A. 2011. La ciudad latinoamericana. La construcción de un modelo. Vi. Urbes. 2(2):207-221.

Cálix, D. H.; Koch, O. S D.; Novelo, R. A. y Mark, E. E. 1991. Flora y vegetación hidrófita de Nacajuca, Tabasco. Colegio de Postgraduados. Tesis. Estado de México, México. 264 p. http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=COLPOS.xis&method=post& formato=2&cantidad=1&expresion=mfn=017017.

Camacho, O. M. T.; Molero, M. E. y Paegelow, M. 2010. Modelos geomáticos aplicados a la simulación de cambios de usos del suelo. Evaluación del potencial de cambio. *In*: Tecnologías de la Información Geográfica: La Información Geográfica al servicio de los ciudadanos. Ojeda, J.; Pita, M. F. y Vallejo, I. (Eds.). 14 Ed. Universidad de Sevilla. Sevilla, España. 658-678 pp. https://idus.us.es/bitstream/handle/11441/66608/CAMACHO.PDF?sequence=1&isAllowed=y.

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. Estudios sociales y humanísticos. 12(1):144-160. http://www.scielo.org.mx/scielo.php?pid=S1665-80272014000100010&script=sci_abstract.

Castillo-Osorio, G. y Moreno-Gaspar, M. I. 2015. La ordenación ecológica del territorio racional y sustentable. Perfil de las ciencias sociales. 5(3):177-206. https://revistas.ujat.mx/index.php/perfiles/article/view/1040.

Dadashpoor, H. and Alidadi, M. 2017. Towards decentralization: spatial changes of employment and population in Tehran Metropolitan Region, Iran. Applied Geography. 85:51-61. https://doi.org/10.1016/j.apgeog.2017.05.004.

Dadashpoor, H.; Azizi, P. and Moghadasi, M. 2019. Science of the total environment land use change, urbanization, and change in landscape pattern in a metropolitan area. Science of the Total Environment. 655:707-719. https://doi.org/10.1016/j.scitotenv.2018.11.267.

Delgado, M L. A.; Matteucci, S.; Acevedo, M.;Valeri, C.; Blanca, R. y Márquez, J. 2017. Causas directas que inducen el cambio de uso el suelo y de la cobertura boscosa, a escala de paisaje, en el sur de Venezuela. Interciencia. 42(3):148-156.

Diaz-Pacheco, J. y Hewitt, R. 2013. Modelado del cambio de usos del suelo urbano a través de redes neuronales artificiales. Comparación con dos aplicaciones de software. Rev. Internac. Cienc. Tecnol. Inform. Geográ. 14:1-22. https://www.geofocus.org/index.php/geofocus/article/view/298/146.

Diaz, P. M. A. 2014. La construcción histórica de las condiciones de posibilidad de un desastre: el caso de dos colonias de Villahermosa, Tabasco. *In*: Montañas, pueblos y agua. Dimensiones y realidades de la cuenca Grijalva. González, E. M. y Brunel, M. M. C. (Coords). 1ra Ed. Colegio de la Frontera Sur: Juan Pablos Editor. Distrito Federal, México. 181-221 pp. http://cuencagrijalva.ecosur.mx/cuenca_grijalva/files/informe_Final/sp03_archivos/03_0709_cap_7_construccion_condiciones_historicas.pdf.

Eastman, J. R. 2012. Idrisi Selva. Guía para SIG y procesamiento de imágenes. Clark University. 17 Ed. Worcester, MA, USA. 321 p. https://clarklabs.org/wp-content/uploads/2016/10/IDRISI- Selva-Spanish-Manual.pdf.

Eastman, J. R. 2016. TerrSet. Geospatial monitoring and modelling system. Manual. Clark University. 1st Ed. Worcester, MA, USA. 393 p. https://clarklabs.org/wp-content/uploads/2016/10/Terrset-Manual.pdf.

Eastman, J. R. and Toledano, J. 2018. A short presentation of the land change modeler (LCM). *In*: Geomatic Approaches for Modeling Land Change Scenarios. Lecture Notes in Geoinformation and Cartography. Camacho, O. M.; Paegelow, M.; Mas, J. F. and Escobar F. (Eds.). 1st Ed. Springer. Worcester, MA, USA. 499-505 pp. https://doi.org/https://doi.org/ 10.1007/978-3-319-60801-3_36.

Estrada-Loreto, F.; Barba-Macias, E. y Ramos-Reyes, R. 2013. Cobertura temporal de los humedales en la cuenca del Usumacinta, Balancán, Tabasco, México. Tabasco, México. Universidad y Ciencia. 2(29):141-151. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0186-29792013000200004.

ESA. 2017. Copernicus open acces hub. From european space agency website: https://scihub.copernicus.eu/dhus/#/home.

ESRI. 2017. Arc Gis 10.2. Retrieved from https://www.esri.com/en-us/home.

FAO. 2015. Evaluación de los recursos forestales mundiales 2015. Compendio de datos (FAO, ONU; FAO), (Ed.). New York: FAO.

Flores-Santiago, A. 1987. La modernización de la agricultura en el trópico húmedo mexicano: veinte años de experiencia en la Chontalpa, Tabasco. Rev. Geogra. Agríc. 13-14(2):104-115. http://bibliotecasibe.ecosur.mx/sibe/book/000044280.

Galindo-Alcántara, A. 2006. Los sistemas de producción bovina en el estado de Tabasco. su impacto en los sistemas naturales. Universidad de la Habana. 155 p.

Gobierno del Estado de Tabasco. 2018. Regiones de Tabasco portal Tabasco. https://tabasco.gob.mx/regiones-de-tabasco.

Henny, C. and Meutia, A. A. 2014. Urban lakes in megacity jakarta: risk and management plan for future sustainability. Procedia Environmental Sciences. 20:737-746. https://doi.org/10.1016/j.proenv.2014.03.088.

INEGI. 2008. Ortoimágenes 2000 y 2008. https://www.inegi.org.mx/temas/imagenes/ortoimagenes/.

Kolb, M. and Galicia, L. 2012. Challenging the linear forestation narrative in the Neo-tropic: Regional patterns and processes of deforestation and regeneration in southern Mexico. Geographical J. 178(2):147-161. https://doi.org/10.1111/j.1475-4959.2011.00431.x.

Lambin, E. F.; Turner, B. L.; Geist, H. J.; Agbola, S. B.; Angelsen, A.; Folke, C. and Veldkamp, T. A. 2001. The causes of land-use and land-cover change : moving beyond the myths. Global Environmental Change. 4(11):261-269. https://doi.org/10.1016/S0959-3780(01) 00007-3.

Lara-Blanco, M. J. and Vera-Cortés, G. 2017. Vulnerabilidad social a desastres en Tucta, Nacajuca. Rev. Mex. Sociol. 79(4):723-754.

López, J. L. N. 2019. Tabasco es el edén de los humedales. Tabasco, México. *Kuxulkab*'. 52(25):39-51. https://doi.org/10.19136/kuxulkab.a25n52.2969.

Lorenzo-Guillermo, J.; Duch-Gary, J.; Perez-Villalba, E. and Monterroso-Rivas, A. I. 2019. Land-use change in the Sierra Alta of Hidalgo in the period 1976-2011. Rev. Geogra. Agríc. 63:63-87. https://doi.org/dx.doi.org/10.5154/r.rga.2018.63.01.

Mishra, A.; Karimi, D.; Ehsani, R. and Albrigo, L. G. 2011. Evaluation of an active optical sensor for detection of Huanglongbing (HLB) disease. Biosystems Engineering. 110(3):302-309.

Morales-Jimenez, C. 1990. La ganaderización de Tabasco. Reflejo de la ineficiencia e irresponsabilidad empresarial en el aprovechamiento y manejo del trópico húmedo mexicano. Rev. de Difus. Cient. Tecnol. y Humanística. 1(2):37-42. http://bibliotecasibe.ecosur.mx/sibe/book/000028507.

Moreno-Casasola, P. y Infante, M. D. M. 2016. Conociendo los manglares, las selvas inundables y los humedales herbáceos. INECOL-OIMT. 1ra Ed. Veracruz, México. 128 p. https://idoc.pub/documents/conociendo-los-manglares-y-selvas-inundables-vnd1j62p9wnx.

Najera-Gonzalez, O.; Bojórquez-Serrano, J.; Cifuentes-Lemus, J. y Marceleño Flores, S. 2010. Cambio de cobertura y usos del suelo en la cuenca del Río Mololoa, Nayarit. Biociencias. 1(1):19-29. http://revistabiociencias.uan.edu.mx/index.php/Biociencias.

Navarro-Pineda, J. M. y Toledo-Sánchez, H. 2008. Transformación de la cuenca del Río Grijalva. Rev. Noticias AMI. 4(16):11-22. http://www.amip.org.mx/htm/RevAMIP/A4NUM16/AMIP41611.pdf.

Palacio-Prieto, J. L.; Sánchez-Salazar, M. T.; Casado-Izquierdo, J. M.; Propin, F. E.; Delgado, C. J.; Velázquez, M. A.; Chias, B. L.; Ortiz, A. M. I.; González, S. J.; Negrete, F. G.; Morales, G. J. y Márquez, H. R. 2004. Indicadores para la Caracterización y Ordenamiento del Territorio. Instituto Nacional de Ecología-SEMARNAT., Instituto de Geografía, UNAM y Secretaría de Desarrollo Social. 1ra Ed. México. 161 p.

Palomeque-Cruz, M. Á.; Galindo-Alcántara, A.; Escalona-Maurice, M. J.; Ruiz-Acosta, S. D. C.; Sánchez-Martínez, A. J. y Pérez-Sánchez, E. 2017. Analysis of land use change in an urban ecosystem in the drainage area of the grijalva River, Mexico. Rev. Chapingo Ser. Cienc. Forestal. Amb. 23(1):106-120. https://doi.org/10.5154/r.rchscfa.2016.03.018.

Palomeque-Cruz, M. Á.; Galindo-Alcántara, A.; Sánchez, A. J. y Jorge, E. M. M. 2017. Pérdida de humedales y vegetación por urbanización en la cuenca del río Grijalva, México. Investigaciones Geográficas. 68:151-172. https://doi.org/10.14198/INGEO 2017.68.09.

Pérez-Sánchez, J. M. 2007. El manejo de los recursos naturales bajo el modelo agrícola de camellones chontales en Tabasco. Ibero forum. 2(4):1-9.

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 Geográficas. 69:33-52. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0188-46112009000200004.

Pinkus-Rendón, M. J. y Contreras-Sánchez, A. 2012. Impacto socioambiental de la industria petrolera en Tabasco: el caso de la Chontalpa. LiminaR. Estudios Sociales y Humanísticos. 10(2):122-144.

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

Salvati, L.; Zambon, I.; Maria-Chelli, F. and Serra, P. 2018. Science of the total environment do spatial patterns of urbanization and land consumption reflect different socioeconomic contexts in Europe? The spatial distribution of the 155 metropolitan regions in 6 European macro- regions (left) and the relativ. Science of the Total Environment. 625:722-730. https://doi.org/10.1016/j.scitotenv.2017.12.341.

Sánchez, M. A. 2005. Uso del suelo agropecuario y deforestación en Tabasco 1950-2000. Universidad Juárez Autónoma de Tabasco. 1era Ed. Villahermosa, Tabasco, México. 123 p. https://books.google.es/books?id=4DVyMyAOWhEC.

Santos, T. y Telleria, J. L. 2006. Pérdida y fragmentación del hábitat : efecto sobre la conservación de las especies. Ecosistemas. Rev. Cient. Técn. Ecol. Med. Ambie. 15(2):3-12. http://www.revistaecosistemas.net/articulo.asp?Id=423%0APérdida.

Vitousek, P, M.; Mooney, H. A.; Lubchenco, J. and Melillo, J. M. 1997. Human Domination of Earth's ecosystems. USA. Science. 5325(277):494-499. http://dx.doi.org/10.1126/science.277.5325.494.

Zamora, S. N.; Pérez, S. E.; Carballo, C. V. R. y Galindo, A. A. 2019. Dinámica de las terrazas fluviales en la subcuenca Grijalva-Villahermosa, México. México. Boletín de la Sociedad Geológica Mexicana. 3(71):805-817. http://dx.doi.org/10.18268/BSGM2019v71n3a10.

Zamora-Saud, N.; Pérez-Sánchez, E.; Carballo-Cruz, V. R. y Galindo-Alcántara, A. 2019. Nota corta Dinámica de las terrazas fluviales en la subcuenca Grijalva. Boletín de la Sociedad Geológica Mexicana. 71(3):805-817. https://doi.org/http://dx.doi.org/10.18268/BSGM2019v71n3a10.

Zavala, C. J.; Castillo, A. O.; Ortiz, C. A. I.; Palma, L. D. J.; Juárez, L. J.; Salgado, G. S.; Rincón, R. J. A.; Moreno. C. E. y Ramos. R. R. 2009. Capacidad de uso del suelo urbano en Tabasco: con base en suelo, uso actual y vegetación. Colegio de Postgraduados. 1ra Ed. Tabasco, México. 189 p. http://bibliotecasibe.ecosur.mx/sibe/book/000048816.

Zavala-Cruz, J.; Palma-López, D. J.; Fernández, C. C. R.; López, C. A. y Shirma, T. E. 2011. Degradación y Conservación de suelos en la Cuenca del río Grijalva, Tabasco. Colegio de postgraduados, Secretaría de Recursos Naturales y Protección Ambiental. 1ra Ed. Tabasco, México. 89 p. https://www.researchgate.net/publication/293944208_Degradacion-y-Conservacion-de-Suelos-en-la-Cuenca-del-Río-Grijalva-Tabasco.