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The effects of land use change on carbon content in the aerial biomass of an *Abies religiosa* (Kunth Schltdl. et Cham.) forest in central Veracruz, Mexico

M. R. Pineda-Lopez[1]*, L. R. Sanchez-Velasquez[1], G. Vazquez-Dominguez[1] and A. Rojo-Alboreca[2]

[1] *Instituto de Biotecnología y Ecología Aplicada. Universidad Veracruzana. Avda. de las Culturas Veracruzanas, 101. Col. E. Zapata. 91090 Xalapa (Veracruz), Mexico*
[2] *Unidade de Xestión Forestal Sostenible. Departamento de Enxeñaría Agroforestal. Escola Politécnica Superior. Universidade de Santiago de Compostela. Campus Universitario, s/n. 27002 Lugo, Spain*

Abstract

Aim of study: Were analyzed patterns and dynamics of forest cover change and land use for the period 1995-2005, and estimated carbon content in biomass in a forest of fir (*Abies religiosa*).

Area of study: Ejido El Conejo in the Cofre de Perote National Park, Veracruz, Mexico.

Material and methods: Spatial data (maps, orthophotographs) were used: (UTM); GRS 80 spheroid; zone 14, datum ITRF92; units: metres. Maps for 1995 and 2005 were constructed and compared. Carbon content in the aboveground biomass of fir (*Abies religiosa*) was estimated using an equation specific to species.

Main results: After one decade, the forested area had increased slightly (0.25%). The main type of land cover change was from shrubland to forest (probability of change 0.41); the change from forestland to shrubland with trees was 0.05%, and from forest to agriculture was 0.02%. Data from 2008 confirmed that the *A. religiosa* forest located in the *ejido* is distributed in largely unconnected fragments, of which some have a high density of young trees. Estimated carbon content in the aboveground biomass (163.51 Mg ha^{-1}) was higher than that estimated for other forests of the same species in Mexico.

Research highlights: It is recommended that ecological corridors be established throughout the reforested area, in order to connect these fragments (and increase carbon sequestration) and favour faunal and floral conservation. Finally, recognition should be given to the high vulnerability of *A. religiosa* forests to climate change, given their high degree of fragmentation and critical altitudinal limit.

Key words: aboveground biomass; carbon storage; ecological corridors; fir forest.

Introduction

Changes in forest landscape resulting from land use changes, *i.e.* deforestation or forest degradation, constitute an important source of ecological impacts that operate at local, regional and global scales (Lambin, 1997). Land use changes can lead to loss of biodiversity and a reduction in the quality of diverse ecosystems at these scales (Hobbs, 1993; Lee *et al*., 1995; Collinge, 1996; Tabarelli *et al.,* 2004; Ghosh, 2004). In Mexico, more than 90% of the original highland area and almost half of the cover by temperate forests have been lost, at an annual rate of approximately 1.1% (OCDE, 2003). However, quantitative information regarding where, when, how much and why landscape changes occur is still incomplete.

Study of land use changes in Mexico is a priority task (Bocco *et al*., 2001) because of the high rate of deforestation that is taking place. It is estimated that almost 80% of the deforestation occurs in the centre and south of the country (Masera, 1996). From the perspective of climate change, not much is known about the impact of land use changes on carbon stores at regional levels. However, it has been estimated that such changes represent a between 8 and 44% of all inputs to global warming (Cook *et al*., 1990; Schimel, 1995). Depending on the type of management regime

* Corresponding author: mariadelrosariop@hotmail.com
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to which they are subjected, forests may act as carbon sources or carbon sinks. In Mexico, data on carbon flows in relation to land use dynamics and carbon emissions are required so that the role of these in terms of the overall balance of greenhouse gas emissions can be determined (De Jong, 2001). Thus, the conservation of temperate forests, specifically coniferous forests, is one option for mitigating global warming. Such forests include those comprising the genus *Abies* (Rzedowsky, 1981; Sánchez-Velásquez *et al*., 1991). There are eight species of *Abies* in Mexico, six of which are endemic (Eguiarte, 1994). Forests of *Abies* do not cover large areas of land, mainly because of the particular ecological conditions under which they develop (between 2,600 and 3,800 m a.s.l., strongly sloping land and cold climates). Most of these forests are distributed within National Parks (Rzedowski, 1981) in the form of isolated patches, and are often restricted to hills, slopes or ravines. The largest continuous areas are found in the mountains surrounding the Mexico valley, followed by the Pico de Orizaba, Cofre de Perote and Nevado de Toluca mountains, amongst others. These areas represent approximately 0.16% of the vegetative cover in the country (Rzedowski, 1981).

In the state of Veracruz, land use change has generated a fragmented forest landscape, as the forests, together with jungle, only constitute 18% of the surface area in the state, whereas livestock farms occupy 47%, cropland 28% and other types of land use occupy 7% in flood zones and semi-arid areas (SEDARPA and CONAFOR 2006). In this state, *Abies* forests mainly comprise *Abies religiosa* (HBK.) Schltdl. et Cham (commonly known as oyamel) and to a lesser extent, *Abies hickelii* Flous & Gausen. Both are shade-tolerant, fast-growing species, although *Abies religiosa* regenerates more successfully in forest clearings (Lara-González *et al*., 2009) or in open areas below the canopy of the shrub *Baccharis conferta* (Sánchez-Velásquez *et al*., 2011). Two of the main area occupied by these species are Cofre de Perote and Pico de Orizaba, although the cover has been reduced as a result of agricultural expansion (Sánchez-Velásquez *et al*., 1991).

The objectives of the present study were as follows: 1) To establish the patterns of change in cover and land use between 1995 and 2005 in an *Abies religiosa* (oyamel) forest in the Cofre de Perote National Park; 2) To estimate the probability of land use change occurring; and 3) To estimate the carbon content in the aerial biomass of the fragmented *Abies religiosa* forests.

Material and methods

Study area

The Cofre de Perote National Park (CPNP) is one of the 60 most important mountain areas in Mexico (CONAFOR 2007), and one of the 13 natural protected areas in the state of Veracruz (CONABIO, 1997). The main type of land use in the state is forestry. Land use has been subjected to diverse policies, ranging from the formation of haciendas in the Colony, land use and ownership restrictions, to forest concessions (Gerez, 1982). Cultivation of the land has historically lead to a decrease in cover by natural forests of *Abies religiosa*, leading to a high degree of fragmentation (Sosa, 1937; Lagunes and Hernández, 1994).

The ejido known as *El Conejo*, of surface area 768 ha, is located at 3.250 m a.s.l. in the CPNP, and is one of the four most populated areas in the Park, with 996 inhabitants, according to the census carried out in 2005 (Gobierno del Estado de Veracruz *et al.*, 2008). The climate in the area is temperate-subhumid, with rainy summers; the mean annual temperature is between 10 and 12°C, and the mean annual precipitation between 1,200 and 1,500 mm (Soto and Angulo, 1990; Meza and Leal, 1997). The main type of soil in the zone is andosol, which is susceptible to erosion (Narave and Taylor, 1997). The ejido contains 22.15% of all *Abies religiosa* (oyamel) forests in the CPNP. In 2005, oyamel forest occupied an area of 338.49 ha, *i.e.* 44% of the total area of the ejido.

Cartographical and digital interpretation of the changes in land use between 1995 and 2005

Spatial data (maps, orthophotographs), with the following general characteristics were used: universal transverse mercator projection (UTM); GRS 80 spheroid; zone 14, datum ITRF92; units: metres. Maps for 1995 and 2005 were constructed and compared. Owing to inconsistencies in the information provided by the sources consulted (Instituto Nacional de Geografía y Estadística, Registro Agrario Nacional), in regard to the orientation of the ejido polygon (surface area, 786 ha), we decided to include a buffer zone of 280 m around the polygon, so that a surface area of 1,044.81 ha was finally considered. The specifications of each of the maps constructed were as follows:

Vegetation and soil use map (1995)

The digital orthophotography provided by the Instituto Nacional de Estadística y Geografía (INEGI) was used. The characteristics were as follows: 1) Orthophotograph code E14B26E; 2) Flight date March 1995; 3) Scale 1:75000; 4) Pixel size 2 m^2.

The polygons were digitalized directly on the screen over the corresponding orthophotos, as follows. The scale of the trace of the polygons (digitalization) was 1:10000, which decreased the error margin (scale of representation 1:15000). The minimum mappable area was approximately 3 × 3 mm, on the same scale as the trace (1:10000), *i.e.* only polygons of approximately 900 m^2 and above (real measurements) were digitalized. The minimum mappable area is established in the official standard NOM-023-RECNAT-2001 (INE 2001), which determines the technical specifications for the mapping and classification in the elaboration of soil inventories (scales 1:20000 and above). For each polygon, the number or labelling of the respective type of vegetation or land use was assigned, and a minimum range of area that each category should cover was defined: 1) In the polygons identified as *cropland*, this type of land use should cover 90% of the area considered. Although isolated trees were found in some polygons in this category, they occupied less than 10% of the area, so that the polygons were still considered as cropland; 2) In the polygons identified as *cropland with trees*, the crops occupied between 60 and 90% of the area (and therefore between 40 and 10% was occupied by trees); the trees were always isolated specimens. Finally, the areas and categories of land use were labelled and quantified, and represented on a map.

Vegetation and land use map (2005)

Digital orthophotos (from INEGI) with the following characteristics were used: 1) Orthophotograph codes E14B26E3 and E14B26E4; 2) Flight date November 2004; 3) Scale 1:40000; 4) Pixel size 1 m^2. The same steps used in constructing the previous map (Vegetation and land use map 1995) were followed, and are therefore not described again.

Changes in land use and vegetation between 1995 and 2005

This map is the product of the integration of the two previous maps by the map overlay method. Each of the previous maps was represented on a 1:15000 scale and contained auxiliary information (hydrological data, routes of communication, etc.) from the topographical map E14B26 (Perote) version 4, scale 1:50000. The information was processed with ArcView ver. 3.2 software from ESRI (1992-1999).

Considering the changes in land use during the period 1995-2005, the probabilities of change in the different categories were calculated by use of a transition matrix:

$$A = [a_{ij}] = \sum_{j=1}^{n} a_{ij} \qquad \text{(Eq. [1])}$$

where A is the matrix of transition between categories of land use, and a_{ij} is the permanence, or change from category i to category j within a certain period. The matrix was used to calculate the probabilities of transition, with the following equation:

$$r_{ij} = \frac{a_{ij}}{a_i} \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n, \qquad \text{(Eq. [2])}$$

where r_{ij} is the probability of transition of category i to category j within a certain period of time.

Estimation of the stores of carbon in the tree biomass

To determine the structure of the population, a square matrix of 1 × 1cm was overlaid on the orthophotograph (scale 1:10000) of the ejido polygon. Seventeen quadrants of 50 × 12.5 m (625 m^2) were located at random in the polygon, and only in the 13 fragments of *Abies religiosa* (which represent the total area covered by this species) (Fig. 1).

The quadrants, which covered a total area of 10,625 m^2, were georeferenced using a GPS. Each quadrant was divided into sub-quadrants of 10 × 12.5 m^2 (125 m^2) to facilitate the sampling and to enable them to be used as permanent plots. The amount of regeneration was measured within a zone of size 6.25 × 10 m^2, chosen by the random number method, and was established in each of the quadrants.

The following features were recorded in each quadrant: altitude, exposure, soil conditions and evidence of disturbance from fire, pests, etc. All individual specimens of tree present in each quadrant were also recorded. The diameter at breast height and the total height of each tree were measured. Two types of tree species regeneration were considered: a) in individuals

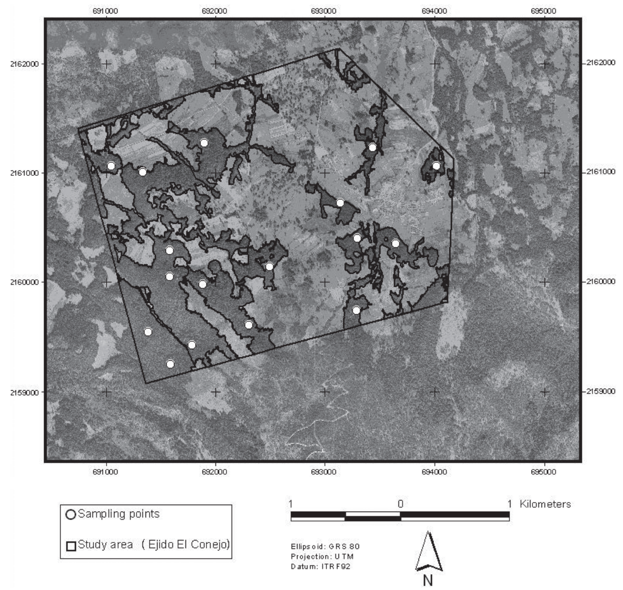

Figure 1. Sampling points in the forest of *Abies religiosa*.

of height < 30 cm, and b) in individuals of height between 30 cm and 1.3 m.

The information on the structure and sizes (heights and diameters) of trees in the stands (fragments) was used to estimate the carbon content, according to the method proposed by the Intergovernmental Panel on Climate Change (IPCC, 1994).

The volume and biomass were estimated from the following equations:

$$v = d^2 \cdot \left(\frac{\pi}{4}\right) \cdot h \cdot f \qquad \text{(Eq. [3])}$$

where:
v = volume (m^3)
d = diameter at breast height (m)
$\pi/4$ = 0.7854
h = height of the tree (m)
f = morphic coefficient = 0.7 (this factor is used to correct the volume estimates for systems involving irregular shapes).

$$B = v \cdot Db \cdot FE \qquad \text{(Eq. [4])}$$

where:
B = biomass (Tn)
v = volume (m^3)
Db = basic wood density (Tn/m^3)
FE = stem expansion factor

The value used for the basic wood density was 0.3874 g/cm^3, as proposed by Rojas-García and Villers-Ruiz (2008). The value used for the stem expansion factor was 1.3 (IPCC, 1994; Rojas-García and Villers-Ruiz, 2008).

The carbon content was calculated by the method proposed by the IPCC (1994), which consists of applying the following equation:

$$CC = B \cdot 0.4648 \qquad \text{(Eq. [5])}$$

where:
CC = carbon content (Tn/ha)
B = biomass (Tn)
0.4648 = proportion of carbon in the dry biomass, for *Abies religiosa* (Avendaño *et al.,* 2009).

Finally, the carbon content in each quadrant was obtained by multiplying the value per hectare by the total surface area of the fragment, giving an estimation of the tonnes of carbon contained during the sampling year.

Estimation of increases in volume and in age

For each fragment of oyamel forest, and equation explaining the relationship between age and volume was developed.

The age of each tree was estimated by expressing t (age) from the equation obtained by Sánchez-Velásquez *et al*. (1991) for the same species (*A. religiosa*) and in the same region:

$$d = \frac{t}{0.00357 \cdot t + 1.3887} \qquad \text{(Eq. [6])}$$

where:
d = diameter at breast height (cm)
t = age (years)

Expressing equation [6] for (t) produces:

$$t = \frac{1.3887 \cdot d}{1 - 0.00357 \cdot d} \qquad \text{(Eq. [7])}$$

To estimate the increase in volume per stand between 1995 and 2005 (*i.e.* a period of 10 years) the diameter of each individual tree in 1995 was calculated from equation [6], as follows:

$$d_{1995} = \frac{t - 13}{0.00357 \cdot (t - 13) + 1.3887} \qquad \text{(Eq. [8])}$$

where t-13 represents the age of the individual tree in 1995 (as the sampling was carried out in 2008).

In a similar way, the diameter of each individual tree in 2005 was estimated as:

$$d_{2005} = \frac{t-3}{0.00357 \cdot (t-3) + 1.3887} \quad \text{(Eq. [9])}$$

These diameters were used to estimate the increase in volume of each stand in the 10 year period, as follows:

a) The volumes of each individual tree in 1995 were estimated; b) the volume was multiplied by the number of individual trees per ha for the corresponding size class; c) the total volumes per ha in 1995 were calculated; d) the same operations (a,b,c,) were carried out for 2005; and e) the increase in volume per ha per stand was calculated by subtracting the total volume for 1995 from the total volume for 2005.

Results

Vegetation and land use map 1995

In 1995, the landscape in the *El Conejo* ejido was dominated by two types of land use: potato cultivation and oyamel forest (*Abies religiosa*); cropland plus forest was the third most common land use (Figs. 2 and 3).

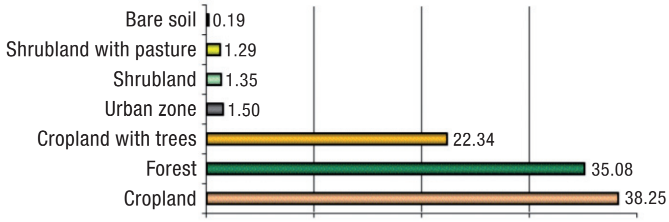

Figure 3. Percentage distribution of types of land use in the *El ejido* in 1995.

Vegetation and land use map 2005

Ten years later, the area of bare soil had decreased slightly. The area occupied by shrubland with pasture, which in 1995 was close to 1.29%, had disappeared by 2005. The area occupied by shrubland, mainly comprising *Baccharis conferta*, increased from 1.35% to 2.41%. The area occupied by tree plantations decreased from 22.34% to 21.90%. Forest cover increased slightly from 35.08% to 35.33% of the ejido, and the area destined to potato cultivation decreased from 38.25% to 36.55% (Figs. 4 and 5).

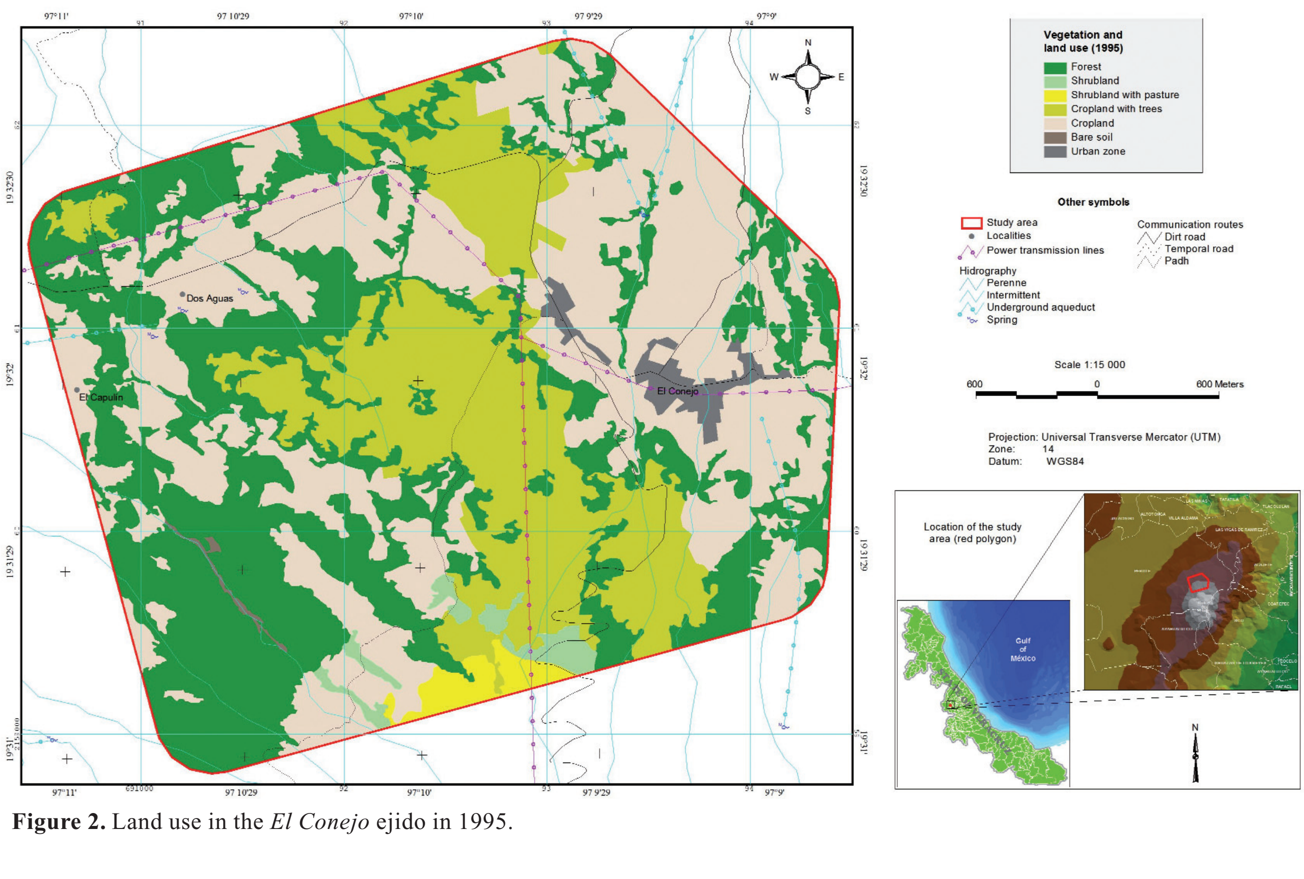

Figure 2. Land use in the *El Conejo* ejido in 1995.

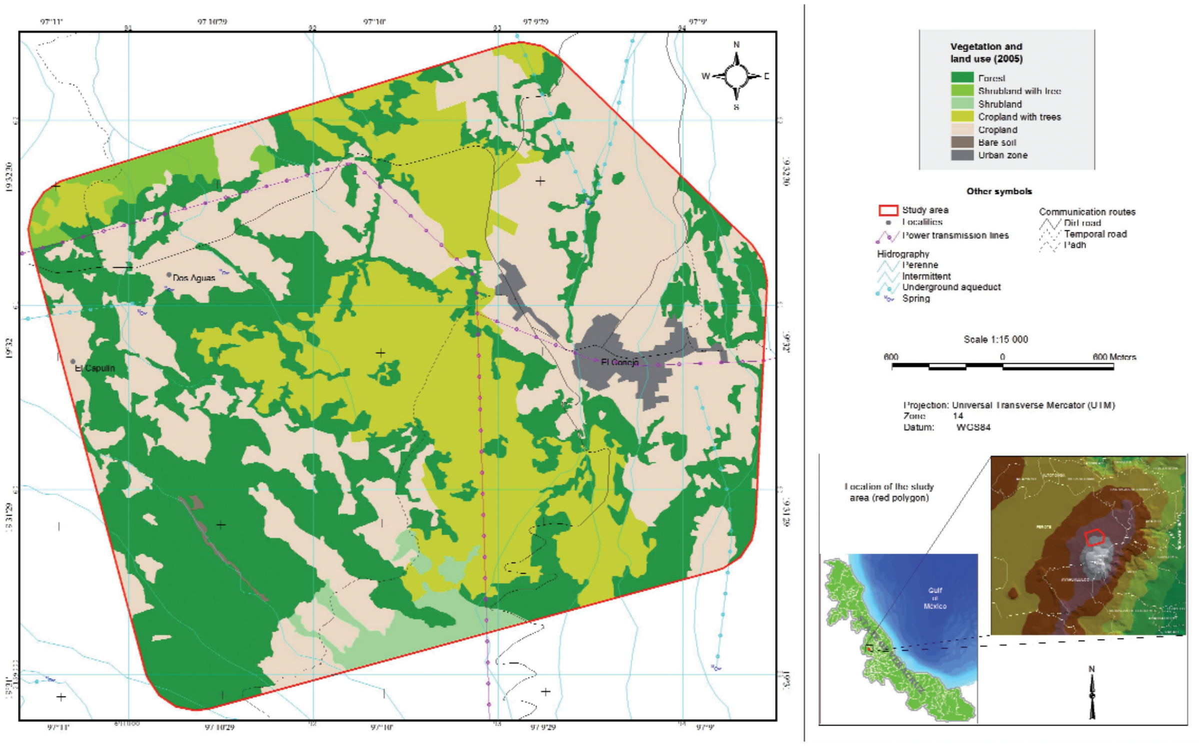

Figure 4. Land use in the *El Conejo* ejido in 2005.

Change in land use and vegetation cover between 1995 and 2005

The landscape of the *El Conejo* ejido remained relatively stable over the 10 year period (1995-2005) (Table 1). The changes did not usually affect more than 1% of the area modified (Table 2).

In terms of probabilities of change (r_{ij}), the forest area was found unlikely to change as most of the changes were from forest to shrubland with trees (probability 5%) and from forest to cropland (4%) (Table 3). In favourable terms, it was found that the land use category that would contribute most to increasing the surface area of forest would be shrubland (probability of change from shrubland to forest, 41%), assuming that the present conditions are maintained (Fig. 6).

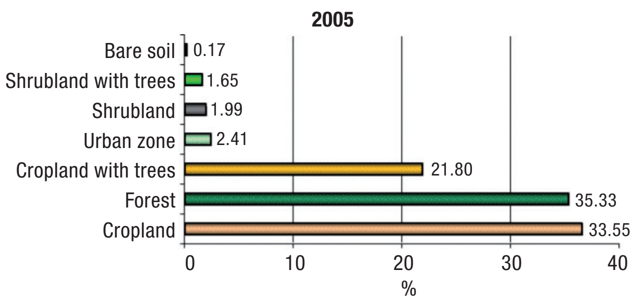

Figure 5. Percentage distribution of types of land use in the *El Conejo* ejido in 2005.

Estimation of carbon content in the aerial biomass

A summary of the data measured during 2008 in the different stands of *Abies religiosa* is shown in Table 4. The density was similar in all except two of the stands (11 and 12), in which the density values were much higher than the mean value. Stand 11 was a very dense, obviously a suppressed stand, as reflected by the height, diameter, volume and cover values. The tree data show that the heights of all stands were more or less homogeneous, within a range between 10 and 20 m, and did not surpass the upper value.

With the tree data obtained, the carbon content was estimated from the volume and biomass calculated (Table 5). It was found that for the total surface area of the forest (219.19 ha), the carbon content was 37.69 Tn of C, which represents 138.34 Tn of fixed CO_2; this value was obtained by multiplying the number of tonnes of carbon per hectare by 3.67, as proposed by Ryan *et al*. (2010). This means that for each hectare of forest lost in the ejido, 138.34 Tn of CO_2

Table 1. Matrix of changes in land use and vegetation in the *El Conejo* ejido in the period 1995-2005 (area in ha)

Category	Vegetation and land use, 2005						
	Forest	Shrubland	Shrubland with trees	Cropland with trees	Cropland	Bare soil	Urban zone
Vegetation an land use, 1995							
Forest	0.3	0	0	0	0	0	0
Shrubland	0	0	0	0	0	0	0
Shrubland with pasture	0	0	0	0	0	0	0
Cropland with trees	0	0	0	0.2	0	0	0
Cropland	0	0	0	0	0.4	0	0
Bare soil	0	0	0	0	0	0	0
Urban area	0	0	0	0	0	0	0

Table 2. Change in vegetation and land use in the period 1995-2005

Type	Area (ha)	%
No change		
Cropland	375.4	35.9
Forest	338.5	32.4
Cropland with trees	222.7	21.3
Urban zone	15.7	1.5
Shrubland	8.3	0.8
Bare soil	1.4	0.1
Subtotal	962.0	92.1
Change		
Forest to Shrubland with trees	16.9	1.6
Cropland to Forest	14.7	1.4
Shrubland with pasture to Shrubland	12.3	1.2
Cropland with trees to Forest	8.9	0.9
Forest to Cropland	6.9	0.7
Shrubland to Forest	5.8	0.6
Cropland to Urban zone	5.1	0.5
Forest to Cropland with trees	4.4	0.4
Cropland to Shrubland	2.6	0.2
Cropland with trees to Shrubland	2.1	0.2
Cropland to Cropland with trees	2.0	0.2
Shrubland with pasture to Forest	1.1	0.1
Subtotal	82.8	7.9
Total	1,044.8	100.0

would be emitted. These values are underestimated, as they only correspond to the aerial biomass of the trees (trunk and branches) and do not take into account the emissions due to loss of carbon from the soil, oxidation of organic matter, or the use of wood burning stoves (widely used throughout the ejido).

Considering the estimated amount of carbon in the aerial biomass (37.69 Tn C), for the area sampled in 2008 (219.19 ha), the estimated forest areas for 1995 and 2005 were used to characterize the loss or gain in the carbon content in the aerial biomass during the period. In 1995, for a forest of surface area 367.03 ha, the carbon content in the aerial biomass was 63.12 Tn, and in 2005 it was 63.58 Tn, considering a surface area of 369.70 ha. In other words, in the 10 year period, the surface area of the *Abies religiosa* forest in the ejido increased by only 2.67 ha, representing an increase in the carbon content in the aerial biomass of the forest of 459.17 Tn, which is the equivalent of 1.68 Tn of fixed CO_2. Comparison between the estimated number of tonnes of carbon in the aerial biomass in 1995 (63.12 Ton C) and the estimated number of tonnes for 2008 (37.69), revealed a loss of 25.42 Tn C, *i.e.* a loss of the carbon content in the aerial biomass of 59.72% with respect to 1995.

Table 3. Matrix of probability of change (r)

Category	Forest	Shrub	Shrubland with trees	Cropland with trees	Cropland	Bare soil	Urban size	Total
Forest	0.92	0.00	0.05	0.01	0.02	0.00	0.00	1.00
Shrubland	0.41	0.59	0.00	0.00	0.00	0.00	0.00	1.00
Shrubland with trees	0.08	0.92	0.00	0.00	0.00	0.00	0.00	1.00
Cropland with trees	0.04	0.01	0.00	0.95	0.00	0.00	0.00	1.00
Cropland	0.04	0.01	0.00	0.01	0.94	0.00	0.01	1.00
Bare soil	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Urban zone	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00

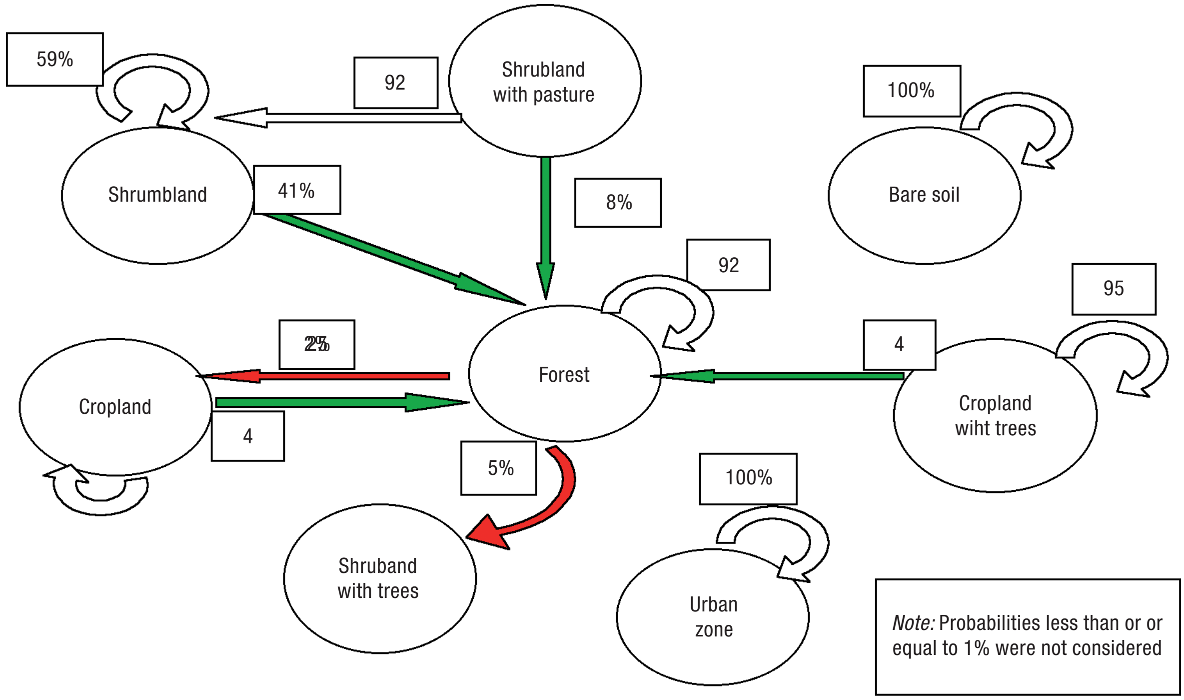

Figure 6. Dynamics of the probabilities of land use change in the *El Conejo* ejido.

The distribution of the carbon content at the landscape level in the *Abies religiosa* forest is shown in Fig. 7. The stands with the lowest carbon contents were those closest to the village (stands 1 to 6), whereas those with the highest contents were those located in the southwest of the ejido and in the highest parts of the mountain (stands 10 to 13). Stands 1, 2 and 3, which were located at least 500 m from the village, contained between 300 and 1,000 stumps with maximum diameters of 20 cm, which reflects a large amount of felling. Stands 4, 5 and 6 (located at between 500 and 1,400 m from the town) contained between 50 and 100 stumps of maximum diameter 20 cm.

Discussion

The long history of forest exploitation in the region (Sosa, 1937; Gerez, 1982, 1983; Jardel, 1986; Gobierno del Estado de Veracruz *et al.*, 2008) has created landscapes such as that under study. The study area

Table 4. Summary of data on the *Abies religiosa* stands sampled in 2008

Stand	Surface area (ha)	Density (ind/ha)	Mean height (m)	Normal mean diameter (m)	Cover (m^2)	Volume (m^3/ha)
1	3.72	1.136	12.02 ± 11.78	0.18 ± 0.18	12.58 ± 14.76	243.23
2	7.88	1.232	18.37 ± 9.50	0.19 ± 0.12	12.75 ± 12.05	449.17
3	9.33	1.008	20.55 ± 10.19	0.24 ± 0.20	18.54 ± 23.26	655.97
4	4.81	1.184	10.50 ± 9.47	0.14 ± 0.16	12.02 ± 18.02	133.96
5	6.89	1.328	14.83 ± 10.19	0.19 ± 0.16	5.88 ± 6.48	390.87
6	7.28	960	14.62 ± 5.26	0.21 ± 0.11	7.37 ± 5.30	340.29
7	19.69	1.392	11.83 ± 7.08	0.14 ± 0.14	9.46 ± 11.85	177.45
8	26.71	1.296	10.97 ± 9.19	0.12 ± 0.11	8.44 ± 9.08	112.55
9	17.46	960	18.39 ± 10.03	0.23 ± 0.14	14.72 ± 14.76	513.45
10	16.75	992	15.65 ± 10.77	0.20 ± 0.20	18.31 ± 21.53	341.40
11	22.84	6.496	8.24 ± 9.46	0.09 ± 0.13	5.47 ± 9.34	238.37
12	47.47	4.752	18.13 ± 8.85	0.19 ± 0.14	12.03 ± 10.27	1,709.90
13	28.36	1.744	20.05 ± 10.91	0.26 ± 0.19	21.40 ± 17.52	1,299.56

Table 5. Estimation of the carbon content in the *Abies religiosa* stands sampled in 2008

Stand	Surface area (ha)	Density (stem/ha)	Volume (m^3/ha)	Biomass (ton/ha)	"C" content (ton/ha)	Total "C" content (ton)
1	3.72	1,136	243.23	122.49	56.93	211.80
2	7.88	1,232	449.17	226.21	105.14	828.53
3	9.33	1,008	655.97	330.40	153.55	1,432.63
4	4.81	1,184	133.96	67.47	31.36	150.83
5	6.89	1,328	390.87	196.85	91.50	630.41
6	7.28	960	340.29	171.37	79.65	579.89
7	19.69	1,392	177.45	89.36	41.54	817.87
8	26.71	1,296	112.55	56.68	26.35	703.73
9	17.46	960	513.45	258.58	120.19	2,098.51
10	16.75	992	341.40	171.94	79.92	1,338.62
11	22.84	6,496	238.37	120.05	55.80	1,274.42
12	47.47	4,752	1,709.90	861.13	400.26	19,000.22
13	28.36	1,744	1,299.56	654.48	304.20	8,627.24
Total						37,694.72

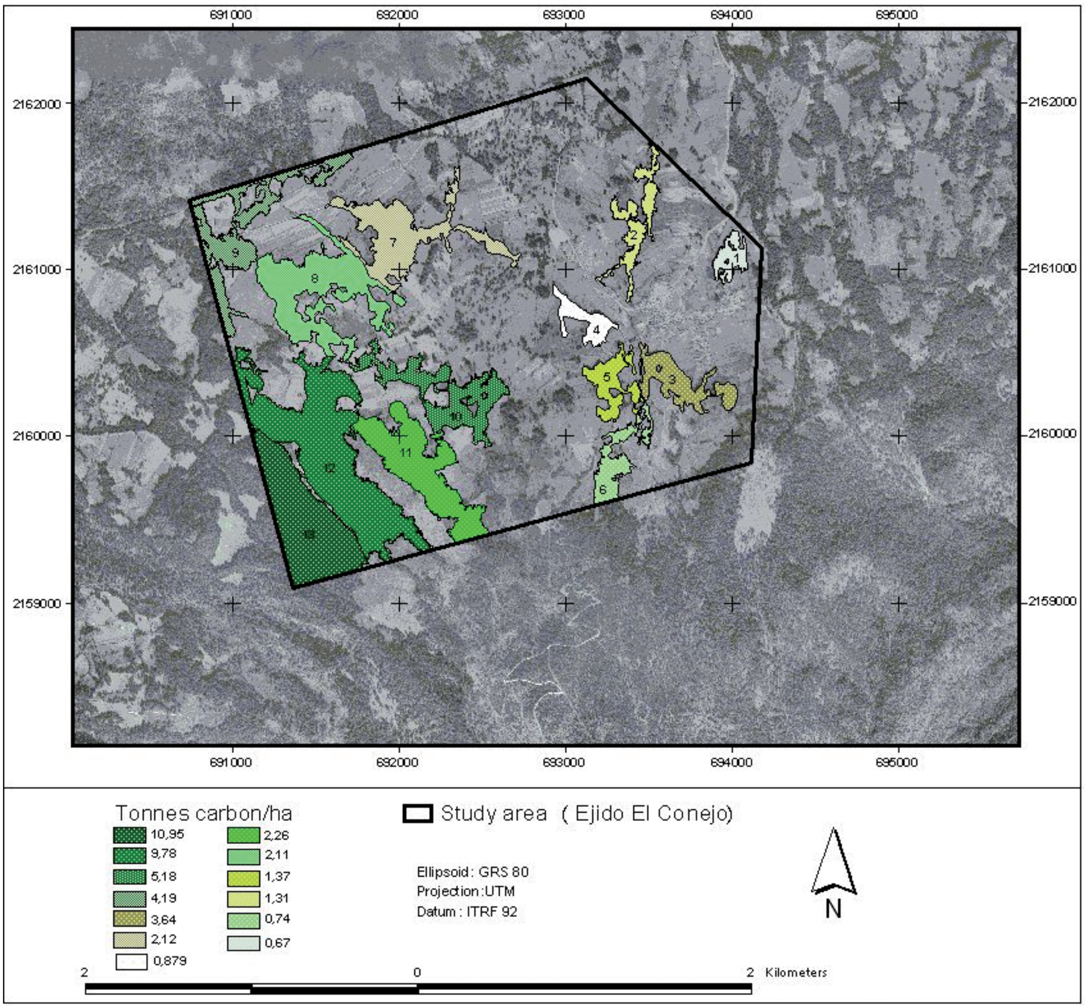

Figure 7. Spatial distribution of the carbon content (tonnes/ha) in the *Abies religiosa* forest in the *El Conejo* ejido.

contains fragmented suppressed forest comprising very dense residual woodland (up to 6496 individual trees per hectare), surrounded by the following landscape units: cropped areas with isolated trees, urban zones, shrubland and bare soil. Forest fragmentation occurs in several tree species throughout the world, as a direct result of the change in land use, for example in *Pinus silvestris* in Scotland (Matti *et al*., 2010), *Picea asperata* in China (Zhong-Sheng *et al*., 2010), and *Astrocedrus chilensis* in Patagonia (Carabelli *et al*., 2006). On the other hand, considering the probabilities of landscape change in the *El Conejo* ejido, assuming that the present conditions are maintained, the most likely scenario is that the forest area will be maintained or that there will be a change from shrubland + pasture to shrubland, both with a probability of 92% of occurring. The predicted maintenance of forest cover contrasts with what has been observed at a worldwide level. It has been estimated that in the second half of the 20th century, the area occupied by forest throughout the world will decrease to only 3,500 million hectares as a direct result of human exploitation (Ghazoul and Evans, 2004). The structure of the *Abies religiosa* forest in the *El Conejo* ejido is currently characterized by high density of young trees, which does not constitute a large store of carbon, but which together with the high density of seedlings present in the forest represents a large potential for carbon sequestration (Baishya *et al*., 2009). This forest also represents an important source of repopulation (Lara-González *et al*., 2009) and a potentially valuable instrument for connecting forest fragments. Biomass quantification in forests has been used as an important tool for estimating the carbon content in tree stands (Lim, 1988; Brown, 1997; Brown *et al*., 1989; Ordóñez *et al*., 2001; Jaramillo *et al*., 2003; Acosta-Mireles *et al*., 2002; Avendaño *et al.,* 2009). Use of this tool has shown that the carbon content per hectare in *Abies religiosa* forests in the ejido (171.97 Tn/ha) is much higher than the carbon content in forests of the same species in other areas of the country, estimated by the same method, proposed by the IPCC (1994), and reflects the high productivity of these forests. Thus, carbon contents of 57 Tn/ha (Fragoso, 2003) and of 28.5 Tn/ha (Zamora, 2007) have been estimated for *Abies religiosa* forests in Michoacán, and of 57 Tn/ha in forest in Mexico State (García and Sánchez, 2009) and 58 Tn/ha in forests in central Mexico (Almeida-Leñero *et al*., 2007), although the latter estimate was not obtained by the same method. Bellon *et al*. (1993) (cited by Torres and Guevara, 2002) estimated that in a period of 100 years the potential carbon capture in Mexico may be between 40 and 130 Tn/ha year, considering as an alternative maintaining a potential area of 6 million hectares under a conservation scheme in Natural Protected Areas (NPA). However, maintaining NPAs does not guarantee carbon capture, because as shown in the present study, maintenance of the forest for a decade did not lead to a very large increase in carbon content, in terms of aerial biomass. On the other hand, it is known that highly reduced or fragmented populations of tree species, such as in the present study, are particularly vulnerable in changing environments (McKay *et al*., 2005). Thus, in accordance with the predictions for Mexico from the point of view of climate change, a drastic reduction in the distribution of conifers (Trejo *et al.,* 2011) and a change or decrease in the distribution of the habitats of various endemic species and/or species in danger of extinction (Gómez-Mendoza and Arriaga, 2007) are expected. In other words, even though the *Abies religiosa* forest in *El Conejo* does not represent a very large reservoir of carbon in terms of aerial biomass (although other reservoirs present must be determined), its location within a PNA has not led to significant increase in the surface area of the forest. Finally, because of the fragmented nature of these forests and their critical altitudinal position in high mountain areas, this species is vulnerable to the effects of climate change. For all of the above reasons, it is recommended that the following possibilities are considered within the Park Management Plan, which is currently under review: a) Creation of reforestation corridors that will connect forest fragments reforested with seedlings that can be extracted from natural forests; b) Focus reforestation efforts in shrubland areas where there is a high probability of a rapid increase in the forest area; and c) Determination of the potential distribution of the species in light of predicted climate change. Finally, a profound review of the forest legislation concerning the Natural Parks in Mexico is required. Not only should the presence of human settlements in this type of territory be recognised, but alternatives that guarantee forest conservation, mitigation of climate change and sustainable land management must be identified.

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