

## Capítulo 4

### Evaluación del estado de conservación del bosque nublado en los Altos de Chiapas, México

Este capítulo reproduce el texto del siguiente manuscrito, a excepción de la sección de Métodos, que aparece resumida:

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#### Resumen

El bosque mesófilo de montaña o bosque nublado es un ecosistema único y de gran valor ecológico. Ello se debe, en parte, a la gran diversidad de especies que alberga y al papel que juega en la captación del agua. Aunque estos bosques se encuentran amenazados a nivel mundial, no existen datos fiables sobre la superficie que ocupan actualmente ni su distribución. Esto impide la elaboración de estrategias concretas de conservación. En el presente trabajo se investiga cuánto bosque nublado queda en Los Altos de Chiapas (México) y cuán fragmentado se encuentra en relación a otras formaciones forestales. Los resultados de este estudio sugieren que todavía existen entre 3,700 y 5,250 ha en el área de estudio. Esta cifra contrasta notablemente con las cerca de 40,000 ha obtenidas por el Inventario Forestal Nacional de México del año 2000. Los remanentes de bosque nublado se encuentran muy dispersos, fragmentados e inmersos en una matriz constituida mayoritariamente por otros tipos de bosques tropicales de montaña. Sin embargo, la existencia de otras formaciones forestales que aparecen entremezcladas con el bosque nublado podría favorecer la conectividad de estos hábitats y mitigar la perturbación a la que están sometidos. Concluimos que es necesario buscar mecanismos para promover: (1) la protección de áreas que contengan los remanentes actuales de bosque nublado en acuerdos establecidos con las comunidades y los propietarios de los predios; y (2) la conservación de, al menos, las funciones ecológicas de las áreas forestales colindantes.

## The extent, distribution, and fragmentation of Montane Cloud Forest in the Highlands of Chiapas, Mexico

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### Abstract

Montane Cloud Forest (MCF) has high levels of species diversity, contributes positively to the catchment water yield, and is a globally threatened habitat type. The shortage of reliable data regarding the area currently occupied by MCF remains an obstacle to operational conservation planning in Mexico. This paper assesses how much Montane Cloud Forests remains in the central Highlands of Chiapas (Mexico) and how fragmented it is in relation to other forest covers. The area covered by MCF was estimated to be between 3,700 and 5,250 ha. This contrasted with the approximately 40,000 ha reported for the same region by the Mexican National Forestry inventory in 2000. MCF was found to be highly scattered and fragmented within a matrix of other tropical montane forest types. However other forest types may be partially buffering the remaining MCF habitats, mitigating their disturbance and enhancing their connectivity. We conclude that mechanisms should be sought to promote: (1) The protection of core areas containing Montane Cloud Forests fragments in agreement with communal and private landowners; and (2) Conservation of the ecological functions of surrounding buffer zones. Such a conservation strategy would match the natural configuration of these endangered habitats.

**Keywords:** Chiapas; Dempster-Shafer; Evergreen Cloud Forest; fragmentation; habitat mapping; Montane Cloud Forest; remote sensing.

### 1. Introduction

Montane Cloud Forest (MCF) is a type of Evergreen Mountain Forest distributed throughout the tropical belt at elevations between 1,500 and 3,000 m (but as low as 600 m in tropical island landscapes) and within a wide range of rainfall regimes (500-10,000 mm/yr) (Hamilton *et al.* 1995). Because of the broad range of conditions in which it occurs, and the difficulty in finding consistent floristic differences between MCF and co-occurring forest types, there is no consensual definition of exactly what MCF is. Hamilton *et al.* (1995) and Hamilton (2001) outlined the following characteristics for Montane Cloud

Forests: (1) It has the capacity to capture or strip water from clouds which may result in increased catchment water yield when compared with other vegetation types; (2) It is found on soils that are wet, frequently waterlogged and typically highly organic (histosols); (3) It holds a high proportion of its biomass in the form of epiphytes; (4) It has a reduced load of woody climbers when compared with lower altitude tropical moist forest; (5) It contains high local biodiversity in terms of herbs, shrubs, and epiphytes, including a high proportion of endemic species.

MCF is a rare type of forest, making up only 2.5 percent of the total area of the world's tropical forests (**Table 4.1**). There are no accurate data as to how much MCF now remains worldwide. Accurate mapping is complicated by lack of resources and difficult ground access. This has led to a tendency to produce potential distributions for MCF within defined altitudinal ranges where it is likely to occur (Bubb *et al.* 2004). Despite this lack of information, there is a consensus that MCF is disappearing rapidly (Bruijnzeel & Hamilton 2000). For example, the Dominican Republic has lost 90 percent of its MCFs (García & Roersch 1996). In Colombia, only 10 percent of the Andean forests remain (Henderson *et al.* 1991). In Ecuador, MCF has disappeared completely from most of the central and western regions (Dodson & Gentry 1991). In Honduras, an annual rate of MCF loss of 4 percent has been estimated, and if these rates continue, MCF would almost completely disappear in less than 20 years (Mejía 2001).

MCF provides important ecological services, the most notable being its potential for water-capture (Bruijnzeel 2001). The conversion of MCF to pasture and croplands often leads to loss of soil properties, resulting in reduced or erratic stream flows to adjacent lowlands (Hamilton 2001). The recognition of the hydrological value of MCF has been one of the main reasons for the establishment of protected areas within them. Examples include the Parque Nacional de la Tigra in Honduras, the Parque Nacional Henri Pittier in Venezuela, the Monteverde Reserve in Costa Rica, and the privately-owned reserve of La Yerbabuena in Mexico.

In Mexico, the distribution of MCF is known to be highly fragmented and restricted to less than 1 percent of the country (Luna *et al.* 2001). It has been estimated that more than 90 percent of the original MCF has been lost, making this vegetation type one of the most threatened in the country. Chiapas has one of the largest areas of MCF in Mexico (Breedlove 1981, Ramírez-Marcial 2001). However, there are no accurate maps of where they can be found, no estimates of deforestation rates, and limited understanding of the socio-economic forces driving such change (Bubb 2001).

In this context, this paper aims at estimating MCF extent, its distribution and degree of fragmentation in the Highlands of Chiapas, Mexico. To fulfil these objectives we performed a land cover classification of Landsat Enhanced Thematic Mapper (ETM+) satellite imagery based on Dempster-Shafer algorithm (Mertikas & Zervakis 2001). MCF extent was estimated from the resulting land cover classification. The probabilistic nature of this classification method allowed estimation of upper and lower credible bounds for the area covered by MCF by modifying the probabilities of each pixel to belong to this class.

In addition we examined the degree of fragmentation, exposure to disturbance, and isolation of the current MCF remnants. The analysis was performed at two different spatial scales: (i) at the class level by considering MCF as a whole; and (ii) at the patch level by considering only the largest habitat fragments. Two approaches were adopted based on: (i) the assumption that MCF habitat patches occur within a highly contrasting hostile surrounding habitat; and (ii) the

**Table 4.1.** Potential Montane Cloud Forest (MCF) as a percentage of all tropical forest and tropical montane forest. Data extracted from Bubb *et al.* (2004).

Region	All tropical forest (km <sup>2</sup> )	MCF as percent all tropical forest	Tropical montane forest (km <sup>2</sup> )	MCF as percent all tropical montane forest
Americas	7,762,359	1.2	1,150,588	8.4
Africa	4,167,546	1.4	544,664	10.5
Asia	3,443,330	6.6	1,562,023	14.6
Global total	15,373,235	2.5	3,257,275	11.7

assumption that MCF patches intermingle with patches of other forest types that may be similar in structure and floristic composition to MCF.

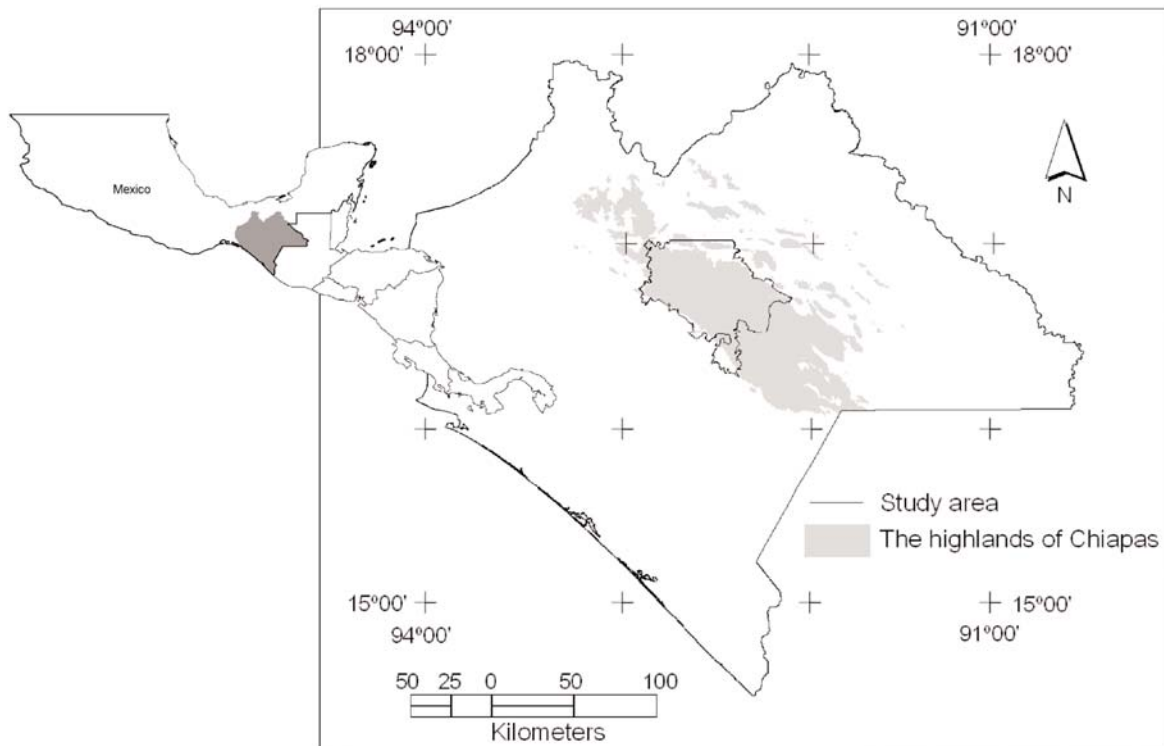
The specific objectives of the study were: (i) To provide a reliable estimation of how much MCF remains in the central Highlands of Chiapas, Mexico, through the analysis of Landsat ETM+ satellite images; (ii) To investigate the conservation value of the existent remnants in terms of size, shape, isolation and distribution of MCF patches; (iii) To assess whether other forest formations play a role in maintaining the integrity of MCF remnants. Because MCF is vanishing rapidly from all Central America, assessing potential sites for conservation must be mandatory in order to provide international organisations with the information they need to implement prompt action. These objectives have not been addressed before for this region and are crucial to help establishing guidelines that can be used in strategies for the conservation of this highly threatened habitat in Mexico.

## 2. Methods

### *Study area*

The study area covers the central Highlands of Chiapas, Mexico, and extends over ca. 3,500 km<sup>2</sup> (**Figure 4.1**). Several forest types are found in the Highlands, including oak, pine-oak, pine, and montane cloud forests (Rzedowski 1978). Elevation ranges from 600 to 2,900 m (mostly above 1,500 m). The topography is abrupt with fairly steep slopes (mean = 14.8°, SD = 9.6°). Mean annual temperature is 13-14 °C, and mean annual rainfall is 1,200-1,500 mm. The underlying geology of the area is carboniferous limestone with many rocky outcroppings. The soils are a mixture of thin lithic renzinas, deeper humic acrisols in forested areas, and rather infertile chromic luvisols.

Most inhabitants belong to Mayan ethnic groups. The main economic activities are traditional agriculture and non-commercial forestry. The traditional shifting



**Figure 4.1.** The state of Chiapas, southern Mexico, and geographical location of the Highlands and the study area within the state.

cultivation or milpa is a rain-fed, labour-intensive system using different cultivars of maize in association with beans, squash, chilli and other edible vegetables.

*Definition of land covers*

For the purposes of this study we defined six classes of land cover: (1) Montane Cloud Forest (MCF); (2) oak forest; (3) pine-oak forest; (4) pine forest; (5) shade coffee plantations; and (6) non forest cover. Non forest cover constituted agriculture fields, pastures, recent fallows, cleared areas, bare soil, and urban areas. The forests themselves have been continuously disturbed over a long time period which has resulted in a complex mosaic of successional stages

of development (Ramírez-Marcial *et al.* 2001, Galindo-Jaimes *et al.* 2002). The successional dynamics in the region are quite difficult to generalise. There is a tendency for early succession stages to be dominated by pine species in drier areas. In contrast the disturbance of humid cloud forest tends to lead to oak dominated communities. Unambiguous definitions of primary and secondary forest are very difficult to apply to this highly anthropogenic landscape. In one sense all the forest in this region, which has been continuously populated for several thousand years, must be considered secondary.

Floristic, structural and physiognomic attributes were used as ground based criteria for identification of MCF habitats. Some indicators of MCF were present

**Table 4.2.** Lines of evidence in support of different hypotheses (MCF = Montane cloud forest; OF = Oak forest; POF = Pine-oak forest; PF = Pine forest; CP = Coffee plantation; NF = Non forest) used in Dempster-Shafer classification procedure. Function type refers to the manner in which the knowledge regarding a certain hypothesis was shaped. Note that maximum probability for evidences derived from expert knowledge was set at 0.8 and 0.6 leaving room for uncertainty concerning our knowledge about the system.

Type	Line of evidence	Supported hypothesis	Function type	Prob. range
REMOTE SENSING	Multi-spectral data worked out through Bayes classification	MCF	Variance/Covariance matrix	0.0-1.0
		OF		0.0-1.0
		POF		0.0-1.0
		PF		0.0-1.0
		CP		0.0-1.0
		NF		0.0-1.0
EXPERT KNOWLEDGE	Elevation	MCF, OF, POF, PF, NF	Linear	0.0-0.8
		CP, OF, POF, PF, NF	Linear	0.0-0.8
	Slope	MCF, OF, POF	Linear	0.0-0.8
		PF, CP, NF	Linear	0.0-0.8
	Distance to human settlements	NF	Distance-based	0.0-0.8
	Landscape perception regarding main vegetation types	POF, PF, NF	Fixed probability	0.0/0.6
		OF, POF, PF, NF	Fixed probability	0.0/0.6
		OF, POF, NF	Fixed probability	0.0/0.6
		MCF, OF, NF	Fixed probability	0.0/0.6
		MCF, OF, POF, NF	Fixed probability	0.0/0.6
MCF, OF, POF, PF, NF		Fixed probability	0.0/0.6	
	CP, NF	Fixed probability	0.0/0.6	

ce of wet soils during the dry season, abundance of mosses, vascular epiphytes and lianas, and preponderance of broad leaved species. Preferential genera of Mexican MCF conditions are *Clethra* L., *Magnolia* L., *Meliosma* Blume, *Styrax* L., *Symplocos* Jacq., and *Ternstroemia* Mutis ex L.f. (Alcántara *et al.* 2002). Only a few species from these genera occur in oak forest or coniferous forest. Indicator species for MCF include *Persea americana* Miller, *Cinnamomum* spp., *Nectandra* spp., *Ocotea* spp., *Magnolia sharpii* Miranda, *Drimys granadensis* L.f., *Meliosma dives* Standl. et Steyerl., *Microtropis contracta* Lundell, *Podocarpus matudae* (Buchholz & Gray), *Weinmannia pinnata* L., or the arborescent fern *Cyathea fulva* Fée. Oak species also tend to differ in these formations from those found in oak and pine-oak forests. Examples include *Quercus acatenangensis* Trel., *Q. benthamii* A.D.C., *Q. lancifolia* Cham. & Schltld., and *Q. sapotaefolia* Liebm. Pine-oak-liquidambar forests were also included as a successional stage of MCF following Breedlove (1981) and Rzedowski (1978).

### Preliminary data processing

A subset from three Landsat Enhanced Thematic Mapper (ETM+) scenes with a resolution of 30 m were used (path 21 row 48 taken on 03/04/2000; path 21 row 49 taken on 19/04/2000; path 22 row 48 taken on 25/03/2000). Each image was geometrically, atmospherically and topographically corrected. A detailed description of these procedures can be found in Cayuela *et al.* (2006a) (**chapter 3**).

### Classification procedure

Land cover classification was performed with the Dempster-Shafer classifier (Eastman 2001), as described in **chapter 3**. This procedure was implemented by combining evidences derived from both multi-spectral data and expert knowledge. Each line of evidence was formalised into one or various probability maps (with values between 0 and 1) supporting one or multiple hypotheses at the same time. After combining all evidences by means of the Dempster-Shafer's algorithm, results were obtained in the form of layers that defined the degree of belief or probability of each pixel belonging to each of the hypotheses

or classification categories. A land cover classification map was then obtained by assigning each pixel to the category that was the most probable after the spectral and ancillary information had been combined (hardening process). We used five lines of evidence (**Table 4.2**):

- (1) Remote sensing data (bands one, two, three, four, five, and seven) that was incorporated into the analysis in the form of Bayes probabilities based on the variance/covariance matrix derived from training sites;
- (2) Elevation, assuming that MCF was more probable at higher elevations (above 2,000 m) and coffee plantations at lower ones (below 2,000 m);
- (3) Slope angle, assuming all forest types but pine forest to occur with higher probability at higher slopes, and pine forest, coffee plantations and non forest areas at lower slopes;
- (4) Distance to human settlements and roadways, using updated roadway and human settlement maps as an evidence for presence of non-forest areas. This information was derived from a road map and a map of localities containing data from population censuses. As the map did not specify the size of the settlements, only the geographical position of the settlement centre, a map representing the effect of settlement size was derived based on a function inferred from population data (see **chapter 3**);
- (5) Landscape perception regarding main vegetation types, for which experts' opinions were collected through participatory mapping. This output a probability map that represented the consensual view of the spatial patterns of vegetation types throughout the study area based on over ten years field experience.

In addition, a polygon layer displaying geo-referenced small coffee holdings (COMCAFE 2001) was used as hard evidence in support of coffee plantations. Further information about this procedure can be found in Cayuela *et al.* (2006a).

Our classification was verified using 303 independent ground field points. The areas where points were taken had an extension of at least 90x90 m (i.e. 3x3

pixels) and were located at least 30 m from the border. This was done to avoid positional errors in georeferencing control points. Completely randomised selection of verification sites was impossible as ground access in the region is limited. A confusion matrix was generated and three kinds of errors were calculated: (i) error of omission; (ii) error of commission; and (iii) overall error with 95 percent confidence intervals. The Tau coefficient, which is a variation of the commonly used Kappa coefficient, was calculated to evaluate the improvement of the classification over a random assignment of pixels to groups (Ma & Redmond 1995). The transformed divergence technique was used to find the separability between the land cover spectral signatures. A value of 2,000 may be considered as excellent 'between-class' separability, values above 1,900 can be considered good separability, and values below 1,700 suggest very poor separability. All classification procedures and analyses were implemented with Idrisi 32 (Eastman 2001).

#### *Estimating Montane Cloud Forest extent*

For each of the six thematic classes we obtained a layer showing the degree of belief given the relevant lines of evidence. Subsequently, each pixel was assigned to the class for which it had the highest degree of belief. From the resulting thematic map we estimated the area covered by MCF as well as for the remaining classes. Sensitivity analysis was carried out by modifying the degree of belief in MCF at regular intervals up and down to 50 percent of its initial value. Following each of these transformations a hardening process was implemented and MCF area was estimated in relation to changes in area for other forest classes. This procedure did not produce conventional confidence intervals based on the likelihood of data given a hypothesis. Instead, the subjective interpretation of probability led to upper and lower credible limits for the amount of MCF remaining that were consistent with the available expert knowledge.

#### *Spatial pattern analysis*

The spatial configuration of MCF fragments was analysed using the following progressive relaxations of the definition of MCF: (1) MCF treated as a com-

pletely contrasting habitat with regard to all other classes; (2) MCF and oak forest treated as similar habitats as opposed to any other class; and (3) MCF, oak forest and pine-oak forest as similar habitats as opposed to any other class. All these analyses were conducted on simple binary maps by combining the target habitats in one group and merging all the other classes in another group. In addition, a co-occurrence matrix was calculated based on the original six classes of land use, from which the percentage of adjacencies (i.e. pairs of patch types appearing side-by-side on the map) between MCF and other classes was estimated.

Analyses of spatial patterns were carried out at two different scales: (i) at the class level, considering MCF as a whole; and (ii) at the patch level, with particular focus on the 20 largest MCF patches. Quantification of the spatial configuration of forest fragments was conducted based on the following set of key metrics selected after reviewing recent forest fragmentation studies: (a) area (ha); (b) core area (total patch size remaining after removing the outer part of the patch; we selected a 30 m edge following Williams-Linera *et al.* 1998) (ha); (c) edge density (m/ha); (d) perimeter-area ratio (equals the ratio of the patch perimeter (m) to area (m<sup>2</sup>)) and (e) patch contiguity index (a measure of patch shape, where values close to 0 indicate low contiguity among pixels within a grid-cell patch and increase to a limit of 1 as connectedness among pixels increases). These analyses were computed using the software FRAGS-TATS 3.3 (McGarigal *et al.* 2002).

### **3. Results**

#### *Extent of Montane Cloud Forest*

Using the categorical land cover map obtained through the Dempster-Shafer classification procedure, we estimated MCF extent in the study area as 4,650 ha, equivalent to 1.4 percent of the total area. Overall, forest cover occupied 28.1 percent of the total area (MCF = 1.4 percent, oak forest = 7.7 percent, pine-oak forest = 8.4 percent, pine forest = 10.6 percent), whereas non forest and coffee plantations occupied approximately 67.4 and 4.4 percent of the study area respectively.

By modifying our degree of belief in MCF by  $\pm 50$  percent we estimated the amount of MCF as between 3,700 and 5,250 ha. These changes in estimated area associated with shifts in the degree of belief in MCF were linked mainly to changes in estimated area of oak forest and, to a lesser extent, of pine-oak forest and pine forest.

### *Spatial pattern of Montane Cloud Forest*

MCF exhibited an intermediate frequency of adjacency between pixels of the same type (51.0 percent), an intermediate frequency of adjacency with other forest types (43.2 percent), and low frequency of adjacency with non forest fragments and coffee plantations (2.9 percent).

**Figure 4.2** illustrates the extent and spatial distribution of MCF cover in simple binary maps when considered: i) at its own; ii) in combination with oak forest; and iii) in combination with oak and pine-oak forest. Metrics for MCF patches are shown in **Figure 4.3**. Because edge density and the contiguity index were highly correlated with patch area and the perimeter-area ratio respectively ( $r > 0.9$ ) we did not report these metrics in the results. Core area was also highly correlated with patch area ( $r > 0.9$ ). However we considered it interesting to report these two metrics separately as they both provide important information about the spatial configuration of MCF. Total area was estimated in 4,600 ha. Adding the oak forest buffer around the MCF patches increased total area to 19,000 ha. When considering pine-oak forest in addition to oak forest buffers, total area rose to 30,000 ha. When using an oak forest buffer number of patches decreased to 5,400 and mean patch area increased to 3.6 ha. When both oak forest and pine-oak forest were considered as buffers for MCF, number of patches decreased to 3,000 and mean patch area increased to 10.1 ha.

Total core area represented a small fraction of total area, ranging from 550 to 1,000 ha when lower and upper bounds under the sensitivity analysis were considered. However it increased to 7,300 ha when including contiguous oak forest habitat patches. This quantity was even higher when adding pine-oak

forest habitat patches rising to 13,000 ha. Mean core area behaved in a similar way to mean patch area but with much lower values. Estimated mean core area was 0.1 ha and increased up to 4.4 ha when considering all woody buffers.

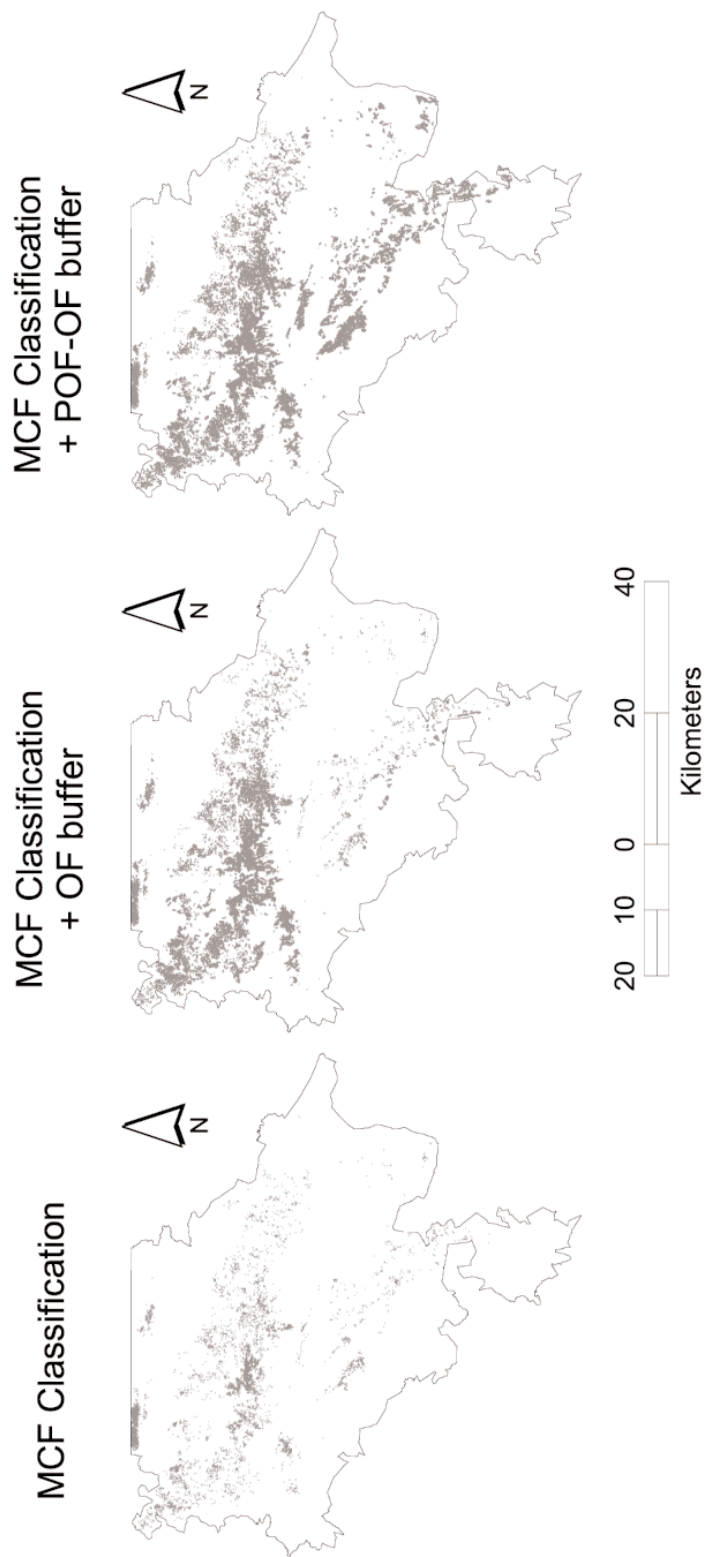
Distribution of fragments based on the perimeter-area ratio was highly skewed towards large values. The perimeter-area ratio for most fragments decreased considerably when other forest formations surrounding MCF patches were considered. Such a response revealed a tendency towards agglomeration of different forest sub-types in larger and less exposed forest fragments.

### *Quantifying spatial pattern on the largest Montane Cloud Forest fragments*

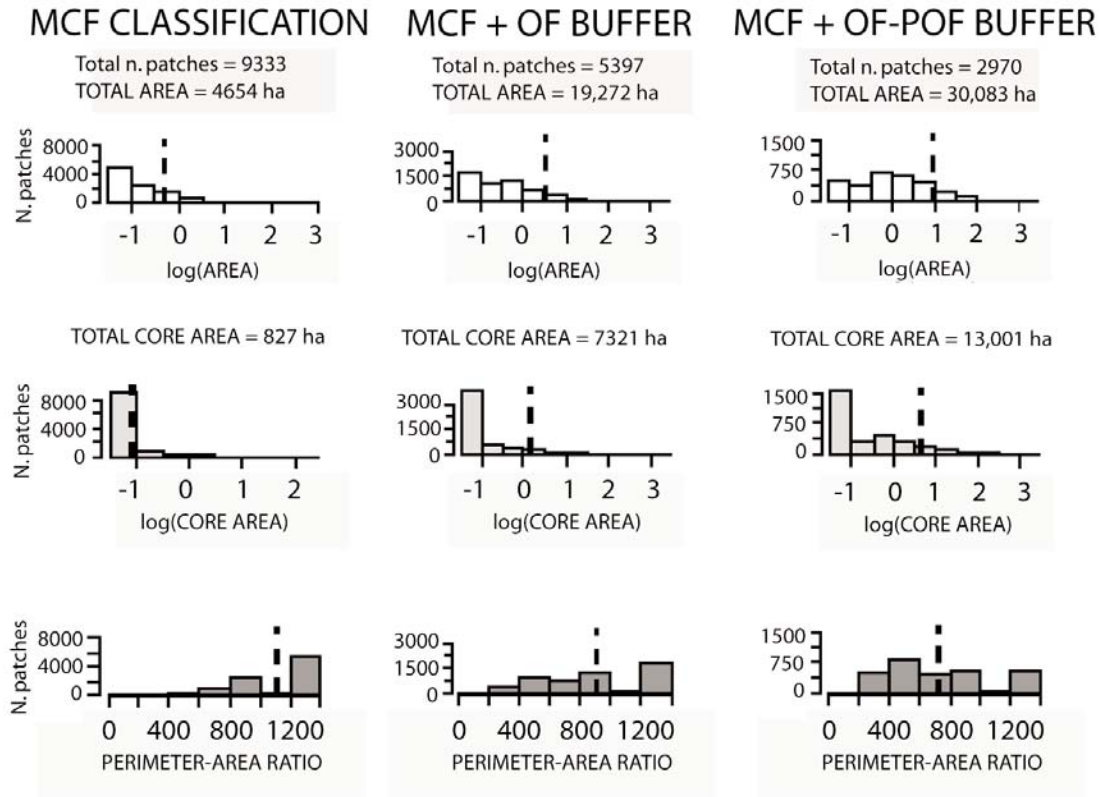
Metrics were computed for the 20 largest patches. These occupied some 31 percent of the total area covered by MCF. **Figure 4.4** shows the patch area, the core area, and the perimeter-area ratio for the 20 largest MCF habitat patches when considering MCF habitat patches on their own and bound to contiguous similar forest habitats (oak forest and oak plus pine-oak forest). The largest patch, when excluding forest formations other than MCF, had an area of 550 ha. The three following largest patches (A, D, E) had estimated areas of 210, 135 and 95 ha respectively. All the remaining 16 largest patches did not exceed 50 ha. Core area was much lower than patch area, the largest patch (L) having some 250 ha, less than half the total area of its corresponding patch area. The perimeter-area ratio was, in general terms, lower for the largest patches.

We restate that the decision to analyse the effect of adding the oak forest and pine-oak forest around MCF was taken in order to draw out the effect of these formations in preventing complete fragmentation and isolation of the remaining MCF patches. In the middle and right columns of **Figure 4.4** it is possible to observe that nine patches (A-I) in the Tzontehuitz mountain range were embedded within a common matrix of oak forest (see **Figure 4.5a**). In this case, all the MCF patches and the surrounding oak forest matrix comprised an area of some 2,300





**Figure 4.2.** Binary maps showing the extent and distribution of MCF when considered at its own (left) and in combination with oak forests (central) and pine-oak and oak forests (right) surrounding it.

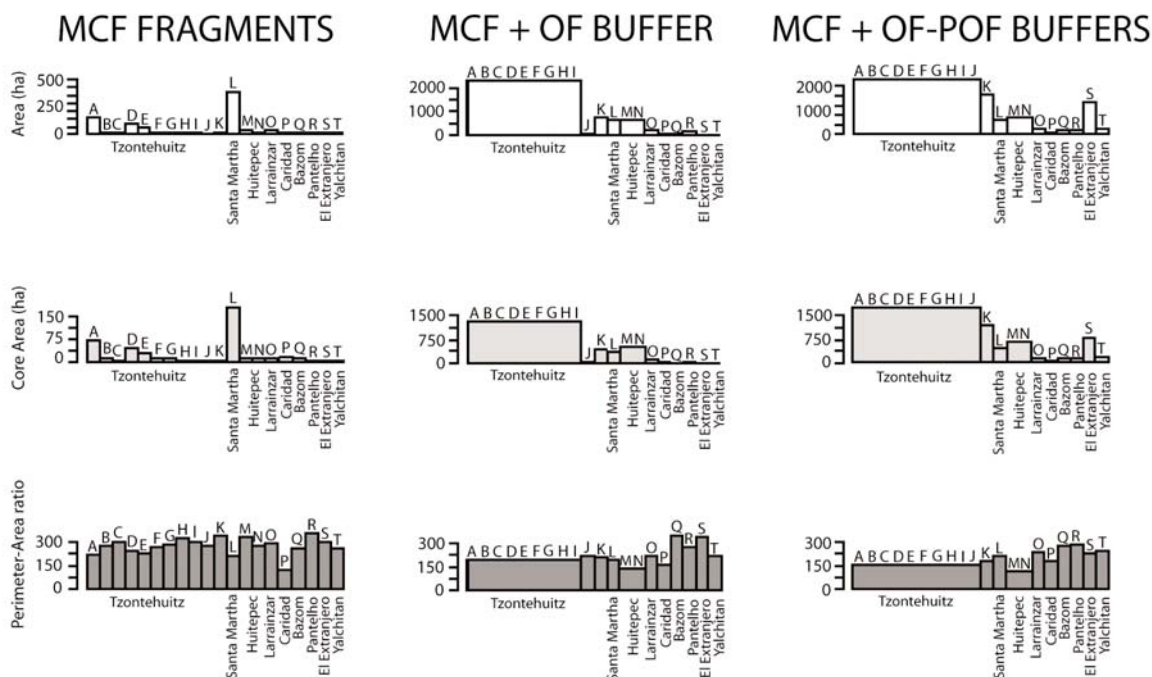


**Figure 4.3.** Distribution of patch metrics (area, core area, and perimeter-area ratio) for MCF under four different scenarios: (1) only the MCF cover (left column); (2) OF buffers around MCF patches (middle right column); and (3) POF and OF buffers around MCF patches (right column). OF = Oak forest; POF = Pine-oak forest.

ha. Adding to this area the cover of pine-oak forest in close contact with MCF, the resulting forested patch area increased up to some 2,800 ha and led to the incorporation of one new MCF patch that was otherwise unconnected (J). Similarly, oak forest cover brought together two of the largest MCF habitat patches at Huitepec Nature Reserve (M-N), leading to a comparatively large mixed forest patch of about 800 ha when pine-oak forest was also considered. In all other cases, inclusion of other forest formations did not result in the linkage of otherwise separated MCF habitat patches, only in an increase in area and core area. This increase was in some cases quite large, such as in El Extranjero (S) where some scattered small patches of MCF (the largest consisting of 23 ha) were surrounded by some 1,600 ha of uninterrupted pine-oak forest.

#### Accuracy assessment

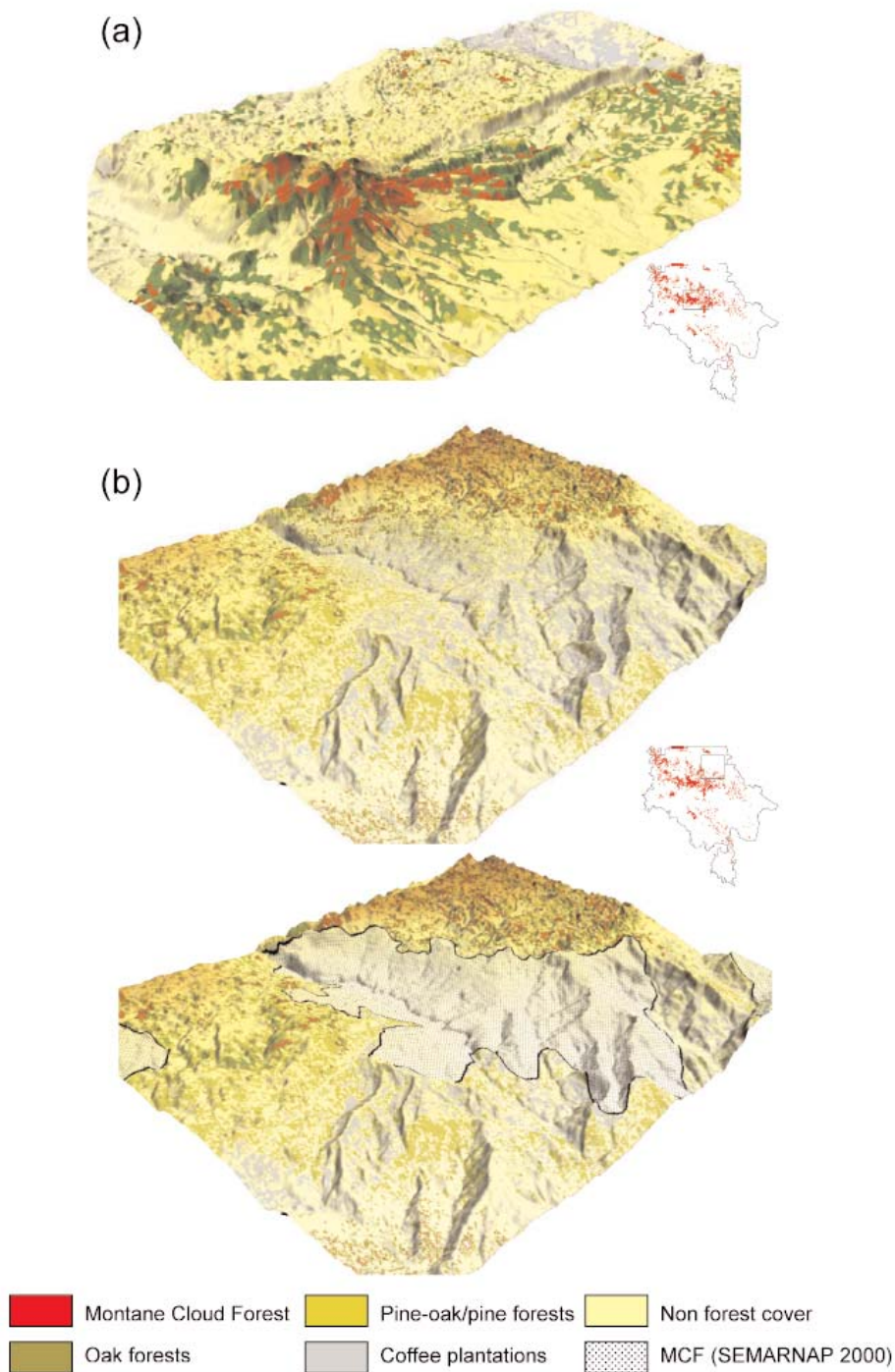
A confusion matrix between thematic classes (**Table 4.3**) revealed the classes that were commonly mixed in the classification process. The Tau coefficient showed a 70.6 percent of agreement between the predicted land covers and field data. This demonstrated an acceptable level of agreement between the predicted land covers and field data (following Monserud & Leemans 1992). The transformed divergence index established a poor spectral separability between pine-oak and pine forests, and between MCF and oak forest in one of the scenes (path 22 row 48). A regular degree of separability was achieved between MCF and pine-oak forest, MCF and pine forest, and oak forest and coffee plantation in some of the satellite scenes. For all other classes, the spectral separability was good.



**Figure 4.4.** Metrics for the 20 largest patches showing the area (top), core area (middle row), and perimeter-area ratio (bottom row), when considering MCF only (left), in conjunction with oak forest (middle) and in conjunction with pine-oak and oak forests buffers (right).

**Table 4.3.** Confusion matrix for Dempster-Shafer classifier using remote sensing in combination with expert knowledge. 95 percent confidence intervals are shown for overall error (OE) and Tau coefficient.

Dempster-Shafer classified land cover	Verification points						Total	Error of commission (%)
	MCF	OF	POF	PF	CP	NF		
Montane Cloud Forest (MCF)	25	9	2	2	0	0	38	34.2
Oak forest (OF)	9	39	6	1	1	3	59	33.9
Pine-oak forest (POF)	0	3	33	5	0	1	42	21.4
Pine forest (PF)	2	0	18	24	0	1	45	46.7
Coffee plantation (CP)	0	0	0	0	20	1	21	4.8
Non forest (NF)	0	2	1	3	5	87	98	11.2
Total	36	53	60	35	26	93	303	
Error of omission (%)	30.6	26.4	45.0	31.4	23.1	6.5	OE	24.7 [19.9-29.6]
Tau coefficient								70.6 [66.0-77.5]



**Figure 4.5.** Dempster-Shafer classification map on a digital elevation model (scale 1:50,000; rotation = 40°; field of view = 45°; tilt = 26°; z-scale = 0.9) showing: (a) the Tzontehuitz mountain range, where some of the largest MCF patches are found; (b) a coffee growing area in the northern range (above) and how this same area is classified as MCF by the Mexican national forestry inventory (SEMARNAP 2000, below).

## 4. Discussion

### *Implications of the study*

From the general trends observed in all Central America, and particularly in Mexico (Cairns *et al.* 1995, Bubb *et al.* 2004), we can assume that MCF loss has been large in the last decades. Current evidences also show that deforestation rates have considerably increased in the last decades in the region (Ochoa-Gaona & González-Espinosa 2000, Cayuela *et al.* 2006c), although it is difficult to ascertain how much of this forest loss could be attributable to MCF due to the lower resolution of temporal satellite data (particularly MSS Landsat satellite imagery). Thus it is very difficult to find a suitable historical reference point.

Nowadays the amount of MCF that remains in the Highlands of Chiapas is extremely small compared to the 350,000 ha that make up the study area. We found two previous estimates of MCF extent in the study area: (1) the Mexican National Forestry Inventory (SEMARNAP 2000); and (2) a report on the situation of the montane cloud forest in northern Chiapas (Bubb 1991). Our results differed in important respects from those presented in these studies.

The SEMARNAP study reports 22,400 ha of mature MCF and 16,200 ha of disturbed MCF with secondary vegetation for the same area. It is not clear how the SEMARNAP study made this distinction due to the difficulties to separate primary MCF from secondary MCF consistently using Landsat satellite imagery (see Sader *et al.* 1989, Steininger 1996). Comparisons with our maps (see **Figure 4.5b**) revealed that most of the disturbed MCFs in the SEMARNAP map were in fact coffee plantations that had been misclassified. The buffering property of other mountain forests which can shelter MCF remnants may extend to agro-ecological shade coffee plantations (Moguel & Toledo 1999). However, in the Highlands of Chiapas, coffee plantations have become altitudinally isolated from the forest type we define as MCF and should not have been classified as MCF.

Bubb's (1991) study reported only 3,500 ha of MCF and provided a much more reliable insight in current patterns of MCF distribution. The principal sources for his maps of MCF distribution were 1982 aerial photographs and 1:250,000 scale maps of land use and vegetation from the National Institute of Statistics, Geography and Information (INEGI) in addition to limited field surveys. Given the large rates of deforestation observed in this area in the last decade we believe that at the time of the study (1990) MCF occupied a much larger area than that reported by Bubb. Apart from changes that may have occurred since this period, the reasons for the differences between our study and this report are clearly due to methodological issues. Bubb's report was limited to sites with 500 ha or more of continuous forest cover as portrayed by the INEGI 1:250,000 map. Therefore, small MCF patches, many of them interspersed with other vegetation types, were disregarded. Here we reiterate a key virtue of our method. Unlike other approaches to imprecise estimation, it did not overlook small forest patches. This is important in this particular conservation context, as these habitats are known to harbour isolated individuals of endangered species, maintain habitat heterogeneity and diversity at the landscape level, and act as natural seed sources for restoration of nearby degraded natural areas (Turner & Corlett 1996).

### *How threatened is the remaining Montane Cloud Forest?*

A key finding of this study was that MCF habitat patches by themselves do not contain large undisturbed core areas. Exposure to disturbance is partly diminished through the existence of the woody buffers. However these larger assorted forest patches often have very intricate shapes due to human disturbance operating inside the forest in addition to disruption from the patch border inwards, probably due to clearance for agriculture at a very local scale (Ochoa-Gaona & González-Espinosa 2000). Thus, MCF core areas embedded within assorted forest patches are also exposed to some degree of human disturbance despite being buffered by other intervening forest types (Ramírez-Marcial *et al.* 2001).

The remarkable heterogeneity of this landscape suggests that careful consideration is needed when assessing the consequences of fragmentation. In contrast with classical island biogeography, landscape mosaic based approaches attempt to model the way organisms perceive and interact with landscape patterns. Their underlying logic assumes a detailed understanding of organisms' ecology (McGarigal *et al.* 2002). Dispersal of some organisms and permeability to ecological processes between the MCF patches occurring within a cluster may be favoured by the intervening forest habitats (Gascon *et al.* 1999). There is thus a need for much more work in this region on how specific organisms are being affected by changes in landscape structure.

A positive note is that no evidence has yet been produced of recent extinction of plant species (M. González-Espinosa & N. Ramírez-Marcial, pers. obs. 2004). Isolated and small patches may maintain large number of species (e.g. > 50 tree species/ha, L. Cayuela, unpublished data). Yet this may be changing, birds and mammals being especially vulnerable to high rates of MCF fragmentation (Pattanavibool & Dearden 2002).

#### *How can ecological functions be conserved?*

Recent deforestation and agricultural exploitation has increased the natural fragmentation of Mexican montane cloud forests (Luna *et al.* 2001). However, as we have stated, MCF habitats in the central Highlands of Chiapas are typically buffered by relatively large amounts of montane forest habitats. This is particularly important in the context of maintaining ecological processes related to water capture. Because MCF currently occupies only 1.4 percent of the study area, maintenance of other surrounding forest formations is necessary to retain the water captured by MCF in the subsoil. Furthermore, MCF that has degraded to oak forest or pine-oak forest due to low-intensity, long-duration disturbance regimes (e.g. selective logging) can still play some role in capturing atmospheric water. In contrast plantations of fast growing exotic species are generally considered to be water consumers rather than water producers (e.g. Sahin & Hall 1996). We therefore stress the need to

place more emphasis on MCF conservation rather than reforestation if maintaining or augmenting hydrological function is the goal.

#### *Mechanisms for conservation*

A critical challenge for conservation planning in this region is the complex social context. Insecure land tenure is a major barrier to establishing a coherent conservation strategy (Thoms & Betters 1998). Progress towards operational prioritisation of areas for conservation has been slow. An exception is the private Huitepec nature reserve. However, most of the MCF area remains outside the reserve and is exposed to logging or permanent deforestation. The threat to this forest is immediate. For example, at least 10 ha of the most valuable species rich forest are known to have been converted to other uses since the images used in this study were taken.

Communal forest ownership causes both challenges and opportunities in the context of management for conservation goals. One of the challenges is that the criteria used for evaluating the success of communal management are inevitably biased towards social and political concerns (Bray *et al.* 2003). Ecological and economic sustainability may be evaluated much less rigorously than would be the case when forests are under state or private ownership. One of the opportunities is that community management is able to set broader strategic goals. The region is moving towards a more secure system of land tenure. Thus communities can be encouraged to adopt a long-term perspective on management decisions. It is important to draw on positive experiences at a national level. However there is a danger of over generalisation. Most of the models of large scale community forest management that have been implemented in other regions of Mexico (Bray *et al.* 2003) have limited transferability to the conservation of small areas of fragmented forest containing species of little commercial value.

An additional hurdle to overcome before small fragments of MCF can receive adequate protection is the historical trend in Mexico towards focusing conservation initiatives around extensive protected areas. In

the context of the fragmented forests and densely populated landscapes of Chiapas there is scope for learning from the European experiences of plant micro-reserves in Valencia, Spain (Laguna *et al.* 2004), or even sites of Special Scientific Interest (SSI) in the UK (Barton & Buckley 1983). Such schemes rely partly on legislation, but also on negotiations based on the good will of the landowners. Recently, a national initiative has been proposed that could enable landowners to obtain benefits from the ecological services that forests provide (SEMARNAT 2003). Because the special importance of MCF is recognised by the inhabitants of the region, implementation of any of the initiatives mentioned above would bring a hope for the future of this threatened vanishing forest.

## 5. Conclusions

The area covered by MCF was estimated to be between 3,700 and 5,250 ha. This contrasts with the approximately 40,000 ha reported by the Mexican national forestry inventory in 2000. MCF was found to be highly scattered and fragmented within a matrix of other tropical montane forest types. These other forests may be buffering the remaining MCF habitats, mitigating their disturbance and enhancing their connectivity. We conclude that mechanisms should be sought to promote: (1) The protection of core areas containing MCF fragments in agreement with communal and private landowners; and (2) Conservation of the ecological functions of surrounding buffer zones.

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