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Biodiversity conservation, traditional agriculture and ecotourism: Land cover/land use change projections for a natural protected area in the northeastern Yucatan Peninsula, Mexico

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Abstract

In addition to preserving ecosystems and biodiversity, natural protected areas (NPAs) in Mexico are homelands for people, largely indigenous, who traditionally base their resource management on a multiple use strategy. We analyzed land use and land cover changes in the Otoch Ma'ax Yetel Kooh NPA in the northeastern Yucatan Peninsula, Mexico, where Yucatec Maya recently incorporated ecotourism to their set of economic activities. We evaluated changes in land use using vegetation maps from 1999 to 2003 and predicted vegetation cover in 2011 by developing a cellular automata and Markovian chains model. We observed slight increases in the area covered by medium stages of secondary succession, while new milpa plots appeared in areas of all succession stages. We used three scenarios to predict land cover in 2011: (a) milpa agriculture implemented at the same rate; (b) milpa agriculture decreases due to the growing demand of ecotourism; and (c) milpa agriculture disappears due to parceling of communally owned land. All scenarios predict slight increases in the area covered by secondary succession at the expense of milpas or younger stages of succession, with no major differences between the three predictive scenarios. Our results provide guidelines for managing the NPA, suggesting that biodiversity conservation, traditional agriculture and ecotourism are compatible activities.

Keywords: Land use and land cover changes; Cellular automata; Markovian chains; Milpa agriculture; Ecotourism; Yucatan Peninsula

1. Introduction

Worldwide, about 370 million hectares of forests are owned by local communities, just slightly less than the 470 million hectares under government protection (Molnar et al., 2004). Natural protected areas (NPAs) are intended to preserve biodiversity through strategies ranging from total prohibition of human activities (Van Schaik and Kramer, 1997; Terborgh, 2000) to promotion of sustainable use strategies (Wells and Brandon, 1992; Janzen, 1999). Some NPAs (see IUCN, 1994) have been established to protect biodiversity as well as accommodate interactions between people and nature, using management activities as a critical preservation element. Programs such as UNESCO's Man and the Biosphere Program, and more recent initiatives such as the Mesoamerican Biological Corridor, emphasize the contribution that varied land uses can make to biodiversity conservation (Miller et al., 2001). The myriad factors influencing land use make success or failure of conservation and sustainable development efforts highly dependent on local contexts, including aspects such as property right systems, local institutions, and local decision-making patterns (Brechin et al., 2002).

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Like other culturally and biologically rich regions in the Tropics (Smardon and Faust, 2006), the Yucatan Peninsula, in southeastern Mexico, contains a diversity of tropical ecosystems in which a number of indigenous communities have managed natural resources based on a highly complex multiple-use strategy (MUS; Faust, 2001; Gómez-Pompa et al., 2003; Barrera-Bassols and Toledo, 2005). Often in use for centuries, this MUS involves a set of productive activities (e.g., agriculture, agroforestry, gardening, cattle ranching, beekeeping, fishing, hunting, gathering and extractive practices) in different land-use systems. Their objective is to maximize the number of options available to maintain a continuous, year-round flow of goods and services for both subsistence and sale (Barrera-Bassols and Toledo, 2005), while minimizing the risks associated with external disturbances.

Rapid social and economic changes at the local, regional, and global scales are now seriously threatening this form of natural resource appropriation. Tourism in the Yucatan Peninsula is an excellent example of these changes. Over the last thirty years, the Peninsula's archaeological and natural sites have become one of Mexico's main tourist attractions, bringing over six million tourists annually to the region (SEDETUR, 2006). Rapid development of tourist infrastructure has resulted in far-reaching social, economic, and ecological impacts that have not bypassed the Peninsula's NPAs. Under these circumstances, local communities experience increasing involvement in the national economy, and a concomitant drive to acquire consumer goods. These forces have been straining local customary natural resource use strategies (Smardon and Faust, 2006). In addition, modifications made to the legal structure of Mexican land tenure have profoundly altered the established land holding scheme. Before 1992, ejidos were areas of land held collectively in usufruct by peasant communities for farming and managing natural resources, and they could not be parceled, leased or sold. After the legal reforms, local communities are allowed to divide their ejido into individually-owned parcels that can then be leased or sold.

The above processes are promoting significant changes in regional land use and land cover. Here we defined land cover as the ecological state and physical appearance of the land surface, and land use as human employment of land (Turner and Meyer, 1994). Understanding the social, economic, and environmental factors that promote land use and land cover change (LUCC) is critical to designing and implementing sound conservation policies for regional biodiversity. Research into LUCC and the factors that influence it can also provide valuable information for development of conservation policies in comparable contexts. Similar studies that analyze the factors that influence LUCC have been carried out in the Yucatan peninsula, most notably in its south-central region in and around the Calakmul Biosphere Reserve (Turner et al., 2004; Manson, 2006; Roy Chowdhury, 2006) and in the "Mayan Zone" in the southeast (Bray et al., 2004). These studies have found that factors both internal to the local communities (e.g., household size, income level) and external (e.g., support from government agencies, access to markets) are good predictors of LUCC trajectories for the analyzed units of land.

In this paper we analyze LUCC in the Otoch Ma'ax Yetel Kooh (OMYK) NPA, 5367 ha of community-owned forests declared a Flora and Fauna Protection Area in 2002. Placed under administration of the National Commission for Natural Protected Areas (CONANP), the NPA is actually managed by local inhabitants. It consists of a large lake surrounded by fragments of old-growth forest that harbor a large spider monkey (*Ateles geoffroyi*) population, as well as many other species. This spider monkey population was the primary reason for the creation of the OMYK NPA.

The Yucatec Maya people living in OMYK manage natural resources based on a complex MUS, with milpa agriculture as its core activity. Milpa is a multi-species system involving domesticated, semi-domesticated and tolerated plant species that combines maize with almost any other crop, tree or shrub species. This rainfall-dependent system is widely used in southern Mexico, is the pivotal element in the Yucatec Maya MUS (Barrera-Bassols and Toledo, 2005), and one of the principal agricultural systems in use on the Yucatan Peninsula. In addition to providing partial control over food security (Faust, 1998), the milpa system is the main source of maize, a sacred food, and an important component of Yucatec Maya identity, which has survived for centuries despite social, economic, and political pressures (Terán and Rasmussen, 1994).

The milpa system involves a cycle of anthropogenic disturbance of forest vegetation followed by a period of forest recovery. Farmers use a fixed site for 2–3 years and then move to a new area, leaving the previous plot fallow and letting the natural vegetation regenerate. Rotation of milpa fields ideally occurs in 20- to 30-year cycles (Levy Tacher and Hernández Xolocotzi, 1992), but in some sites where demographic pressures are increasing or milpa is no longer the main productive activity, farmers use shorter fallow periods.

In some cases, growing regional tourism has caused incorporation of ecotourism into the MUS. One of the communities in OMYK has taken advantage of tourist traffic to the nearby Coba archeological site and the ease with which spider monkeys can be observed in this community's lands. Its members decided to preserve part of their lands, open trails into the forest and serve as guides, charging an entrance fee to take tourists to see the monkeys. From its outset twenty years ago, ecotourism in OMYK has been managed by community members, who have organized themselves into a cooperative. Some have decided to specialize as tourist guides, considerably reducing the time they devote to other traditional activities, while others still follow traditional lifeways and have kept milpa as their main activity. The dynamic of ecotourism in the OMYK area will probably change notably with the recent arrival of large tourist agencies. These agencies usually operate by paying a monthly fee to local communities in exchange for exclusive access to a community's natural sites, and then hire local people as employees.

In the future, milpa agriculture in OMYK may be threatened by a combination of government natural preservation and agricultural policies. The federal government is currently designing a management plan for natural resource use in OMYK. Some federal natural preservation programs explicitly promote sustainable activities in NPAs (CONANP, 2002), while state programs (e.g., Gobierno del Estado de Campeche, 2004; Gobierno del Estado de Yucatán, 2006) often conceive traditional activities like milpa as inefficient production systems and as sources of disturbance. Moreover, most regional agricultural programs emphasize improving productivity through technological packages (e.g., hybrid seeds, fertilizers and herbicides), with little or no concern for their cultural and environmental impacts. Finally, regional development programs see tourism as the main solution to natural resource conservation (Klepeis, 2003) and regard traditional productive and extractive activities as environmentally harmful.

Although OMYK is administered by the CONANP, ejido lands within the protected area are still owned by local communities. Members of the ejido that includes OMYK are currently discussing whether or not to parcel their land under the Program for Certification of Ejido Land Rights and Titling of Urban House Lots (PROCEDE). This program provides a legal framework within which ejido members (ejidatarios) can vote to divide communal lands into individually-owned parcels, providing them the possibility to own, and consequently lease and/or sell their individual parcels (Haenn, 2006). If they decide to do so, no parcels could be created within the OMYK NPA, which would immediately become federal government property. Two consequences would be that all milpa agriculture would have to be done outside the NPA, and that the newly private parcels surrounding OMYK would soon be sold to third parties, quite likely tourist industry developers.

Identifying the causes of LUCC in the OMYK NPA is an important step towards successful biodiversity preservation within it. Developing predictive LUCC models that incorporate both ecological and socioeconomic data (Geoghegan et al., 2004; Goetz et al., 2003) can contribute novel information to the decision-making and preservation policy development processes. Regression and transition have been the main approaches for modeling LUCC (Theobald and Hobbs, 1998). Regression based models assume that the observed land use patterns respond to a range of variables explored through a regression logistic method (Turner et al., 1996; Lambin, 1997; Bray et al., 2004), and transition models explore how future patterns of land use will respond to a series of initial conditions based on cellular automata and Markov chains or other methods (Turner, 1988; Clarke et al., 1997; Clarke and Gaydos, 1998; Wang and Zhang, 2001; Soares-Filho et al., 2002).

The cellular automata is a simple model able to predict the spatial patterns based on probabilistic estimations related to a series of initial conditions (Wolfram, 1984; Silvertown et al., 1992). Integrated with Markovian transition matrices, Markov-Cellular Automata (M-CA) models are able to use existing knowledge of factors known to modify land use and land cover, representing them as space and time variables and estimate future trends in LUCC (Silvertown et al., 1992; Wang and Zhang, 2001; Soares-Filho et al., 2002). The simplicity of their implementation has permitted their inclusion in commercial software and they have been used to reproduce several dynamic spatial phenomena (Soares-Filho et al., 2002).

In an effort to develop a LUCC model for the OMYK NPA, we characterized LUCC occurring between 1999 and 2003 using remote sensing data and ground truthing. We then used this data to develop an M-CA model that predicted land cover up to 2011 under different land use scenarios. These scenarios were based on both the current land use patterns that reflect the main activities of OMYK inhabitants, and on the future tendencies suggested by socioeconomic data and current land policy modifications.

2. Materials and methods

2.1. Study area

OMYK is located in the northeastern Yucatan Peninsula (20°38′N, 87°37′W) (Diario Oficial de la Federación, 2002), 18 km north of the Coba archaeological site and 26 km south of Nuevo Xcan in the state of Quintana Roo, Mexico (Fig. 1). Regional climate has two seasons, a rainy season from May to November and dry season from December to April. Mean annual temperature is 24.3 °C, and mean annual precipitation is 1,265 mm (CNA, 2005). The dominant vegetation is classified as medium semi-evergreen forest (approximately 93% of total cover) and exhibits different successional stages. Milpa agriculture is the main productive activity in the area, and has produced a land cover mosaic of managed and unmanaged vegetation from recently abandoned plots to older than 50 years old forest, interspersed with agricultural fields, vegetation corridors, water bodies and homegardens. This heterogeneous land cover is commonly found in the humid tropics of Mexico, especially where cattle ranching is not a widespread activity (Challenger, 1998). Faunal biodiversity remains high despite anthropogenic changes in the vegetation. Endangered species such as jaguars (*Panthera onca*), pumas (*Puma concolor*), black howler monkeys (*Alouatta pigra*) and black-handed spider monkeys (*Ateles geoffroyi*) have been reported in the area. In addition to being the main tourist attraction, the spider monkey population has been under study for ten years, making OMYK one of the most important primatology research sites in Mexico (Ramos-Fernández et al., 2003).

The region is still characterized by large forested areas with low rural population density, although accelerated tourist development along the nearby Caribbean coast (e.g., Riviera Maya) is bound to change this. Overall human population in the NPA and its environs is approximately 300, divided among three communities and seven smaller communities (hamlets or rancherías). The communities of Punta Laguna (approximately 100 inhabitants) and Yodzonot (approximately 50 inhabitants) are inside the NPA. All the inhabitants of these communities are indigenous Yucatec Maya, and most preserve many of their ancient cultural traditions, such as language, religious ceremonies, agricultural practices and traditional natural resource appropriation practices. Resource management in these communities involves several economic activities (milpa agriculture, homegardening, beekeeping, hunting, charcoal production, sheep ranching, gathering, ecotourism and handcraft production) occurring within different land use units (milpa plot, homegardens, secondary forest, old-growth forest, and lagoons); being milpas its pivotal component. Just outside the NPA limits is the community

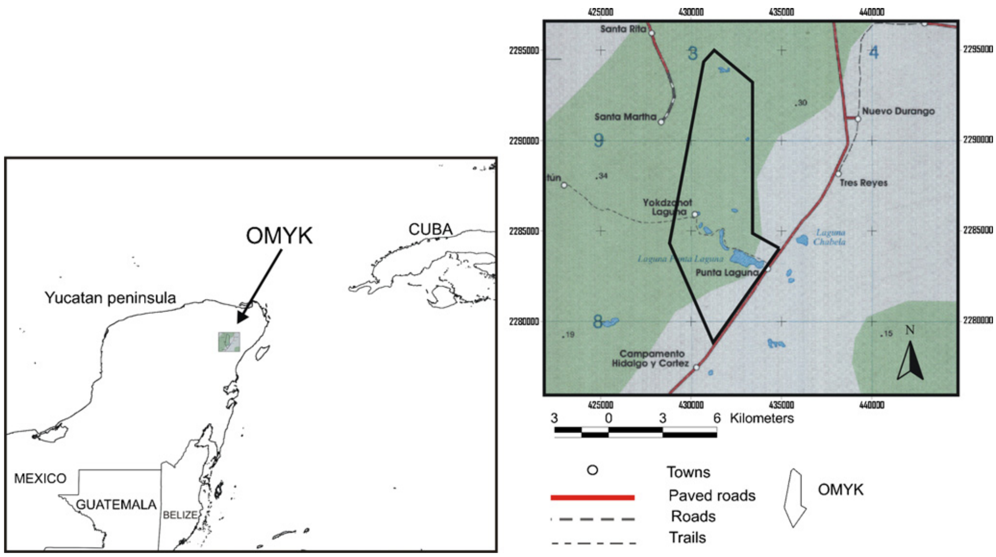

Fig. 1. Location of the Otoch Ma'ax Yetel Kooh Natural Protected Area.

of Campamento Hidalgo (approximately 100 inhabitants) and seven hamlets that use NPA lands for some of their productive activities.

Households in the OMYK area participate in a dual economy. First, they produce some goods for sale (honey, charcoal, handcrafts and provide environmental services such as ecotourism) and acquire other goods (maize, coffee, sugar, medicines, clothing, shoes, tools, cooking utensils, and even cars). Second, they grow maize, beans, squash, chili and other fruits and vegetables for subsistence use, and extract subterranean water, medicinal plants and wood (for fuel and raw material) as common property resources.

2.2. Socioeconomic analysis

The socioeconomic analysis was aimed at examining current land-use practices and their spatial distribution, as well as the different land-use strategies implemented by households within the NPA. This analysis was needed to identify the forces behind LUCC in OMYK, since landscapes are transformed by natural resources appropriation and implementation of productive activities, in addition to ecological processes. Our intention with this analysis was to reveal the ecological, economic and social conditions under which the OMYK ecosystem is managed. It also provided the empirical evidence needed to interpret the MUS applied in OMYK and provide a clearer understanding of how households' productive strategies are implemented on multiple spatial scales, creating a variety of managed land use units.

Socioeconomic data was collected between April 2004 and October 2005. Data collection was done via participant observation, informal and semi-structured interviews, and a survey with semi-closed questions. All the above were conducted with the assistance of a bilingual interpreter who was not from OMYK and whose native and second languages were Yucatec Maya and Spanish, respectively.

Data collection was designed to gather both quantitative and qualitative information. Semi-structured interviews were carried out in 29 of the 30 households inside the NPA, and were focused on household activity implementation. When possible, interviews were held in householder's milpa plot. Special emphasis was placed on gathering data on milpa plots (distance to house, surface area, crops, activities implemented and labor allocation). An additional 23 semi-structured interviews were carried out to gather data on household homegardens (variety of species and uses). Informal interviews and semi-closed questions were used to evaluate their views on ecotourism activities in the area. Emphasis was placed on informant perceptions of the possibility of allocating more time to new economic activities (ecotourism) instead of traditional ones (milpa agriculture, beekeeping, etc.). Finally, a semi-structured interview was held with a tourist agency executive interested in working in OMYK.

Future LUCC scenarios were projected using socioeconomic analysis data, and the factor of possible land tenure changes in OMYK. To build these scenarios, we classified households into three groups based on a broad generalization of productive strategies: milperos; field assistants; and mixed. This generalization incorporates the fact that most traditional activities are carried out in the milpa land use unit. Thus, milperos are those involved mainly in traditional activities, field assistants are focused more on providing a service to tourists (tour guides) or scientists (research assistants), and the mixed group consists of households engaged in both milpa and field assistance activities.

2.3. Vegetation analysis

Characteristic vegetation in the OMYK NPA is medium semi-evergreen forest in different successional stages, although milpa and small patches of seasonal swamp forest and grassland are also present.

Vegetation maps were generated using various tools to validate the different described land use and vegetation succession categories in OMYK. Initially, a 1999 panchromatic IRS image (6 m ground resolution) was interpreted and digitalized (Espadas-Manrique et al., 1999; Espadas-Manrique and

González-Iturbe, 2003). The visual interpretation of land use categories and vegetation successional stages, as well as the mapping of the different trails in the NPA (~47 km) were aided by performing ground verifications and by conducting participatory mapping exercises with local inhabitants. They have a vast knowledge of plant species, forest successional stages and land-use history which could be translated into spatial references given the scale at which we were working at. By these processes were defined the following land use and vegetation successional stages categories: agricultural units (milpas; 0–1 year); four forest successional stages (2–7; 8–15; 16–29; and 30–50 years); old-growth forest (>50 years); bodies of water; and other vegetation covers (e.g., seasonal swamp forest, seasonal swamp grassland). Later, a 2003 SPOT image (5 m ground resolution) was interpreted using the same categories for land use and vegetation successional stages defined for the 1999 map. Additionally, for this image we used bands 2, 3 and 4 to digitalize, and differentiate among textures, forms and color patterns (Carta Linx, Hagan et al., 1999; IDRISI32, Eastman, 2001). For both the 1999 and 2003 maps, aerial images from reconnaissance flights (2000 and 2004) were used to correct polygon inconsistencies and generate cover vectors. Finally, the accuracy of the classification of successional stages was evaluated by sampling a total of 128 sites spread throughout the NPA between 2003 and 2006. The successional stage category was assigned correctly in 90% of the sites.

Milpas are prepared by cutting the lower canopy vegetation. Some of the cut vegetation is collected for charcoal or firewood, while the rest of the vegetation and any large trees are burned on site. Maize and other crops (e.g., squash, beans, chili, seasonal fruits, etc.) are then planted. The first successional stage after milpa abandonment was classified as 2–7 years (about 5% vegetation cover), and is characterized by thick herbaceous and shrubby vegetation, as well as re-sprouting trees. In general, younger successional stages are characterized for having higher density of stems and species that gradually decrease with fallow age, while basal area increases in older stages. The second (8–15 years) and third (16–30 years) successional stages (together about 25% cover), are largely dominated by *Bursera simaruba* (L.) Sarg., followed by *Lysiloma latisiliquum* (L.) Benth., and *Caesalpinia gaumeri* Greenm. The fourth, and predominant, successional stage in OMYK is vegetation from 30–50 years old (about 55% cover). Here, some of the important species are *L. latisiliquum*, *Metopium brownei* (Jacq.) Urban., and *Piscidia piscipula* (L.) Sarg. Vegetation older than 50 years was classified as old-growth forest (about 7.5% cover), and is distributed around the lagoons and in the north of the NPA. *Brosimum alicastrum* Sw is the most important species in this category. Other common tree species are *Malmea depressa* (Baillon) R.E. Fries, *Manilkara zapota* (L.) P. Royen and *Ficus maxima* Mill. Spider monkeys in OMYK spend most of their time in the old-growth and 30–50 years successional forests (Ramos-Fernández and Ayala-Orozco, 2003).

An important element in our study was the use of different data sources in a relatively small study area (5367 ha), which allowed us to carry out a detailed interpretation and digitalization of vegetation successional stages, rarely accomplished in LUCC studies (Read et al., 2001; Read and Lam, 2002). Since this landscape is mainly shaped by the effects of agriculture, past and present, local knowledge was crucial to developing the vegetation maps. They provided information on land use history (where and when milpas were cultivated and abandoned, fire history, hurricanes, etc.) and the area's floral composition (local plant names). Although the defined successional stages (2–7; 8–15; 16–29; and 30–50 years) have variable durations, we consider this classification more accurate than arbitrary assignment of year ranges to label succession categories. Other studies in the southern Yucatan Peninsula have demonstrated that local inhabitants' participation can help to improve dating successional stages (Lawrence et al., 2004; Pérez-Salicrup, 2004), whereas others have stressed that the integration of remote sensing and local-level research improves detail and classification accuracy (e.g., Roy Chowdhury et al., 2004).

2.4. Land use and land cover changes analysis

LUCC models are important for environmental evaluation. Factors that cause land cover change, such as land tenure policies, human activities or vegetation succession, can be analyzed in terms of their contribution to observed changes, and then employed in projecting possible future LUCC scenarios (Flamm and Turner, 1994; Goetz et al., 2003; Bray et al., 2004). We used a Markov Chain and Cellular Automata model (M-CA) to project future LUCC scenarios based on several factors identified as important causes of observed land use changes: (1) tendencies of local inhabitants to perform both traditional and new economic activities; (2) management policies; and (3) local land use patterns over the past 4 years.

M-CA models are a useful, simple method for projecting future land cover based on changes observed in the past (Soares-Filho et al., 2002; Weng, 2002; Theobald and Hobbs, 1998). Here we used a hybrid M-CA model, available as a routine in the IDRISI Kilimanjaro GIS software (Eastman, 2003), which analyzes images of observed land use and land cover from at least two different dates (in this case 1999 and 2003), producing a transition probability matrix, a transition area matrix, and a set of conditional probability images.

The transition probability matrix expresses the probability that a cell or pixel could change from one land-use category in 1999 to any other category over the projected period. This matrix is the result of cross tabulation between the images from the two dates, adjusted by proportional error and translated into a set of probability images, one for each land cover category. The transition area matrix expresses the number of cells or pixels that could change from one category of land use in 1999 to any other land use map category over the projected period. It is produced by multiplying each column in the transition probability matrix by the number of cells of the corresponding land use in the later image. The conditional probability images-set shows the probability that each land cover category could be found at each cell or pixel in a future number of specified time units. These images are calculated as projections based on the later of the two land cover images.

M-CA models combine global transition probabilities between land cover categories with local transition rules to predict future land cover. This method uses an iterative process that establishes the number of time steps used in the simulation. For OMYK, we determined the number of years to project into the future based on the difference between 1999 and 2003 (4 years), and then used the same time interval (4 years) in projecting future land cover (first to 2007 and then to 2011). This model included the assumption that changes were small during the analyzed time periods and that the probability of change for each land cover category was constant through time. In other words, we used the transition probability matrix created from observed change between 1999 and 2003, as well as the transition probability matrices from 1999 and each scenario's map, to produce maps of predicted land cover in 2011. Our choice of the periods to analyze and to project are based on the crucial changes occurring in socioeconomic conditions within the NPA, as well as on the land tenure and NPA management policies (see Section 3).

In the first projection scenario (Scenario 1), land use cover maps for 1999 and 2003 were projected to 2007 and then to 2011 under the assumption that the change observed between 1999 and 2003 would occur at the same pace from 2003 to 2007. Two additional scenarios (Scenarios 2 and 3) were run in which the probabilities of observed change were altered according to socioeconomic analysis results and current land tenure policy in the NPA. In Scenario 2 we decreased by 5% the future probability that all succession categories would change to a new milpa. This hypothetical reduction was based on the results of the socioeconomic analyses, which suggested a tendency for households to devote increasingly more time to ecotourism and less to milpa and traditional activities, as well as a tendency of local inhabitants to emigrate and abandon their milpas (see Section 3). In Scenario 3 we eliminated the possibility that any successional stage would change to a new milpa. This hypothetical disappearance of milpas was based on the possibility that land tenure and/or NPA policies would result in the prohibition of new milpas being made within the NPA (see Section 3). In this scenario, all milpa polygons existing in 2003 were classified in the first successional stage after abandonment and no new milpa polygons were allowed. In addition, all three scenarios specify that changes cannot occur in human settlements, roads, or lagoons at any time in the projected period.

Land covers were organized into discrete categories using ordinal scales to establish changes predicted to occur in those areas. Thus, for Scenario 1 we projected to 2007 and 2011 using the map from 2003 as a simulation starting point, while for Scenarios 2 and 3 we used modified versions of the 2003 map as starting points to project to 2007 and 2011.

Through a Multi-criteria evaluation (procedure in combination with CA-Markov) a suitability map for each land cover category, establishing the inherent suitability of each cell or pixel for each land cover category, was produced. The number of iterations was established given the number of years to be projected. To assign a lesser weight to the suitability of the most distant pixels, we used a default 5×5 kernel filter which considered the nearest suitability areas. Within each time increment, the conflict between land cover category and change to another category was resolved with a multi-objective land allocation (MOLA) procedure. This allocates relative suitability weights and the area corresponding to each cell or pixel. At the end of each iteration, we overlaid a MOLA operation to produce a new land cover map.

3. Results

3.1. Socioeconomic data

The MUS implemented in OMYK has substantially shaped the area as we see it today. Current land cover diversity is partially the result of the interplay between natural regenerative forces (forest regeneration) and human forces that transform forest ecosystems, as shown in the different land use units, successional stages and their interrelationship (Fig. 2). The milpa land use unit forms the core of the productive strategy and it has determined the different successional vegetation stages in OMYK. An agreement among the communities not to do productive or extractive activities in old-growth forest has resulted in an unbroken scale of successional stages between the milpa land use unit and the old-growth forest land use unit.

In its most diverse version, understood as management of all land use units and implementation of all activities, the households in OMYK manage a total of five land use units. Following this strategy, households consisting of an average of five members implement a total of 13 activities (handcraft manufacturing is normally a domestic activity and was therefore not included in the five land use units).

(a) Milpa: household members cultivate as many as 16 different plant species in an average plot of approximately 3 ha; they may also do beekeeping, produce vegetal charcoal, gather firewood and hunt game in the same plot.
(b) Homegardens: agroforestry systems located around houses; household members recognized the use of 131 species, mainly domestic animals, fruit trees, and other plant species that have food, medicinal, religious or ornamental applications.
(c) Aquatic systems: fishing and ecotourism.
(d) Secondary forest: gathering of medicinal plants, firewood, and wood for home construction; hunting wild game; and sheep herding.
(e) Old-growth forest: ecotourism and scientific research.

Most households (90%) implemented a strategy based on use and management of three to four land use units (Fig. 3). Secondary forest and homegardens were used by all households, followed by milpa, which was used by nearly all the households. This indicates that inhabitants continue following a rationale of partial control over food security, and confirms that new activities have not yet entirely substituted traditional ones. Only 3% of households implemented a strategy based on use of two land use units (secondary forests and homegardens), and 7% used management of all the land use units.

Milpa agriculture covered 155 ha (3% of the NPA), an area that remained constant (albeit in different locations) over the 4 years from 1999 to 2003. Approximately 80 ha of milpa are

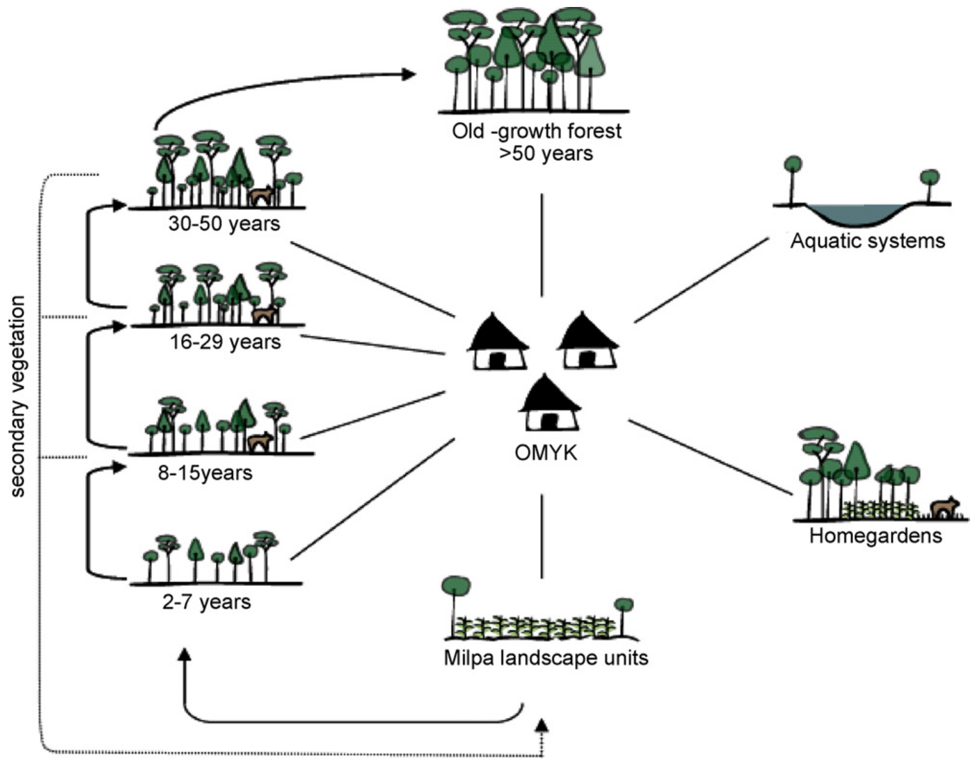

Fig. 2. Natural resource management scheme in OMYK. Arrows indicate transitions between land use units caused by either secondary succession (solid lines) or human activities (dotted lines). The activities implemented in each land use unit are: (1) Milpa: agriculture, charcoal production, beekeeping, hunting and firewood gathering; (2) secondary vegetation: hunting, firewood gathering, wood for house construction, medicinal plants, sheep ranching; (3) old-growth forest: ecotourism and scientific research; (4) aquatic systems: fishing and ecotourism; and (5) homegardens: agroforestry.

cultivated by the inhabitants of the two villages situated inside OMYK, Punta Laguna and Yodzonot, and the remaining 75 ha by inhabitants of villages just outside the NPA boundary. Milpa plots in OMYK were an average of 2 km from households.

3.2. Future scenario projections

Based on land use unit management and the main household activities, we determined the three most common productive

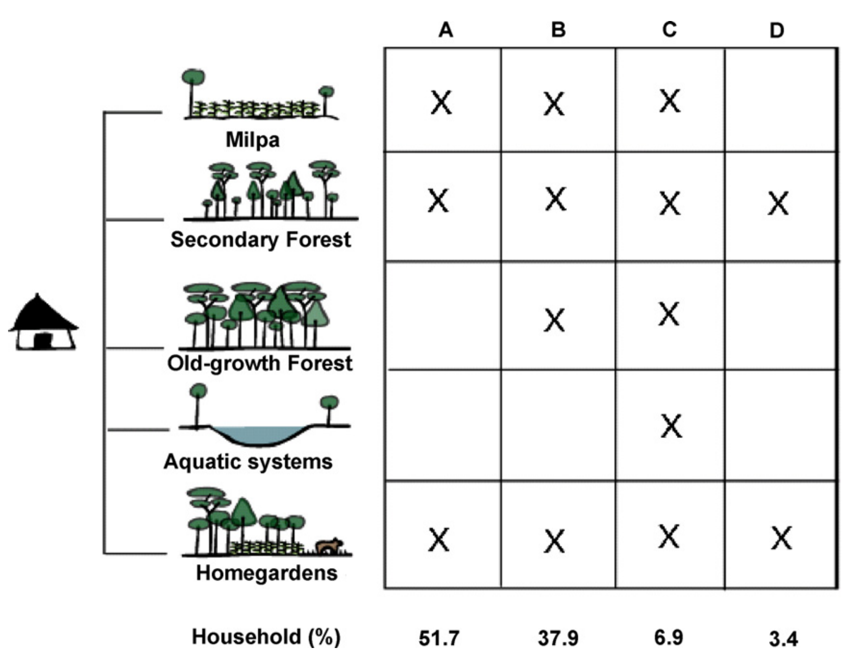

Fig. 3. Land-use patterns of households in OMYK. Columns A–D indicate the four combinations of land use units managed by households. The percentage of households engaged in each land-use pattern is indicated below each column. For example, 51.7% of households engage in combination A, i.e., management of milpa, secondary forest and homegardens land use units.

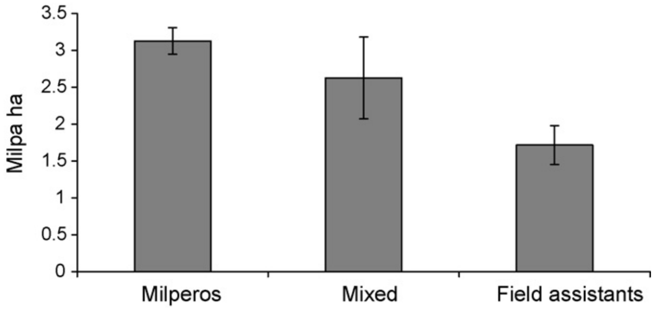

Fig. 4. Average milpa plot size (ha) per household in each productive strategy category (Milpero, Mixed and Field assistant). Error bars show standard errors. One-way ANOVA $F = 8.11$, $P < 0.01$. Tukey HSD test Milpa vs. Field assistant, $P < 0.01$.

strategies in OMYK (see Appendix A). Since all households managed homegardens and second-growth forests, despite differences in their other productive activities, these two land use units were not explicitly used to define the strategies:

1. *Milperos*: households dedicated primarily to management of milpa land use units. All the Yodzonot households (100%) and 43% of those in Punta Laguna engage in this strategy.
2. *Milperos/field assistants* (*mixed*): households with milpa as the main activity (possibly without some of the activities done in the milpa plot), that also work as field assistants (either as tourist guides or research assistants). This strategy is employed by 24% of the households in Punta Laguna and none (0%) in Yodzonot.
3. *Field assistants*: households for which the main economic activity is work as tourist guides or research assistants, with minimal work in a small milpa or paying someone to cultivate their milpa. Seven households (33%) use this strategy in Punta Laguna and none (0%) in Yodzonot.

Average milpa surface cultivated by household decreases as the primary household activity focuses less on milpa. Therefore, the highest average milpa surface was used by households in the Milpero strategy, followed by those in the Mixed strategy and finally those in the Field assistant strategy (Fig. 4).

Three scenarios of possible future productive activity dynamics in the OMYK NPA were generated by incorporating the household strategy results, the possible parceling of ejido lands and the presence of tourist agencies in neighboring communities.

Scenario 1. Current conditions, in which milpa agriculture is implemented at the same rate as during 1999–2003. Main assumptions:

(a) Milpa agriculture will remain the principal activity of most households.
(b) Tourist use of OMYK will remain relatively low and will be independent of commercial tour operators.

Scenario 2. Milpa agriculture will decrease in response to increased demand for field assistants. A LUCC rate of <5% per 4-year period is assumed. Main assumptions:

(a) Tourism in the NPA will increase mainly because of agreements between local inhabitants and one or more tourist agencies. Tourists arriving independently can enter the NPA but will not have access to the infrastructure built and managed for exclusive use of the tourist agencies (usually zip-lines, canoes and palapas). These assumptions are based on the experiences of nearby communities working with tourist agencies.
(b) Tourist agencies will hire a significant number of local people, men and women. Most will be hired part-time, as is the case in nearby communities.
(c) Milpa agriculture in the NPA will gradually decrease as ecotourism employment opportunities increase. Based on the informal interviews and semi-closed questions, the rate of decrease in milpa activity was assumed to be the inverse of the rate at which households change strategies. Total area under milpa cultivation will decrease 5% every 4-year period, equal to 6 households making the transition from the Milpero strategy, diversifying activities, and entering the Mixed strategy (Milpero/Field assistant). This will translate into a reduction of milpa plot area from 3.1 to 2.6 ha per household. Some households in the Mixed strategy will enter the Field assistant strategy, abandoning most traditional activities. This will be equivalent to a reduction in milpa plot area from 2.6 to 1.7 ha per household. Households already in the Field assistant strategy will remain in the same category (see Appendix B).

Scenario 3. Milpa agriculture in the NPA disappears due to parceling of ejido lands. This scenario implies the immediate disappearance of this activity. As mentioned previously, if the ejidatarios decide to parcel their communal land, none of the lands inside the NPA would be parceled, and would immediately become federal territory. As a result, all parcels, and therefore any milpa plots, will be outside the NPA.

3.3. Vegetation maps for 1999–2003 period

The most extensive vegetation in the protected area is the 30–50 year successional stage, which occupied over 50% of the NPA area (Fig. 5). Local inhabitants reported that most of the old-growth forest in the area was damaged and drastically reduced by forest fires after Hurricane Beulah in 1967. Old-growth forest (almost 8% of total area) remains one of the least represented vegetation categories in OMYK, and is limited to areas around the lagoons and one fragment in the north of the NPA. The remaining non-milpa cover is second-growth vegetation (2–7, 8–15 and 16–29 and 30–50 years) that reflects, to some extent, anthropogenic perturbations, mainly milpa agriculture.

Analysis of land cover changes between 1999 and 2003 demonstrated that the area covered by milpa plots remained constant (Table 1). Of the 2003 milpa cover: about 27% was in existing plots (milpa cultivation is normally done two consecutive years in one plot); 47% was in the 30–50 year stage; 14% in 2–7 year stage; 26% in combination between the 8–15 and 16–29 year stages; and no plots were opened in old-growth

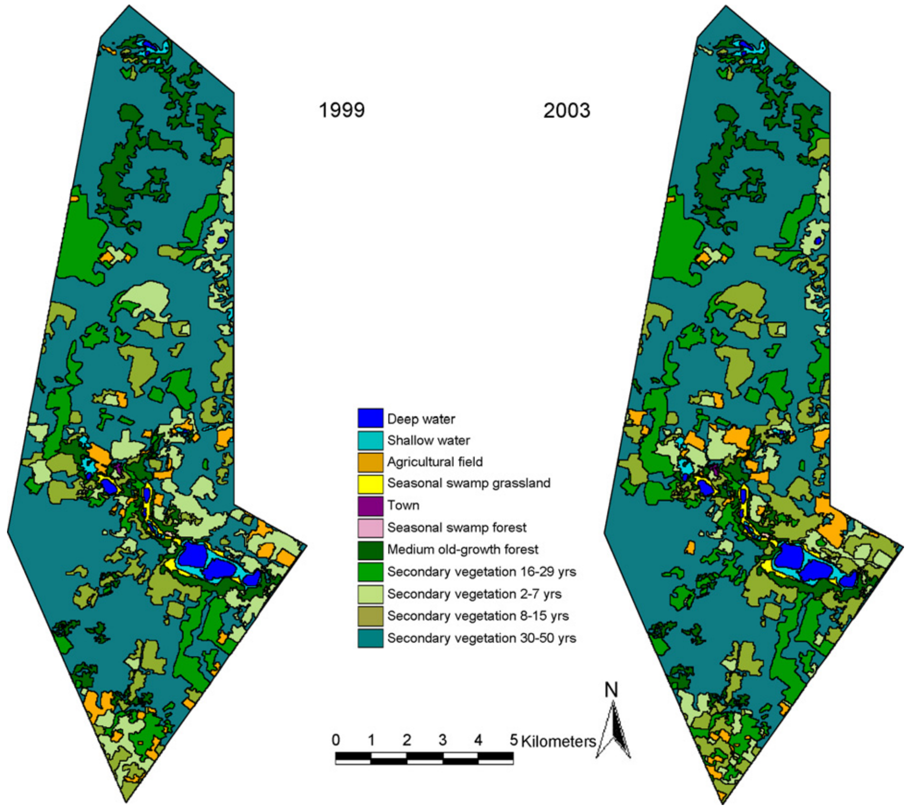

Fig. 5. Vegetation maps of OMYK from 1999 and 2003.

forest. The 2–7 year successional stage is not optimum for starting a new milpa due to its relatively low nutrient availability, so the high percentage of milpa (14%) in this category may be in response to: (1) settlement proximity; (2) ease of access (most plots are near the main paved road or existing trails, such as the Punta Laguna-Yodzonot trail); or (3) easier clearing of vegetation (clearing a used milpa is easier than opening a new one, especially when agriculture may no longer be the main activity).

Significant changes in the vegetation successional stage cover occurred in 1999–2003, particularly in the early successional stages (Table 1). The 2–7 year category decreased 46%, mainly due to approximately 355 ha that entered the 8–15 year category. The latter increased 34%, even though about 168 ha of this stage entered the 16–29 year category in 2003. The 30–50 year category changed very little.

3.4. Future land cover projections

Using the changes in vegetation categories between 1999 and 2003, we constructed Markovian transition probability matrices (Table 2). These indicated that vegetation categories from the 16–29 year stage onward were the most stable classes, with probabilities of remaining in the same category of close to 1.0, while earlier stages were the most dynamic, with probabilities between 0.3 and 0.5.

These probabilities were used to project land cover changes, assuming (in Scenario 1) that the probability of change between categories remains constant. The 2003 vegetation covers (Table 1) were thus modified according to the probabilities in Table 2 to produce new vegetation maps (Markovian probabilities). The exact location of the changes depends on the cellular automata algorithm (included in the model), such that

Table 1
Cross-tabulation of land cover change between 1999 and 2003

	Milpa	2–7 years	8–15 years	16–29 years	30–50 years	Old-growth forest	Total for 2003
Milpa	42.4	21.1	15.3	2.9	72.1	0.9	154.6
2–7 years	111.4	166.8	3.4	1.9	9.5	0.0	292.9
8–15 years	0.1	354.9	315.0	0.2	0.1	0.2	670.5
16–29 years	0.1	0.3	167.9	543.6	0.1	0.0	712.0
30–50 years	0.1	0.5	0.1	2.1	2 938.8	0.0	2 941.8
Old-growth forest	0.4	0.0	0.0	0.0	0.1	408.2	408.7
Total for 1999	154.7	543.5	501.8	550.7	3020.7	409.3	

Columns represent the number of ha in 1999 that changed to a different vegetation type (rows) in 2003.

Table 2
Markovian probability matrices of change between vegetation categories from 1999 (column) to 2003 (row)

	Milpa	2–7 years	8–15 years	16–29 years	30–50 years	Old-growth forest
Scenario 1						
Milpa	0.2745	0.0388	0.0305	0.0053	0.0239	0.0021
2–7 years	0.7255	0.3068	0.0069	0.0034	0.0031	0.0000
8–15 years	0.0000	0.6544	0.6278	0.0000	0.0000	0.0000
16–29 years	0.0000	0.0000	0.3348	0.9874	0.0000	0.0000
30–50 years	0.0000	0.0000	0.0000	0.0039	0.9730	0.0000
Old-growth forest	0.0000	0.0000	0.0000	0.0000	0.0000	0.9979
Scenario 2						
Milpa	0.2654	0.0385	0.0298	0.0053	0.0223	0.0021
2–7 years	0.7346	0.3071	0.0076	0.0034	0.0047	0.0000
8–15 years	0.0000	0.6544	0.6278	0.0000	0.0000	0.0000
16–29 years	0.0000	0.0000	0.3348	0.9874	0.0000	0.0000
30–50 years	0.0000	0.0000	0.0000	0.0039	0.9730	0.0000
Old-growth forest	0.0000	0.0000	0.0000	0.0000	0.0000	0.9979
Scenario 3						
Milpa	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2–7 years	1.0000	0.3456	0.0374	0.0087	0.0270	0.0021
8–15 years	0.0000	0.6544	0.6278	0.0000	0.0000	0.0000
16–29 years	0.0000	0.0000	0.3348	0.9874	0.0000	0.0000
30–50 years	0.0000	0.0000	0.0000	0.0039	0.9730	0.0000
Old-growth forest	0.0000	0.0000	0.0000	0.0000	0.0000	0.9979

the probability of change in any given cell depends on previously calculated probabilities and on changes in neighboring cells during the observed period (in this case, 1999–2003). Using this model, vegetation covers were generated for each of the three scenarios (Tables 3–5).

For the three Scenarios, we projected vegetation cover in OMYK for 2011, showing the proportion of surface covered by different vegetation types in three images: one for 1999, another for 2003, and finally the projected year, 2011. Partially because of the periods utilized, old-growth forest cover showed no change in the projection, whereas the 30–50 year stage cover showed a gradual, minor decrease. In Scenario 1, earlier successional stages showed the most significant changes: 8–15 year cover declined from 671 ha in 2003 to 505 ha in 2011; and 16–29 year cover increased from 712 ha in 2003 to 1154 ha in 2011.

Milpa cover in this projection (Scenario 1) decreased from 155 ha in 2003 to 72 ha in 2011. This responds to the cumulative probability that the change of any vegetation type into milpa is less probable than the cumulative probability that milpas will change into other categories and therefore milpa cover will gradually decrease (Markovian matrix, Table 2). The appearance of milpas, however, is subject to decisions made by NPA inhabitants, such that the probabilities shown in Table 2 are only an approximation of what drives their appearance.

Given this, we decided to project LUCC in OMYK under two additional scenarios: Scenario 2, assuming a 5% decrease in new milpas between 1999 and 2003 due to households transitioning

Table 3
Scenario 1 (assuming no changes in milpa cover): cross-tabulation of land cover change between 2003 and 2007 and 2007–2011

	Milpa	2–7 years	8–15 years	16–29 years	30–50 years	Old-growth forest
2003–2007						
Milpa	48.7	3.1	11.3	0.0	25.7	0.3
2–7 years	106.0	105.3	0.0	0.1	0.1	0.0
8–15 years	0.0	185.2	436.5	0.0	0.0	0.0
16–29 years	0.0	0.0	223.0	711.7	0.0	0.0
30–50 years	0.0	0.0	0.0	0.0	2915.4	0.0
Old-growth forest	0.0	0.0	0.0	0.0	0.0	408.3
2007–2011						
Milpa	35.3	0.0	6.6	2.9	26.9	0.2
2–7 years	49.8	108.1	2.1	0.2	5.2	1.6
8–15 years	3.9	103.4	390.2	0.1	5.9	1.5
16–29 years	0.0	0.0	222.8	931.5	0.0	0.0
30–50 years	0.0	0.0	0.0	0.0	2877.5	0.0
Old-growth forest	0.0	0.0	0.0	0.0	0.0	405.0

Columns represent the number of has in 1 year (2003 and 2007) that changed to a different vegetation type (rows) in other year (2007 and 2011).

Table 4
Scenario 2 (assuming a 5% decrease in new milpa cover): cross-tabulation of land cover change between 2003 and 2007 and 2007–2011

	Milpa	2–7 years	8–15 years	16–29 years	30–50 years	Old-growth forest
2003–2007						
Milpa	45.4	2.8	10.8	0.0	21.2	0.3
2–7 years	102.7	108.3	0.0	0.0	3.2	0.0
8–15 years	0.0	189.2	437.0	0.0	0.0	0.0
16–29 years	0.0	0.0	222.9	711.8	0.0	0.0
30–50 years	0.0	0.0	0.0	0.0	2916.8	0.0
Old-growth forest	0.0	0.0	0.0	0.0	0.0	408.3
2007–2011						
Milpa	30.2	0.0	5.0	3.0	24.5	0.1
2–7 years	46.3	107.8	1.8	0.2	5.2	1.5
8–15 years	3.9	106.4	396.0	0.1	5.5	1.7
16–29 years	0.0	0.0	223.3	931.4	0.0	0.0
30–50 years	0.0	0.0	0.0	0.0	2881.6	0.0
Old-growth forest	0.0	0.0	0.0	0.0	0.0	405.0

Columns represent the number of has in 1 year (2003 and 2007) that changed to a different vegetation type (rows) in other year (2007 and 2011).

into alternative activities such as ecotourism (see Section 3.2; Markovian probabilities in Table 2); and Scenario 3, assuming the total disappearance of milpas (see Section 3.2; Markovian probabilities in Table 2) (Tables 4 and 5).

No notable differences occurred in the area covered by the different categories when comparing Scenario 1 and Scenario 2. The area covered by different vegetation types in OMYK under Scenario 2 was practically indistinguishable from those under Scenario 1 (Table 6).

The probabilities of change between categories under Scenario 3 were quite different from those of Scenarios 1 and 2. Specifically, all 1999 milpa cover changes to the 2–7 year successional stage, and later successional stages show similar probabilities of changing to an older stage. If disturbance is limited to milpa agriculture, then Scenario 3 would imply habitat regeneration (i.e., fewer successional stages). Milpa is clearly not the sole disturbance, and other disturbances (e.g., hurricanes and fires) can also produce successional stages.

Despite the hypothetical disappearance of milpa cover in 2003 under Scenario 3, most vegetation covers had similar patterns to those in Scenarios 1 and 2. Only the 8–15 year successional stage showed a different pattern compared to the previous scenarios: it increases from 502 ha in 1999 to 689 ha in 2011 (Table 6). The large increase in the 2–7 year successional stage produced by disappearance of milpa cover eventually becomes indistinguishable from the milpa cover pattern in the other two scenarios.

4. Discussion

We used a M-CA model for projecting LUCC in the near future for the OMYK NPA by developing three different land use scenarios for the period 1999–2011. Model results showed no major differences in land cover in the three scenarios, even when all milpa agriculture was eliminated (Scenario 3) (Cramer's V coefficient > 0.99 and Kappa index of agreement > 0.98). This is mainly due to the way milpa agriculture is done and the small

Table 5
Scenario 3 (assuming milpa cover disappears after 1999): cross-tabulation of land cover change between 2003 and 2007 and 2007–2011

	Milpa	2–7 years	8–15 years	16–29 years	30–50 years	Old-growth forest
2003–2007						
Milpa	0.0	0.0	0.0	0.0	0.0	0.0
2–7 years	0.0	181.0	0.6	0.0	73.9	0.0
8–15 years	0.0	267.3	447.2	0.0	0.0	0.0
16–29 years	0.0	0.0	223.0	711.8	0.0	0.0
30–50 years	0.0	0.0	0.0	0.0	2867.4	0.0
Old-growth forest	0.0	0.0	0.0	0.0	0.0	408.5
2007–2011						
Milpa	0.0	0.0	0.0	0.0	0.0	0.0
2–7 years	0.0	74.2	0.5	0.9	67.3	0.0
8–15 years	0.0	181.1	491.0	4.5	10.4	1.5
16–29 years	0.0	0.1	223.0	929.4	0.0	0.0
30–50 years	0.0	0.0	0.0	0.0	2789.7	0.0
Old-growth forest	0.0	0.0	0.0	0.0	0.0	407.0

Columns represent the number of has in 1 year (2003 and 2007) that changed to a different vegetation type (rows) in other year (2007 and 2011).

Table 6
Observed hectares of land cover in 1999 and 2003, and projected land cover for 2011, for the three scenarios

	Milpa	2–7 years	8–15 years	16–29 years	30–50 years	Old-growth forest
Scenario 1						
1999	154.8	543.5	501.8	550.7	3020.7	409.3
2003	154.6	292.9	670.5	712.1	2941.8	408.8
2011	71.9	167.0	505.0	1154.3	2877.5	405.0
Scenario 2						
1999	154.8	543.5	501.8	550.7	3020.7	409.3
2003*	148.0	299.5	669.9	712.1	2941.6	409.5
2011	62.9	162.7	513.7	1154.7	2881.6	405.0
Scenario 3						
1999	154.8	543.5	501.8	550.7	3020.7	409.3
2003*	0.0	447.6	669.9	712.1	2941.2	409.5
2011	0.0	142.8	688.6	1152.5	2789.7	407.0

Scenario 1: assuming no changes in milpa cover; Scenario 2: assuming a 5% decrease in new milpa cover; Scenario 3: assuming milpa cover disappears after 1999. Areas in 2003 were modified to produce scenarios 2 and 3.

* Modified version of the 2003 map as starting point to project to 2007 and 2011.

overall proportion of NPA surface it accounts for (approximately 3%).

Because the projected period is relatively short (8 years), the most perceptible differences between scenarios were in early vegetation successional stages cover. In longer projections differences would begin to appear in older successional stages as more area in early successional stages would change into latter stages. This partially explains why the 30–50 year successional stage, the most abundant vegetation type, and the old-growth forest stage (>50 years) exhibited no major changes under any of the three scenarios. But, if in fact most of the old-growth forest in the area was damaged and deforested 40 years ago because of the fires after Hurricane Beulah, we can expect that a significant area will reach 50 years of succession around 2020. This is salient for two reasons. First, this vegetation cover supposedly harbors the highest biodiversity – although traditional milpa agriculture and fallow milpa also contribute to biodiversity (Barrera-Bassols and Toledo, 2005; Faust, 2001; Terán and Rasmussen, 1994). Umbrella species like spider monkeys need large areas and high tree diversity since they spend 80–90% of their waking hours feeding on the fruit of 50–150 tree species (Ramos-Fernández and Ayala-Orozco, 2003). Although they are not restricted to old-growth forest, they spend a larger proportion of their time in this vegetation type than in any other (Ramos-Fernández et al., 2004).

Second, in recent years Mexican natural preservation policy has begun to explore alternative approaches by incorporating community-owned forests into NPAs promoting maintenance of undisturbed forest (CONANP, 2006). Undisturbed forest is the most promoted vegetation type in these preservation policies, and consequently the tendency has been to encourage local inhabitants to abandon productive activities that modify old-growth forest cover (e.g., milpa agriculture) and switch to "environmentally friendly" activities (e.g., ecotourism). Indeed, southern Mexico is currently experiencing a growing demand for natural "adventure" sites that is supported and promoted by government environmental protection agencies with the goal of decreasing land-use pressure and creating alternative income sources. This official preference is apparently based on the assumption that normal productive and extractive activities are harmful to local environments and should be replaced by other, more "sustainable" activities. This interpretation focuses on apparently destructive short-term changes (such as the felling and burning of forest to open milpa plots and hunting for subsistence), and assumes that tourist activities are non-destructive. Here, we demonstrate that, at least in terms of the medium-term land cover change caused by milpa agriculture, this activity can be considered to be sustainable and therefore not harmful to the local environment. In addition, the assumption that tourist activities are non-destructive has been questioned by Gössling et al. (2002), who have called for research on global ecotourism's "ecological footprint". Given the aforementioned possibility that old-growth forest will increase in the long term, as well as the current agreement among local inhabitants not to make milpas in this vegetation type, we believe that the prospects for the successful conservation of biodiversity in the protected area are quite high.

A typical recommendation under present conservation policy would be that local inhabitants abandon traditional productive activities (Scenarios 1 and 2) and focus on ecotourism (Scenario 3), both to preserve the NPA's biodiversity (more old-growth forest = biodiversity) and because milpa agriculture is considered an inefficient productive system. Our results, however, show that under Scenario 3 the projected land cover is basically indistinguishable from the land covers projected under Scenarios 1 or 2. At least during the 12-year period analyzed (1999–2011) milpa agriculture as developed by OMYK inhabitants did not seem to have significant negative impacts on vegetation cover. This is partially due to the absence of strong demographic pressures in OMYK and because increasing population does not necessarily translate into more milpa plots given the presence of alternative economic activities. In other words, milpa agriculture as practiced at OMYK in the very recent past and projected into the future under the conditions defined in this study does not seem to have substantially compromised NPA biodiversity. Traditional Yucatec Maya agriculture has been suggested as a useful strategy for increasing biodiversity because it produces a mosaic of different successional stages (Barrera-Bassols and Toledo, 2005; Faust, 2001). Public policy makers should take this into account, acknowledge that diversification of activities in a land use unit mosaic can play a role in NPAs, and not focus exclusively on promoting abandonment of traditional productive activities.

How incorporation of new activities like ecotourism into the Yucatec Maya MUS in OMYK will affect their interactions with local flora, fauna, and ecosystems remains to be seen. On the one hand, 20th Century ethnographies (e.g., Redfield and Villa Rojas, 1962, Terán and Rasmussen, 1994) reported traditional Mayan land uses as being apparently sustainable, both in terms of the natural environment (e.g., maintenance of soil fertility) and their social environment (e.g., labor-time allocation). On the other hand, tourism in OMYK has definitely brought in additional monetary income, for purchasing goods or making investments, and has reversed earlier emigration patterns. Most household members have been able to complement their monetary income without having to leave their community in search of temporary jobs, which has a positive impact on family well-being. These new activities, however, often generate relatively significant amounts of money and are less labor intensive (except in the case of full-time research assistants), which represents a drastic change in the MUS. Changes include regular wages for research assistants and frequent payments for tour guides. More regular monetary income has led some inhabitants to abandon or modify some traditional activities, mainly milpa agriculture and activities developed in this land use unit. For instance, the greater importance given the income from alternative economic activities may cause some households to reduce the size of their milpas and/or use younger successional stages with poorer soils. Interview data suggested that households with members working as field assistants tended to choose new milpa plots based on ease of access and the presence of younger, more easily cleared vegetation. These changes may have several consequences, including: abandonment of traditional activities; loss of local knowledge; a consequent dislocation from the environment; decreased food security; and loss of risk-reduction mechanisms incorporated by traditional practices.

If Scenario 3 becomes the future of OMYK, it will have a number of repercussions. Yodzonot, for instance, is in the middle of OMYK, so if the NPA becomes federal property and milpa agriculture is no longer permitted within it, inhabitants will have to locate their milpa plots 4 km from the village; probably an untenable situation. Given that the ejido system allows members to move to other communities, the most likely outcome will be that the eight families living in Yodzonot would move to Punta Laguna since many of the households in the two settlements are related through kinship and/or marriage. This sudden expansion of Punta Laguna and abandonment of Yodzonot would pose serious social and ecological challenges. The complete ban on agricultural practices within the NPA would lead to intensification of milpa agriculture just across the road, which is unprotected land, as well as outside the southern boundary where milpa plots are frequently cultivated by communities outside the NPA (Fig. 5). Also, it is very likely that peasants will continue to have their milpas, in part because of the Direct Rural Support Program (PROCAMPO), a cash transfer program that started with North American Free Trade Agreement (NAFTA) for compensating peasants for the negative price effects of trade liberalization of basic crops. As some analyses have pointed out (de Janvry et al., 1997; Sadoulet et al., 2001), PROCAMPO has turned out to be a payment for welfare support, rather than a program for facing NAFTA's challenges.

Scenario 3 would also cause effects not shown in the model but that would significantly impact the area's biodiversity. For instance, rising tourist traffic in the area and continuous presence of visitors in the forest could create more trails in the old-growth forest, impacting vegetation through soil compaction and fragmentation, and consequent prevention of vegetation regeneration. More tourists in the old-growth forest, primary spider monkey habitat, would also produce more noise, possibly distressing the monkeys, reducing their feeding time and affecting essential social behaviors. Tours in the forest could affect the breeding areas, feeding habits and other activities of other animal species, including hunting target species, as well as protected species like monkeys and tropical birds. Increased human traffic would also affect local inhabitants' relatively easy access to target species such as deer, ocellated turkeys, and wild pigs, that form a substantial portion of the animal protein consumed in rural Yucatec Maya communities.

Although the scenarios project only slight changes in vegetation cover during the analyzed period, traditional activities and management institutions could experience larger changes. Parceling ejido lands would increase ecological and social pressure on common property resource management institutions that have existed for decades. The situation in and around OMYK is just a small example of the land tenure metamorphosis currently occurring in Mexico. This country is unique among the 11 most forested countries in the world in that approximately 80% of its forest is owned by local communities and managed by local institutions. The land tenure reforms of 1992, however, have made it possible for community-owned land to be allocated to private holders. Some government agencies and environmental organizations have taken this opportunity to encourage the purchase of large tracts of land to maintain and/or promote preservation. This approach is at odds with the federal PROCAMPO program, which may be responsible for promoting the opening of some milpa plots in forest with less than 20 years regeneration. Indeed, local informants have stated that many of the plots on the Peninsula that were cleared and planted with the intention of receiving PROCAMPO funds were never weeded or harvested. Government subsidies for cattle and sheep ranching also continue.

It is interesting to compare our results with those of other LUCC analyses and models performed in the Yucatan peninsula. For instance, in the area surrounding the Calakmul Biosphere Reserve, Vance and Geoghegan (2002) and Roy Chowdhury (2006) found that the deforestation probability of a given household's plot can be partially predicted by internal household characteristics such as ethnicity, family size, and income level from different activities. Also, external factors such as access to governmental subsidies (e.g., PROCAMPO) and other institutional subsidies, as well as access to external markets to sell their goods, are predictors of deforestation. While in our study we are interested in the internal and external factors that determine milpa production, our approach is somewhat different to the above mentioned studies. Our socioeconomic analysis showed that as households included ecotourism as a new activity, their own tendency to make a milpa decreased. This led us to develop our predictive model, not as a way of explaining actual LUCC patterns but in order to explore how these patterns would appear if the actual tendencies (or a set of new ones) were to continue into the near future.

Bray et al.'s (2004) study in the "Maya Zone" in the southeastern Yucatan peninsula, determined the physical and institutional factors that maintain low rates of deforestation in different ejidos that manage their resources in a very similar way to the one we study in OMYK. This study showed that one of the factors that foster the creation of "sustainable landscapes" is the existence of rules and decision-making procedures that allow ejidos to incorporate new activities (such as sustainable timber extraction) while maintaining their traditional activities (such as milpa production). Even though the spatial scale and methods of analysis between this study and ours are different, our main conclusions are quite similar, underscoring the role of local institutions for the achievement of sustainability both within and outside protected areas.

The OMYK case highlights the complexity of contemporary Yucatec Maya natural resource management strategies. People living and using the OMYK NPA still implement a diversified forest management system that maintains many of their traditional activities and techniques, while constantly adapting to social, economic, and ecological changes. These adaptations have often been achieved without compromising the primary objective of maximizing the number of available livelihood options in the present and future. Incorporation of some alternative economic activities, like ecotourism, and their intensification through the support of government programs, threatens some of these options and highlights the importance of frequent evaluations to determine these activities' ecological and social impacts.

The models used here to predict future LUCC scenarios based on ecological and socioeconomic data, can be a powerful tool with which to evaluate community conservation efforts and the sustainability of traditional resource management in other parts of the global south. As Bray et al. (2004) argued, landscapes that are heavily used by humans can still retain many crucial ecosystem processes and biodiversity, and therefore the 'narratives' behind LUCC drivers need to be evaluated to provide the proper information for the development of effective preservation policies.

What the best strategy is for achieving biodiversity preservation in NPAs is still open to debate, but successful preservation clearly cannot be attained without addressing the livelihoods of the people living in NPAs. Our research suggests that community-based conservation, in which local inhabitants protect part of their holdings while continuing most or all of their traditional activities within a protected area, is a feasible approach.

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Appendix A

	Community	Strategy	Did milpa last year	Milpa (ha)	Distance to milpa (km)	Years working in ecotou-rism activities	Willing-ness to reduce milpa and increase ecotourism activities	Willing-ness to abandon milpa
Milpero				3.1	2.1			
Household 1	Punta Laguna	m-bk-c-et	Yes	4	3	1	Yes	No
Household 2	Punta Laguna	m-c-bk-et	Yes	3	3	1	Yes	No
Household 3	Punta Laguna	m-c-bk-et	Yes	2	3	1	Yes	No
Household 4	Punta Laguna	m	Yes	4	2	1	Yes	No
Household 5	Punta Laguna	m-bk-c-et	Yes	3	2	1	Yes	No
Household 7	Punta Laguna	m-bk-c-et	Yes	4	1.5	1	Yes	No
Household 11	Punta Laguna	m	Yes	3	3	1	Yes	No
Household 12	Punta Laguna	ND	ND	ND	ND	ND	ND	ND
Household 13	Punta Laguna	m	Yes	2	1	1	Yes	No
Household 23	Yodzonot	m-c	Yes	2	2	0	Yes	No
Household 24	Yodzonot	m	Yes	4	1	0	Yes	No
Household 25	Yodzonot	m	Yes	3	1.5	0	Yes	No
Household 26	Yodzonot	m	Yes	3	ND	0	Yes	No
Household 27	Yodzonot	m	Yes	3	ND	0	Yes	No
Household 28	Yodzonot	m	Yes	3	ND	0	Yes	No
Household 29	Yodzonot	m-bk-c-et	Yes	4	ND	0	Yes	No
Household 30	Yodzonot	m	Yes	3	ND	0	Yes	No

Appendix A (*Continued*)

	Community	Strategy	Did milpa last year	Milpa (ha)	Distance to milpa (km)	Years working in ecotou-rism activities	Willing-ness to reduce milpa and increase ecotourism activities	Willing-ness to abandon milpa
Mixed (Milpero + Field assistant)			2.6	2.5				
Household 8	Punta Laguna	m-bk-et-c	yes	4	3	5	Yes	Yes
Household 9	Punta Laguna	m-et	yes	2	3	7	Yes	Yes
Household 10	Punta Laguna	m-et	yes	3	1	3	Yes	Yes
Household 14	Punta Laguna	m-et	ND	ND	ND	ND	ND	ND
Household 21	Punta Laguna	m-et	Yes	1.5	3	20	Yes	No
Field assistant			1.7	2.0				
Household 15	Punta Laguna	et-m-bk	No	2	1	3	Yes	No
Household 16	Punta Laguna	ra-et-m	No	1.5	1	ND	ND	ND
Household 17	Punta Laguna	ra-et-m	No	1.5	1	5	Yes	No
Household 18	Punta Laguna	ra-et-m	No	1	2	10	Yes	No
Household 19	Punta Laguna	ra-et-m	No	1	3	11	Yes	No
Household 20	Punta Laguna	et-bk-m	Yes	2	3	9	Yes	Yes
Household 22	Punta Laguna	et-m	No	3	3	9	Yes	Yes

m = milpa, bk = beekeeping, c = charcoal production, et = ecotourism, ra = research assistant.

Appendix B

Scenario 1	Community
Milpero	
Household 1	Punta Laguna
Household 2	Punta Laguna
Household 3	Punta Laguna
Household 4	Punta Laguna
Household 5	Punta Laguna
Household 7	Punta Laguna
Household 11	Punta Laguna
Household 12	Punta Laguna
Household 13	Punta Laguna
Household 23	Yodzonot
Household 24	Yodzonot
Household 25	Yodzonot
Household 26	Yodzonot
Household 27	Yodzonot
Household 28	Yodzonot
Household 29	Yodzonot
Household 30	Yodzonot
Milpero + Field assistant	
Household 8	Punta Laguna
Household 9	Punta Laguna
Household 10	Punta Laguna
Household 14	Punta Laguna
Household 21	Punta Laguna
Field assistant	
Household 15	Punta Laguna
Household 16	Punta Laguna
Household 17	Punta Laguna
Household 18	Punta Laguna
Household 19	Punta Laguna
Household 20	Punta Laguna
Household 22	Punta Laguna

Appendix B (*Continued*)

Scenario 2	Community
Milpero	
Household 1	Punta Laguna
Household 4	Punta Laguna
Household 5	Punta Laguna
Household 23	Yodzonot
Household 24	Yodzonot
Household 25	Yodzonot
Household 26	Yodzonot
Household 27	Yodzonot
Household 28	Yodzonot
Household 29	Yodzonot
Household 30	Yodzonot
Milpero + Field assistant	
Household 8	Punta Laguna
Household 14	Punta Laguna
Household 2	Punta Laguna
Household 3	Punta Laguna
Household 7	Punta Laguna
Household 11	Punta Laguna
Household 12	Punta Laguna
Household 13	Punta Laguna
Field assistant	
Household 15	Punta Laguna
Household 16	Punta Laguna
Household 17	Punta Laguna
Household 18	Punta Laguna
Household 19	Punta Laguna
Household 20	Punta Laguna
Household 22	Punta Laguna
Household 9	Punta Laguna
Household 10	Punta Laguna
Household 21	Punta Laguna

Appendix B (*Continued*)

Scenario 3	Community
Milpero	
Household 4	Punta Laguna
Household 25	Yodzonot
Household 26	Yodzonot
Household 27	Yodzonot
Household 28	Yodzonot
Household 30	Yodzonot
Milpero + Field assistant	
Household 8	Punta Laguna
Household 14	Punta Laguna
Household 7	Punta Laguna
Household 12	Punta Laguna
Household 13	Punta Laguna
Household 1	Punta Laguna
Household 5	Punta Laguna
Household 24	Yodzonot
Household 23	Yodzonot
Household 29	Yodzonot
Field assistant	
Household 15	Punta Laguna
Household 16	Punta Laguna
Household 17	Punta Laguna
Household 18	Punta Laguna
Household 19	Punta Laguna
Household 20	Punta Laguna
Household 22	Punta Laguna
Household 9	Punta Laguna
Household 10	Punta Laguna
Household 21	Punta Laguna
Household 2	Punta Laguna
Household 3	Punta Laguna
Household 11	Punta Laguna

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