
Volume 256, issue 11, 20 November 2008
ISSN 0378-1127
ELSEVIER
Forest Ecology and Management

Forest Ecology and Management 256 (2008) 1971–1983

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Is community-based forest management more effective than protected areas? A comparison of land use/land cover change in two neighboring study areas of the Central Yucatan Peninsula, Mexico

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ARTICLE INFO

Article history:
Received 27 September 2007
Received in revised form 17 July 2008
Accepted 19 July 2008

Keywords:
Forest conservation
Land use/land cover change
Protected areas
Community forest management
Central Yucatan Peninsular Region

ABSTRACT

The importance of the role of local community forestry institutions towards forest conservation is exemplified through a comparison of two adjacent areas within the Central Yucatan Peninsular Region (CYPR) in which Land-Use Cover Change (LUCC) analyses were conducted. We also used logistic regression analyses to examine key environmental, socioeconomic and institutional drivers associated with deforestation. One of the areas, La Montaña (LM) at Hopelchen, Campeche, is part of the northern section and buffer zone of the Calakmul Biosphere Reserve (CBR) as well as part of the Mesoamerican Biological Corridor. LM is an agricultural forest frontier region economically dependent on productive activities. The other study, Zona Maya (ZM), found at the municipality of Felipe Carrillo Puerto in Quintana is characterized by having developed community-based forestry enterprises with world wide recognition. In addition, the major tourism industry in nearby Cancun and Riviera Maya provide an important source of off-farm labor and temporary migration. Results show contrasting annual deforestation rates among the two study areas, being greater in the Campeche site (0.7% from 2000 to 2005) compared to Quintana Roo (−0.002% from 2000 to 2004). Logistic regression results show that the occurrence of land clearing at LM is significantly related to demographic variables as well as soil-environment types and conservation status did not reveal to relate to LUCC processes at all. At Quintana Roo, despite twice the population density, population variables at large did not strongly correlate to forest clearing. Rather forest conservation or maintenance was shown to be influenced by local community forestry institutions and a landscape zoning provided by larger management goals from the part of the communities. Greater availability of wage labor for the prominent tourism economy may also reflect a lesser dependence on agriculture and contribute to the much lower deforestation rate. Nonetheless, results show that community forest management can play an effective role in forest conservation. We argue for a regional land use management approach as a conservation strategy in which local inhabitants are considered key actors.

1. Introduction

The effectiveness of protected areas for biodiversity conservation has been an on-going debate for over a decade (Hayes, 2006; Wilshusen et al., 2002). There is no question that these areas contribute towards biodiversity conservation (Bruner et al., 2001). The discussion revolves more on when and how they become effective conservation strategies. Some argue that protected areas are more effective when decision-making and management adopts a more exclusionary approach towards local communities (Bruner et al., 2001; Brandon, 1995). Others argue that protected areas are more effective when local communities participate in decision-making regarding conservation and resource management, especially within surrounding lands or buffer zones (Hansen and DeFries, 2007; DeFries et al., 2007). A third argument sustains that protected areas alone do not guarantee effective conservation, and rather, there is a growing agreement that many types of protected areas are needed, including those that integrate human populations as management actors (Nepstad et al., 2006). Moreover, successful biodiversity conservation is frequently observed in

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doi:10.1016/j.foreco.2008.07.036

regions that are not under any official protected area status and where local communities benefit from their own local management of land and natural resources (Hayes, 2006). In these cases, strong local institutions and rules regarding land and natural resource use are critical for biodiversity conservation, and many times these local institutions do not result from protected area programs or policies (Brechin et al., 2002; Hayes, 2006).

In Mexico, one of the world's biologically megadiverse countries (Mas et al., 2002), the question of whether protected areas are effective in protecting its biodiversity has already been brought up (Bray et al., 2007; Durán et al., 2005; Mas, 2005). This concern has been raised, especially considering its past and recent land use change and deforestation processes. According to the 2005 *Global Forest Resource Assesement*, Mexico ranks 4th in deforestation with an annual loss of 395,000 ha per year from 2000 to 2005 (FAO, 2006). While deforestation is apparently slowing compared to the 1990s which exhibited losses of over 500,000 ha per year (Velásquez et al., 2002), the current national trend remains worrying. Deforestation processes are associated with habitat elimination and fragmentation, loss of biological diversity, reduction in ecosystems services (water, nutrients and carbon cycling) and even climate change (Achard et al., 2002; Velásquez et al., 2002; Lambin et al., 2001), all of which severely undermines the effectiveness of a protected area.

A more difficult question to answer is whether in Mexico protected areas are more effective when they directly involve local communities in the management of land and natural resources. Actually, it has been reported that the protected areas policy in Mexico has historically ignored local inhabitants, and that conflicts with local communities are recurrent (Garcia-Frapolli et al., in press). Even in one of the most studied and recognized protected areas in Mexico in terms of biodiversity and conservation values, Los Tuxtlas Biosphere Reserve in Veracruz, the issue of community involvement regarding management and decision-making has not been adequately addressed, evaluated and much less, implemented. In fact, Los Tuxtlas may be representative among the worst cases in Mexico with respect to anthropogenic impacts within buffer zones (Dirzo and García, 1992; Mendoza et al., 2005).

On the other hand, Mexico offers some of the most successful examples of community-based forest management cases in the world that have had a positive impact regarding forest conservation (Bray et al., 2003, 2007; Merino, 2003). This is important since Mexico is unique in that over 50% of its forests are under community ownership, ranking second in the world (Antinori and Bray, 2005). Some studies aimed at assessing Land-Use Cover Change (LUCC) processes have clearly demonstrated forest cover maintenance and landscape sustainability in some of these community-owned and managed forest regions (Durán et al., 2005; Ellis and Beck, 2004; Bray et al., 2004). This leads to the alternative question of considering if local and community-based land and natural resource management institutions are as effective as or more in conserving forests and protecting biodiversity than protected area policies. If that is the case, it is important to determine how can these local and community-based institutions be fostered and integrated in order to make protected areas more effective.

This paper presents a comparison of LUCC in two neighboring study sites in the Central Yucatan Peninsula Region (CYPR) of Mexico, one representing a protected area and the other a community-based forest management region. We build upon the current body of knowledge on LUCC in community forest regions and protected areas, specifically for the Yucatan Peninsula, by evaluating and comparing these two adjacent and similar regions. One of the areas comprises a group of 12 community forest based *ejidos* (communally held land) in the state of Quintana Roo and the other a group of 8 *ejidos* located within the buffer zone and part of the core area in the northern Calakmul Biosphere Reserve (CBR) in the neighboring state of Campeche. We evaluate and discuss the dominant pathways in LUCC and the major drivers and factors involved in deforestation and forest conservation processes occurring in the CYPR. Our comparison allows us to discuss the role and effectiveness in forest cover conservation of protected areas programs related to the CBR, local and community-based institutions regarding land use and community forestry, as well as the influence of other factors within a shared geographical region. The LUCC research and discussion presented in this paper combines both previous and current research conducted by the authors dating back more than ten years (Porter-Bolland et al., 2006a, 2007, 2008; Bray et al., 2004; Ellis and Beck, 2004).

2. The Central Yucatan Peninsula Region

Seasonally dry tropical forest dominate the landscape of the CYPR, particularly mid-statured forests growing on well drained terrain, and low-statured forests on low-lying areas, where deep clays waterlog during the rainy season (Perez-Salicrup, 2004). Forest types vary in deciduousness ranging from deciduous, to semi-deciduous or semi-evergreen. These forest types conform patchworks of successional stands, mostly resulting from natural (e.g. hurricanes and fire) and human-induced disturbances, intermixed with agricultural areas and to a lesser degree with other vegetation types such as savannas or marsh vegetation near permanent or semi-permanent water bodies (Flores and Espejel, 1994; Ucan et al., 1999). The climate is characterized by a marked dry season of 4–6 months from December through April with a mean annual temperature ranging from 24 to 26 °C, and a mean annual rainfall ranging from 1000 to 1500 mm, although presenting large variations from year to year (Porter-Bolland et al., 2007; Bray et al., 2004).

The topography consists of low undulating hills and flat terrain. Soils were formed mostly by the dissolution of calcareous rocks and over time have resulted in a Karst topography (Flores and Espejel, 1994). Drainage is subterraneous with no superficial flows of water, except in the rainy season during storms and periods of inundation, when rain can be very intense and water moves in temporary surface flow channels. Lowlands are water-nourished by filtration during the humid season and become dry to varying degrees depending on recharge through the dry season (Gates, 1992).

The area has a long history of human occupation. High population densities during the Mayan Classic period were common throughout the area, having a strong impact on the landscape (Folan, 1999; Deevey et al., 1979). After the Mayan collapse, lower population densities gave way to forest recovery (Turner et al., 2001). In the subsequent centuries, land use and regeneration processes resulting from the low population's continuous cycles of management and abandonment gave way to the existing human–environment system that characterizes the Maya forests (Turner et al., 2001; Sánchez, 1999; Gómez-Pompa and Bainbridge, 1995).

3. Study area

The two areas we selected for this LUCC analysis within the CYPR (Fig. 1) are, at the westernmost side, the area known as La Montaña (LM), which is part of the municipality of Hopelchen in the state of Campeche. This area comprises 202,500 ha and includes 8 *ejidos*, containing a population that approximates 5000

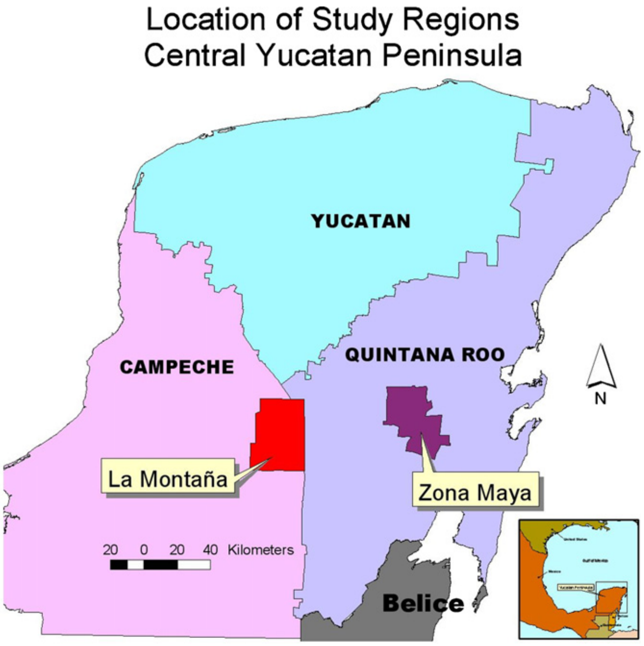

Fig. 1. Location of La Montaña, Hopelchen, Campeche and the Zona Maya, F. Carrillo Puerto, Quintana Roo study areas.

people and with a population density of 2.5 inhabitants/km^2 (Porter-Bolland et al., 2007; INEGI, 2001). At the easternmost side we have selected a portion of the Zona Maya (ZM), which is found at the municipality of Felipe Carrillo Puerto in the state of Quintana Roo. This area includes 12 *ejidos* and some private property, totaling an extension of 162,979 ha with a population of around 8000 inhabitants and a population density of 5 inhabitants/km^2 (INEGI, 2001).

Both ZM and LM are very similar with respect to their biophysical and landscape characteristics, as well as culturally in that their communities are mostly Yucatec-Mayan speaking with a smaller proportion of immigrant colonists. Moreover, land tenure is mostly communally held land, or *ejido*s, that mostly achieved titling during the post-revolution era, during the 1930s and 1940s (Galletti, 2000; Richards, 1991). During this period, large *ejido* sizes of over 20,000 ha were established in response to *chicle*[2] production needs (Acopa and Boege, 1998; Galletti, 1994). After mid 20th century, however, both in the Quintana Roo side and in the Calakmul region, immigrants from nearby Mayan communities in the state of Yucatan as well as from other states in Mexico began to settle, particularly in the 1960s and 1970s. During this period, most of the remaining land was granted to the new migrant communities as much smaller *ejidos* oriented towards agriculture rather than *chicle* production. However, population densities still remained relatively low (lower than 5 people/km^2; Bray et al., 2004; Porter-Bolland et al., 2007).

Recent history drew differing paths for the regions under study. The once rivaling populations (the Mayan leading groups during the Cast War were at LM, the "*pacificos del sur*", and at the ZM the "*rebeldes*"), developed into differing socioeconomic regions (Dumond, 1997; Ramayo-Lanz, 1996) which we specify below.

[2] *Chicle* is a resin tapped from the chicozapote tree (*Manilkara zapota* L. Van Royen) that is used for making chewing gum and other products. During the first half of the XX century, it was an important export product (Acopa and Boege, 1998).

3.1. La Montaña, Campeche

At LM, land use activities consist mostly of *milpa* agriculture (traditional Mayan shifting cultivation) and forest extraction for subsistence. While traditionally cash has been generated mostly by selling *chicle* to outside markets, more recently honey production has gained importance. Currently, markets and prices for *chicle* have been drastically reduced, however, honey has enjoyed a well established market, mostly at the international level, and some of the beekeepers are currently organized in unions and export to Europe. Commercial scale timber exploitation in the area begun in the 1960s by external concessionaries, when the Zoh Laguna mill extended their activities to the north (Galletti, 2000), and lasted for several decades, leaving an impoverished forest with reduced populations of the most valuable species. Today, there still remain important volumes of other commercial species, but organization for its management is missing. Only a few communities are selling small quantities of timber to outside companies, mainly as stumpage volumes, and there is also evidence of illegal timber extraction in some localities (Porter-Bolland et al., 2006a).

The insertion of the area to regional economic activities begun to be promoted during the 1970s and 1980s, through different government programs for cattle, rice and apiculture, as occurred in much of Campeche (Gates, 1999a,b). Also, south of LM, the Xpujil region, began changing drastically with sponsored and sporadic immigration after the construction of highway 186 (Escarcega-Chetumal) in 1967 (Turner et al., 2001), eventually setting pressure to a certain degree to the north, at LM. However, LM remained practically isolated until the construction of the Xpujil-Dzibalchen road in 1995, finally bringing better access into the region. Recently, cattle ranching has been gaining importance in this area, favored by infrastructure development and other government policies. Additionally, pressure from the north is occurring, particularly by the rapid expansion of Mennonite populations, since in the year 2000 part of one of the *ejidos* at LM was acquired by a community of Mennonites (Porter-Bolland et al., 2007).

Development and economic activities at LM have been developed in an unorganized manner, behaving as a typical agricultural frontier in tropical forest regions as elsewhere in the Calakmul region (Vester et al., 2007; Myers et al., 2000; Porter-Bolland et al., 2007). At LM, the majority of households are dependent on productive activities and forest resources for sources of cash. Emigration of people at LM seeking wage labor opportunities is very recent and minimal. Temporal migration to specific tourism and urban centers (e.g. Playa del Carmen, Cancun, and Merida), and for temporary farm labor in other regions is beginning to be more common. However, earnings through these means have been reported to be significant to the economy of only very few families (Porter-Bolland et al., 2006b).

World attention to the region began with the establishment of the CBR, the largest tropical reserve in Mexico. It was created in 1989 and registered in the UNESCO Man and the Biosphere Program in 1993. Part of the 723,185 ha that conform the CBR, fall within LM. Also, LM has been established as part of the Mesoamerican Biological Corridor. This is a multiregional project that comprises several countries from Central America, and whose budget was approved by the Global Environmental Facility (GEF). In Mexico it became effective since 2002. The project is intended to coordinate activities directed both for biodiversity conservation and sustainable development at specific territories (Ramírez, 2003). In that way, conservation at LM has been established as a priority at the national and international levels. At the same time, it is an area that has become to be considered as a "hot spot" of deforestation (Turner et al., 2001).

3.2. The Zona Maya, Quintana Roo

As in LM, the population of the ZM study area practice *milpa* agriculture mostly for subsistence purposes. *Chicle* and timber extraction are also traditionally important economic activities, as are other types of agroforestry systems. Other economic activities that are gaining importance for families to different extents are apiculture and ecotourism (Bray and Klepeis, 2005; Dalle et al., 2006). The economy of ZM, as compared to LM, is more dependent on its forests, since after more than two decades of external support and a policy favoring community forestry, the development of Community Forestry Enterprises has occurred in many of the *ejidos*.

Development of community forestry management was strengthened and institutionalized through the *Plan Piloto Forestal* (PPF) since the early eighties. This initiative emerged with support from the state and external agents, particularly the German Development Assistance Agency (GTZ), in order to provide technical and financial assistance to *ejidos* that wanted to manage their own forests. Before that, forest exploitation in the area occurred through concessions to outside companies and local people benefited little. The PPF was established after different economic, social and environmental factors, internal and external, favored the encouragement of community-based forestry over the renovation of the concession Maderas Industriales de Quintana Roo (MIQRO), which had been in effect for over 25 years (Taylor and Zabin, 2000; Galletti, 1998; Bray and Wexler, 1996).

A major contribution of the PPF was to transform an already strong and economically important state controlled forestry sector that had been run by MIQRO since the 1950s, into a communally owned and managed forestry sector through Community Forest Enterprises (Antinori and Bray, 2005). Moreover, community forestry encouraged *ejidos* to plan land use activities at the landscape level, determining specific areas for certain land uses, such as the *Areas Forestales Permanentes* or Permanent Forest Areas (PFA) in which long term management plans restrain from land use conversion (Dalle et al., 2006; Bray and Klepeis, 2005; Galletti, 1998). Mostly, forestry activities have focused on the extraction of precious timbers (mahogany and Spanish cedar), and on Lesser Known Species (LKS), mostly for the production of railroad ties (Dalle et al., 2006; Richards, 1991), and more recently for the use of wood as "palizada" or pole wood, used for construction (Racelis, personal communication).

As in LM, the ZM's integration to the national economy accelerated in the 1970s with road construction and agricultural promotion. Road construction in ZM was even more prominent and extensive than in LM. Moreover, the ZM region was particularly impacted by the prominent tourism development in the state of Quintana Roo since the 1970s due to its closeness to major tourism centers such as Cancun and the Mayan Riviera (Torres and Momsen, 2004; Juárez, 2002). While it is evident that the tourist-oriented economy in Quintana Roo is providing sources of wage labor and opportunities for cash incomes in the Zona Maya, the specific impacts on emigration, agricultural production and natural resources in this specific region have yet to be researched and documented. What also stands out is that tourism is favoring the development within a few *ejidos* in the ZM of ecotourism community enterprises and the sale of handicrafts (Dalle et al., 2006). Nevertheless, households in the ZM area stand out for being currently involved in forest-based economic activities through Community Forestry Enterprises (CFE).

4. Methods and analyses

LUCC analyses presented for both study areas in the CYPR are based on remote sensing methods using Landsat imagery data and spatial logistic regression to examine different variables or major potential drivers that can explain the occurrence of deforestation (or forest conservation). In this paper, we synthesize LUCC research conducted by the authors in LM (Porter-Bolland et al., 2007) combined with an updated LUCC analysis for the ZM, utilizing land use-land cover (LULC) data from a previous study (Bray et al., 2004; Ellis and Beck, 2004), but considering a different analysis area and updating the LUCC analysis to include the year 2004. A different analysis area for the ZM was selected in order to represent a similar area of comparison with our LM study area and additionally include a similar number of large ejidos established during the earlier agrarian reforms of the 1930s and 1940s particularly oriented for *chicle* production. The overall objective of combining and presenting past and current LUCC research in both study areas is to strengthen the authors' long-term ecological research (LTER) commitment to evaluate LUCC processes and its principle drivers, in addition to monitoring the environmental and socioeconomic changes in order to promote natural resource conservation and sustainable development in the region.

4.1. Remote sensing analyses

For the case of LM, Campeche, we present LUCC research and results for the periods of 1988–2000 and 2000–2005 in which remote sensing methods are specifically described in Porter-Bolland et al. (2007). The three scenes used for the LM study area include a Landsat 7 TM from April 27, 1988, a Landsat 7 ETM from March 21, 2000 and a Gap-Filled Landsat 7 ETM from January 20, 2005 (Path 20, Row 47). All three images underwent orthorectification and radiometric calibration to reduce atmospheric effects and represent true reflectance values using ENVI 4.0. Furthermore, image subsets were made to represent the LM study area according to *ejido* community boundaries. LULC classes were derived by supervised classifications using GPS ground truthing points (collected in the field during May 2005) for training site development. Supervised classifications were performed using the parallelepiped algorithm in ENVI 4.0. For the 2005 LM image, seven LULC classes were generated: (1) upland semiperennial forest, (2) upland semi-deciduous forest, (3) lowland flooded forest, (4) secondary or fallow vegetation, (5) agriculture, (6) aquatic vegetation, and (7) water. An accuracy assessment of the 2005 classification was conducted based on 114 randomly selected GPS points collected during a field visit in 2005 as LULC reference data and following the National Biological Survey and National Park Service Vegetation Mapping Program accuracy assessment procedures (ESRI et al., 1994). Accuracy assessment results, shown in Table 1, resulted in an overall accuracy of 82.4%, with a 90% confidence interval of 76–89%. The 2005 classification was used in guiding the supervised classifications for the 1988 and 2000 image.

Similarly, for the updated ZM analysis, we use LULC data obtained from previous LUCC research for the periods of 1984–2000, where remote sensing methods are detailed in Bray et al. (2004) as well as Ellis and Beck (2004). However, we use a subset of this data and modified the analysis area in order to include a set of 12 community forestry-based ejidos occupying an area similar to the LM study site. Moreover, we updated and integrated a recent LUCC analysis to include the periods 2000–2004. The Landsat images relevant to this study were a Landsat 5 TM scene from November 11, 1984, a Landsat 7 ETM scene from March 21, 2000 and a Gap-Filled Landsat 7 ETM from January 20, 2004 (Path 19, Row 47). All images were orthorectified and underwent radiometric calibration, reducing atmospheric effects and creating reflectance values using ENVI 3.1 and 4.0 for the 2004 image. In order to update our LUCC analysis, the 2004 image was subset to include our current ZM study area. A supervised classification was

Table 1
Contingency table for thematic accuracy assessment for La Montaña 2005 land use-land cover classification, showing producer's and user's accuracies and Kappa Statistic with 90% confidence intervals

Map class	Reference point class							
	FV	AG	AV	LFF	UDF	UPF	Total	Producer accuracy (%) (90% CI)
Fallow vegetation (FV)	13	1		2	2	1	19	86.7 (71–100)
Agricultura (AG)	1	15					16	93.7 (80–100)
Aquatic vegetation (AV)			2				2	40.0 (0–100)
Lowland flooded forest (LFF)			2	9	1		12	50.0 (22–78)
Upland semidecid. forest (UDF)			1	2	11		14	73.3 (58–89)
Upland semiperen. forest (UPF)	1			5	1	44	51	97.8 (95–100)
Total	15	16	5	18	15	45	114	
User accuracy (%) (90% CI)	68.4 (45 –91)	93.7 (80–100)	100 (90–100)	75 (55–95)	78.6 (59–99)	86.3 (80–92)	Overall accuracy: 82.45%, 90% CI: 76.0–88.9%; kappa statistic: 76.5%, 90% CI: 68.9–84.1%	

then performed using the maximum likelihood algorithm in ENVI 4.0 and based on GPS ground-truthing points for training site development collected in the field during 2005 and 2006. For the 2004 ZM image, six LULC classes were generated: (1) upland semiperennial forest, (2) lowland flooded forest, (3) secondary or fallow vegetation, (4) aquatic vegetation, (5) agriculture, and (6) water. Again, an accuracy assessment of the ZM 2004 classification was conducted based on 65 randomly selected GPS points collected during the last field visit in 2006 as LULC reference data, and following the National Biological Survey and National Park Service Vegetation Mapping Program accuracy assessment procedures (ESRI et al., 1994). Accuracy assessment results, shown in Table 2, resulted in an overall accuracy of 83.1%, with a 90% confidence interval of 75–91%.

For the ZM LUCC analysis, we extracted LULC data for 1984 and 2000 obtained from the results of previous research (Ellis and Beck, 2004; Bray et al., 2004) which applied a unsupervised classification (ISODATA procedure in ENVI 3.0) using principal component analysis (PCA) images to better extract vegetation cover and land use information. Moreover, these classifications were also guided using over 200 GPS ground-truthing points collected between 2000 and 2001 (Bray et al., 2004). Similar LULC classes generated for the 2004 ZM image were also obtained for the final 2000 and 1984 LULC images. For this current analysis, we use a subset of the original 1984 and 2000 LULC data from Bray et al. (2004), corresponding to our current 2004 ZM study and analysis area and facilitating LUCC comparisons with LM study area.

To evaluate LUCC and deforestation we reclassified all our LULC classifications for LM and ZM to include only two categories: (1) forest (upland semiperennial, lowland flooded and upland semideciduous) and (2) non-forested (agriculture and fallow vegetation). Change detection was then determined by intersecting the binary images for two time periods (e.g. 1984 and 2000 and 2000 and 2004) yielding two images with four land cover change categories: (1) new deforestation (2) remained deforested (3) remained forested and (4) forest regrowth. Water and aquatic vegetation LULC classes were masked out for the change detection analyses. In this respect, our new LUCC analysis for the ZM differs from past analyes (Ellis and Beck, 2004; Bray et al., 2004) where lowland flooded forests were also masked out. ArcView 3.2a with the Spatial Analyst extension from ESRI was used for the LUCC analysis. Deforestation rates were calculated for the periods 1988–2000 and 2000–2005 for LM and 1984–2000 and 2000–2004 for ZM applying the formula $dn = [S2/S1]^{1/n} - 1$, a standardized deforestation indicator for environmental monitoring in Mexico, where dn = deforestation rate, S2 = forest cover in time period two, S1 = forest cover in time period one and n = number of years between time periods (Palacio-Prieto et al., 2004).

4.2. Logistic regression analyses

We perform binary logistic regression to examine different variables that may result in present deforestation or forest conservation in LM (2005) and the ZM (2004). Spatial environmental and socioeconomic variables common to both study sites are used. However, we also included key variables unique to each study area with respect to its protected area or community-based forest management condition. For our binary response or dependent variable we use the 2005 forest/non-forest image for LM and the 2004 forest/non-forest image for ZM, where 1 is assigned to deforested areas and 0 to forested areas. For LM, spatial data used as explanatory variables for the logistic regression included: (1) distance to roads, (2) distance to settlements, (3) spatial population distribution (based on populations of settlements), (4) ejido size, (5) ejido population, (6) distance to water, (7) distance to lowland flooded forests, and (8) designated conserva-

Table 2
Contingency table for thematic accuracy assessment for Zona Maya 2004 land use-land cover classification, showing producer's and user's accuracies and Kappa Statistic with 90% confidence intervals

Map class	Reference point class					
	FV	AG	LFF	UPF	Total	Producer accuracy (%) (90% CI)
Fallow vegetation (FV)	15	4	0	0	19	68.1 (48–88)
Agriculture (AG)	1	8	0	0	9	66.7 (35–98)
Lowland flooded forest (LFF)	1	0	4	0	5	100 (90–100)
Upland semiperen. forest (UPF)	5	0	0	27	32	100 (98–100)
Total	22	12	4	27	65	
User accuracy (%) (90% CI)	78.9 (63–95)	88.9 (70–100)	80.0 (33–100)	84.3 (70–98)	Overall accuracy: 83.07%, 90% CI: 74.7–91.4%; kappa statistic: 74.6%, 90% CI: 63.2–85.9%	

tion status according to the CBR zoning (i.e. transition zone, buffer zone, core zone). For the ZM we use similar and complementary spatial explanatory variables including: (1) distance to roads, (2) distance to settlements, (3) spatial population distribution, (4) ejido population, (5) number of ejidatarios, (6) ejido size, (7) distance to water, (8) distance to lowland forests, (9) ejido Permanent Forest Area (PFA), and (8) timber volume extracted per ejido between 1993 and 1997.

Spatial layers used for explanatory variables were derived from GIS data (e.g., roads and settlement locations) and the 2000 socioeconomic census data obtained from the National Institute for Statistics, Geography, and Informatics (INEGI, 2001). The *ejido* and land tenure boundaries were acquired from maps obtained at the National Agrarian Registry and *ejido* data, such as timber volume extracted and PFA, were obtained from the Secretary of the Environment and Natural Resources (SEMARNAP, 2000). CBR boundaries and conservation zoning data was obtained from the Mexican National Council for Biodiversity (CONABIO). Spatial layers representing distance from roads, water, lowlands and settlements were developed using standard distance buffer operations. Spatial population distributions were obtained through kriging of population values for all settlement location points in the study areas. Additional layers were developed by joining spatial features representing *ejidos* with relevant population or *ejido* attribute data. ArcView 3.2a with the Spatial Analyst extension (ESRI) was used for GIS processing needs.

While limited by the availability of spatial data, explanatory variables were selected to represent several of the possible causes of deforestation (or forest maintenance) due to economic, demographic or institutional forces. Distance to roads, for example, is associated with socioeoconomic and infrastructure development. Most roads were established after the 1970s as a result of policy and institutional measures to develop these regions. The creation of *ejidos* and their characteristics are also largely due to the interaction between institutional forces of land reform. Variables such as distance to settlements, *ejido* population and population distribution largely represent demographic factors that are often associated with deforestation. We consider these variables critical to our comparison of protected areas vs. community forest management in forest conservation. In the case of LM, we include a conservation status or zoning variable (e.g. core, buffer and transition zones) which were created from institutional processes related with the creation of the CBR. Finally, with respect to the ZM, we include variables representative of *ejido* involvement in community forest management such as timber volumes extracted and extent of PFAs (an area over which a logging management plan operates). These also represent institutional and policy factors occurring at both national and *ejido* scales.

For the logistic regression statistical analysis, we used 125 randomly selected points generated within the LM analysis area. A test for spatial autocorrelation was performed on the residuals of the response variable (forested = 0 and deforested = 1) associated to these points yielding a Morańs Index of −0.003 with a *Z* score of 0.325, failing to reject the null hypothesis that there is no spatial autocorrelation. For the ZM analysis area, we used 97 randomly generated points, and performed a similar test for spatial autocorrelation resulting in a Moran's Index of −0.016 and a *Z* score of −0.22, which indicates that there is no spatial autocorrelation as well. For each random point, we extracted the cell values corresponding to the various spatial layers representing the dependent (forest or deforested) and explanatory variables. The logistic regressions were executed in XLStat 2007 using the Stepwise Backward Logit Model.

5. Results

Figs. 2 and 3 show recent LULC images for LM (2005) and ZM (2004), respectively. These images show the heterogeneous forested landscape common to both study areas, which consists of a matrix of upland and lowland flooded forest with patches of agricultural and fallow LULC types, resulting from anthropogenic impacts. The lowland flooded forests are indicative of topographical depressions and drainage patterns in the landscape. Moreover, LULC images also show the drier conditions present at LM study area with the presence of upland subdeciduous forest (absent in the ZM study area) and much fewer water bodies and aquatic vegetation represented in the landscape.

Despite similar forested landscapes, our results show very different and diverging LUCC processes both for LM, our protected area case, and the ZM, our community forest management example. The logistic regression results help support and explain the contrasting deforestation and forest conservation pathways observed in LM and the ZM, respectively, and point out some of the variables representing the major drivers or underlying causes responsible for these pathways.

5.1. LUCC in La Montaña

Fig. 4 shows images representing LUCC dynamics derived for LM for the periods 1988–2000 and 2000–2005, and are quantitatively described in Table 3. Our results show a definite and increasing deforestation process in LM with rates of −0.3% during the period 1988–2000 and −0.7% during the period 2000–2005. Even though large proportions of forest are maintained in the landscape (88% between 1988 and 2000 and 84% between 2000 and 2005) there is a clear trend of forest loss (6.2% between 1988 and 2000 and 7.0% between 2000 and 2005) that surpasses forest

Table 3
LUCC in La Montaña, Hopelchen, Campeche 1988–2000 and 2000–2005, and Zona Maya, Felipe Carrillo Puerto, Quintana Roo (1984–2000 and 2000–2005)

LUCC	La Montaña (ha)		Zona Maya (ha)	
	1988–2000	2000–2005	1984–2000	2000–2004
Remained forested	177,942	169,999	128,066	134,414
Total area (%)	88	84	81	86
Forest regrowth	5404	7848	12,941	6652
Total area (%)	2.6	3.9	8.2	4.2
Remained deforested	4093	8848	8427	10,550
Total area (%)	2.0	4.4	5.3	6.7
New deforestation	12,565	14,271	6969	4871
Total area (%)	6.2	7.0	4.4	3.6
Annual rate	−0.3	−0.7	−0.0004	0.002

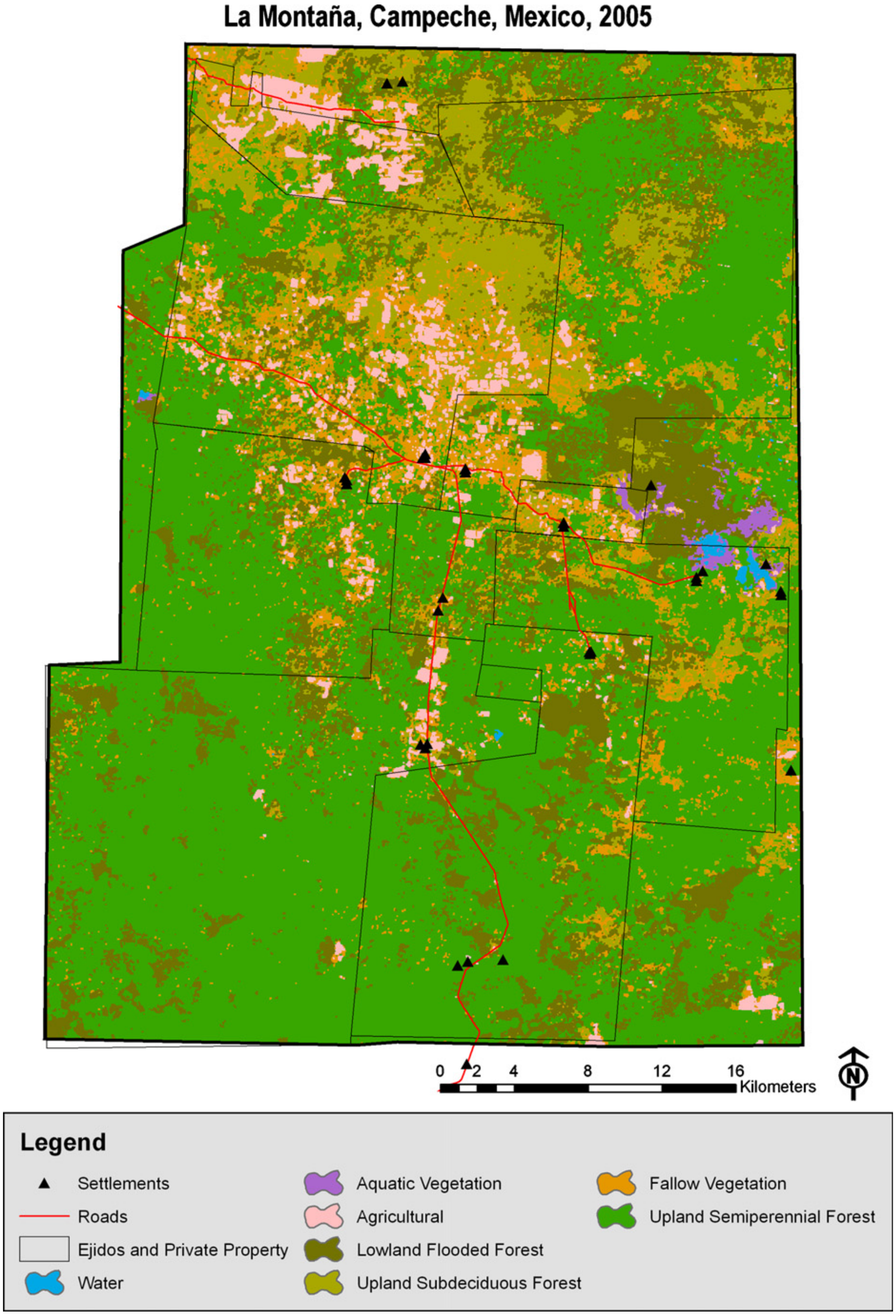

Fig. 2. Land use/land cover classification for 2005 of La Montaña, Hopelchen, Campeche.

regrowth (2.6% between 1988 and 2000 and 3.9% between 2000 and 2005).

The LM increasing trend of deforestation has been previously related to a pattern of agricultural expansion in which for the most part, land is being cleared for *milpas* and subsequently converted to pastures for rearing cattle, bypassing any fallow period or chance for forest regrowth. Based on a spatial analysis conducted previously, we determined that this LUCC pattern occurs mostly in transition areas between lowland flooded forests and upland forests and in proximity to roads, and we concluded that this trend of agricultural expansion, especially for pasture, is due in part, to infrastructure development and government agrarian policies (Porter-Bolland et al., 2007). The latter supported by other authors who associate deforestation with neoliberal reform initiatives that have brought about agricultural development programs such as the PROCAMPO (The Programa de Apoyo Directo al Campo, implemented by the Secretariat of Agriculture—SAGARPA, since 1994), which has increased cash crop production and pasture establishment in the region (Keys and Roy Chowdhury, 2006; Klepeis and Roy Chowdhury, 2004; Klepeis and Vance, 2003; Turner et al., 2003).

Also, increases in deforestation rates during the most recent period of 2000–2005 at LM, has occurred largely by the recent establishment of a Mennonite community within one of the *ejidos* of LM study area (during the year 2000). The agricultural expansion of the Mennonite community is much different than that observed for the Mayan communities, since it is characterized by much larger market-based agricultural clearings for corn, for the most

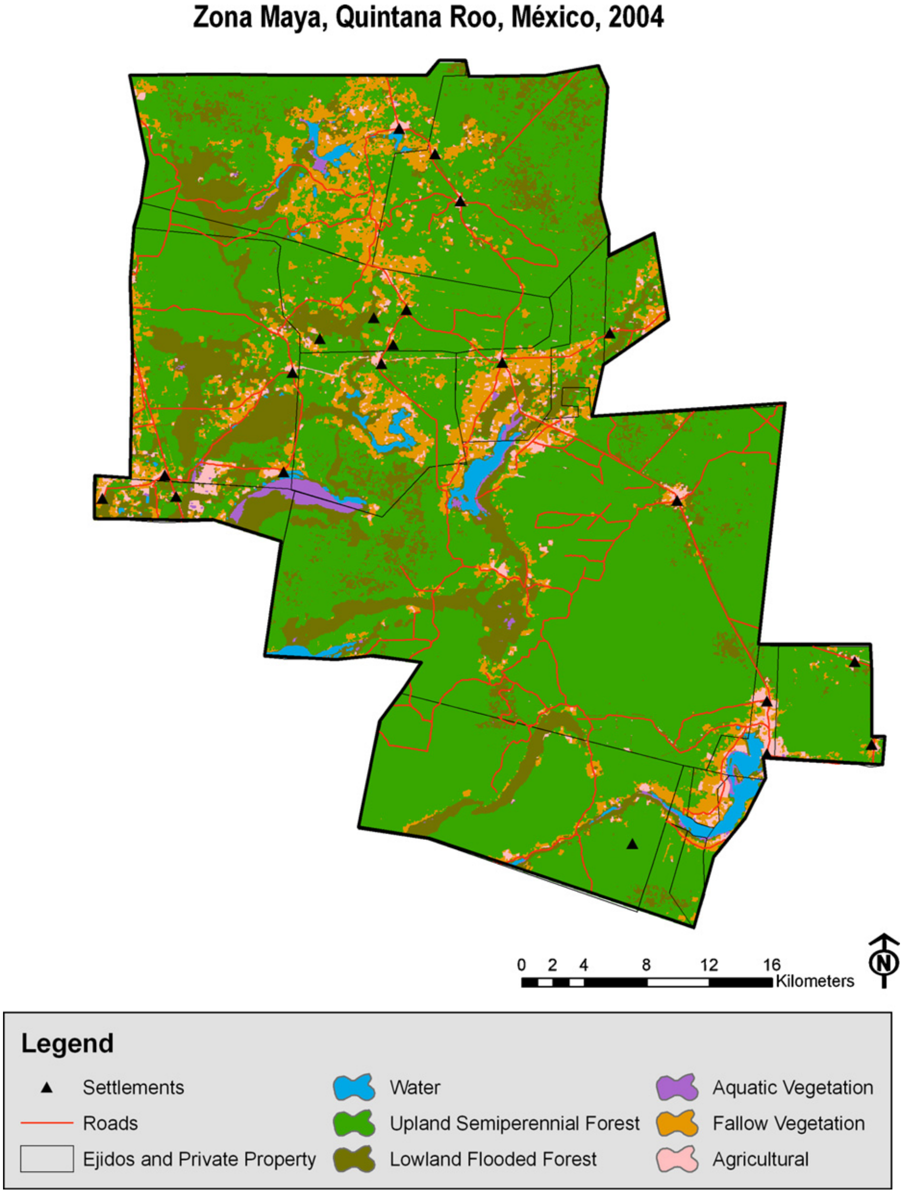

Fig. 3. Land use/land cover classification for 2004 for a portion of Zona Maya, F. Carrillo Puerto, Quintana Roo.

part, involving mechanized agriculture with use of agrochemicals. The fact that our study area includes the recent settlement of a Mennonite community cannot be ignored or excluded in this analysis, since it demonstrates the reality and a critical issue within the LM study area that a portion of common property *ejido* land was sold to outsiders. In 1992 the *ejido* based agrarian system was reformed allowing the parcelization and sale of *ejido* lands (Antinori and Bray, 2005). It is still vague to the authors if this sale of land to the Mennonites was legitimate or not, considering that communal *ejido* forest lands cannot be sold, nevertheless, it is important to our research in the CYPR to document and monitor the impacts related to selling and privatization of lands. This reflects some of the negative consequences propelled by neoliberal reforms, such as in land tenure issues, that ultimately influence LUCC processes (Antinori and Bray, 2005; Taylor and Zabin, 2000).

5.2. Logistic regression for La Montaña

The logistic regression results for LM, summarized in Table 4, offers additional insight in order to explain LUCC pathways for this area. Our overall logistic regression model for LM was significant (−2 log (likelihood): $\chi^2 = 21.6$, $\rho < 0.0001$; Goodness of Fit: R^2 (Nagelkerke) = 0.4) and the most significant explanatory variables were (1) population spatial index ($\chi^2 = 6.1$, $\rho = 0.01$), (2) *ejido* population ($\chi^2 = 5.2$, $\rho = 0.02$), and (3) distance to lowland flooded

Table 4
Binary logistic regression model (stepwise-backward) and results for the probability of deforestation in La Montaña, Hopelchen, Campeche

Variables	β	S.E.	Wald Chi^2	$Pr >$ Chi^2
Intercept	−3.229	4.243	0.579	0.447
Distance to roads	0.000	0.000		
Distance to settlements	0.000	0.000		
Population distribution	0.004	0.001	6.080	0.014
Distance to water	0.000	0.000		
Distance to lowland flooded	−0.944	0.515	3.352	0.067
Conservation zoning	0.000	0.000		
Ejido population	0.002	0.001	5.250	0.022
Ejido size	0.000	0.000		

Model: −2 log likelihood: $\chi^2 = 21.6$, d.f. = 3, $\rho < 0.0001$; Goodness of Fit: R^2 (Nagelkerke) = 0.5.

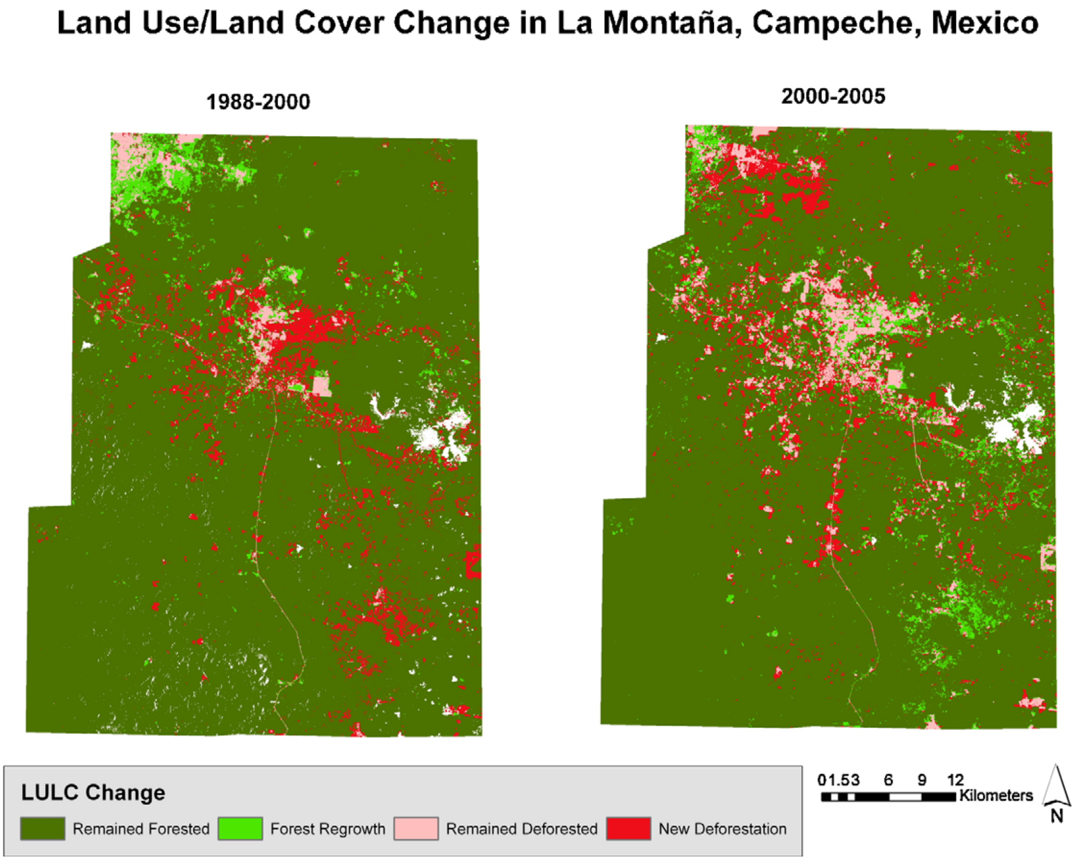

Fig. 4. LUCC processes in La Montaña, Hopelchen, Campeche for the periods 1988–2000 and 2000–2005.

forests ($\chi^2 = 3.3$, $\rho = 0.06$). Explanatory variables that did not show to be significant were distance to roads, as well as the conservation status variable.

Logistic regression at LM, therefore, indicates that population is strongly and positively related to deforestation processes and pattern in this area and confirms previous LUCC analysis that a great deal of this deforestation occurs in transition zones between lowland flooded and upland forest, due to preferred soil conditions for agriculture (Porter-Bolland et al., 2007). Interestingly, proximity to roads was not significantly related to deforestation in our logistic regression model for this area. Nevertheless, it is important to bear in mind that several authors have stated that forecasting of highway construction and amplification is currently considered one of the greatest threats to biodiversity at the CBR, particularly at its southernmost part (Vester et al., 2007; Amor Conde et al., 2007).

Also, and contrary to what would be expected, the conservation status variable (or conservation zoning established by the CBR) was also not significantly related to forest conservation or the occurrence of deforestation, raising questions concerning the effectiveness of the CBR in reducing deforestation and protecting biodiversity at this area.

5.3. LUCC in Zona Maya

Fig. 5 shows images representing LUCC dynamics derived for the ZM study area for the periods 1984–2000 and 2000–2004, and these are quantitatively described in Table 3. In contrast to LM, deforestation rates in the ZM study area are very low or even negligible (−0.0004%) from 1984 to 2000, and actually experience slight net forest regrowth or transition in the 2000–2004 period (0.002%). Over 80% of the landscape remains forested in the ZM study area, and forest cover actually increases 5% from its extent in 1984, due to a relatively large percentage of forest regrowth (8.2%) occurring during 1984–2000. Forest regrowth during this initial period coincides with the establishment of the PPF and PFAs for community forest management.

In that sense, while a greater percentage of deforested areas exist in ZM (5.3% during 1984–2000 and 6.7% from 2000 to 2004) compared to LM, there are much lesser proportions of new deforestation (4.4% during 1984–2000 and 3.6% during 2000–2004) than that of forest regrowth (8.2% occurring during 1984–2000 and 4.2% from 2000 to 2004). In the ZM, land clearing is mostly for *milpa* agriculture rather than for cattle rearing and clearing patterns tend to be more localized in transition zones from lowland areas to upland forest areas, such as around water bodies and lowland flooded forests. A major difference in land use dynamics in the ZM that contrast with LM, is that clearings are smaller and subsequent conversion to pasture is minimal. Consequently, the use of fallow periods is also more prevalent in the ZM study area, and agriculture is confined as a result of larger management goals that have lead to land use zoning and the designation of PFAs. It is important to consider that the ZM's nearness to the touristic zone may provide its inhabitants with more access and opportunities to wage labor in major tourism poles, whereas population at LM, a much more remote and isolated region with minimal outside visitors, is more dependent on productive activities for cash income or self sufficiency. The latter may exert a difference reflected in landscape processes.

5.4. Logistic regression for Zona Maya

The logistic regression model for the ZM (Table 5) was also significant (−2 log (likelihood): $\chi^2 = 29.6$, $p < 0.0001$ and Goodness of Fit: R^2 (Nagelkerke) = 0.5), and the most significant

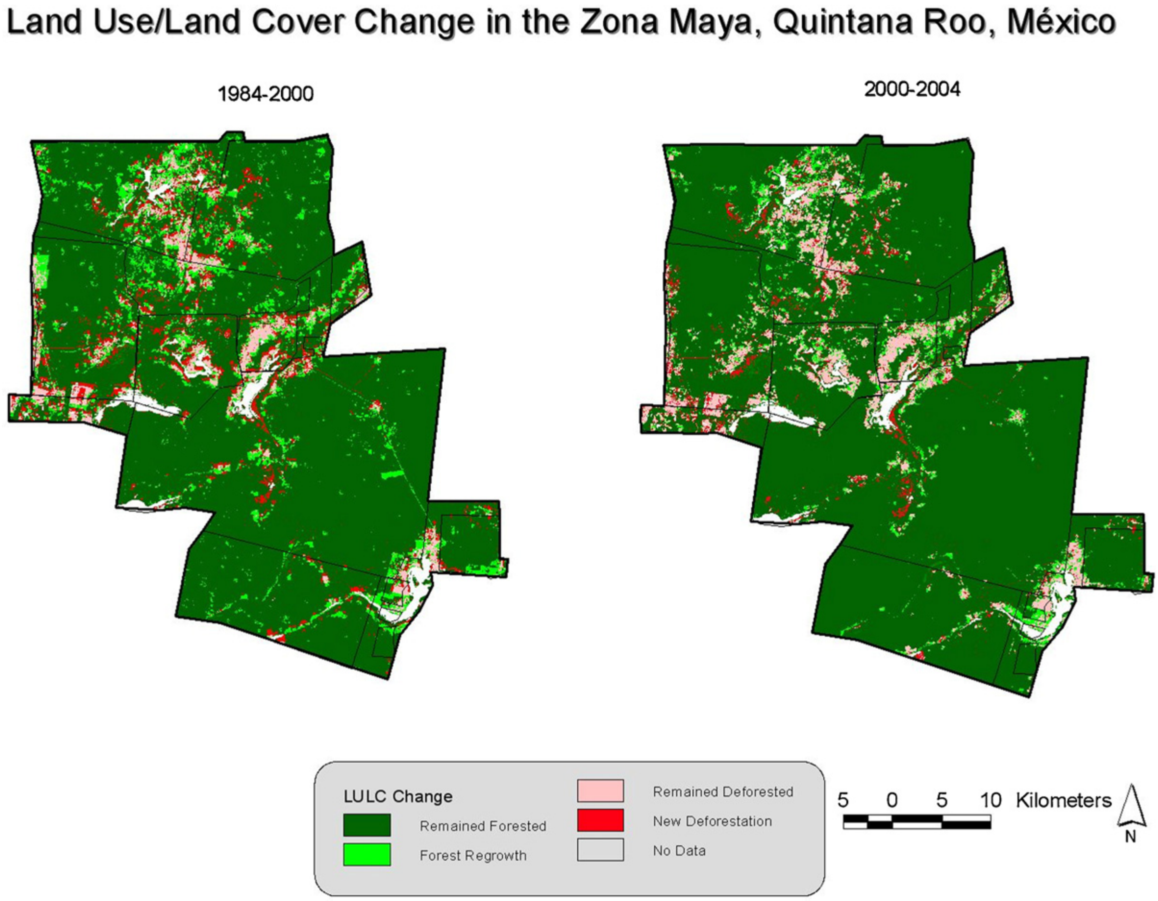

Fig. 5. LUCC processes in the Zona Maya, F. Carrillo Puerto, Quintana Roo for the periods 1984–2000 and 2000–2004.

explanatory variables were (1) number of *ejidatarios* ($\chi^2 = 3.4$, $p = 0.06$), (2) *ejido* size ($\chi^2 = 4.6$, $p = 0.03$), 3) distance to lowland flooded forest ($p = 0.008$), and (4) area under PFA ($\chi^2 = 4.9$, $p = 0.03$). *Ejido* population, and population distribution variables were not strongly correlated with forest clearing.

Overall, for the ZM we see a pathway of forest maintenance and regeneration and our logistic regression results provide some conclusions as to LUCC trends observed in this study area. Interestingly, despite twice the population density in the ZM compared to LM, *ejido* population and population distribution variables were not strongly correlated with forest clearing. However, there was a strong positive correlation between land clearing and the number of *ejidatarios*, representing the male household members with entitlement to *ejido* land for agricultural uses which have been previously designated and zoned out to *ejidatarios* through local *ejido* rules and leadership. There may be the case that the population at the ZM with no land title rights for agricultural production, which is the case with some of the younger male head of households that are not *ejidatarios*, is more involved in wage labor, as explained above, and do not imply a greater influence on deforestation processes. Since there is also a positive relationship between the size of the *ejidos* and the number of *ejidatarios* they contain, it is not surprising that this variable would also be strongly related to the deforestation process in the ZM study area. Furthermore, similar to our LM model, land clearing was also associated to nearness to lowland forest areas as noted in the change analysis images, reflecting suitable land for agriculture. The key finding in our model, however, is the negative significant relationship between the presence and size of PFAs (also positively correlated with *ejido* size) and forest clearing. That is, PFAs are positively correlated with forest maintenance observed in the ZM. These results conform to previously published results which showed that large *ejidos* with large PFAs conserve larger portions of forest cover (Ellis and Beck, 2004; Bray et al., 2004).

Table 5
Binary logistic regression model (stepwise-backward) and results for the probability of deforestation in a portion of the Zona Maya, F. Carrillo Puerto, Quintana Roo

Variables	β	S.E.	Wald Chi^2	$Pr > \text{Chi}^2$
Intercept	−5.945	4.971	1.430	0.232
Distance to roads	−0.552	0.377	2.145	0.143
Distance to settlements	0.378	0.249	2.298	0.130
Number of *Ejidatarios*	0.023	0.012	3.440	0.064
Ejido population	0.000	0.000		
Ejido timber volume	0.000	0.000		
Ejido permanent forest area	−0.001	0.001	4.925	0.026
Population distribution	0.003	0.002	2.149	0.143
Ejido size	0.001	0.000	4.631	0.031
Distance to water	0.000	0.000		
Distance to lowland flooded	−0.576	0.216	7.101	0.008

Model: −2 log likelihood: $\chi^2 = 29.6$, d.f. = 7, $\rho < 0.0001$; Goodness of Fit: R^2 (Nagelkerke) = 0.5.

6. Discussion

As we have demonstrated through LUCC analysis and its relation to explanatory variables, contrasting processes at the landscape level in the two neighboring regions reflect the complex interactions between land use and land cover occurring at multiple spatial and temporal scales as coupled human–environment systems influenced by socioeconomic, policy and institutional factors, also exemplified in other cases (Bray and Klepeis, 2005; Rindfuss et al., 2004; Turner et al., 2003; Klepeis and Turner, 2001). At LM, the dominant LUCC pathway can be summarized as that of deforestation for agricultural expansion, typical of forest frontier regions. The latter is mostly driven by population growth and distribution in the region combined with the effects of government agrarian policies following neoliberal tendencies. These tendencies promote increased establishment of lands under production (i.e., pasture establishment for cattle) and the selling and privatization of lands within communal property (e.g. purchase of land by Mennonite community). In particular, cattle rearing and pasture establishment has been greatly expanded in the last years, although the activity has not proven to be significant for a families' economy, it is considered a means of saving and to provide *status quo* to producers (Porter-Bolland et al., 2008). It is also worth emphasizing that government programs in the area assisting pasture and cattle establishment are substantial and increasing (Porter-Bolland, personal observation from April 2008).

Given the above, despite the establishment of the CBR in 1998, deforestation in LM increased even more compared to the period before its establishment. Apparently, local practices and institutions of Mayan communities living in LM regarding land and natural resource use have inadequately been influenced by the Mesoamerican Biological Corridor and other conservation initiatives in counteracting the deforestation process and the agrarian policies that drive it. The same has been observed in the southern most part of the CBR (Vester et al., 2007; Keys and Roy Chowdhury, 2006; Turner et al., 2003).

In comparison, the dominant LUCC pathway in the ZM can be described as one of forest conservation or maintenance, largely driven by local community forestry institutions, which were strengthened with the PPF, and which created PFAs for community forestry activities. The latter has resulted in stronger local institutions at the *ejido* level, implementing stricter rules on agricultural land uses mostly designated to *ejidatarios* as well as agricultural and forestry zoning within these *ejidos*. The zoning of *ejidos* has presumably discouraged the expansions of land under agriculture and particularly for cattle rearing. Forestry activities may represent an economic incentive that deters the adoption of such practices as well. The latter is exemplified by a comment of a producer in one of the smaller communities of ZM (*Reforma Agraria*) who told us that although they originally arrived to the area from Tabasco with the idea of fomenting cattle ranching, they were now focusing on forestry activities and actually reverting some of the originally established pastures to forest plantations. In addition, higher availability of wage labor at urban centers given the area's nearness to tourism poles has been reported to decrease the dependence on farming throughout the state, and this may have an influence on the processes observed at a landscape level (Torres, 2003). Nonetheless, this is a very important socioeconomic factor which merits further research, particularly concerning its impacts in LUCC in the ZM.

The forest clearing occurring at the ZM study area is for the most part for small-scale and subsistence-based *milpa* agriculture and strongly reflects the number of *ejidatario* families clearing and managing agricultural areas, with no agricultural expansion being visible at the landscape level. Contrary to LM, in the ZM, institutions at the national and regional level, mainly those created by the PPF, and at the *ejido* level through community resource management regulations, as well as possibly other socio-economic characteristics such as wage labor opportunities brought about by the prominent tourism-oriented development in Quintana Roo, have presumably been conducive to forest conservation and even regeneration. The later has been observed by different authors that relate the conservation of the forest cover in the area to policy and institutions, particularly the PPF that created and strengthened the consolidation of CFEs, favoring forest management (Bray et al., 2006; Richards, 1991). Other factors leading to forest conservation may be the result of cultural practices and a pre-existing conservation ethic related to values and uses conferred to specific forest species, forest types or management units at the landscape level (Dalle et al., 2006).

In this sense, our results show that the portion of the CYPR considered as a "hot spot" for conservation, deforestation pathways result from a combination of key drivers, mainly population and unfavorable agricultural and land tenure policy. Unfortunately, protected area status or programs have been ineffective in reducing deforestation. However, in the case of ZM, despite the presence of the same national and regional policy drivers, and in fact with more settlements, population and roads, the presence of working community-based forest management institutions and local *ejido*-based land and resource management institutions as well as other factors such as temporal migration to urban centers for wage labor related to the tourism industry, have been conducive to maintaining forest cover and counteracting a deforestation process.

In an analysis conducted by Mas et al. (2003), regarding the different factors affecting forest maintenance in a nationwide study, they concluded that the effect of protected area status on deforestation was actually very weak, and rather that deforestation was strongly correlated to remoteness, topography and soil type. In a subsequent LUCC study, Mas (2005) evaluates the effectiveness of the Calakmul Biosphere Reserve (CBR) in protecting forests. In this study, an unfavorable picture of the impacts of people in the buffer zones of the CBR is presented, concluding that the main factors controlling deforestation were the type of soil and the distance from settlements and from roads. It is important to indicate that the CBR is not an isolated case, but that it is common as exemplified by other regions of the world with high rates of forest loss and fragmentation surrounding protected areas (Nagendra et al., 2006; Curran et al., 2004; Sánchez-Azofeifa et al., 1999).

Correspondingly, a few recent studies have compared LUCC in community forest management regions in Mexico with regard to protected areas and have demonstrated that they can be as effective or more in maintaining forest cover (Durán et al., 2005; Bray et al., 2007). Durán et al. (2005) compared a group of community forest management *ejidos* (communally owned land tenure) in the states of Guerrero and Quintana Roo with a group of 67 protected areas in Mexico and reported that both groups of *ejidos* managed to conserve over 95% of the original forest cover in a period of over 20 years while protected areas maintained 98.8%. A similar deforestation study considers the southern portion of the Yucatán Peninsula, including 12 community forest concessions in the Peten Region of Guatemala and a group of 7 community forestry *ejidos* in Quintana Roo, Mexico, and the protected areas of the Maya Biosphere Reserve in Guatemala and the Calakmul Biosphere reserve (Bray et al., 2007). On an average, they demonstrate lower deforestation rates in the community forests (0.16%) than in the protected areas (0.33%). The highest rates were observed in densely populated protected areas (0.69%) and community forest settlements of recent conformation (0.71%), both occurring within the Maya Biosphere Reserve in Guatemala. The results of the above studies, as well as this work, show the positive outlook that the role of community forest management can play towards having effective forest conservation in Mexico.

We are aware that forest cover maintenance or conservation that results from forest management for timber may not guarantee biodiversity conservation at all levels. For that assessment, other studies should be conducted in order to monitor changes in biological groups and ecosystem functioning. In that case, the role of protected areas for conservation cannot be ignored, but rather, different management goals should encompass a regional land use management approach, in which protected areas are not envisioned as islands isolated from surrounding areas (DeFries et al., 2007). Rather, conservation policy should focus on fostering local organizational and institutional processes that derive in internal capacities to conduct decisions and activities collectively (Rodríguez et al., 2007; Bray et al., 2006). That is, fostering management alternatives that improve the livelihood of people living in the vicinity of protected areas, congruent to conservation goals.

Management alternatives in the area of LM relate to timber and non-timber forest products, including *chicle* tapping and honey production, which both have commercial potential. For honey, there is an increasing demand, particularly from the international market and the area has the potential both for increasing production and for providing added value to the product (i.e., organic honey). Sustainable timber management should also be promoted as the area holds important volumes of valuable species. Other activities relate to agroforestry systems and to the knowledge base inherent to current population in the area regarding forest management (Porter-Bolland et al., 2006a,b, 2008). All of these options can be directed for increasing the wellbeing of families without necessarily compromising the forest cover in the region, provided sustainable processes of production are fostered.

For the above to occur, local institutions should be strengthened at LM. The importance of building local institutions, that is, formal and informal rules guiding decisions of a group with regards to a common good, is fundamental for managing common resources such as forests (Ostrom, 1990). Social, technical, organizational and administrative capital should be built on existent initiatives. External agencies (governmental and non-governmental) should provide credibility to local agents, generating real mechanisms of governance and effective accountability (Brechin et al., 2002), which is currently lacking at LM (Porter-Bolland et al., 2006b). The ZM, although different from LM in many important aspects, may well provide certain lessons to the area, particularly regarding its process of developing effective CFEs. A regional approach to conservation should therefore conceptualize the political and social dimensions of conservation, addressing issues related to the needs and aspirations of the local population, and recognizing the potential roles of diverse alliances at different levels (Nepstad et al., 2006). These are issues to be considered in light of developing a framework for a more effective and socially just conservation strategy (Schmidt-Soltau and Brockington, 2007).

Acknowledgements

Partial funding of this resarch was provided by CONABIO Project BJ013. The authors would also like to thank the Organizción Ejidal de Productores Forestales de la Zona Maya and the Universidad Autonoma de Campeche for their support in the field.

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