Land-Use / Land-Cover Change in Yucatán State, Mexico: An examination of political, socioeconomic, and biophysical drivers in Peto and Tzucacab

Research

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Abstract

This paper presents results from an analysis of contrasting land-cover patterns of deforestation in the neighboring municipalities of Peto and Tzucacab, Yucatán State, México using Landsat satellite imagery and socio-demographic archival information for 1988, 1994, and 2001. The variables that most likely explained land-cover differences between these municipalities were not internal variables as had been initially thought, such as ethnic composition and population growth, but rather, other social and biophysical drivers. Based on these findings and supporting documentation, these drivers include specific government, land-intensification and economic development initiatives and biophysical conditions related to soil fertility.

Introduction

Yucatán State – an Overview

The Mexican state of Yucatán is classified into three regions based on vegetation and agricultural development. The sisal region (north-central) is noted for its production and processing of henequen (*Agave fourcroydes* Lemaire), a native plant species of the Yucatán Peninsula that had been used for fiber production since pre-Hispanic times up until the beginning of the 1960s when synthetic fibers were developed and international demand for natural sisal plummeted (Baklanoff & Brannon 1987, Climo 1978). The second region, the eastern "livestock" region, concentrates 65% of the state's cattle (INEGI 2006). Finally the agricultural region (southern), where Peto and Tzucacab are located, supports the production of maize and citrus (INEGI 2006). Traditionally, southern plantations and haciendas produced sugar cane and cattle. During the 1970s the government financed small irrigation projects in the southern zone with mechanized farming equipment to establish collective **ejido** projects that combined cattle ranching and cash crop farming activities (Gurri & Moran 2002).

These development programs initiated during the 1970s in Yucatán state have significantly impacted the traditional swidden agriculture (**milpa**) system, the dominant food subsistence production system in the Yucatán Peninsula for the region's Maya population (Sohn 1999). Typically grown as corn (*Zea mays* L.) without fertilizer or insecticide use in a polyculture with other crops on small areas (typically 0.5-2.5 ha.), it is based on the periodic practice of slash and burn of forest vegetation. A **milpa** field is traditionally cultivated manually for two years before yields decrease by nearly 50% due to soil fertility loss and weed prevalence. Because of this, lands are left fallow after the second year for soil recovery (Terán & Rassmusen 1994). In recent years, however, given the henequen crisis, the emphasis on livestock, and other land-use intensification projects, the traditional 15 year fallow cycle needed for adequate soil nutrient recovery has been reduced to an average 5-year fallow cycle (Baklanoff & Brannon 1987).

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Objectives

There is a critical need to understand the relationships between cleared and forested landscape patterns and agricultural land use dynamics within tropical forests (García-Barrios & González-Espinosa 2004, Geoghegan *et al*. 2001, Klepeis 2003, Lambin *et al*. 2000). This study hopes to contribute to land-use/land-cover change research in dry tropical forest regions to better understand deforestation patterns and change trajectories by examining recent land-use changes, policy development, and agricultural intensification processes within two neighboring municipalities in the Mexican state of Yucatán from 1988 to 2004.

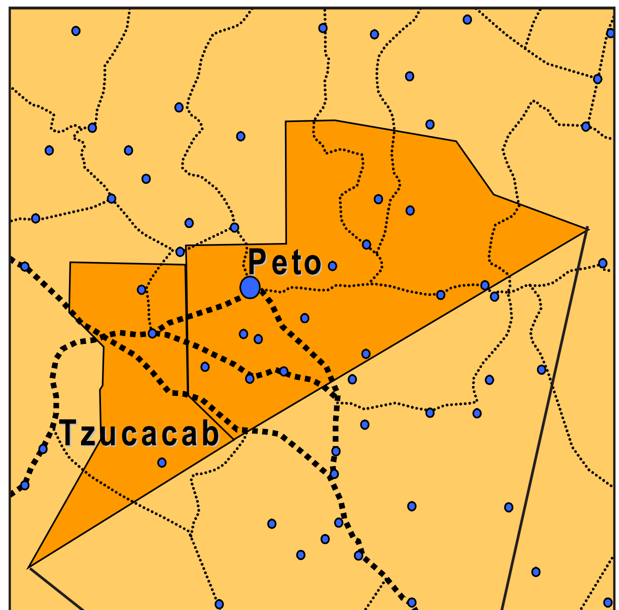
The following five drivers considered to explain these land cover differences between these two neighboring municipalities are:

1. ethnicity
2. distance from roads and markets
3. policy changes that influence agricultural intensification
4. population and migration patterns
5. biophysical factors

The study region

The municipalities of Peto (central point at 88.34^{0} N longitude and 20.04^{0} E latitude) and Tzucacab (central point in 89.02^{0} N longitude and 20.01^{0} E latitude) are located in the central portion of the state of Yucatán (Figure 1) and encompass approximately 171,000 hectares. The forest cover of the region is tropical dry forest. The exposed rocky, shallow soils of Yucatán State, less than 10 cm in depth (Ceccon *et al*. 2003), support the principal land uses of mono-cropped henequen production in the Henequen Zone (northern part of Yucatan); secondary low deciduous forests for firewood, timber, and medicinal plants; **milpa**, the traditional shifting cultivation of maize, beans, and horticultural crops; and home gardens consisting of trees, shrubs, crops and animals (Zarate-Hoyos 1998).

The most recent population census of Mexico (2000) shows Peto with 21,284 inhabitants, of which 73% have Mayan origin with a population density of 0.18 people/ha. Tzucacab has 12,577 inhabitants, 65% Mayan population, and a population density of 0.25 people/ha. (INEGI 2006) (see Table 1). Land tenure in this area is the **ejido** system, but division of the land began in 2000 after the Constitutional Amendment (1994) of Article 27.



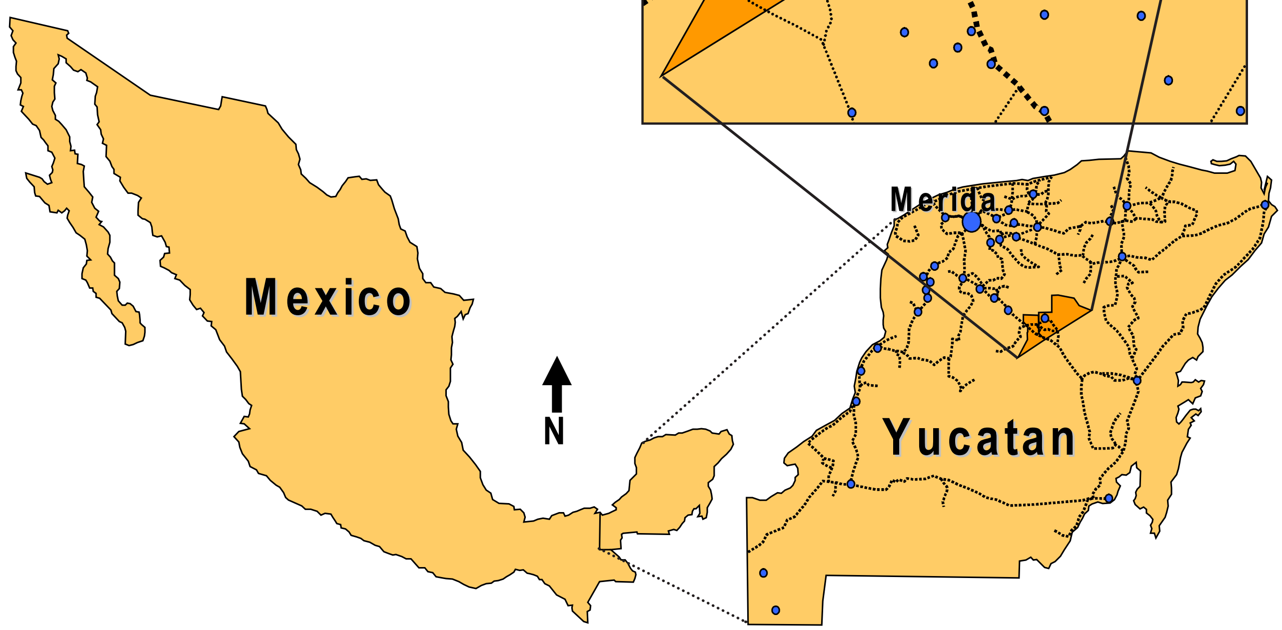


Figure 1. The study site municipalities of Peto and Tzucacab are located in the Yucatan Peninsula, Mexico. The most populated city in Yucatan is Merida.

Table 1. Population distribution in Peto and Tzucacab Municipalities. Source: INEGI (2006)

Municipality		Total	Male	Female
Peto Total		21,284	10,539	10,745
	Rural	4,712	2,471	2,241
	Urban	16,572	8,068	8,504
Tzucacab Total		12,577	6,359	6,218
	Rural	3,335	1,727	1,608
	Urban	9,242	4,632	4,610

Research process

Our methodology consisted of two main parts. The first part involved lab analysis of remote sensing and socioeconomic data and to hypothesize the rationale for differing land-cover patterns within these two neighboring municipalities. The second part involved a ten day field visit to these sites in March, 2004 to assess our predictions.

We analyzed remote sensing data from 1988 TM Landsat, 1994 TM Landsat, and 2001 ETM Landsat satellite images. An unsupervised classification using 100 classes was initially conducted. From this classification, classified images with forest, non-forest, clouds, and shadows were obtained. Clouds, shadows, roads, and urban areas were neutralized by masking them, which resulted in classified image of forest and non-forest classes. The non-forest class includes agricultural fields (both **milpa** and agro-industrial production) and pastures. Classification accuracy was tested using 23 training samples from our visit to the site in March, 2004. Soils and climate data were downloaded from INEGI (2006) in a 1:1,000,000 scale but information from Juan Jimenez (UADY, personal communication) and observations in the field better confirmed the before-mentioned differences. Demographic data was obtained through review of the last population census and housing for the year 2000, as well as other historical data in INEGI (2006), the official Mexican institution for demographic information. Policy data, including development and implementation, was obtained through secondary sources (literature) and the World Bank and Inter-American Development Bank databases.

Distance to roads and Merida as a main market were calculated using a GIS tool. Fieldwork in March, 2004 was concentrated on obtaining training samples to verify accuracy of image classification. However, observations of local markets and trucks on the roads, in addition to interviewing local residents, confirmed that Merida was the main market for these municipalities. Informal discussions and interviews showed a general consensus among technicians in both municipalities and local peasants about population, markets, production in **milpas**, and impacts of the Constitutional Amendment of Article 27, PROCAMPO (Programa de Apoyo Directo al Campo), and the International Fund for Agricultural Development (FIDA), to cross check our predictions in the field.

In preparation for the last census, municipal boundaries were reorganized by INEGI. Unfortunately, this information was not available for this study; therefore municipal boundaries from CIESIN (Center for International Earth Science Information Network), the closest to the INEGI cartographic data, were used. We acknowledge that there are differences between these boundaries that do change the number of patches and their sizes. The main patterns, however, have not significantly changed.

Satellite Imagery Analysis

The initial research step examining land-cover patterns in Peto and Tzucacab from satellite images show Peto consisting of forest "patches" mixed with small areas of agricultural land and Tzucacab with larger cleared areas (pasture or large-scale agriculture), especially along the main road (Highway 184) (Figure 2).

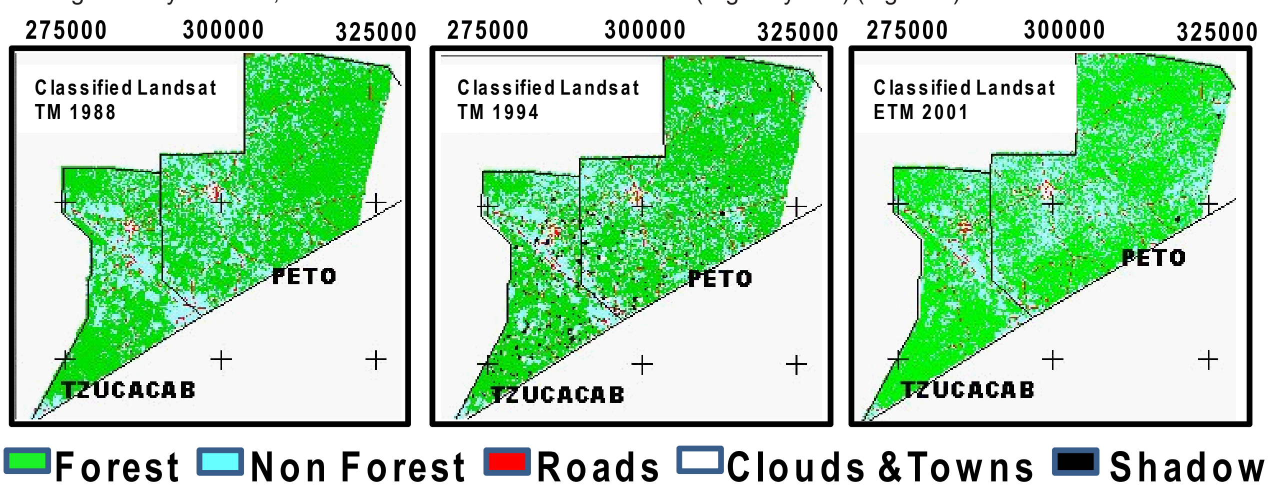


Figure 2. Contrasting patterns of land-cover between Municipalities of Peto and Tzucacab are observed through TM Landsat (1988, 1994) and ETM Landsat (2001) satellite images.

Table 2. Differences in land-cover patterns in Peto and Tzucacab through patch number and size in 1988 and 2001.

Year 1988	**Forest**			**Non Forest**		
Municipality	Area (ha.)	# of patches	Average size (ha.)	Area (ha.)	# of patches	Average size (ha.)
Peto	68398	2741	25	26674	7534	4
Tzucacab	27557	1782	15	16238	2813	6

Year 2001	**Forest**			**Non Forest**		
Municipality	Area (ha.)	# of patches	Average size (ha.)	Area (ha.)	# of patches	Average size (ha.)
Peto	61275	5594	11	33819	17640	2
Tzucacab	30216	1983	15	13581	2941	5

To more closely examine these differing land-cover patterns, patch number and size were further examined (Table 2). Although forest cover appears to have increased in Tzucacab, of importance to this study of understanding land-cover/land-use relationships is the larger non-forest areas (pasture or large-scale agriculture) that Tzucacab has, compared to Peto, that have also persisted over time (1988-2001). In contrast, Peto's land-cover pattern consists of smaller non-forested patches. And while sizes of both forest and non-forest patches in Peto have decreased over time, the number of non-forested patches (and overall deforestation) in Peto has increased.

Results

From the satellite imagery observations, five drivers were predicted to explain these contrasting patterns of land-cover. As previously mentioned, these drivers are: ethnicity, distance from roads and markets, policy changes that influence agricultural intensification, population and migration patterns, and biophysical factors. Analyses of the data obtained from field research and socio-economic data are presented in the following paragraphs.

Driver 1: Ethnicity and land uses

Our initial prediction pointed to ethnic differences between the municipalities of Peto and Tzucacab to account for contrasting patterns of land-cover. Subsistence swidden agriculture, the traditional Maya agriculture, generally consists of small fields typically 0.5-2.5 ha (Terán and Rassmusen 1994). Considering that the traditional 15 year fallow cycle has been reduced to an average 5 year fallow cycle today (Baklanoff and Brannon, 1987), we interpreted these small patches in Peto to be subsistence, swidden agriculture plots and, therefore, predicted that Peto may have a higher indigenous Maya population, compared to that of Tzucacab.

Visitation to both municipalities in March 2004, as well as information obtained from municipality offices in both Peto and Tzucacab, and cross-checked with INEGI census data, revealed that the two municipalities do not significantly differ in ethnic composition (Table 3).

Driver 2: Distance from roads and markets

Closer examination of the satellite imagery suggests that distance to major roads and access to markets may be important drivers to explaining contrasting patterns of land-cover and land-use. The fact that Tzucacab is located next to Highway 184 with direct routes north to Merida and other markets is an important driving force that may explain why large pasture areas, which we predicted as cattle ranching and large-scale/commercial agriculture, is located here in Tzucacab, and not in the municipality of Peto (Table 4). Past studies have shown relationships between commercial agriculture and increased deforestation probability with closer road and market access (Chomitz and Gray, 1996; Wickham et al. 2000; Kaimowitz and Angelsen 1998; Nepstad et al. 2000; Laurance et al. 2001.) As mentioned earlier in this paper, observations of local markets and trucks on the roads, in addition to interviewing local residents, confirmed that Merida was the main market for these municipalities. Upon closer examination of distances to Merida, however, the main town in each municipality does not significantly differ. Distance to Meri-

Table 3. Traditional population and land tenure in Peto and Tzucacab. Sources: Municipalities of Peto and Tzucacab office data and INEGI.

Municipality	**Maya population**	**% of Maya population**	**Number of ejidos**	**Area in ejidos (ha.)**	**Average size of ejidos (ha.)**
Peto	13,400	73	33	68,000	2,100
Tzucacab	7,000	65	26	38,000	1,500

da, therefore, cannot be considered a major driver to land-cover differences between Peto and Tzucacab.

Table 4. Distance to main markets using the highway 184 from Peto and Tzucacab.

Municipality	Distance to reach Highway 184 from small towns		Distance to Merida
	Minimum distance	Maximum distance	
Peto	10 km	60 km	165 km
Tzucacab	0 km	18 km	150 km

Driver 3: Policy Changes 1994 Constitutional Amendment

Our third prediction pointed to the 1994 constitutional amendment allowing the privatization of **ejido** landholdings to explain differences in patterns of deforestation within the two municipalities.

The revolution of 1910 brought about major land reforms in Mexico. Article 27 established agrarian reform and the break-up and distribution of haciendas to the peasant population in the form of communally held village lands called **ejidos** (Baklanoff and Brannon 1987). The 1994 amendment to the Mexican Constitutional land tenure (Article 27) provided ejidatarios the option of privatizing their land. Gurri and Moran (2002) state that the Mexican congress did this in order to modernize agricultural production and substitute maize for higher value crops. Furthermore, Gurri and Moran (2002) indicate that horticulture and citrus cultivation have been consistently promoted in Yucatan State since the 1970's and, therefore, predict that peasants in central Yucatan after this amendment would be intensifying and increasing the amount of land dedicated to commercial agriculture.

From the larger areas of non-forest observed from the satellite images in Tzucacab, we predicted that some ejidatarios may have privatized their landholdings and sold off their parcels to individuals, corporations, or enterprises interested in large-scale agriculture or cattle ranching. Under this scenario, in the aggregate, multiple individual parcels could amount to a significant land coverage, accounting for these larger non-forested areas observed in Tzucacab. While Peto and Tzucacab municipalities confirmed that the 1994 Constitutional Amendment is having an impact, the number of **ejidos** that have been privatized and the number of ejidatarios that have sold their individual parcels is not well known or documented. Information obtained in the field (ejidatario personal communication, 2004) indicated that beginning in 2000, landholders and ejidatarios in Peto had divided their **ejido** into aproximately 20 hectares of land per family. Furthermore, we were informed that the biophysical conditions (such as poor fertility and rocky soils) make much of this land unsuitable for many production systems. In addition, the majority of residents do not possess the financial resources to invest land into other uses. This factor forces ejidatarios, who have less space for slash and burn agriculture and long fallows, to concentrate their agricultural labors in small areas; this may explain **milpa** intensification. In the end, this may create an incentive to sell their parcels off to those who have the financial ability to convert the land to alternate uses, such as large-scale/commercial agriculture and cattle ranching.

PROCAMPO and IFAD

In addition to the 1994 Constitutional Amendment, additional development programs and policy may play an important role in explaining land-cover/land-use differences within the two municipalities. PROCAMPO (Programa de Apoyo Directo al Campo = Direct Rural Support Program) is an agrarian subsidy program under NAFTA (North American Free Trade Agreement) that began in 1994. The main philosophy behind PROCAMPO was to change subsistence agricultural production to another activity, oriented to markets that increase agricultural production and peasants' income (Mexican Government Agricultural Policy). According to Klepeis and Vance (2003), this program was designed to help smallholders increase market production to decrease their reliance on subsidies and extensive swidden cultivation. Further examination of PROCAMPO's impact in Peto and Tzucacab, however, suggests that increases in market production have been negligible. Furthermore, PROCAMPO has actually encouraged deforestation. Specifically, smallholders have been encouraged to increase the size of their **milpa** to receive larger subsidies which, in many cases, has resulted in planting pasture.

Another agency that influenced change from forest to pasture in this area was IFAD (International Fund for Agricultural Development). IFAD has an experimental farm located in Tzucacab, very close to Highway 184, where research is conducted on cattle ranching and cattle introduction with home gardens and **milpas** to improve peasant profits (Tzucacab municipality officials, personal communication). We observed cattle in home gardens and **milpas** in Tzucacab and household interviews revealed that most feel cattle are a viable alternative. The IFAD program has had a greater influence in Tzucacab, due to the large cattle pasture areas already present and the short distance to beef markets, and is, therefore, encouraging the persistence and development of pasture areas in Tzucacab.

Driver 4: Population and Migration Patterns

Our fourth prediction pointed to demographic information collected from INEGI (Figure 3) that shows that while there was a significant population increase from 1980 to 1990 (a 21% increase in Peto and a 27% increase in Tzu-

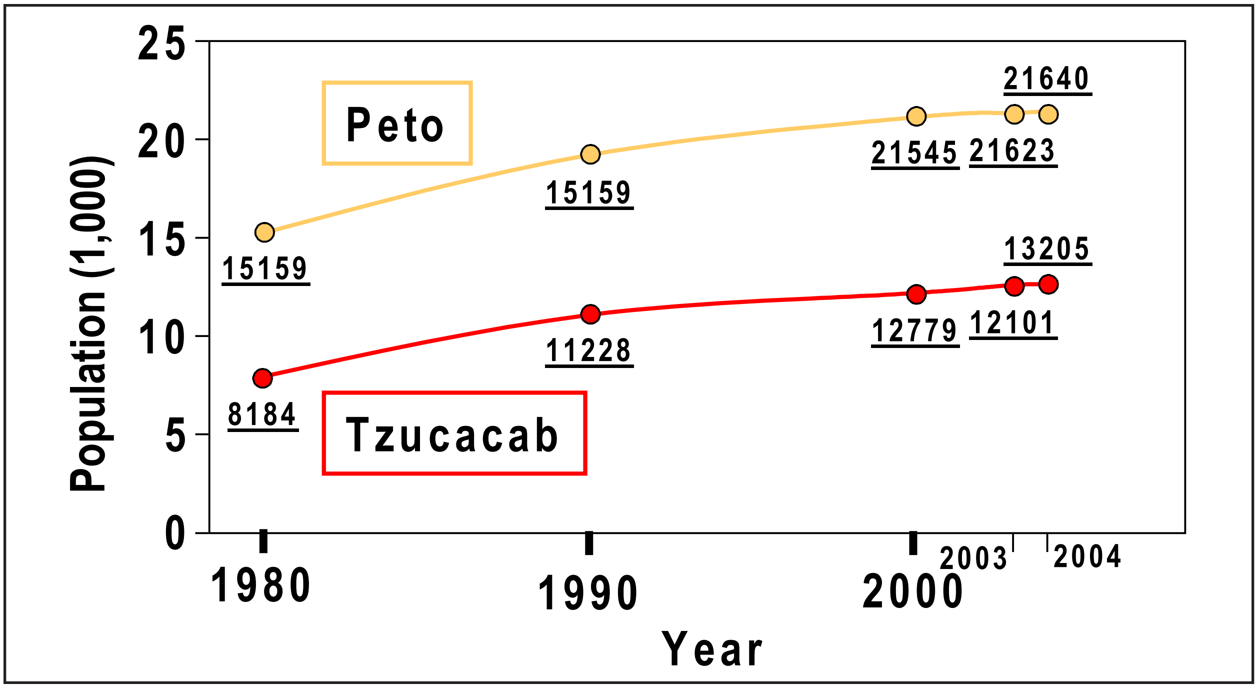


Figure 3. While there was a significant population increase from 1980 to 1990 (a 21% increase in Peto and a 27% increase in Tzucacab), the populations for 2000, 2003, and 2004 remain stable. Source: INEGI.

cacab), the populations for 2000, 2003, and 2004 remain more or less stable. Based on this information, we have assumed that population growth is not significantly impacting patterns of deforestation in Peto and Tzucacab.

Sohn et al (1999) stresses that population growth since the 1980s has led to a greater number of families depending on the same land. This trend resulted in an overall increase in **milpa** plots and a reduction of forest cover within **ejido** lands. While this may have been seen from 1980-1990, our field visit in March, 2004 verified our assumption that population growth had not significantly impacted land-cover/land-use patterns. While long-term population growth and economic development do not usually occur without intensification and agricultural growth, intensification and agricultural growth do not necessarily follow population growth (Lambin et al. 2000). According to Baños (1996), emigration (out to urban areas) within Yucatán state is high among younger generations. In addition, while the younger generations associate themselves primarily with non-agricultural activities, older Mayan generations are still using the land traditionally.

Driver 5: Biophysical factors

The physical environment may also influence land-cover / land-use patterns. Many models show that areas more suitable to agriculture, such as forests in more level, drier, and higher-fertility areas with adequate drainage are more likely to be cleared (Kaimowitz and Angelsen 1998). Additionally, patch size of forest and arrangement may also reflect environmental factors, such as topography or soil type (Turner, 1989).

Peto sits at an altitude 10-50m above sea level while Tzucacab, because of its location at the “Sierra de Ticul” (a geological fault) has an elevation between 50-220 m above sea level (Goldacker et al., 2006). It is the more fertile and developed soils that appear around the “Sierra de Ticul” in the south-east of Yucatan that allow mechanization and the cultivation of cash-crops (Graefe, 2003). Outside this area, the geology consists of low-lying tertiary limestone soils (Goldacker et al., 2006; Duch, 1991) which explain the shallow and rocky soils in Peto. It is this soil type that would impede modifications and use of modern technology for agricultural intensification.

Conclusions

Based on field work and interviews, internal drivers such as ethnicity and population growth are not considered significant drivers to explain differing land-cover patterns in Peto and Tzucacab.

Although the proximity that Tzucacab has to Highway 184 with direct routes north to Merida appears to be an important factor, closer examination of distances to Merida from each municipality’s major town does not significantly differ. Distance to Merida, therefore, cannot be considered a major driver to land-cover differences between Peto and

Tzucacab. The major drivers identified as explaining contrasting deforestation and land-cover patterns between these neighboring municipalities include specific government land intensification and economic development initiatives, including PROCAMPO and IFAD, and biophysical conditions related to soil fertility. Specifically, areas of Tzucacab have slightly better soil conditions for large-scale agriculture and pasture growth.

The combination of horticultural and citrus cultivation promotion in southern Yucatán, better soils in Tzucacab to support mechanized agriculture due to its location at the foot of the Serrita de Ticul (and geologic characteristics), and the government-sponsored development assistance Tzucacab has also had explains Tzucacab's land-cover characteristics of large clearings and other non-forested patches, compared to that of Peto. In contrast, the biophysical conditions in Peto (such as poor fertility and rocky soils) appear to make much of this land unsuitable for many production systems. Furthermore, Peto residents have not had the resources to invest land in other uses. Individualization of land tenure in Peto may also have played a role in concentrating and intensifying their agricultural labors in small areas.

Considering 60% of Yucatan's total surface area is under some form of agricultural, forest, or cattle use and management (Zarate-Hoyos, G. A. 1998), this examination of contrasting deforestation and land-cover patterns within two neighboring municipalities in Yucatán state complements the body of research analyzing relationships between deforestation and agricultural land-use dynamics within tropical forests (Abizaid and Coomes 2004; Perera 2001; Roth 2001; Lambert 1996). This paper also addresses the new paradigm in natural resource management that integrates ecological, demographic, and socioeconomic factors to better understand interactions between humans and ecosystems.

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