8 Land use scenarios: a communication tool with local communities

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Abstract

The municipality of La Huacana in the Mexican state of Michoacán, is currently undergoing a process of intense land use change, which has severe environmental repercussions. This dry tropical region has a high rate of population emigration leading to the abandonment of crop land, largely due to the low agricultural yields. At the same time small-estate holders are converting the forest cover to pasture. All of these topics have resulted in land degradation and increased water depletion, which are already some of the most severe problems in the region.

Landsat and ASTER images dated 2000, 2003 and 2006 were classified in order to generate land use/cover maps of the municipality. Then, we modeled land use/cover changes using DINAMICA, a spatially explicit model for land cover change modelling. The selection of the variables used to explain the land use/cover transitions was determined using the information obtained in a workshop carried out on the Rural Development Council Assembly along with a statistical analysis based upon the land use/cover changes maps for the period 2000-2003 derived from the remotely sensed data. The 2006 land use/cover map obtained through the model calibrated on 2000-2003 data was compared with the map derived from 2006 ASTER images analysis. This comparison showed a reasonable performance of the model. As the next step, the model was used to mimic three possible scenarios for 2015 that encompass a plausible range of future trajectories of deforestation. The first one assumes that 2000-2003 deforestation trends will continue, the "cattle" scenario assumes that deforestation rates will increase and finally the "sustainable" scenario assumes that the communities will implement protected areas and that deforestation due to cattle ranching will decrease.

The perspective of local inhabitants and authorities was useful to conceptualize the model. Showing the different scenarios to the community and local authorities could be a valuable tool for making future decisions and to become aware of the need to establish strategies to protect the community's resources.

Keywords: land use change, model, scenarios, local communities

8.1 Introduction

Current research on land use change has matured in terms of theories, models and tools. In addition, interdisciplinary research is gaining relevance; the studies have a more holistic approach than in the past and interdisciplinary scientific collaboration is being promoted (Briassoulis 2000).

The modalities of land use change study differ depending on the goals pursued. In general terms, two main approach trends may be distinguished:

1) Studies focused on monitoring land use change, i.e., measuring conversion. Despite its descriptive nature, such studies are essential and often the results are used as data for more elaborate studies. At present, land use changes are detected mainly through satellite image data. Multiple techniques have been developed, however, no optimal application exists that may be applied to all cases. New techniques continue to be developed, allowing for the effective use of remote sensing data techniques, which are increasingly more diverse and complex (Lu et al. 2004).

2) Explanatory studies attempt to understand the mechanisms acting in land use change and, in particular, to establish the forces and factors that promote such changes. One framework to understand the causes of land use/cover change is that of proximate sources and driving forces. In this framework, proximate causes refer to activities that directly affect the environment, while driving forces indicate the underlying social processes that give rise to the proximate actions effecting landscape change (Chowdhury 2006).

Proximate causes may be grouped into three broad categories: i) expansion of crop land and pasture, ii) harvesting or extraction of wood, and iii) expansion of infrastructure. In terms of scale, these factors operate at the local level. On the other hand, driving forces may be grouped into five categories of factors: i) demographic, ii) economic, iii) technological, iv) political and institutional, and v) a complex of socio-political or cultural factors. Those factors operate at the local level, or indirectly from the national or even global level (Geist and Lambin 2001).

Within this trend of explanatory studies are the models for the simulation of land use change dynamics, making predictions of future changes under several hypothetical scenarios.

In this study, we investigate the magnitude (rate and location) of the land use/cover changes in the municipality of La Huacana in the Mexican state of Michoacán, as well as the driving factors and probable areas to undergo land use change in the near future. The information is provided by a model of land use/cover change, which was run under three scenarios that encompass a plausible range of future trajectories of deforestation.

8.2 Test areas and data sets

8.2.1 Test area

The municipality of La Huacana has an area of 1,950 km^2 and is located in the southern portion of the state of Michoacán, Mexico, between the coordinates 18º 13' and 19º 04' N; and 102º 13' and 101º36' W, as is shown in Fig. 8.1. The elevation varies from 160 m in the margin of the Tepalcatepec River up to 2,060 m in the north-eastern limit of the municipality.

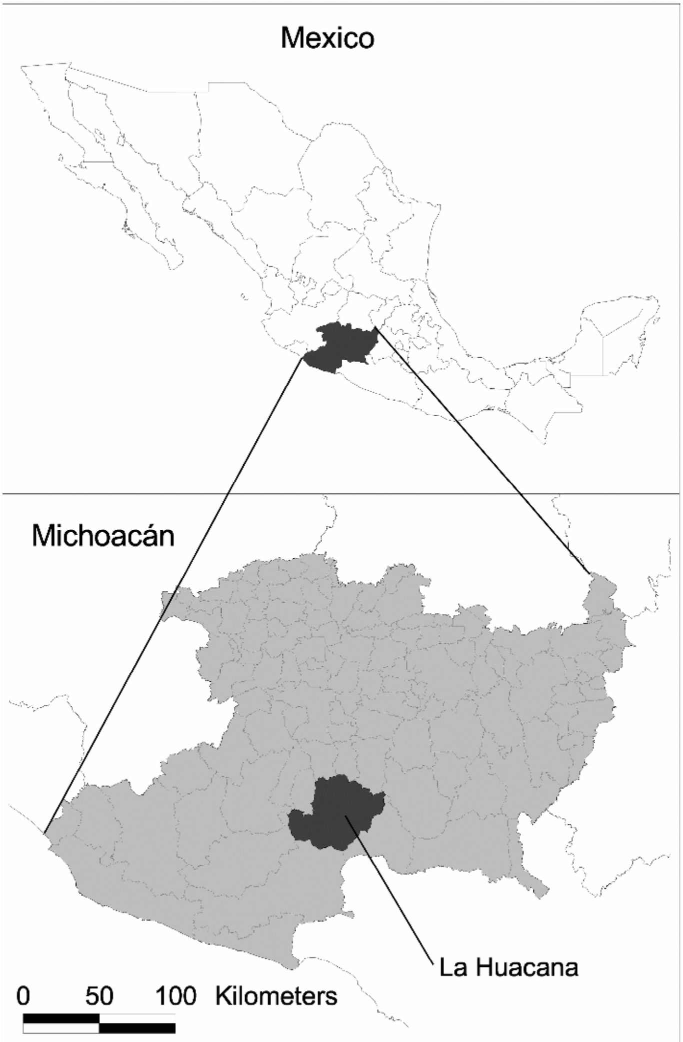

Fig. 8.1 The State of Michoacán and La Huacana Municipality

The municipality is part of the dry tropical environment in which the dominant land covers are the low and median (sub)deciduous tropical forests. These vegetation types are widely found in Mexico (Burgos and Maass 2004) but are undervalued and insufficiently studied and modelled due to the analytical and technical difficulties for their study; difficulties which are in part derived from the sharp seasonal changes displayed by these forests that have no foliage between 6 to 8 months (Rzedowski 1986). In addition, these forests are among the ecosystems with the highest biodiversity levels, and at the same time being among the most vulnerable to change (Trejo and Dirzo 2000). A Natural Protected Area (Infiernillo-Zicuirán) is being designed in order to protect this biodiversity. This reserve is expected to operate in 2008 and will include an important part of the municipality.

The temperature varies depending on the elevation, the lower part (less than 800 m) has higher temperatures with an annual average temperature of 26°C, this area is part of the so-called “Tierra caliente” (warm lowlands). The annual average temperature is 26°C at sea level and decreases 4°C for each 1000 m gain in elevation (Vidal 2005). In the region the annual precipitation is less than 600 mm, with some variations related to the elevation and temperature as mentioned above.

In 2000, the municipality of La Huacana had 33,986 inhabitants distributed in 118 settlements, of which only two are considered urban and the other 116 as rural (i.e. with less than 2,500 inhabitants) (INEGI 2000). There are two main types of land tenure: private property and community lands (ejidos). Each ejido has representatives who meet each month in a Rural Development Council Assembly, where subjects of common interest are discussed.

According to an official demographic survey, the degree of marginality is very high for 57 of these localities, high for 60 and only one is medium. This marginality index is based on factors, which indicate the availability of the main services; such as water, electricity, the number of inhabitants per household, and the proportion of illiteracy (CONAPO 2000).

In Mexico international migration, especially to the USA, has increased dramatically in the past decades and involves mostly small-rural-town farmers travelling frequently to the USA, motivated by the absence of employment and low salaries among other reasons. Abandonment of crop land, especially in marginal and less productive areas has become an important trend in land use change in areas like La Huacana. This process, which follows the migration trend, seems to facilitate ecosystem recovery (López et al. 2006).

The land use dynamic is dominated by different levels of degradation and not only by the complete clearing of the forest cover. People use the tropical dry forest for different activities like pasture, extraction of wood and firewood, and these activities impact the forest's openness differently.

8.2.2 Data sets

The datasets used were: two Landsat ETM images (path/row 28/47) taken in January 31, 2000 and February 8, 2003; three Aster images: two taken in April 5 and the other in April 30, 2006; INEGI's digital topographic cartography scale 1:50,000; very high-resolution (1 to 2 meters on the ground) digital aerial photography of 2000; INEGI´s orthophotographs scale 1:20,000, made from aerial photographs, taken in 1995 and 1996 (resolution 2 meters) and ejidos cartography from the National Agrarian Registry.

8.3 Methodology and practical application to the data sets

8.3.1 Data Processing

In order to prepare input layers for DINAMICA, and to asses land use change, the materials had to be processed, as described below:

- Geometric correction and interdependent visual interpretation (FAO 1996) of the Landsat ETM and Aster images. In a previous study, a digital supervised classification approach was used, but the results were poor due to spectral confusion between land cover classes in dry tropical forest environment (Cuevas 2007). Interdependent interpretation, which consists of interpreting first the oldest image and then using this first delineation as a reference when interpreting the second (recent) image, ensured the highest level of consistency between the classification of recent and historical sets of images.
- The original topographic data sets were processed in order to obtain some of the layers used as explanatory variables in the model.
- A digital elevation model (DEM) and a slope map were derived from the contour lines using the ILWIS program.
- To calculate distances to roads, streams and urban areas the coverage features were converted to raster and the Euclidian distance to the closest source was calculated for each cell using the Arc/Info GIS.

8.3.1.1 Classification

The classes employed to classify the images are shown in the Table 8.1:

Table 8.1 Land use/cover classes

Acronym	Land use/cover category
TF	Temperate forest
DTF-c	Dry tropical forest (closed)
DTF-so	Dry tropical forest (semi-open)
DTF-o	Dry tropical forest (open)
RV	Riparian vegetation
M	Malpaís
RFA	Rainfed agriculture
IA	Irrigated agriculture
HA	Humidity agriculture
HS	Human Settlement
Mi	Mines

The pasture land class was not included as a separate class because it was easily confused with Rainfed agriculture; therefore they were combined.

Once the areas of land use/cover types were obtained for each period, the rate of change, r, was calculated by using the following equation (FAO 1996):

$$r = 1 - \left(1 - \frac{A_1 - A_2}{A_1}\right)^{1/t} \tag{8.1}$$

where A1 is the area covered by a given land use/cover at time 1, A2 the area at time 2 and t is the number of years for the period of analysis.

8.3.2 Spatial transition probabilities

The spatial transition probabilities used to estimate the most favourable areas to experience land use change, were calculated using weights of evidence. The weights of evidence are derived from the Bayesian method of conditional probability, and its strong performance has been proven in combining evidence mainly in medicine and geology (Bonham-Carter 1994). This is a data-driven method, applied when sufficient data are available to estimate the relative importance of evidence by statistical means (Almeida et al. 2003). An advantage of this method is that it is not constrained by the classical assumptions of parametric methods, which are often violated by spatial data.

In general terms, the weights of evidence as previously stated, are derived from the posterior or conditional probability, this is, the probability that an event (D) occurs (for example a specific transition of land use change), given the presence of certain evidence (B) (explicative variable), and it can be expressed by:

$$P[D \mid B] = \frac{P[D \cap B]}{P[B]} \tag{8.2}$$

where P[D | B] is the conditional probability of an event D occurring, given the presence of the evidence B.

Algebraic manipulation allows us to represent the conditional probability in terms of its odds ratio and then to define positive and negative weights (W+ and W-) as follows:

$$W^{+} = \log_e \frac{P[B \mid D]}{P[B \mid \overline{D}]} \tag{8.3}$$

$$W^{-} = \log_e \frac{P[\overline{B} \mid D]}{P[\overline{B} \mid \overline{D}]} \tag{8.4}$$

where,

B = presence of an evidence (conditional factor),

$\overline{B}$ = absence of an evidence (conditional factor),

D = presence of an event,

$\overline{D}$ = absence of an event,

W^{+} indicates the importance of the presence of the factor for the occurrence of the event. If it is positive the presence of the factor is favourable for the occurrence of the event and if it is negative it is not favourable.

W^{-} is used to evaluate the importance of the absence of the factor for the occurrence of the event, when it is positive the absence of the factor is favourable for the occurrence of the event, and negative when it is not.

DINAMICA uses a fixed transition matrix within each phase. This matrix describes a system that changes over discrete time increments, in which the value of any variable in a given time period is the sum of fixed percentages of the value of the variables in the previous time period. The sum of fractions along the column of the transition matrix is equal to one. The diagonal line of the transition matrix needs not be filled in since it models the percentage of unchangeable cells.

The transition matrices were derived by means of the Markovian chain property (Eq. 8.5), in order to project the trends of change on an annual basis (Bell and Hinoja 1977, Soares-Filho et al. 2002).

$$P^t = HV^tH^{-1} \tag{8.5}$$

where P is the original transition matrix, H and V are its eigenvector and eigenvalue matrices, and t is the fraction or a multiple of its time span.

8.3.3 DINAMICA's Cellular Automata

As a cellular automata system, DINAMICA represents the landscape as a regular n-dimensional array of cells that interact within a certain vicinity, and the state of each cell in the array depends on the previous state of the cells within a cell neighbourhood according to a set of transition rules. All cells are being updated simultaneously at discrete time steps (Soares-Filho et al. 2002).

8.3.4 Field methods

8.3.4.1 Land use sampling

Field work in La Huacana was conducted during July 2006. An exploratory visit was made to gather information on land use/cover and areas of change in the region. Due to limitation of the accessibility and security on the study area, an opportunistic sampling following the main roads, emphasizing on areas that have experience changes on their land use/cover was used. The samples were described with help of municipality workers with a good knowledge of the area, although they do not have a formal education. Information on dominant vegetation type was recorded. Field work was done in order to visualize the dynamic of change in the region and to collect information to classify the satellite images, verify the land use/cover classification and asses the accuracy of the resulting land use/cover maps. A GPS receiver was used to record the position of the samples. Ancillary information used to support the routes were a topographic map scale 1:50,000 from INEGI and a false colour image at scale 1:100,000.

8.3.4.2 Interviews with key informants

A workshop was held in the La Huacana ejido's council assembly in which, based on maps and images of the region, the participants were able to recognize the converted areas and suggest the reasons why changes occurred. Additionally, the participants carried out a prospecting exercise for the areas that, in their opinion, are most susceptible to land use change in the near future. The people worked in three different groups, depending on the region they pertain to: La Huacana, Zicuirán and Infiernillo. These regions have different availability of water and therefore different opportunities of land uses.

Each group had to answer the three same questions. They were provided an anaglyph built encoding a three-dimensional image in a single picture using as input the orthophotographs and the DEM. This anaglyph was used to allow the groups for geographic visualization as they answered the questions. These were:

- Which areas have experienced recent land use changes?
- What kinds of changes have been experienced and what are the causes of those changes?
- In the near future, which are the areas which are most likely to change?

The conclusions of each group were presented and discussed in a plenary session.

Also some interviews with the municipal authorities were conducted in order to obtain a general view of the municipality.

8.3.5 Application of DINAMICA

The model was calibrated using the period 2000-2003 and run to generate a map for 2006 (for validation purpose) and to 2015 (scenarios). All data used in this application were represented at 30 m x 30 m raster cell. The cells form a 2,160 by 1,665 grid, there are a total of 3,596,400 cells defining the region for simulation.

The maps that were constructed identified 11 distinct land use/cover categories from which we are focusing on seven land use changes or transitions that are shown in the Fig. 8.2. From those transitions five are in the direction of the degradation and only two are of recovery.

The selection of the variables used to explain the seven land use transitions was determined by the statistical analysis of the data (weights of evidence computing) and using the information obtained in the workshop and the interviews with key informants. The six variables used in the statistical analysis of land use change were elevation, slope, distance to the main rivers, distance to roads, distance to human settlement and land tenure.

We used the Cramer's coefficient to test the variables independence and eventually exclude a variable due to dependence. Cramer's V is a statistic measuring the strength of association or dependency between two (nominal) categorical variables in a contingency table. The closer the index is to 0, the smaller the association between the categorical variables. On the other hand, a value being close to 1 is an indication of a strong association between the variables.

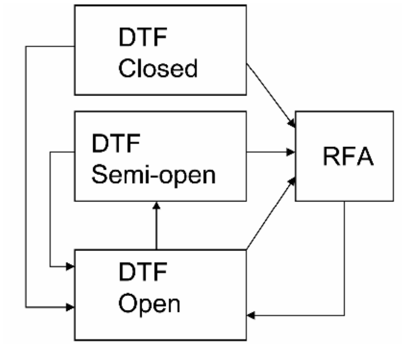

Fig. 8.2 Land use transition

8.3.6 Scenarios

The trend scenario maintains the same trend of 2000-2003 and therefore is based upon the same change matrix and behaviour of explanatory variables.

To run the "cattle" scenario one variable was added consisting in the categorization of the according to the possibility of maintaining their cohesion, or selling their lands to small-state holder who convert the dry tropical forest to pastures for the cattle. Also the rate of deforestation was increased proportionally to the incremental trend of the price of the cattle and to the governmental support.

The sustainable scenario is based upon an increase of the incentives for the conservation of the tropical dry forest and for the sustainable use of the resources, like the promotion of "sustainable cattle" and protected area implementation. To run this scenario the boundaries of the planned Natural Protected Area of Infiernillo-Zicuirán was added as a new variable. As the current municipal policy focused on conservation is expected to continue, the rate of deforestation was decreased and the ejidos obtain economical benefits for not changing the current land use of their lands.

8.3.7 Integration of local knowledge

The information gathered during the workshop and the interviews was used in different phases during model construction (Fig. 8.3). First it helped to select the explanatory variables used as conditional factors of the different land use transitions. Second, it was useful as expert knowledge in the modification of the weights of evidence, and finally it helped to conceptualize the different possible future trends.

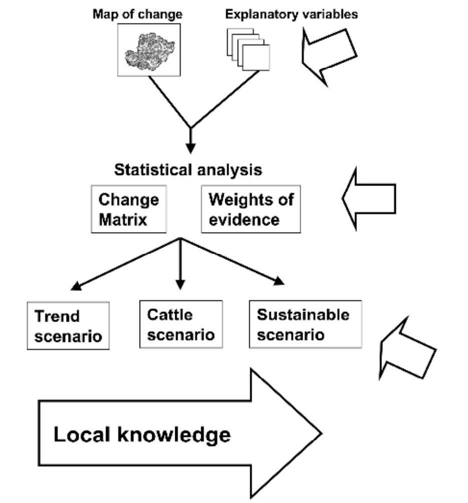

Fig. 8.3 Local knowledge in different stages of model construction

8.3.8 Validation

To validate the land cover prospective model, we applied it to the 2003 map in order to model known land use/cover (2006). The evaluation of the model was then based on the comparison between the simulated and the observed maps. As pointed out by Paegelow and Camacho Olmedo (2005), modelled land cover maps can be very close to reality but the correctness is due for a major part to persistence. The comparison was therefore focussed on change areas (both observed and simulated changes). Spatial models require a comparison within a neighbourhood context, as even maps that do not match exactly pixel-by-pixel could still present similar spatial patterns and likewise spatial agreement within a certain pixel vicinity. To address this issue several vicinity-based comparison methods have been developed. For example, Costanza (1989) introduced the multiple resolution fitting procedure that compares a map fit within increasing window sizes. Pontius (2002) presented a method similar to Costanza (1989), but that now differentiates errors due to location and quantity. Power et al. (2001) provided a comparison method based on hierarchical fuzzy pattern matching. Couturier et al. (2007) used a fuzzy approach based on the epsilon band approach. In turn, Hagen (2003) developed new metrics, including the Kfuzzy, considered to be equivalent to the Kappa statistic, and the fuzzy similarity which takes into account the fuzziness of location and category within a cell neighbourhood. The method implemented in DINAMICA is a modification of this latter approach.

The fuzzy similarity test is based on the concept of fuzziness of location, in which a representation of a cell is influenced by the cell itself and, to a lesser extent, by the cells in its neighbourhood (Hagen 2003). The overall similarity of a pair of maps can be calculated by averaging the two-way similarity values for all map cells. As random maps tend to score higher, it is recommended picking up the minimum fit value from the two-way comparison. This last approach was used in the present study.

8.4 Results

8.4.1 Data from fieldwork

8.4.1.1 Land use samples

A total of 77 field samples were collected, eight of them are out of the study area. Fig. 8.4 shows the distribution of the field samples into the study area and Table 8.2 gives a summary of the samples according to the legend.

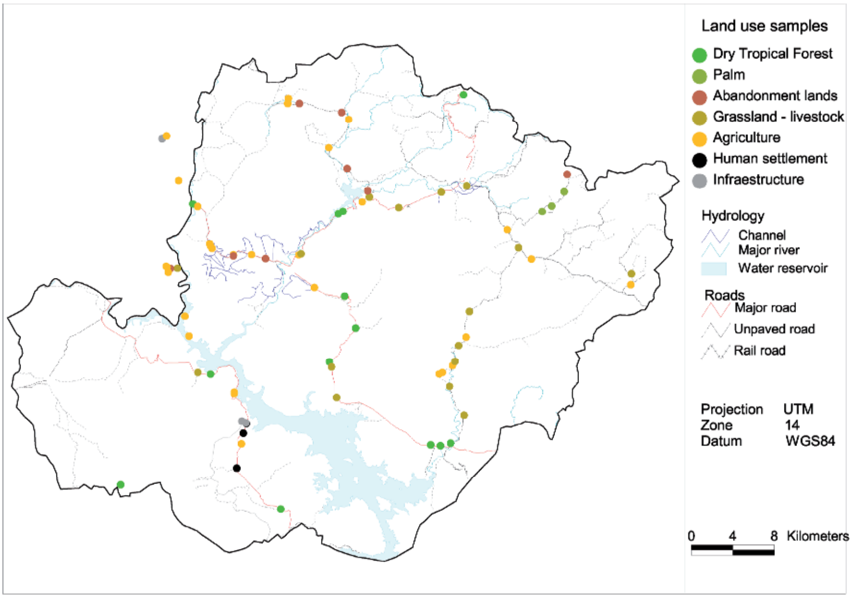

Fig. 8.4 Land use samples

The number of points in the categories grassland and agriculture are considerably larger than the other classes, because the field work was conducted along the main roads and paths, and so correspond mainly to the cultivated lands.

Table 8.2 Summary of field samples by land use/cover type

Land use/cover	Number of samples
Tropical forest	13
Palm	4
Abandonment lands	8
Grassland - livestock	16
Agriculture	30
Human settlement	3
Infrastructure	3

8.4.1.2 Interviews with key informants

A workshop was carried out in the Rural Development Council Assembly of July 20 2006; the attendants of the meeting are the representatives of the ejidos and of some groups of producers. There were 55 persons at this meeting. Most of them are peasants that have a good knowledge about the region but the most of them do not have a formal education.

- Areas that have experienced recent land use change

The information derived from the workshop, about the areas that have experienced recent land use changes, is shown in Table 8.3.

Table 8.3 The areas in La Huacana showing the most change according to the workshop participants

Region Subject	La Huacana and Surroundings	Zicuirán dam and surroundings	Infiernillo dam and surroundings
Most changing areas	Zapote Jorullo Pedregosa Fincas de Inguarán Naranjito El Estradito Cuimbio Manga de Cuimbio La Huacana Ichamio La Sauda Ojo de Agua San Ignacio El Valle Cerrito Colorado Agua Blanca Puerta La playa Mata de Plátano Los Copales	Zicuirán dam' border Najanjo de Tziritzícuaro Manga Chávez Zicuirán Caja de Zicuirán	Piedra verde Villahermosa Cerro Condémbaro Potrerillos Nuevo Cento Barajas Las Cuátaras Cupan del Río San Francisco de los Ranchos

Most of the mentioned locations are names of the towns which could be located on a map and overlaid with the land use map of 2006. From the total of 28 points, 18 are located on Rainfed agriculture and Grassland, three on Irrigated agriculture, five on Human settlement and only two were on Deciduous forest.

For the Infiernillo area the workshop revealed that the most important changes of land use change happened forty years ago when the Infiernillo dam was constructed, then ten or fifteen years ago when the electric line and the gas pipeline were constructed, and most recently with the construction of the highway.

- Types and causes of land use changes

In terms of the information about the types and causes of the land use changes, the information was shared in the three work groups with minor differences. Among the main type of land use changes that the people were able to recognize are the deforestation, land abandonment and the increase of the drought derived from the deforestation. Also mentioned was that the use of agrochemicals has created contamination and erosion.

As one of the causes of the deforestation, the belief that cattle ranching is more cost effective on human induced grassland than in the native forest was mentioned. Another cause is the illegal crops. Land abandonment is perceived to be related to the low prices of the agriculture products and the high rate of migration of young people to the United States. Those abandoned lands are now covered with mesquite *(Prosopis spp)* scrubs. The construction of infrastructure was identified as other cause of change, but as was mentioned before this is not a recent issue. For the Infiernillo area, another change was the promotion of the agriculture after the dam was built.

- Identification of possible areas for future change

The possible areas identified by the participants as likely to see change in the future are listed in Table 8.4. Noteworthy is the municipality's effort to reforest some areas.

8.4.2 Land Cover Mapping

Table 8.5 summarizes the area of each cover class along with the respective rate of deforestation. Close and semi-open dry tropical forests areas have significantly decreased. On the other hand, the category with significantly gained area is the rainfed agriculture, a category which includes pasture lands. The 2000 and 2003 land use/cover maps are shown in Fig. 8.5. The rates of deforestation found are in agreement with other estimations, although they can still be considered high (Trejo and Dirzo 2000, Bocco et al. 2001, Mas et al. 2004). It is also worth noting that the rate of deforestation increased dramatically during the second period (2003-2006). However, this can be partially attributed to the fact that cleared areas are more easily identified with the ASTER images used in 2006 than the Landsat images used earlier due to their higher spatial resolution. Therefore, some of the deforested patches detected in 2006 already existed, which can lead to an overestimation of the deforestation rate during the last period and an underestimation during the first one.

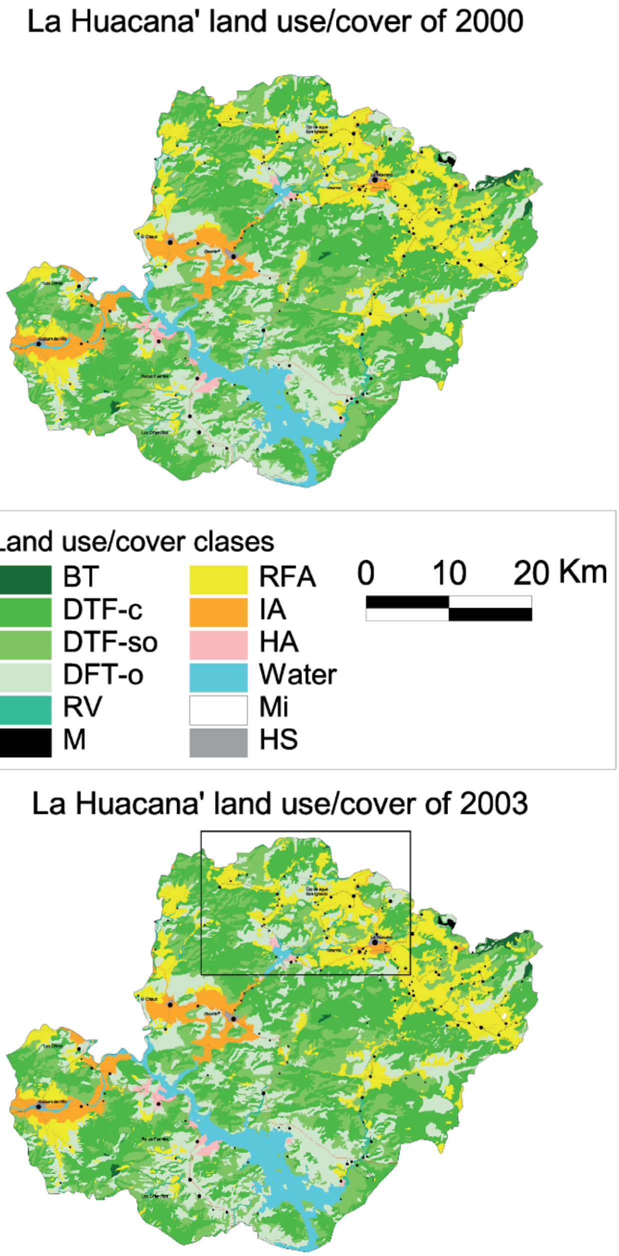

Fig. 8.5 La Huacana land use/cover map of 2000 (top) and 2003 (down)

Table 8.4 Areas with more possibilities to experience change in the near future according to the workshop's participants

Region Subject	La Huacana and surroundings	Zicuirán dam and surroundings	Infiernillo dam and surroundings
Future changes	Reforesting zones: Puerta La Playa, Zapote, Pedregosa, Salitrillo	If there is no conscience it will be more degradation and some species of trees and animal could be lost.	Strip from Potrerillos to Pocitos, towards the dam.
	Water: COINBIO's program	Less agriculture	Cerro Condémbaro (advancing of the agriculture border)
	Water pollution because the mines: Inguarán, Cuimbio, Pueblo Viejo	Less cattle	Infiernillo dam' border (reforestation planning)
		More migration	

Table 8.5 La Huacana' land use/cover areas in 2000 and 2003

Land cover class	2000 (Ha)	2003 (Ha)	2006 (Ha)	Rate 2000-2003 (%/yr)	Rate 2003-2006 (%/yr)
Temperate forest	902	902	890	0.00	0.46
Dry Tropical forest (closed)	66,118	65,720	62,441	0.20	1.69
Dry Tropical forest (semi-open)	36,512	36,375	35,604	0.13	0.71
Dry Tropical forest (open)	39,440	39,441	41,302	0.00	-1.55
Riparian Vegetation	1,770	1,770	1,707	0.00	1.20
Malpais	128	128	128	0.00	-0.05
Rainfed agriculture (inc. pasture lands)	30,572	31,097	33,326	-0.57	-2.33
Irrigated agriculture	7,757	7,763	7,800	-0.03	-0.16
Humidity agriculture	1,410	1,414	1,411	-0.09	0.06
Water body	8,889	8,889	8,888	0.00	0.00
Human settlement	32	32	32	0.00	0.13
Mine	405	405	405	0.00	-0.03

8.4.3 Change Analysis

The overall transition rates for the seven transitions analyzed are shown in Table 8.6. These were calculated by mean of a cross-tabulation operation between the initial (2000) and final (2003) land use/cover maps.

Table 8.6 Matrix for transition rates for La Huacana, 2000-2003

	DTF-c	DTF-so	DTF-o	RFA
DTF-c	0.9934	---	0.0025	0.0041
DTF-so	---	0.9945	0.0034	0.0022
DTF-o	---	0.0018	0.9912	0.0070
RFA	---	---	0.0023	0.9977

The results of the test for correlation between variables have shown that most of the values were lower than 0.3 for the Cramer's Coefficient (V). Only the correlation between land tenure and slope had a value of 0.7, but both variables were maintained.

Transition probabilities were calculated for each cell by means of the weights of the evidence method. Among the six factors defined, only the land tenure is in binary form. The other five are continuous data, which were transformed into ranked variables.

For the five transitions involving degradation, the distance to roads is the factor with the highest weights of evidence values, followed by the distance to urban areas. Roads appear as one of the strongest predictors of deforestation in dry regions, as it has proved to be in tropical deforestation as well (Kaimowitz 1998). Forest is converted to agriculture, plantations and cattle pastures where roads and rivers provide easy access.

The proximity to the main rivers also appears as an important factor that drives the deforestation and this makes sense if we consider that the availability of water in the study area is very important in determining land use. The low values of elevation and slope seem to be prone to deforestation because they are used for agriculture. The community land tenure (ejidos) tends to decrease the deforestation rate.

For the two transitions that imply a certain degree of forest recovery, which are concerned with land abandonment of land previously used for agriculture activities, the behaviour of factors analyzed changes completely. The areas, which exhibit recovering forest, appear to be far from urban areas and not very close to the roads. This transition also happened far from the main rivers, at higher elevations and in areas with steeper slope. The presence of ejidos is favourable to the vegetation regrowth.

8.4.4 Scenarios to 2015

Fig. 8.6 shows the 2006 land use/cover map, initial date of the simulation and the simulated 2015 maps according to the three scenarios respectively for a portion of the municipality (the square in Fig. 8.5 shows the location of this area). The more conspicuous difference between scenarios is the surface of rainfed/pasture cover.

8.5 Validation and discussion of results

The three land use/cover maps derived from remotely-sensed imagery were evaluated with the municipal staff, who have a good knowledge of the area. Also the classification of 2000 was evaluated using very high resolution digital aerial photography, while the classification of 2006 was evaluated with the field work information. Although these evaluation approaches did not allow for the obtaining of a statistically robust index of accuracy, the reliability of the maps was considered satisfactory.

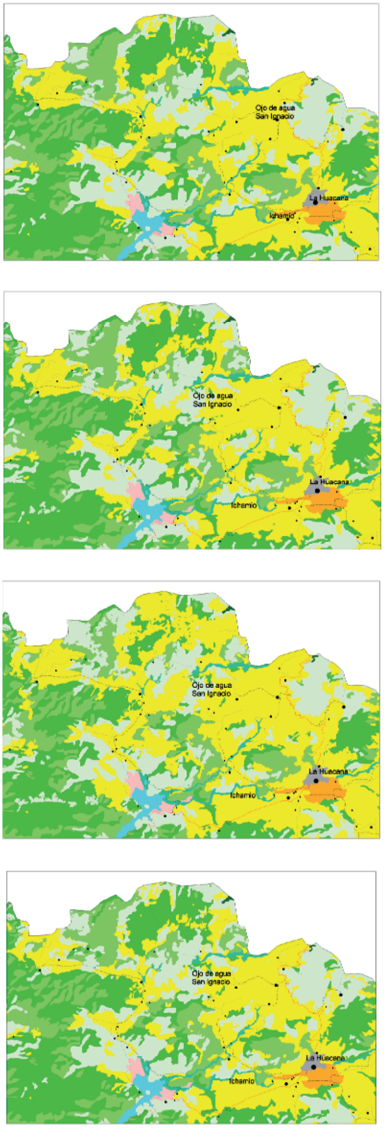

Fig. 8.6 Initial land use/cover map (observed 2006, top), trend scenario to 2015 (second from top), cattle scenario to 2015 (third from top) and sustainable scenario to 2015 (down)

In order to assess the simulations, we used the trend and the cattle model, calibrated using the 2000-2003 period, to produce two maps for 2006 (Fig. 8.7 shows the simulated map of 2006 using the trend model). These two simulations were compared with the observed 2006 land use/cover map (Fig. 8.8) with the fuzzy method of the reciprocal similarity map using windows from 1 to 73 pixels. Based upon one pixel window, this evaluation corresponds to a strict (no fuzzy) evaluation in which only exact coincidences of changes between the simulated and observed 2006 land use/cover maps are considered as correct. In juxtaposition, the accuracy assessment tolerates positional shift between the simulated and the observed patches of change, based upon a large window (73 pixels is equivalent to more than two kilometres). Fig. 8.9 shows the fuzzy similarity index as a function of window size (positional fuzziness) for 2006 maps derived from the trend and cattle scenario, respectively. No scenario was able to predict the exact position of change (with window size of one, the index is near zero). The explicative variables do not strictly control the spatial distribution of change and only a small part of the area which fulfils the conditions to change actually changed. When increasing the tolerance to positional error, the index augments importantly indicating that the model was able to identify coarsely the location of change. The cattle scenario has a better performance mainly because the quantity of change was higher and therefore closer to the observed change during 2003-2006 than the quantity computed by the trend scenario. Nevertheless, all the simulated landscapes are realistic in terms of the spatial pattern of changes: the size, shape and distribution of simulated patches of change are similar to the observed ones.

8.6 Conclusion and outlook

Simulated 2015 land use/cover maps derived from three scenarios of land use change were elaborated using a spatially explicit model in the municipality of La Huacana, a dry tropical forest region of Mexico. They show the plausible distribution of land use/cover in the municipality taking into account three configurations of possible future trends: i) the trend scenario (amount and patterns of change are the same as during 2000-2003, the calibration period), ii) the cattle scenario (loss of the ejidos social cohesion and increasing conversion of dry tropical forest to pastures for the cattle) and, iii) the sustainable scenario (promotion of “sustainable cattle” and protected area implementation). The different scenarios do not present dramatic changes due to the short time of simulation (2006 to 2015) and because most of the area remains without change. Based upon the comparison between the simulations between 2003 and 2006 and the observed

2006 map, the model is not expected to predict the location of futures changes accurately, but rather to identify roughly the areas of change and simulate a realistic future landscape with regards to the spatial pattern of change. Overall generally underestimated, obtaining realistic simulated maps can be very important for certain simulation purposes, such as for the elaboration of scenarios presented to communities or the assessment of change on fragmentation habitats. The research done on the performance's evaluation of spatially-explicit models is mainly focused on the spatial co-incidence between simulated and observed maps.

Also further research is needed to evaluate the model for its capacity to predict the spatial patterns of future landscapes.

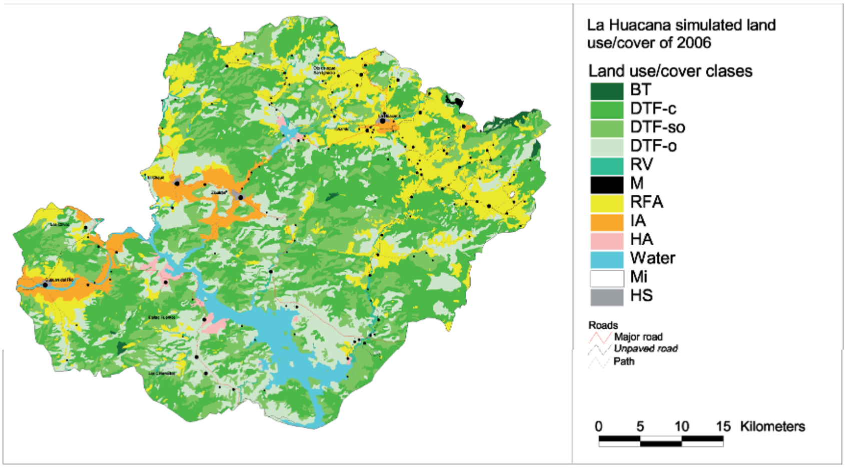

Fig. 8.7 La Huacana simulated land use/cover map of 2006

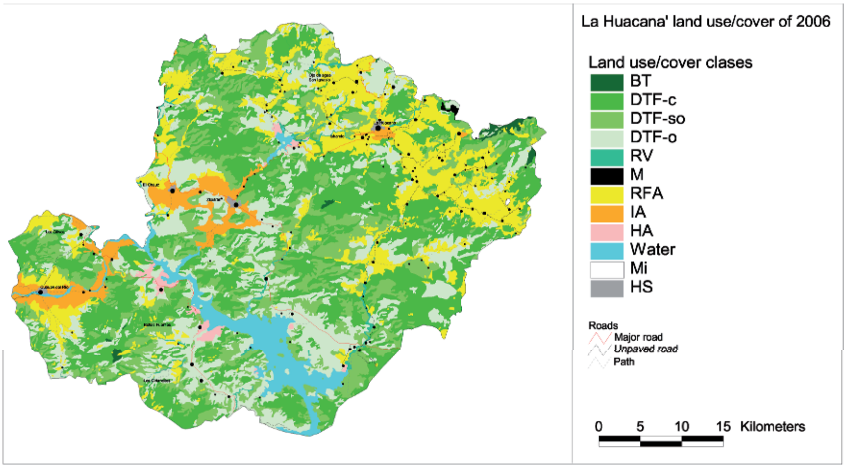

Fig. 8.8 La Huacana use/cover map of 2006

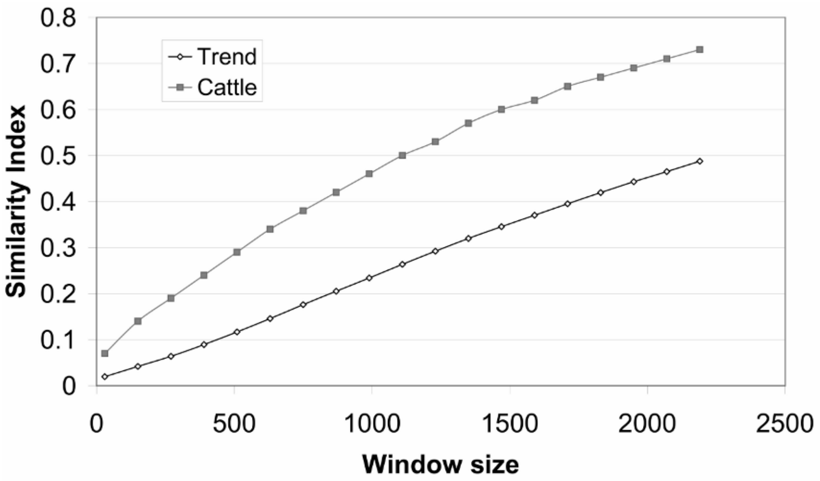

Fig. 8.9 Fuzzy Similarity Index as a function of window size (positional fuzziness)

The chosen approach to calibrate the model may be considered a trade-off between a “supervised” model with manual establishment of a knowledge base and an “automatic” approaches, which derive the relationships between changes and explicative variables only from the changes observed during the calibration period. As the model was calibrated upon a short period (3 years) the amount of change was minimal and therefore a purely statistically approach can be misleading due to its sensitivity to atypical events. For example, in a case in which a large clearing occurs at a certain distance from a road, a model based on the automatic approach will show that the probability of change at this distance is very high when a more progressive relationship between deforestation probability and distance is thought to represent better than the general trend. A manual editing of the weights of evidence allows for a reduction of the bias due to this lack of statistical representation. Moreover the editing of weights of evidence allows for the integration of expert knowledge and elaborating scenarios.

The simulated maps are presently under analysis by the municipal authorities and will serve as an input to promote discussion on environmental policy in the municipality. In order to improve the communication with communities, it can be useful to provide them with realistic landscape visualisations in a 3D environment, demonstrating how their landscape will change (Stock et al. 2007). Coupling land use/cover modelling and visual communication (i.e. realistic landscape visualisations), which engage the emotions, may substantially enhance awareness-building of the implications of land use/cover change, and may help motivate behavioural change at the individual to societal levels (Sheppard 2005).

Alternative futures derived from land use/cover modelling, and mediated by landscape visualisation-based tools is therefore a promising tool, which will be explored in further research.

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