



**LANDSCAPES AND FRAGILE ECONOMY: ECOSYSTEMS AND AGROECOSYSTEMS IN THE COATEPEC- LA ANTIGUA BASIN, VERACRUZ MEXICO**

**[PAISAJES Y ECONOMIA FRAGIL: ECOSISTEMAS Y AGROECOSISTEMAS EN LA CUENCA COATEPEC-LA ANTIGUA, VERACRUZ MÉXICO]**

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**SUMMARY**

The objective of this study was to obtain landscape fragility indexes (LFI) as a way of acquiring trustworthy data for a sustainable use of soils in the Coatepec- La Antigua basin, in Veracruz, Mexico. For collecting landscape data, an altitude transect was done from 3200 m on the east side of the Cofre de Perote mountain, up to the sea level, close to the city of Veracruz. National forestry inventory data and soil use charts were used along with GIS techniques to generate images showing landscape fragility resulting from soil use. Geographical data were contrasted with socioeconomic characteristics in the region and with the social value of landscapes for the inhabitants. Results show that high LFI (grade 5) correspond to only 2.8% of the landscape; a 22.5% were classified as medium-high (grade 4), and are related to high and medium forest in the mountain range. The most fragile areas are located in the upper parts of the basin, which is coincidental with the highest marginality indexes, the highest population density, and factors of socioeconomic fragility such as international migration fluxes and lower income.

**Keywords:** Landscape; vulnerability; geostatistics; interpolation; sustainability; territorial ordering.

**RESUMEN**

El objetivo del trabajo fue obtener índices de fragilidad del paisaje (IFP) como una forma de proporcionar datos confiables para el uso sostenible del suelo en la Cuenca Coatepec- La Antigua, Veracruz, México. Se incorporó un transecto altitudinal de colecta de datos de paisaje, desde los 3200 m en la cara oriental del cofre de Perote, hasta el nivel de mar, cerca de la ciudad de Veracruz. Se utilizaron datos del inventario nacional forestal y cartas de uso del suelo para, con sistemas de información geográficos para generar imágenes que muestran la fragilidad de los paisajes por uso del suelo. Los datos geográficos fueron contrastados con las características socioeconómicas de la región y el valor social de los paisajes para la población que los habita. Los resultados muestran que los IFP altos (5), se localizan en el 2.8 % del paisaje, el 22.5 % se clasificaron como medio-alto (4), e inciden en zonas de bosque, selva mediana y selva alta, en la zona de montaña. Las áreas más frágiles se localizan en las partes altas de la Cuenca, lo cual coincide con los mayores índices de marginalidad, mayor densidad de población y factores de fragilidad socioeconómica como flujo migratorio internacional y menor ingreso.

**Palabras claves:** Paisaje; vulnerabilidad; geostatística; interpolación; sostenibilidad; ordenamiento territorial.

**INTRODUCTION**

Worldwide economic and social transformations occurring in the latter half of the twentieth century have caused severe changes on the landscape. Such changes directly affect society, natural areas and the overall economy. Since landscape is the area in which

natural elements live, as well as those other elements modified or introduced by humans, shaping the landscape of a specific field within a given period depends strongly on the model for resource exploitation and territorial ordering that the dominant socioeconomic structure imposes (Jiménez and Porcel, 2008).

Landscape is formed by a number of anthropogenic and natural factors (such as topography, vegetation, fauna or climate), which are exposed to different types of stress, and that are likely to be affected by events that vary in space and time (Sanchez *et al.*, 2007; Kepner and Mueller, 2007). However, landscape is also considered as the cultural dimension of nature, because the transformation of the sites is strongly influenced by society, making it a reflection of their performance (Abbott and Garcia, 2006).

Scientific analysis of landscape has become extremely important for integrated planning of a particular territory. In the search for balance between the paradigms of development and environmental conservation, the concept of sustainability rests at the foundations. Landscape is analyzed to determine its quality and the fragility or vulnerability components. Here, fragility refers to its susceptibility to change when developing an application on it, while expressing its degree of deterioration (Nilolova *et al.*, 2007). From this point of view, landscape fragility can be determined by indirect methods based on factors that define the physical environment (Galán *et al.*, 2009). Landscape fragility can also be defined as a generic quality intrinsic to the territory. Values inherent to natural deterioration, cultural, and visual perceived values, can be measured directly in the field and calculated by a series of indices (Claval, 2002, Martínez *et al.*, 2003). However, whenever some use or action is exerted on the land, such values are subject to change (Galán *et al.*, 2009, Rodríguez-Loínaz *et al.*, 2007).

According to Muñoz-Pedrerros (2004), landscape fragility, is a way of establishing landscape vulnerability, making it an important aspect to consider when planning land use and territorial ordering activities that result in agroecosystems and human settlement. Determining landscape fragility is a tool to support the solution of the most serious problems humanity is facing such as environmental degradation (Martí and Pérez, 2001, Díaz *et al.*, 2007). Landscape fragility results in a reduction of the quality of regional environmental services, on land productivity, and in the poverty of its inhabitants. Thus, a more elaborate concept of nature conservation should include a combination of two principles: the need for resource planning based on very accurate inventories, and taking preventive measures to ensure that resources are not depleted.

Tools such as geographic information systems (GIS) are of relatively recent use. GIS techniques are essential for studies of landscape and environment given their ability to synthesize a large number of variables and creating models that allow obtaining quality maps and/or environmental fragility. Data field reading and its inclusion into a GIS vector and raster

images, define the assessment, mapping and expression of the average values for the units. Hence, the use of GIS provides a quick and easy analysis of geospatial information, generating the display of territorial patterns from the behavior of some variable (s) of interest, in this case, and landscape fragility (Martínez *et al.*, 2003).

While one usual objective of this type of work is territorial ordering and land use planning and management, as two linked aspects, it should be recognized that social problems in the studied territory, represents a number of important factors to be considered, as manifestation of actions that underlie the potential transformation of ecosystems and agro-ecosystems. Thus, it is important to consider that the geospatial recognition of territorial spaces should be enriched with socio-economic values by anthropogenic impacts that occur in landscape patterns, as a way of supporting decisions on territory, but considering that in the end, society is the final client for this type of research. Therefore, the objectives of this study were to determine landscape fragility indexes (LFI) in ecosystems and agro-ecosystems of the Coatepec-La Antigua basin, likewise, to define their territoriality, to quantify current land surface fragility, and to analyze some socio-economic factors contributing to the landscape, specifically to provide elements that contribute to decision-making and regional sustainable management.

## MATERIAL AND METHODS

In order to determine landscape fragility indexes (LFI) fieldwork was conducted. an altitudinal transect between Cofre de Perote and the coastal area of the municipality of Antigua in the state of Veracruz, Mexico. This encompasses the area between 97° 07'34 "and 96°19'23" of west longitude and between 19°30'50" and 19°16'44" of north latitude. The transect was a sampling band designed and sized according to the area of interest, and in accordance with Garitacelaya *et al.*, (2009) recommendations. A total of 18 variables of study were considered as LFI indicators as well as their descriptors. The identification and definition of the variables was conducted based on a literature survey and expert opinion (Table 1). The variables and descriptors were weighted according to their contribution to the fragility.

The respective values of fragility, were obtained according to the formula:

$$LFI = \sum_{i=1}^n (P * n)_{pp_i}$$

Where:

P=Evaluated indicator

$n$ =Descriptors for each indicator  
*LF*=Landscape Fragility Index  
*pp*=Weighted parameters assessed

This process resembles that of making an inventory, and was based on a detailed analysis of the area of study, where sampling stations were established. The method is useful in studies of natural environment for field data collection. From this point of view, this is a landscape analysis which gives some weight to the components and integrates them into a spatial perspective that makes it easy to clarify the properties inherent to a geosystem as a whole (Cotler and Priego, 2007). For collecting information in the field, a systematic equidistant mesh consisting of 147 sampling points separated by a distance of 2.5

kilometers was traced on a Google Earth image of the study area. Within the mesh, information was collected on the variables listed in Table 1 to obtain the data that fed the calculation of LFI.

Central areas mapping technique was used to determine the main area of influence or activity of an organism, object, or resource, and involves the identification of characteristics of an area from a set of points. Such points can be used to define one or more polygons, using space techniques commonly used to create an analysis of patterns of human or other organisms activity within a geographic area (Sutton and Costanza, 2002).

Table 1. Indicators and descriptors used in the landscape analysis of the Coatepec-La Antigua basin. Veracruz, 2010.

Indicators	Descriptors
Altitude (masl)(a higher altitude means greater fragility)	1) < 500; 2) 501- 1000; 3) 1001- 150; 4)1501- 2000; 5) > 2000
Slope, % (a tilter slope, means greater fragility)	1) < 15; 2) 16 - 30; 3) 31 – 45; 4) 46 - 60, 5) 61 - 75; 6) > 76
Erosion ( more erosion means greater fragility Presence is accounted for.	1) Low, 2) Moderate, 3) High
Stoniness, %	1) <10 low, 2) 11-20 moderate, 3) 21-30 high, 4)> 30 severe
Canopy coverage, % (broader coverage means less fragility)	1)> 86; 2)71 – 85; 3) 51 – 70; 4) 36 - 50; 5)< 35
Diversity of vegetal strata (lesser number of strata means greater fragility)	1) Herbaceous layer); 2) herbaceous layer and shrubs; 3) canopy; 4)Herbaceous layer or shrubs and canopy; 5) all three levels of vegetation
Components	The inclusion of components depends on landscape
Land use (in order of importance to fragility)	1) Forestry, 2) Crops, 3) Livestock, 4) Urban
Roads	1) Trails; 2) Backroads; 2) Highways
Buildings	1) Local Material; 2)Concrete
Perturbations (presence of drainage canals or landfills means greater fragility)	1) Low = 1 time, 2) Moderate, 2 to 3 times; 3) High, more than 4 times
Streams	1) With vegetated levees; 2) Without vegetated levees
Water springs	1) With vegetated levees; 2) Without vegetated levees
Wildlife plunder (flora and fauna)	1) None; 2) Some; 3)Severe
Wildlife Presence	1) Yes 2) No
Mulch (ground cover in cm)	1) Less than 8 .1; 2) 6.1-8; 3) 4.1-6; 4) 2.1-4; 5) more than 2
Natural vegetation stage	1) Mature ; 2) Resetting ; 3) Exclusion
Margination (greater margination means greater fragility)	Availability of official statistical information (INEGI) on the municipalities
Population density (bigger population density means greater fragility)	Availability of official statistical information (INEGI) on the municipalities

Source: authors

The LFI obtained from the network of points was subjected to spatial interpolation, which is a process of predicting the values at sites not evaluated or measured in the same region (Burrough, 1997, Ibarra *et al.*, 2009). Thereby, a raster image was generated and used to describe the real world as a regular array of cells, normally square and spaced the same distance in their coordinate axe. For this purpose, the Inverse Squared Distance Optimization (IDO) method was applied, which basically depends on the choice of the power parameter, and the strategy used in the search for neighbors, under the assumption that things that are closer to others are more similar to those that are not (ESRI, 2004, Gregoire and Valentine, 2003). In this sense, the greatest weight is assigned to the nearest point and this weight decreases gradually as the distance increases, depending on the  $\beta$  potential coefficient (Diaz *et al.*, 2008). The weight of a point using this method is expressed as:

$$w_i = N \left( \frac{1}{d_{e,i}} \right)^\beta / \sum_{i=1}^N \left( \frac{1}{d_{i,e}} \right)^\beta$$

Where:

$N$  = Total number of points

$d_{i,e}$  = Distance between  $e$ , the point to estimate, and the point  $i$

$\beta$  = Power coefficient

The value of the point of interest was estimated by considering the weighted average of the measured variable ; each point was weighted by the distance from the estimated point. For a network of  $N$  points, the basic equation is:

$$P_e = \sum_{i=1}^N w_i P_i$$

Where:

$P_e$  = Estimated data on the site  $e$

$p_i$  = data measured at point  $i$

$w_i$  = Denotes the weight of the point

$i$  = Represents the estimated point at site  $e$

$N$  = Total number of points near the site  $e$ , which will be used to estimate the data on the site  $e$ .

LFI descriptive statistics showed an average of 37.57 with a standard deviation of 4.45, in a range from 27 to 46. A slight negative skewness (-0.34), pointed out that data were moderately skewed to the right. Goodness of fit twas evaluated by Anderson Darling test, which is recommended as a powerful test for this purpose (Diaz, 2009). The calculation of this statistic

was made with respect to the normal, log-normal, and Weibull distributions, and  $A^2$  critical values were 1.48, 2,138, and 0.877, respectively, indicating less adjustment for the first two cases. Since the p values for normal and lognormal distribution were less than 0.05, and for the Weibull distribution was 0.024, the decision was, with an error lesser than 5%, to reject the null hypothesis that data conformed to normal and log-normal distributions. Based on the quantiles of the Weibull distribution, the levels of disaggregation of the LFI were categorized as shown in Table 2.

Table 2. Categories of Landscape Fragility Index for the Coatepec-La Antigua basin. Veracruz, Mexico, 2010.

Landscape Fragility Index	
less than 34.02	low (1)
34.02 - 36.95	low – medium (2)
36.95 - 39.16	medium (3)
39.16 - 41.42	medium – high (4)
greater than 41.42	high (5)

This geostatistical process involved the use of the digital elevation model (INEGI, 1995), to generate a continuous surface map using information of a data every 90 meters, in a process known as "rasterizing information." Once the surface map was generated with information from the LFI, the vector layer of land use was overlaid in order to obtain the estimated area for each type of use, with their respective category of LFI on a map in a tabular format, using information from the national forest inventory (IGE-INE, 2002), and charts of land use from INEGI (2007) (series II and III).

Finally, we applied a standard questionnaire to a sample of 300 people for information on the residents' socioeconomic characteristics at every analyzed landscape, ensuring that sample structure resembled that provided by INEGI (2005) for the municipalities in the area.

## RESULTS AND DISCUSSION

### Altitude and land use

Current spatial delimitation of hypsometric areas provided information on the relationship of altitude above mean sea level and the occupied area, regarding its distribution in the area of study (Figure 1). Altitudinal strata range from 3.233 m, corresponding to the eastern slope of the Cofre de Perote, to sea level in the municipalities of La Antigua and Paso de Ovejas. It was found that the spatial dispersion of sampling points in the field (white circles inside the image), almost covered the entire altitudinal landscape variability.

According to the different contrasts (in gray in Figure 1), the existence of natural limits linked to altitude is also shown. Altitude affects land use options, and defines the level of impact of anthropogenic disturbances that take place in the working area. Therefore, it is important to note that distributed along altitude there are three major agro-ecosystems in the basin. At the top, coffee is the most important economic activity given the 32, 657 ha planted, and 4,915 ejido peasants, and 7,489 small owners (SIAP, 2010); here, Coatepec is the best potential area for cultivation. In the intermediate zone, occupying the intermontane area and the coastal plain, sugarcane cultivation and sugar mills make up the regional economy, integrated by 18,323 ha established in the municipalities of Puente Nacional, Actopan, Paso de Ovejas, La Antigua, and Emiliano Zapata. Finally, in the coastal plains and flood zones, cattle is the main activity and is carried out in both, ejido production units and private property, with about 258,195 heads of cattle in the study area (SIAP, 2010).

Statistics show that landscape in the area are differentiated by altitude, but it's worth noting that one of the factors exerting the greatest pressure on landscapes has been the people who inhabit them, their spread and growth, as it is a variable that has determined the use and modification of basin ecosystems in cultivated areas.

### Natural vegetation and current land use

Spatial delimitation of current land cover in the upper basin is shown in Figure 2. There is a high degree of fragmentation of natural vegetation areas, such as cloud forests and jungles. Cloud forest is one of the most important and diverse ecosystems, even though it occupies less than 1% of the total land area in Mexico, it contains 10 to 12% of all existing species of plants and animals (Manson *et al.*, 2008). Furthermore, the distribution of cloud forests and other mountain forests in the upper basin makes them very important for the provision of environmental services, such as the capture and purification of water, control of soil erosion and rivers sedimentation, as well as the regulation of natural disasters such as landslides and floods. In the worked area, cloud forest plays an important part of the basin, but is highly fragmented and disturbed due to the overlapping of growing areas such as coffee agroecosystems under the forest canopy, as well as livestock areas, and densely populated towns and cities, whose function has been determined historically and economically, as discussed below.

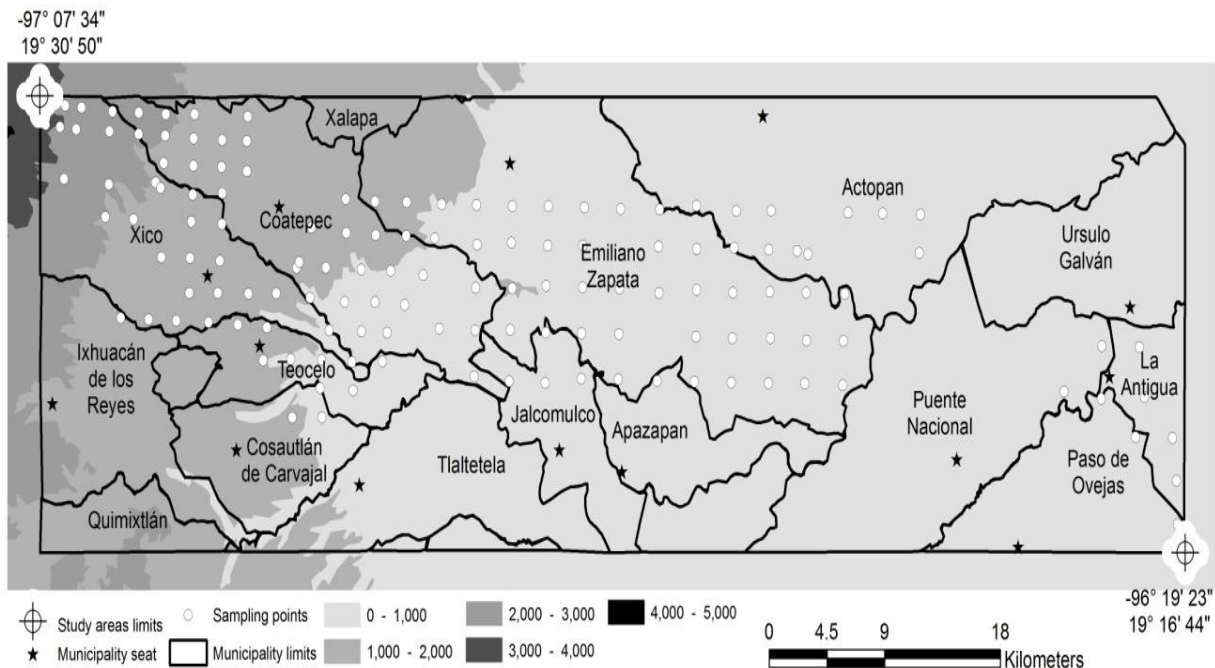


Figure 1. Altitudinal ranges in the study area. Cuenca Coatepec-La Antigua, Veracruz-Mexico, 2010.

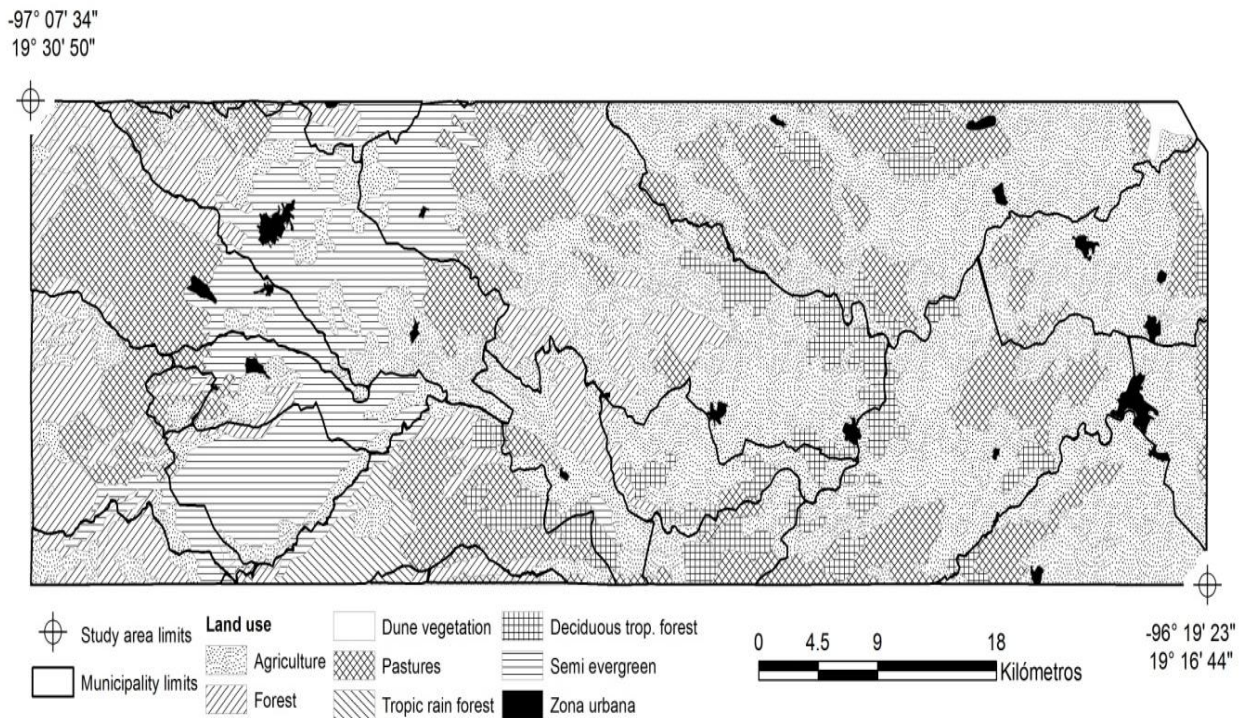


Figure 2. Patterns of current land use: ecosystems and agro-ecosystems of the Coatepec-La Antigua basin, Veracruz-Mexico, 2010.

One of the most important areas in the upper basin is what for methodological purposes was classified as agriculture area, consisting mainly of coffee, embedded in areas of cloud forest (Figure 2). However, within the same area there are lands that were cleared for establishing pasture establishment, as found by georeferenciation during the study. However, coffee agroecosystems represent a major regional economic source for the number of production units and families who depend on coffee and other forest products and shade species to survive. Coffee orchards are set under the shade of some native species characteristic of cloud forests. Production systems are of the "rustic" type, but there is also traditional polyculture which mixes exotic and native species, the latter showing the greater disturbances (Bárcenas and Ordoñez, 2008). This authors indicated that agroforestry production systems such as coffee, should be considered as an important part of production strategies for sustainable development or as a system of sustainable soil use. Although the vegetation structure of some agroforestry systems such as shade-grown coffee can be very similar to native forests, and despite retaining at some extent the structure and function of the ecosystem they replace, the management of a plantation is not strictly correlated with the functions of the forest and the quality of services given to the society (Hernández-Martínez,

2008), due to the input and output of crop products, as well as the constant human intervention.

The coffee area is adjacent to the middle basin landscapes, which is notable for the presence of low and deciduous forest; however, during the transect it was noted that much of the connectivity of these ecosystems have been disturbed by the presence of orchards, mostly custard apple, mango "manila", citrus and sapodilla, showing that forests have been cleared to establish orchards. It is precisely here that begins the large area of sugar cane production, which extends to the coastal zone, occupying the coastal plains and flood plains, and is interspersed with grasslands, mainly introduced species, and native species to a lesser extent. The current land use shows that most of the work area is in agricultural use, next in order of importance, is the presence of grasslands, because livestock is an important economic activity, while the semi - evergreen tropical forest median ranks third (Table 3). These three land uses together make up 79% of the study area.

#### **Spatial distribution of ecosystems and agro-ecosystems in the basin**

LFI for land use were quantified overlaying a GIS, the calculated LFI, and the land use in the area according to INEGI (2007). an approximation of the spatial

distribution and the amount. Figure 3 shows the spatial representation of the area on a map. The map was obtained after performing the interpolation using the values of LFI using IDO. The highest LFI (5) was found in a small proportion of territory, near to Cosautlán municipality; while and LFI classified as medium-high (4) was located in the municipalities of Teocelo, part of Ixhuatlán, Cosautlán, Xico, Coatepec, and Xalapa , where the field georeferenced noted the existence of coffee farms.

Tabla 3. Use of land use in the Coatepec-La Antigua basin, Veracruz-Mexico, 2010.

Soil Use	Total (ha)	(%)
Agriculture	92,386	43.7
Pastures	48,212	22.8
Semi - evergreen tropical forest	27,330	12.9
Deciduous tropical forest	12,915	6.1
Cloud forest	11,673	5.5
Oak forest	8,300	3.9
Pine forest	4,829	2.3
Tropical rain forest	3,166	1.5
Urban zone	2,208	1.0
Dune vegetation	630	0.3
Fir forest	267	0.1
Total surface	211,916	100

LFI medium (3) incorporated forest areas of the Cofre de Perote, as well as the municipalities of Apazapan and Emiliano Zapata. LFI medium-low (2) and low (1) were found mainly in the basin intermediate zones and in the coastal area plains. Therefore, the highest levels of fragility, are located in the western part of the study area, comprising forest ecosystems and grasslands. LFI decrease eastward, with the exception of the municipality of Jalcomulco, where a lower LFI was estimated.

In summary, data suggest that the most vulnerable areas are located at higher altitudes, a situation that points to cloud forest areas, heavily processed by the existence of a large number of towns with high levels of marginalization, as well as coffee plantations, coffee mills, pastures and road infrastructure consisting of trails, lanes, paths, and roads. It is clear that there are also strong effects on the modification of the hydrological cycle. The changes to the ecosystem impact directly the quality of environmental services that this type of ecosystem offer, and indirectly affects the quality of life of the people dwelling in the cloud forest.

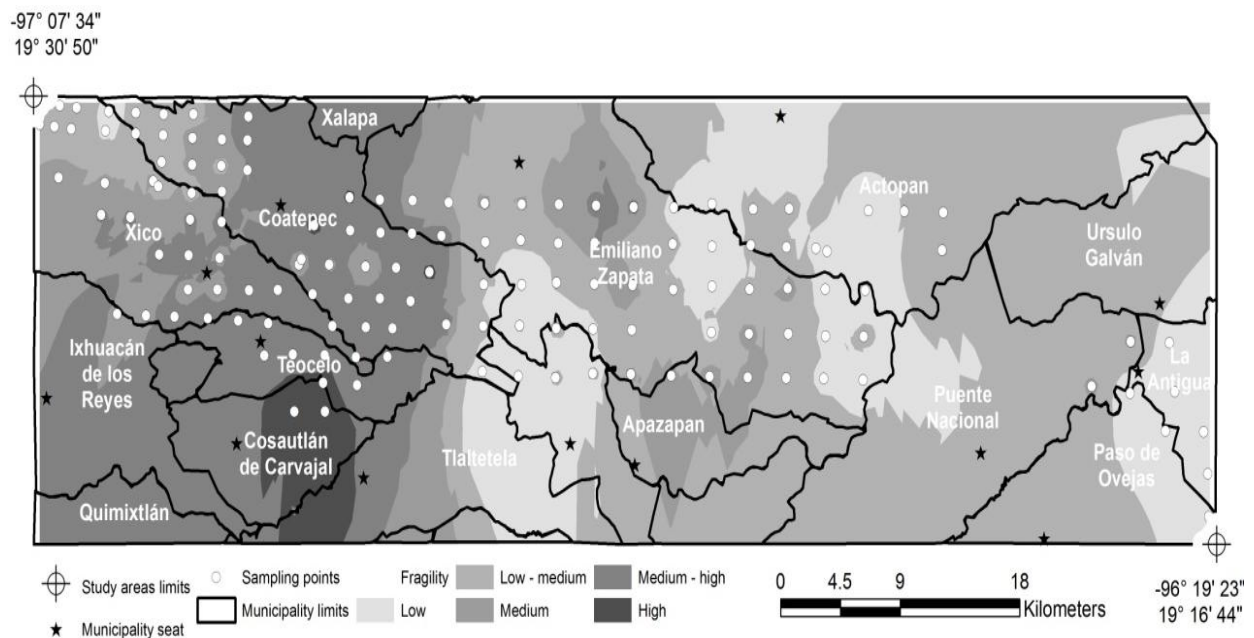


Figure 3. Spatial distribution of Landscape Fragility Indexes (LFI) in the Coatepec-La Antigua basin, Veracruz, Mexico, 2010.

Using the information obtained from Figure 4, the LFI was broken down for the prevailing land use in the study area (Figure 5). Among the most important uses of land in the area, the agriculture-based agro-ecosystems have a great proportion of LFI into medium-low (2) level. Given the size of the area, land use as pastures is second in importance and a great deal show a LFI medium-low (2). Tropical forest ecosystems come in third place; for the most part, their LFI is classified as medium-high (4). Deciduous tropical forest has over 50% of its surface with a low-medium LFI (2), while a large area of the tropical rain forest (77.2%) showed a LFI medium-high (4).

Upper basin has the presence of important ecosystems for the provision of a range of services essential to the functioning of society and the economy, such as springs and vegetation canopy that protects the soil from erosion and reduces the risk to disasters. There, cloud forest occupies 11, 673 ha, with 68.4% of the surface classified with a LFI of medium-high (4). Oak forest area, with 8, 300 ha had a low LFI (1) in 44.4% of its total surface. The pine forest with 4, 829 ha, and the fir forest with only 267 ha has a low-medium LFI (2) with 51.2 and 84% of their surface into this category, respectively. Finally dune vegetation in the coastal plain is the area was less fragile, since lied into medium-low (2) and low (1) LFI (Figure 4). It is noteworthy that within the sampled area, the municipality of La Antigua exhibited a high population density, similar to that found in populations inhabiting the cloud forests.

Also, in the vicinity of the mountains of Cofre de Perote, LFI falls into a medium-high category and comprises 22% of the total studied area. Here, fragility affects areas of forest, tropical forest, and tropical rain forest, which are intended for grazing and agriculture. This is an indicator that shows that the mountain area is more vulnerable or fragile, given its current characteristics and its potential for further future changes in land use. for this reason, interventions on the floor of this area should consider plans for sustainable management and reduction of environmental impact. In general terms, the LFI of the study area showed that only 2.8% are high (5), that 22.5% is medium-high (4), and 12.5 average (3). Thus, 37.8% of the basin area has a LFI classified from medium to high.

### **Connections of the fragility of ecosystems and agro-ecosystems, with anthropocentric factors**

To clarify the complex relationship between nature and society, and their role in environmental changes affecting the planet, a deeper diachronic study is required. The premise is that economic activities impact natural environment and thereby affect the

capacity of adaptation that society has to its own actions.

Therefore, it is clear that low socio-economic sustainability of regional states the close articulation of natural resources with forms of using land, the market, the forms of social organization, the population and its distribution; but these factors themselves alter the relationship between culture and nature (Gonzalez-Jacome, 2004; Zorrilla, 2005), generating a number of situations that make imbalances between decisions whose rationality is based on development arguments. Historical connections between nature and people in the area of work were analyzed by several authors, for instance, González-Jácome (1999) identified some ecological features particular to the work area, which slowly disappeared, as happened in the plain coast, between La Antigua and Veracruz municipalities, where population and environment are interrelated to create an impact that permeates in changing the landscape. González-Jácome noted that the population was undermined by two famines that occurred from 1454 to 1457, and from 1504 to 1506 after the Conquest, and as a result of epidemics, most notably yellow fever. She also speculates that this disease caused the physical and "unhealthy" conditions of the wetland, which ended in promoting drainage and filling ponds, streams and wetlands in the plains surrounding the city of Veracruz. Siemens (1998) described a similar situation that restricted the hydrological functions of wetlands in the lowlands. Moreover, Sluyter (2004) proved the existence of a reconfiguration on the old wetland area, near the city of Veracruz. Inhabitants in pre-Hispanic times grew corn in some 2000 ha of raised field of chinampas type. The fields were abandoned in 500 AD, which seems to coincide with decreasing population, so at the arrival of the Spaniards, the region was almost uninhabited (Siemens, 1998).

In these same landscapes Sluyter (2004) also found the presence of traces of burned vegetation, which when analyzed by the radio-carbon method, determined the existence of extensive and persistent burnings during the colonial period. Such burnings were carried out during the fall as a way to induce sprouting and to create grazing areas. In this way, the landscape and physical characteristics have played an important role in regional economic history, as in the colonial period, because during the dry season, cattle had to graze fresh forage in wetlands, and during summer rains the animals were taken to Piedmont lands. Although Sluyter (2004) emphasizes that the colonial model of livestock grazing had an impact on local ecology and population, displacing native agriculture (fruit, corn and beans) for the opening of rangelands since the sixteenth century, and burning practices had to change and fragment the landscape of grasslands and deciduous forests located from the



coast to the foothills, forming a homogeneous area of grassland. Siemens et al. (2006) points out that currently in Mexico, there is not a real reassessment of wetlands as a resource in itself, nor are valued and preserved as in several countries in Europe or America. Although in Veracruz there is a noticeable increasing environmental awareness, institutional incentives and control on the use of land and water are still tentative.

Near La Antigua, in the current sugarcane area, Gonzalez-Jacome (1999) cited several sources pointing to the existence of large forested areas between Cempoala and Quiahuitlán, which was abandoned in 1543 by the death of the native inhabitants, to settle a sugar refinery that occupied their areas of food and water sources. The dominant land use that occurs today was defined in the sixteenth century, when livestock settled in the coastal strip, and fertile coastal areas and intermontane were used for sugar plantations. Later, during the Porfirio Diaz dictatorship, the use of land was endorsed with the creation of large areas of pasture for livestock and cash crops. From the previous discussion, it is clear that the introduction of new species such as sugarcane and coffee, as well as domestic animals, strongly contributed in transforming the landscape. Moreover, the growth and spread of the coffee area prompted the opening of access roads to the production area and the construction of highways. Even though road infrastructure makes possible development, it does not cause in itself a territorial transformation (in terms of economic development). The availability of roads also induce changes in the patterns of population distribution (Obregón-Biosca, 2010), as happened with the introduction of railways in Veracruz in the late nineteenth century.

Some of the patterns of population emerged from the colonial period, due to settlers' movement to higher ground seeking milder climates and escaping from the "unhealthy" swamps and the heat. So various factors favored the existence of a high population density in the upper basin, especially in coffee areas (Figure 6), which is higher than the state of Veracruz average (99.2 inhabitants/km<sup>2</sup>), and that of the lower basin, except for La Antigua municipality (CONAPO, 2007).

## Population and environment

Nowadays, population growth and housing demand in Coatepec and Xalapa have increased pressure on natural resources in the cloud forest. Coffee plantations have been moved at altitudes below 700 m, where coffee development and productivity is less than that achieved at higher altitudes. Moreover, the expansion of housing and urban areas within the coffee zone contributes to the gradual and imminent reduction of the water recharge area, anticipating an imbalance due to increased demand and the deterioration of water surface bodies, as a result of changing land use.

CONAPO figures (2007) reported higher levels of marginalization in municipalities in the upper basin, mainly those that have coffee agroecosystems in cloud forest areas, with the exception of Coatepec. Likewise, the survey showed a significant association between productive landscape and the marginalization in the study areas ( $p = 0.00$ ). Population in a productive landscape such as sugar cane fields and cattle pastures, live in areas with lower degrees of marginalization; however, inhabitants of coffee landscapes are found in areas with higher rates of exclusion.

The variable family income indicated that this differs according to the productive landscape in which the respondents live ( $p = 0.00$ ). Some 53% of families living in coffee landscapes earn a household income below 2 minimum daily wages, while this income is perceived only by 14% of those residing in sugar cane areas and 36% dwelling in cattle pasture areas, Figure 7 shows that in the coffee area, the reported higher family incomes do not exceed \$ 13,200 Mexican pesos per month, while in the cane growing areas and in the cattle pasture areas, the reported income is higher. The line corresponding to respondents living in sugarcane landscapes located in the coastal part of the work area, represents the highest family income in the sample, while the lowest in the distribution are found in the upper basin in the of coffee plantations area.

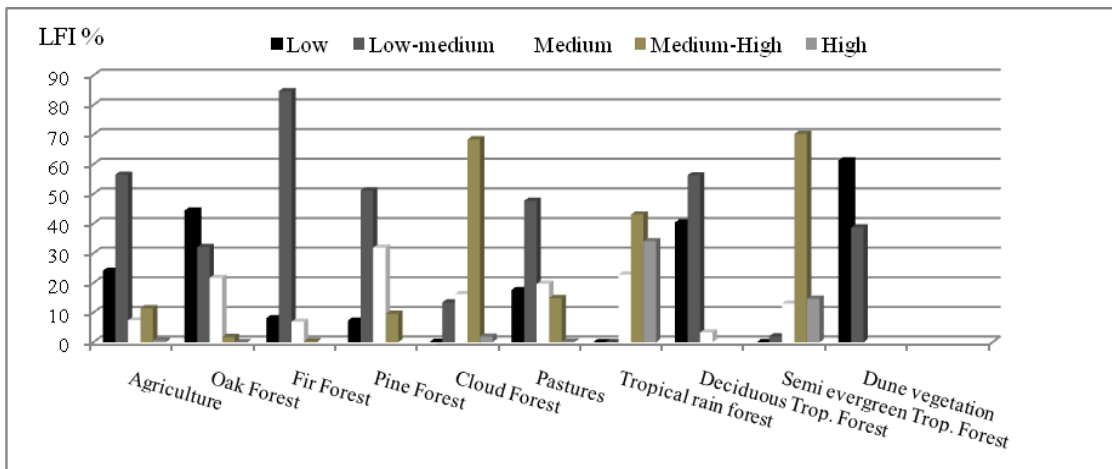


Figure 4. Landscape Fragility Indexes (LFI) for different agro-ecosystems of the Coatepec-La Antigua basin, Veracruz, Mexico, 2010.

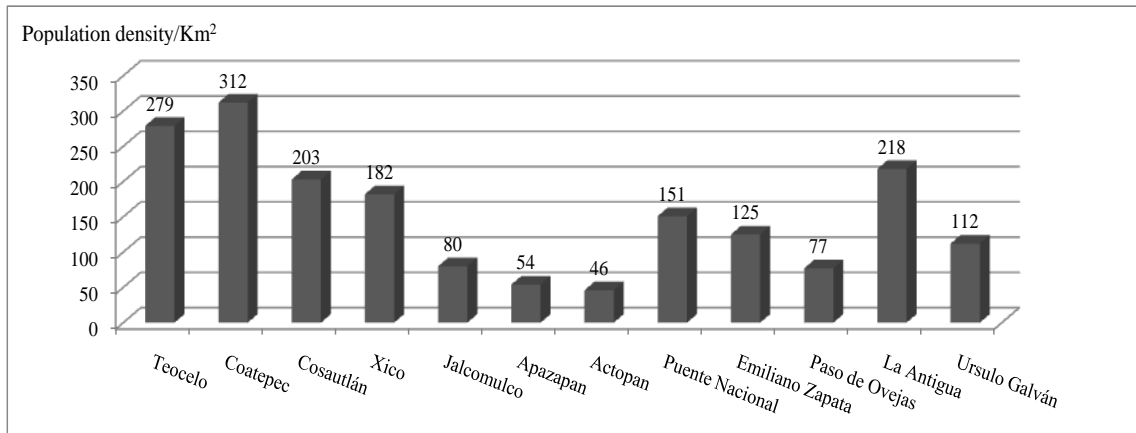
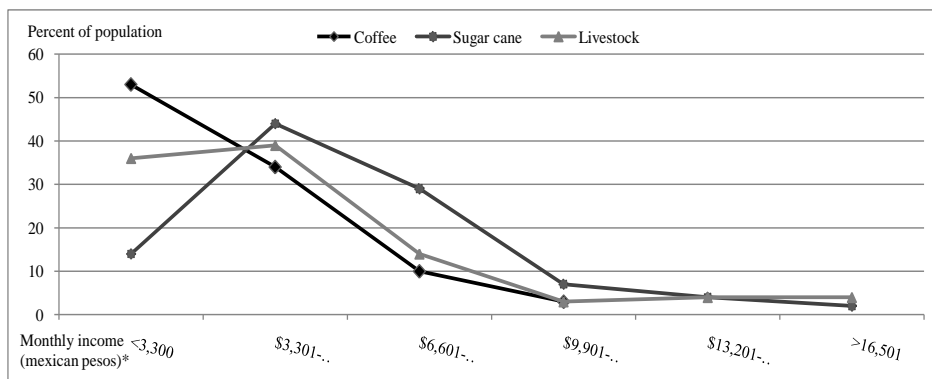


Figure 5. Population density per km<sup>2</sup> in municipalities in the study area. Coatepec-La Antigua basin, Veracruz, Mexico, 2010.



\*one USD dollar= 12.50 mexican pesos

Figure 6. Family income distribution reported by respondents in the Coatepec-La Antigua, Veracruz basin, Mexico, 2010.

The respondents' monthly income, measured in minimum wages, showed a wide dispersion and a significant dependency according to sex ( $p = 0.00$ ) and age group ( $p = 0.025$ ). In this sense, unlike men, more than half of the interviewed women did not perceive any income (54.1%). About 85% of men with an income are between 25 and 60 years-old; this situation is similar for women (75%). However, at both extremes of age, the situation differs according to gender, thus 20% of women receiving an income are from 18 to 24 years-old, while in the case of men only 13% has an income. An opposite situation happens with the group of age 60 and older, in which the percentage of men who receive income is twice (10%) than of women in the same age group (5%). Other variables that were significantly related ( $p = 0.00$ ) with individual income, were occupation and education.

Some authors have argued that the global political-economic framework hit the coffee economy, so the global coffee market imbalance resulted from global structural changes and the establishment and rise of neoliberal policies were the cause of increased poverty and marginalization affecting coffee and sugar cane areas, generating strong migratory processes (Del Angel and Rebolledo, 2009; Martinez, 2007; Mestries, 2003, Perez, 2003) as in the study area. International migration is an emerging phenomenon, observed in the area since early this century, and has been identified as a survival mechanism in the absence of sustainability of agricultural systems and economic systems (Del Angel and Rebolledo, 2009; Mestries, 2006). Although the interviews applied showed that migration flows were not homogeneous and presented significant differences ( $p = 0.00$ ) according to the productive environment in which families are embedded, it was found that those families that live in cattle landscapes exhibited lower incidence of migration among its members, contrasting with families that were found in cane production areas, where half of them have members who have migrated, whereas in coffee growing areas, 35% of households have international migrants among this members. In this sense, the data confirm the arguments of the authors mentioned above.

Economic expectations of the population living in the Coatepec-La Antigua basin, regarding the use of natural resources, has been one of the determining factors in the actions that on the territory have been drawn out and that preclude changing environments.

The field work showed that some towns of Puente Nacional, Actopan, Emiliano Zapata and La Antigua municipalities, formerly producing staple foods such as beans, maize and papaya, modified land use about the 1990's, and simplified ecosystems even more, by replacing sugar cane or pasture for cattle ranching. At the end of the 1990's, in towns of La Antigua and Paso

de Ovejas, part of the area planted with mango "manila" was also replaced by sugar cane. In the case of mango orchards, respondents noted that due to the advanced age of the trees, the removal of plantations was difficult; in turn, short-cycle crops had low profitability and more difficulties to produce them than sugar cane.

Del Angel and Rebolledo (2009) noted that the substitution of various crops for sugar cane was based on a relationship of farmers with sugar mills. The presence of a sugar mill ensures that the product will have access to market as well as a provision of supplies and services. Other associated benefits are job security, health services and retirement. But the phenomenon of switching from crops to sugar cane is more complex. During the last two decades of the last century occurred a progressive decrease of government support to rural based activities along with a reduction of regional workforces in several industries that used to keep the regional population as a floating workforce. This is particularly the case of employment contraction in the industrial zone of the city of Veracruz which began in the late 1980's.

Literature reviewed suggests how the link between economy, society and nature determines the modification of natural landscapes. Moreover, the study results show that physical and socioeconomic variables can generate detailed spatial representation of the fragility of an area and provide opportunities for territorial ordering and better resources management.

## CONCLUSIONS

Landscape Fragility Indexes (LFI) for the Coatepec - La Antigua basin were obtained. Such LFI's allowed to quantify the current weaknesses in various ecosystems and agro-ecosystems. Landscape fragility found in the study area is a variable essential for territorial ordering, land management and rural development planning. LFI shows the risk and potential economic and environmental consequences if the landscape should be modified.

The work suggests that the historical use of ecosystems and agro-ecosystems of the basin, is now reflected as a vulnerability as a whole. Currently, the most important land uses based on the occupied surface are: crops (43.6%), grasslands (22.8%), and tropical forest (12.9%), the remainder (21%) includes several ecosystems and agroecosystems, being one of the most important the cloud forest that occupies only 5.5% of the entire surface.

In the lands for crop use, 56.5% had LFI levels considered as medium-low (2), 47.7% of grassland show a medium-low (2), and 19.7% average (3). Semi - evergreen tropical forest ranks third in importance

and most LFI observed were medium-high (4). Deciduous tropical forest has 56.3% of its LFI classified as low-medium (2). Tropical rain forest shows 77.2% of LFI considered as medium-high (4) to high (5). Cloud forest ranks fifth in importance, with LFI placed as medium-high (4) in 68.4% of the surface. Oak forest had low LFI exhibiting a LFI of (1) in 44.4% of the total area. Pine and fir forest had LFI with low-medium rates (2) at 51.2, and 84% respectively. Finally, dune vegetation mostly had LFI considered as medium-low (2) or low (1).

Only 2.8% of the total landscape was classified in the highest category, as LFI (5), a 22.5% was considered as medium-high (4). These two top categories are located mainly in forest, tropical forest, and tropical rain forest, with some parts devoted to pasture and crops. Given its current characteristics and the possibility of a change in land use, the mountain area is more vulnerable or fragile. Also, if some actions on the floor are intended, they should consider sustainable management plans and environmental impact.

Socio-economic analysis allowed observing changes in land use in different historical moments. Changes in land use over time have led to strong processes of fragmentation of mass vegetation, increasing their vulnerability especially in the upper parts of the basin. The most vulnerable areas are located on the upper parts of the basin, which coincides with the most marginalized areas, and with lower family income and higher population density. Other factors of socio-economic fragility showed that migration flows were not homogeneous presenting significant differences related to the production environment, since families living in areas of sugar cane and coffee production have international migrants among its members. The concept of order is an important way to organize land use in terms of the fragility of the landscape and the social will to create forms of socio-economic and ecological sustainability. Actions for ecological restoration or related to sustainable development in the region should consider the diversity of actors involved. Some people may have more economic expectations on landscape and land-use than thinking only in preservation, because historically, this has been a part of their strategies of life and perception of how to improve their life quality.

The generation and promotion of development strategies compatible to the work area should include social participation, ie participative strategies in which social actors can discuss and explore ways for land management, based on the pursuit of sustainability. Since a great deal of the population has internalized the importance of certain areas for conservation purposes it might be possible to take advantage of this positive attitude.

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*Submitted October 10, 2010– Accepted December 01, 2010*  
*Revised received December 14, 2010*