Cuando se quiere tumbar un trecho de selva hay que hacérselo saber a los *yuntzilob* de la milpa, los *balam col*, los *chacob* y los *kuilob kaaxob*. De ese modo, nada malo sucederá mientras uno trabaja. Los balam col se yerguen en los cuatro puntos cardinales de la milpa y la protegen. Los *chacob* son los dioses de la lluvia. Los *kuilob kaaxob* son los guardianes de la selva no cultivada, de los animales salvajes y de las aves. Genéricamente se le dá a todos estos espíritus "propietarios" el nombre de *yuntzilob.* Cuando uno desmonta la selva, y antes de prenderle fuego a los arbustos secos, se mezcla un poco de *zaca*, la masa básica de maíz con agua y miel, y se ofrece a los *yuntzilob* con una breve oración para pedir excusas por el daño que va a hacer. Son los *kuilob kaaxob* quienes reciben la primera ofrenda, porque son ellos quienes cuidan la selva virgen. Justo antes de prender fuego a los árboles y los montones de hierba seca, el milpero debe hacer una ofrenda más de *zaca* al *mozon ik*. Éste es un remolino de viento reconcentrado e identificable al que convoca el milpero con un silbido bajo y con su ofrenda, y que aparece con un estruendo característico para esparcir las llamas parejamente a todo lo ancho de la milpa. Las ofrendas que se hacen en la milpa se colocan sobre una mesa, un altar hecho con postes en forma de horquilla similares a los de las casas mayas, pero en una escala mucho más pequeña.

El sueño del camino maya. El chamanismo ilustrado.
Richard Luxton y Pablo Balam.

Chapter 1

Characterization of spatial and temporal fire trends in tropical Mexico: the case study of Chiapas

Abstract

In tropical areas, fire research is an important aspect of ecological assessment because tropical and subtropical areas present the vast majority of the world's fires today. Moreover, the problem of fire in these countries shows the effect of increased human and climatic pressures, which provoke interactions between fire and the transformed landscapes. In this context, the tropical Mexican State of Chiapas represents an interesting case study, because there is an available fire data set from its Department of the Environment and Natural Resources, and it has similarities with other tropical areas. This study represents an approach to the problem of fire in this state, where, although fire is recognized as a major disturbance, little has been done to quantify and characterize its impacts, nor to identify the factors that lead to that fire situation. A first description of fire trends will be given, comparing it to the trends of the rest of the Mexican Republic. Fire regime will be described in terms of fire sizes and types of fires. Among the factors revised, Chiapas' fire trends will be contrasted to variations in rainfall, ENSO variability, vegetation flammability characteristics, or more socio-economical aspects, such as land tenure. The results indicate that fire regime in Chiapas is characterized by a large number of small fires (80 % of the incidences in fires between 1 and 250 ha). However, these small fires are only responsible for a reduced percent of the total burned area (22%). Large forest fires play, therefore, an important role in the ecology of Chiapas' forests (8% of the incidences and 62% of the area burned in fires larger than 500 ha). Most of these fires are, however, surface fires of low intensities (80% of the incidences), that mainly affect non-forested land (shrubs and herbaceous layers). Among the structural causes that frame the problem of fire in Chiapas, several points must be remarked: i) a marked seasonal distribution of rainfall, ii) a habitual use of fire in traditional land activities and a lack of real alternatives, assigns humans the root of the fire problem, iii) a marked sensitivity to the presence of ENSO episodes, specially concentrated in rainforests, iv) a land tenure distribution that displays remarkable pressure on national lands, and v) particular flammability characteristics of its forests that concentrates fire in pine-oak ecosystems under non-ENSO conditions. The results of this study can serve as the basis for future ecological assessment focusing on the role of fire in Chiapas ecosystems.

Key-words: fire regime, Chiapas, Mexico, El Niño, land tenure, rainfall pattern

INTRODUCTION

Changes in socioeconomic and climatic conditions have modified the spatial and temporal dynamics of fire in recent decades, altering fire regimes all over the world (Pyne 1995). However, an analysis of fire patterns along time and space is necessary in order to evaluate the ecological, economic and social consequences of fire (Johnson and Gutsell 1994). This analysis will lead to the identification of problem areas, and will allow us to model and predict future scenarios. To achieve these objectives, fire data sets and statistical analyses are essential tools, as they offer the opportunity to improve knowledge about the role of fire in ecosystems (Mérida 2000). In the case of tropical areas, fire research is an important ecological assessment because tropical and subtropical areas present the vast majority of the world's fires today (Dwyer et al 1999) with biomass burning estimates of 3260 -10450 Tg yr-1 (Cardoso 1999). Moreover, the problem of fire in these countries presents its own peculiarities, which mainly refer to the deliberate cause of most fires, related to the habitual use of fire as a traditional land tool (Fule and Covington 1997). Besides, Cochrane et al. (1999), Goldammer (1999) and Laurance and Williamson (2001) reported the existence of fire positive feedbacks in tropical forests, which refer to an enhanced fire frequency and fire intensity in rainforests that had previously been burned. Several authors have also reported the development of diverse synergisms between fire and some pressures, such as El Niño droughts (Malingreau et al. 1985; Goldammer 1993; Taylor et al. 1999), or the presence of fragmented rainforests surrounded by pastures or logged forests (Uhl and Kauffman 1990; Holdsworth and Uhl 1997; Nepstad et al. 2001). All these factors enhance the transformation of closed-canopy rainforests into degraded savannahs, with several anthropogenic fire climax stages in-between (Mueller-Dombois and Goldammer 1990; Goldammer 1999). These disturbances are also responsible for decreasing the quality of tropical habitats, altering their contribution to global CO_2 balances and decreasing their ecological services (Goldammer 1990; Smith et al. 1992).

In this context, the tropical Mexican State of Chiapas represents an interesting study case, because there is an available fire data set from its Department of the Environment and Natural Resources (SEMARNAT), and it has similarities to other tropical areas. Thus, Chiapas presents more than 8.000 plant species (State Government 1992), being a world hotspot of biodiversity and endemisms favored by its diversity of climates and ecological conditions (Miranda 1975; Breedlove 1981; Challenger 1998). This diversity of ecological gradients determines the existence of several ecosystems with different fire patterns. As in the case of other tropical regions, Chiapas also presents a high demographic pressure combined with low socioeconomic and educational status (INEGI 1997). Forest resources are suffering from over-exploitation (Valera-Hernández 1994), and there is increased anarchical use of fire. The combination of all these factors leads to important land use changes that severely threaten the conservation of natural resources (Ochoa-Gaona and González-Espinosa 2000). Thus, Chiapas is one of the most problematic Mexican States in terms of forest fires, occupying the fifth position in the list of Mexican States most affected by fires (WWW1). Furthermore, fire was considered as an important disturbing agent in the National Forest Inventory, and Chiapas was categorized as one of the most sensitive tropical areas on Earth in 1987, because of its forest fire problems (Villafuerte et al. 1997). This is even more important considering that another point in common between Chiapas and other tropical areas relates to the importance of global climatic phenomena, such as El Niño, which severely influence the depletion of tropical forest resources (SEMARNAT 1999). Even though the concern about fire in this tropical State has long been reflected in the large amount of existing legislation (see review in Román-Cuesta 2000), little effort has been made to determine its role as a disturbance agent, and exhaustive research on its ecology and interactions with its ecosystems has yet to be done.

This study analyses several characteristics of fire regime in this tropical biome, including the frequency, extent and magnitude of fire episodes. The main objective is to characterize the temporal and spatial distribution of fire in the State of Chiapas, framing these trends in the context of fire in the rest of the Mexican Republic. Furthermore, because of the importance of determining stressors that lead to this fire regime, this study also deals with the relationship of some of them, such as the role of El Niño-Southern Oscillation (ENSO), vegetation types and land tenure, with the variables which define the fire regime in Chiapas. These analyses will give us clues to improve our knowledge of fire presence and the role of fire in tropical ecosystems, detecting sensitive areas and predicting future fire scenarios, such as those associated with the presence of El Niño years.

STUDY AREA

Climate, vegetation and population in Chiapas

Chiapas is a southern tropical Mexican State, located between 14^{o} 32’ and 17^{o} 59’ latitude north, and 90^{o} 22’ and 94^{o} 14’ longitude west. It has an area of 75635 km^2 (3.8% of the Mexican territory), and was composed by 111 municipalities grouped into nine economical regions (Figure 1). Due to its location in the tropical area, Chiapas has a climate corresponding to the warm and semi-warm groups (A type of climate regarding the Köppen climatic classification), with different degrees of humidity. It also presents temperate and semi-cold climates (C, Köppen climatic classification), mainly in areas higher than 2000 m. The latter climate is the most fire-prone, due to vegetation flammability and the presence of a six-month dry period combined with high temperatures (usually starting in May and finishing at the end of October). Mean annual precipitation in Chiapas reaches 1982 mm (range: 1000->4500 mm; series: 1941-1996; WWW2).

According to the 1994 National Forest Inventory, sixty-four percent of the State was forested (5148104 ha, 3293196 ha of arboreal area), mainly covered by rain forests (42%), temperate forests (22%) and grasslands (27%) (Valera-Hernández 1994). However, during recent decades, vegetation has been affected by diverse human pressures, increasing the number of fragmented forests, with a progressive substitution of species-rich forests by species-poor and more flammable fragments, and an increment of fire risk, as described in other tropical areas (Laurance et al. 1998; Cochrane et al. 1999). Moreover, in several regions, extensive areas of rain forests have been substituted by pastures for cattle production (Villafuerte et al 1997), increasing the possibility of fire propagation to the adjacent forest areas (Román-Cuesta et al.

submitted). Main disturbing agents relate to demographic pressure, land use changes, fire, logging activities, reduction of soil fertility and an asymmetrical economic relationship between the Indian and the Mestizo societies (Ochoa-Gaona and González-Espinosa 2000).

As most fires in Chiapas have an anthropogenic cause, population plays a major role in determining fire trends. The population of Chiapas in 2000 was 3920515 inhabitants (INEGI 2000). Economic regions with higher population densities are located in the central plateau of Los Altos (115 inhabitants/km^2) and in the south-west of the State, on the border with Guatemala. The Frailesca region (west-center), shows the lowest values, with 25 inhabitants/km^2. The mean annual growth rate in Chiapas was one of the highest in the Mexican Republic in 1997, although it has shown a tendency to decrease in recent years (INEGI 1997). More than 60% of the population is rural (INEGI 1997), the majority being involved in subsistence farming.

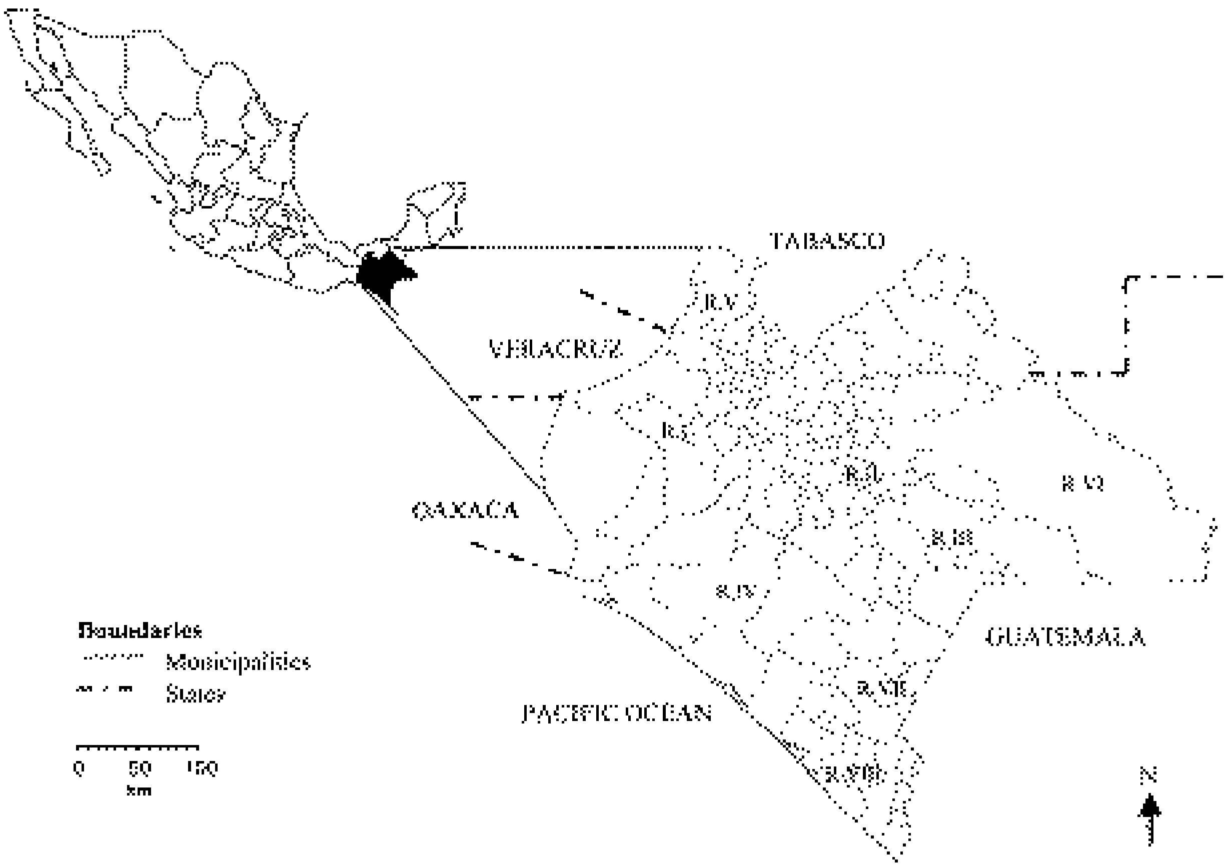

Figure 1: Geographic location and administrative division of Chiapas.

METHODS

Data sets

This study considers a forest fire as "*any harmful event caused intentionally or fortuitously by fire, which occurs in areas covered by vegetation, trees, grasslands, scrubs, brushwoods and, in general, in every different plant association*" (POE 1999). This definition excludes all intentional burnings related to land practices that use fire, excepting those where fire spreads out of the established field area (mainly related to the absence or inefficiency of security measures).

1) Fire data

Fire data available depended on the temporal scale considered:

A) *1984-1999 fire database of Chiapas and the Mexican Republic.* Data for Chiapas were obtained from SEMARNAT (1999). The information was on a year basis and at the State scale. Variables available included the number of fires, total burned areas (ha), mean fire area and the affected areas (ha) categorized by layers (herbaceous, shrubland and arboreal layers). Data for the Mexican Republic were a compilation of fire data of all the Mexican States, achieved from SEMARNAT. They were on a year basis. The available variables were: number of fires, total burned area and mean fire area.

B) *1993-1999 fire field reports.* Fire data for this period exclusively focused on Chiapas and corresponded to the available fire field reports at a municipal scale compiled in diverse SEMARNAT offices. Information contained in these reports was much more detailed than the previous database and included:

1) Fire location: it included two types of information:
   - Names of the municipalities and field area where fire occurred. Accurate location of fires was not possible because the majority of the described locations did not appear in the cartographic maps. This fact forced us to work at a scale of municipality.
   - Land tenure: SEMARNAT'S reports mainly considered four major tenures: ejidos, communal lands, State owned lands and private properties (see the land tenure data paragraph for further explanations).
2) Duration: date (day, month, year) when fire started and ended.
3) Causality: it included several categories:
   - Negligence: pasture burns, agrarian activities, forestry activities, industries, campfires, cleaning-oriented fires, smokers, etc.
   - Intentional: land indefinition problems, social problems among communities, authorization permits for forestry exploitations, illegal hunting, etc.
   - Others causes: lightning, train rails, electric lines, military training, forestry works, etc.
4) Fire evaluation: this section informed about vegetation and fire types:
   - *Vegetation affected*, divided into layers and into vegetation communities.

     Layers:

     - Herbaceous communities: non woody vegetation with a maximum height of 1.5 m.

- Shrublands: woody vegetation with a maximum height of 3 m.
- Arboreal layers: DBH higher than 10 cm and height above 3 m.

This study considers *non arboreal areas* as those containing herbaceous communities and shrublands, and *forested areas* as the combination of arboreal and non-arboreal areas.

Vegetation communities: different communities were identified: coniferous forests, coniferous-broadleaf forests, broadleaf forests, tropical rain forests, montane rain forests, low montane rain forests, shrublands in arid and semi-arid areas, and herbaceous vegetation.

· Fire types: there were three fire types, although most fires in Chiapas were mixed fires, combining these fire types.

- Surface fires: they affect herbaceous layers up to a height of 1.5 m.
- Crown fires: fire reaches the crowns, mainly by torching processes. Crown fires, understood as fires killing aboveground parts of the dominant vegetation and substantially changing the aboveground structure, are not frequent in Chiapas. Thus, when referring to crown fires, it should be understood as moderately affected areas with several crown-affected stands.
- Ground fire: fire spread through the underground (roots, organic debris and the soil organic horizon).

Fire field reports with surface and crown mixed fires with 0 ha for the arboreal layers, were considered as surface fires, while crown fires where those where tree crowns were affected at some point.

5) *Altitude*: elevation above sea level.

2) Vegetation data

This information was obtained in a digital format at a scale of 1:250.000 from the National Forest Inventory (1994) from LAIGE (Image laboratory) at ECOSUR-San Cristóbal de las Casas (El Colegio de la Frontera Sur). The surface of each municipality occupied by each vegetation type was obtained by means of a GIS system, by overlaying a grid of 100 m-pixel side, and calculating the values per municipality.

3) Land tenure data

General land property data were obtained from INEGI (1997). These values were used to standardize the total fire values of each land tenure category, so that relative values could help to visualize trends. Land tenure in the Mexican Republic has a long list of categories but this study mainly considered the four major tenures described in SEMARNAT reports:

- *Ejido*, is the minimum administrative unit. It legally appears with the donation of land to a community. They are formed by an assembly, *ejidal* commissioners and a guard counsel.
- Communal land: this land tenure is very similar to the *ejido* but differs in two points: a) land was already owned by the community, and b) land is commonly worked, without individually owned plots of land.

- State owned land: Mexico has a National System of Protected Areas, which includes those areas where biodiversity and ecological characteristics are of relevant importance. Chiapas has 38 protected areas, some of them are National lands and some others are State lands (being administrated by the federal or the State Administration respectively). Activities in these areas are restricted and regulated by law.
- Private property: there are three categories of small properties, agrarian, cattle and forested.

The State areas occupied by these tenures are: 3022105 ha of ejidal lands, 976489 ha of communal lands, 342786 ha of national lands and 2503904 ha of private properties (INEGI 1997).

4) Climatic data

Climatic data included: mean annual precipitation values for the State of Chiapas and for the Mexican Republic, during 1984-1999. These data were obtained from the Mexican Meteorological Service (WWW2).

Indexes used

1) Frequency index: it is the standardized value of the number of fires that occur in the State of Chiapas and the Mexican Republic per year. It informs about the potential of an area to suffer fire incidences. It allows to establish comparisons among diverse locations, because it is standardized by the forested area of each site. It is calculated as:

FI= Number fires/[forest area (ha)/10000]

2) Area index: it is the standardized value of the burned area affected in the State of Chiapas and the Mexican Republic, per year. It informs about the amount of land that is affected by fire. It is calculated as:

DI= [Burned area (ha)/Forest area (ha)]*100

3) The Southern Oscillation Index (SOI): the Southern Oscillation Index (SOI) has been used by several authors to relate variations of the El Niño phenomena to fire variables (Swetnam and Betancourt 1990; Stahle and Cleaveland 1993). The SOI is a monthly index that refers to the variations of the atmospheric pressure at sea level, in two weather stations located at two extremes of the Pacific Ocean (Tahiti and Darwin). Monthly data of sea level pressure are contrasted to historic values (1951-1980) (WWW3), in order to detect biases from the mean. High biases represent potential El Niño years, because this phenomenon represent a series of climatic variations that include modifications in the sea surface temperature and global alterations of wind circulation and precipitation patterns. In this study, SOI values were calculated as the mean value of the months where El Niño phenomenon was strongest, that is, December, January and February. As SOI values are global measures, the same values have been considered for Chiapas and the Mexican Republic.

To solve the problem of the temporal autocorrelation among data, Mantel test analyses (Koenig 1999) were carried out. This test was separately applied to values of the State of Chiapas and the whole Mexican Republic. In both cases, variables included were: i) fire variables: number of fires for each season, burned areas by land covers (only in the case of the State of Chiapas), total burned areas and mean burned areas; ii) climatic variables: mean annual rainfall and mean rainfall for the dry season; iii) SOI Index values. All these variables were analyzed for the period 1984-1999. The correlation of several variables (number of fires, total and mean burned areas) between Chiapas and the Mexican Republic was also tested. All values in the text are given as mean±standard deviation.

RESULTS AND DISCUSSION

Characterizing fire regime in the State of Chiapas and comparison with the Mexican Republic

During the period 1984-1999, in the State of Chiapas there were 302±263 (mean±standard deviation) forest fires per year (0.059 fires per 1000 forested ha), with a mean area per fire of 181 ha. If we consider that there were no repeated fires, the total area affected represented 11.5% of the State area and 17% of its forested land. Twenty-eight percent of the total burned area reached the arboreal layers at some point, representing 7.6% of the arboreal area of Chiapas, and 4.8% of Chiapas forested land. The most severe fire seasons in Chiapas were 1986 and 1998 (Figure 2a), with 202604 and 198808 hectares affected, respectively. The maximum number of fires corresponded to 1987, with 646 forest fires. The least severe years were 1990 and 1999, with less than 10000 ha each. The minimum number of fires was obtained in 1994, with 117 incidents. Low values for the total burned area did not necessarily imply low impact in the arboreal layers.

During the same period, in the Mexican Republic there was a mean annual fire incidence of 7891±4349 fires (0.056 fires per 1000 forested ha), very similar to the value obtained in Chiapas. These fires affected a mean area of 36 ha per fire, considerably lower than the value for Chiapas. If we consider that there were no repeated fires, the total affected area represented 2.3% of the Mexican Republic and 3.2% of its forested land. When analyzing the contribution of Chiapas to the total values for the Republic, they represented 19% of the total area burned and 3.8% of the incidents. The most severe fire seasons in the Mexican Republic were 1998, 1988 and 1989. The years with the maximum number of fires were 1998, 1988 and 1993, while the minimum values were found in 1992 (Figure 2b). These trends did not coincide with those of Chiapas.

Figure 3a shows how the fire frequency index in Chiapas almost doubled the values for the Mexican Republic during the 1980s. However, in the last decade, the values of Chiapas have decreased until reaching lower values than the national levels. For this period, frequency indexes presented similar thresholds [0-1.4] both for Chiapas and the Mexican Republic. In terms of burned area (Figure 3b), Chiapas displayed a much more stressed cyclic behavior than the Republic, with values that exceeded several times the rest of the country, especially in the peak years of 1986, 1987 and 1998 (20 times higher in 1986 and 8 times higher in 1998).

Regarding the relationships among fire variables and rainfall values for the case of Chiapas (Table 1). Mantel tests indicated that the number of fires were correlated to the total area burned both in Mexico and Chiapas, but more strongly in the case of the Mexican Republic (R=0.87 for the Mexican Republic and R=0.64 for Chiapas).

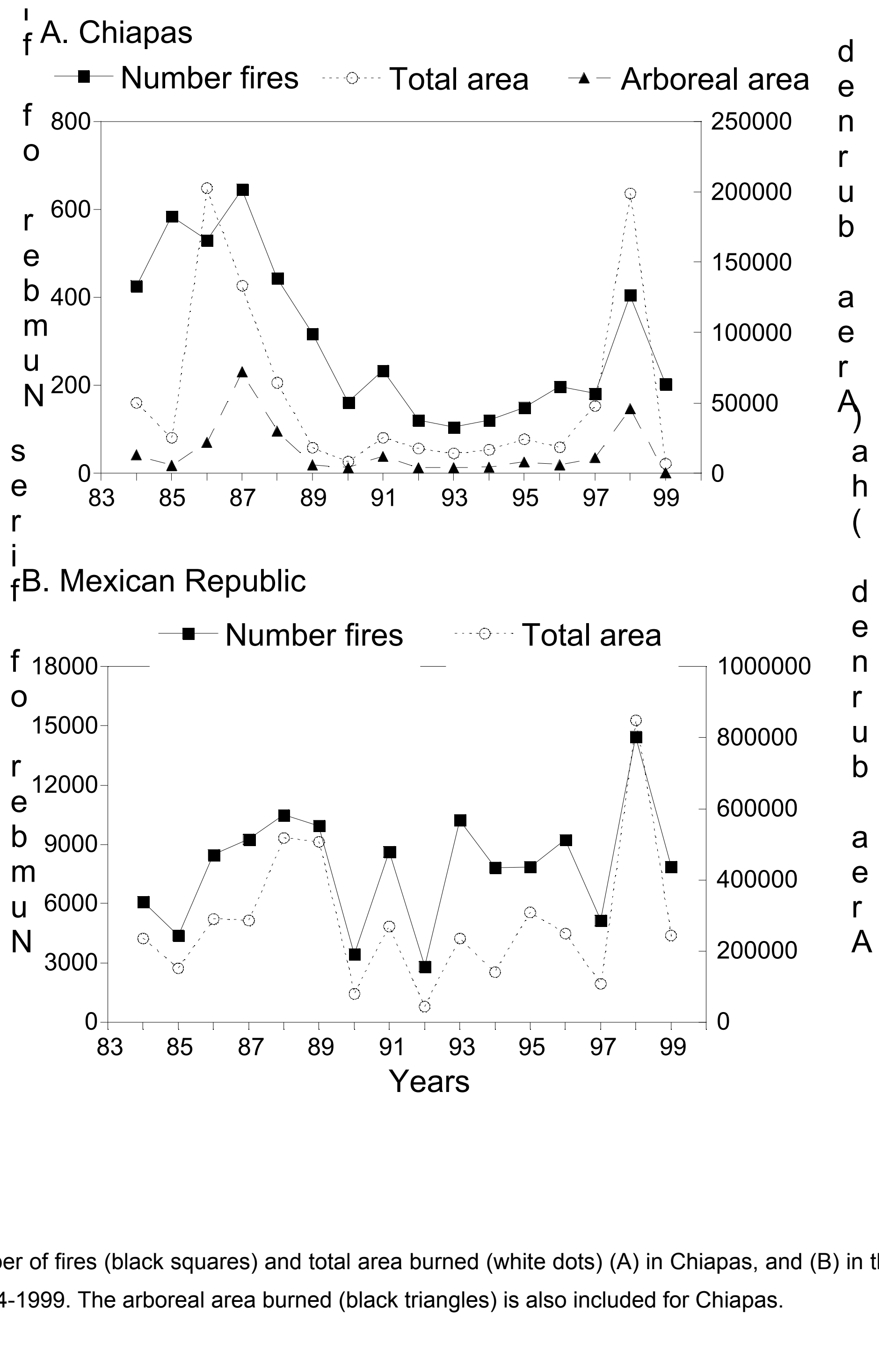

Figure 2. Total number of fires (black squares) and total area burned (white dots) (A) in Chiapas, and (B) in the Mexican Republic, during 1984-1999. The arboreal area burned (black triangles) is also included for Chiapas.

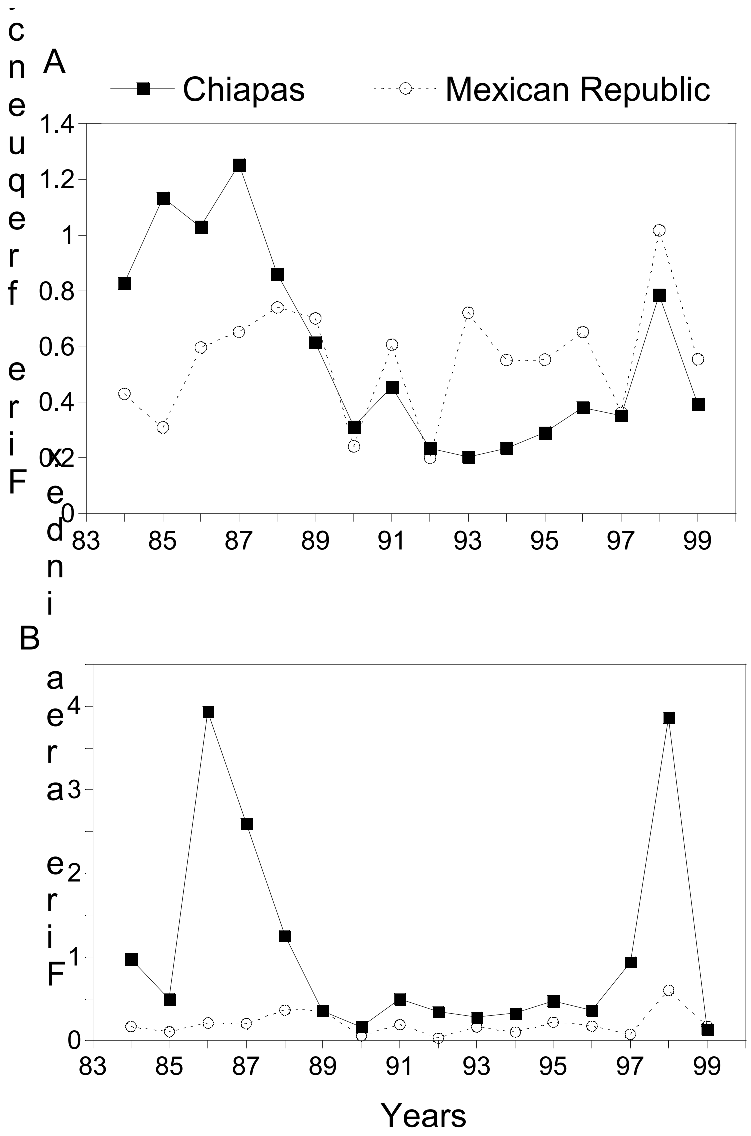

Figure 3. (A) Fire frequency index and (B) fire area index for Chiapas (black squares) and the Mexican Republic (white circles) during 1984-1999.

This could be related to the importance of large forest fires in this tropical State which are few in number but affect large areas (Figure 4). In the case of Chiapas, the total burned area was more strongly correlated to the area corresponding to non-arboreal layers (R=0.97) than to that of arboreal layers (R=0.74). This result agrees with the main fire type in the State. When contrasting fire variables for the two places, the total area burned in the Republic was slightly positively correlated with the total area burned in Chiapas (R=0.54). However, there was not a significant relationship between the mean area of the two sites, or between the number of fires. Considering this weak relationship between the total burned areas, and the independence between mean areas and the number of fires in both places, it can be suggested that Chiapas presents a peculiar fire situation, which does not follow the trends in the rest of the country.

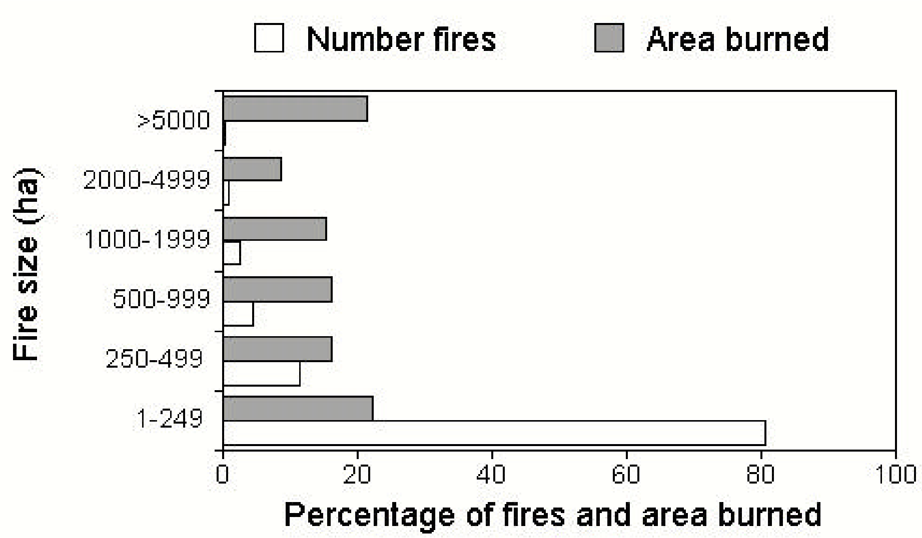

Figure 4: Percentages of fire incidence (white frame) and total area burned (grey) of fires of different sizes (in ha) in Chiapas, during the period 1993-1999.

Fire sizes and fire types in Chiapas

In terms of the size distribution of fires, almost all fires grew larger than 1 ha (less than 2% of connates during 1993-1999). Fire incidence was concentrated (80%) in small fires (i.e. those with areas between 1 and 250 ha), being responsible for only 22% of the total burned area (Figure 4). Large fires (i.e. those larger than 500 ha) represented 8% of the incidents and 62% of the total area burned, with special attention to those above 5000 ha, which were responsible for 22% of the affected area during the seven-year period, with just 0.3% of the incidents (Figure 4). Focusing on large fires, there were 32 municipalities (29%) that suffered at least one large forest fire during 1993-1999. One of these municipalities (Villacorzo) had 32 large forest fires, while others (Cintalapa, La Concordia and Villaflores), suffered 13, 15 and 16 large fires, respectively. In spite of these high numbers, severe effects on the arboreal layers represented only 4.6 % of

Table 1. Mantel correlation coefficients for fire variables in Chiapas (A), and the Mexican Republic (B), for the period 1984-1999. ** Significant R values at the 0.01 level. * Significant R values at the 0.05 level. n.s. not significant relationships. Annual rainfall and rainfall in the dry season refer to the mean values for the period 1984-1999 in Chiapas.

A. Chiapas

	Mean area burned	Total area burned	Arboreal layers	Non arboreal layers	Annual rainfall	Dry season rainfall
Number of fires	n.s.	0.639**	0.683**	0.543*	n.s.	n.s.
Mean area burned (ha)		0.888**	0.564*	0.895**	n.s.	n.s.
Total area burned (ha)			0.741**	0.969**	n.s.	n.s.
Area of arboreal layers (ha)				0.553*	n.s.	n.s.
Area of non arboreal layers(ha)					n.s.	n.s.
Annual rainfall (mm)						n.s.

B. Mexican Republic

	Mean area burned	Total area burned	Annual rainfall	Dry season rainfall
Number of fires	0.870**	0.663**	n.s.	-0.635**
Mean area burned (ha)		0.907**	n.s.	n.s.
Total area burned (ha)			n.s.	n.s.
Annual rainfall (mm)				0.515**

the total area affected by large forest fires during this period. However, it is important to point out that many of the municipalities affected by these large fires have natural protected areas: Los Chimalapas rainforest ecosystem (Cintalapa), La Selva del Ocote (Ocozocoautla), or La Selva Lacandona (Ocosingo), which represent the northern distribution of these ecosystems in North America, and are hotspots in biodiversity and endemisms (WWW4). The effort to fight against these large fires and prevent them is, therefore, doubly enhanced, because almost all the municipalities most affected by large forest fires during the period 1993-1999 were listed as fire priority areas (WWW5).

As in the case of other tropical ecosystems (Cochrane et al. 1999), the most frequent types of fires were surface fires, accounting for 80±9% of the incidents, and 60±21% of the total affected area, during the period 1993-1999 (Table 2). Regarding other types of fires, tropical areas also present mixed fires that reach crowns at some point (torching episodes related to each tree susceptibility), or isolated crown fires in given areas. In Chiapas they accounted for 15±6.5% of the incidents and 31±18% of the total burned area (Table 2). Severely burned areas affected 36735 hectares of arboreal layers (12 % of the total area burned in that period), which represented 0.7% of the State forested area and 1% of its arboreal area. Stand-replacement fires (mainly crown fires) are not frequent in Chiapas. When they occur, they are frequently associated with severe drought conditions and represent a future fire risk (if there is no land use change) during the following decades, as unburned fuels remain there and dry out (Taylor et al. 1999). Under severe drought, not only flammable forest types (pines or its mixed communities) can burn, but also potentially non-flammable vegetation such as *Abies* communities, tropical rain forests, and evergreen cloud forests.

Factors influencing the fire regime in Chiapas

Causes determining fire characteristics in any biome can be divided into structural and immediate ones. Structural causality refer to the ecological or socio-economic conditions that frame the fire problem (Vélez 1990), while immediate causality refers to those human activities that provoke fire in a direct or indirect way. In tropical areas, among the ecological structural causes, it is important to mention the existence of a natural seasonal variation in rainfall. In Chiapas, this seasonality divides the year into a rainy season (May to October) and a dry season (November to April), in general terms. Forest fires follow this rainy scheme (Figure 5), involving a concentration of human and material resources to fight against fire, in this specific part of the year; with the consequent limitations in terms of attending all fires. Regarding the duration of the dry season, a tendency has been observed for the fire season to extend to the first months of the rainy season, either because rain comes later, or because the accumulated drought stress of some years requires more time to recover. An analysis of the relationship between rainfall and fire variables in Chiapas for the period of 1984-1999, did not yield much explanation (Table 1, Figure 6). Thus, Mantel test analyses between total annual rainfall values and fire variables in Chiapas were not significant for any variable. Years with little precipitation (1993) did not necessarily present high values of incidence or area burned, while years with enhanced rain (1988) sometimes presented high values of area burned. Rainfall in the dry season (November-April), was negatively correlated with the number of fires in the Mexican Republic (R=-0.635)

(Table 1), and this relationship was not significant in the case of Chiapas.

Table 2. Percentages of (A) fire incidence and (B) total burned area corresponding to each type of fire in the State of Chiapas, during the period 1993-1999. Hectares in Table B represent the total area burned by each type of fire during these seven years.* Those reports that did not contain information about fire types have not been included.

A

Years	Surface fire	Surface and crown fire	Surface and ground fire	Surface, ground and crown fire
93	90.1	9.9	0	0
94	94.0	6.0	0	0
95	76.2	23.2	0.7	0
96	78.3	21.1	0.6	0
97	84.9	13.4	1	0.5
98	67.3	21.2	0.2	10.4
99	92.0	8.1	0	0
Mean± SD	83±10	15±7	0.36±0.4	1.6±3.6

B

Years	Surface fire	Surface and crown fire	Surface and ground fire	Surface, ground and crown fire
93	65.2	34.8	0.0	0.0
94	37.4	61.9	0.0	0.0
95	97.0	2.9	0.1	0.0
96	47.0	45.8	1.2	0.0
97	61.2	37.3	0.1	1.3
98	40.3	20.4	8.9	27.3
99	83.2	16.1	0.7	0.0
Mean± SD	62±22	31±20	1.57±3	4±10

An analysis of the relationship between rainfall and fire variables in Chiapas for the period of 1984-1999, did not yield much explanation (Table 1, Figure 6). Thus, Mantel test analyses between total annual rainfall values and fire variables in Chiapas were not significant for any variable. Years with little precipitation (1993) did not necessarily present high values of incidence or area burned, while years with enhanced rain (1988) sometimes presented high values of area burned. Rainfall in the dry season (November-April), was negatively correlated with the number of fires in the Mexican Republic (R=-0.635) (Table 1), and this relationship was not significant in the case of Chiapas.

Another structural climatic variable playing an important role in fire trends of this tropical area is the El Niño phenomenon. The influence of this factor was remarkable in the period 1984-1999, coinciding with severe effects on other tropical areas, such as Brazil's fires in 1987 (Setzer and Pereira 1991).In Chiapas, the presence of El Niño was related to variations of the SOI index (Figure 6), which showed a clearly marked pattern between the most serious El Niño episodes -in terms of fire incidence and arboreal impact- and negative minimum values of the SOI index (Figures 2a and 6). Thus, during the period analyzed, El Niño 1986-1987 and El Niño 1997-1998 represented two peaks in the number of incidents and the total burned area (Figure 2a). El Niño 1998 alone was responsible for 28% of the total arboreal area affected by fires during 1993-1999. The non existence of marked trends in El Niño years for the Mexican Republic may suggest that vegetation in tropical States might be more sensitive to climatic variations than in other areas.

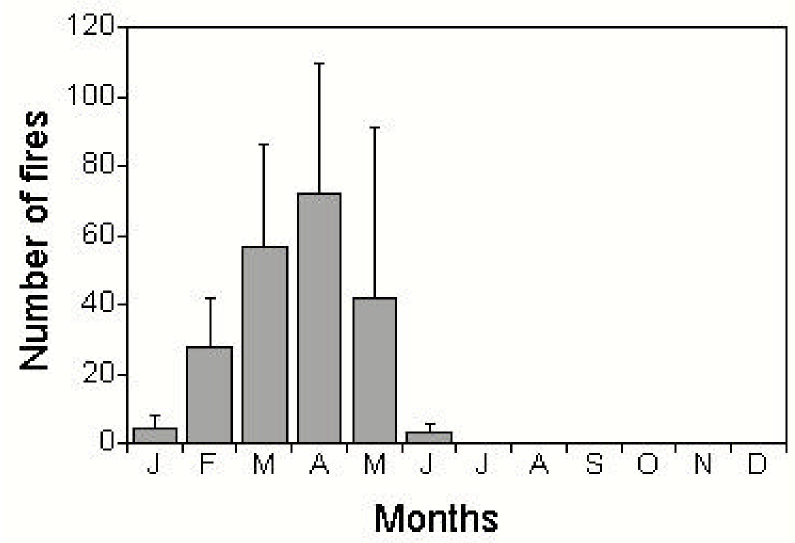

Figure 5: Seasonal distribution of the number of fires in Chiapas during 1993-1999. Values represent mean (±standard deviation) values per month.

No clear patterns were observed between rainfall patterns and El Niño values (Figure 6). Thus, the relationship between the SOI index and the rainfall patterns during the dry season was not significant (Mantel test, p=0.52): SOI minima were not necessarily related to rainfall depletions, neither was the opposite trend found (Figure 6). However, the 1998 El Niño fire season was related to the lowest rainfall values in the months of April and May in the last seventy years, both for Chiapas and for the Mexican Republic (WWW6). Outside these months, rainfall levels were normal and the dry seasons of both 1987 and 1998 were not recorded as rainfall minima in the period considered. This suggests that the El Niño phenomenon concentrates on given months, rather than extending the drought for the whole dry season. An analysis of precipitation outside these months can dilute the influence of El Niño on rainfall values and, consequently, fire risk.

The types of vegetation and their flammability properties can also be considered as a structural cause related to fire dynamics in tropical areas. In the case of Chiapas, non-arboreal layers were those most affected during the period 1993-1999 (71±14%), mainly due to surface fires. Even though several studies demonstrate that controlled fire can be an excellent tool to improve stand quality and to reduce fire risk for many pine communities (Minnich 1998; Fule and Covington 1997), fire does not always benefit the genus *Pinus*, especially the most mesic species (e.g. *P. ayacahuite* and *P. pseudostrobus* in Chiapas) (Richardson 1998). Fire can jeopardize the permanence of many pinewoods which, even if they are not destroyed, will be prone to regeneration difficulties (Miranda 1975; Richardson 1998).

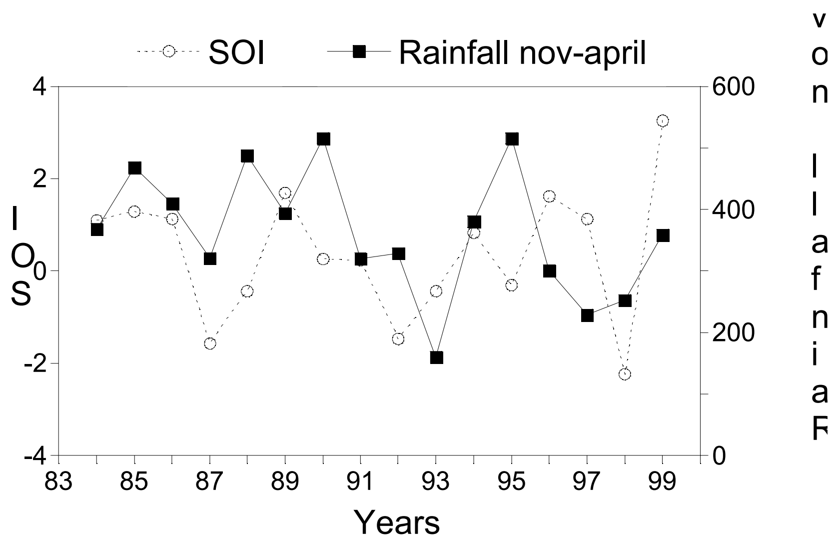

Figure 6: Rainfall (mm) during the dry season in Chiapas (mean values for the months of November to April) (solid squares and continuous line), and Southern Oscillation Index values (SOI, open circles and dashed line) computed for the months of December, January and February, during the period 1984-1999

Moreover, trees affected by this type of fires (39% of the affected arboreal layers), are weakened and become more vulnerable to pests and illnesses (Rodríguez 1996). Among arboreal layers, pine-oak communities accounted for 74% of the incidents, and 61% of the total area burned in the State during the period 1993-1999 (Table 3). These values represented 15% of the total area occupied by pine-oak communities in the State, 5.3% of the arboreal area in the State, and 3.4% of the total forested area in the State. Of the total area of pine-oak communities affected by fires, 54% was burned by surface fires, while almost the remainder corresponded to fires which reached the crowns at some point (Table 3). These communities have high flammability and are also located in areas of high human pressure. In the case of warmer forests, even though tropical rainforests are potentially non-flammable communities (Uhl and Kauffman 1990) they accounted for 7% of the incidents, and 18% of the total area burned in the State (Table 3), representing 3% of the total area occupied by rainforests in the State, 1.6% of the arboreal area in the State and 1% of its total forested area. The most frequent fires affecting these communities were mixed fires that affected crowns at some point (55% of their total burned area). These values, however, were mainly related to the 1998 El Niño fire season. In the case of evergreen rainforest communities, it has been shown that frequent surface fires together with moderate logging activities produce a positive feedback in future fire risk (Cochrane et al 1999; Goldammer 1999). The level of damage in the affected vegetation communities is related to the proneness of the affected ecosystems to the presence of fire and the existence of adaptive mechanisms to tolerate fires (Goldammer 1990). Thus, surface fires in tropical rainforests are not innocuous, due to the thin bark of woody species and the relatively-long time of fire residence on the contacted trees, even with a small fire length and intensity (Uhl and Kauffman 1990). These surface fire reduce the percent of canopy cover in the long term, and enhance future fire susceptibility and severity, as well as changes in species composition (Cochrane and Schulze 1999).The impact on montane tropical cloud forests (sensu Breedlove 1981) represented 0.3% of the fires, and less than 1 % of the total area burned in the State. Ninety-two percent of the total area burned in the cloud forest was due to surface fires (Table 3). Effects on

Table 3. Impact on the main vegetation communities during the period 1993-1999 in Chiapas. Areas are given in hectares. Crown fires include all those mixed fires that affected crowns at some point and the affected arboreal layers were higher than 0 ha. There are 190 fires (19420 ha) not included in this table, with either no information about the impact on their vegetation or affecting vegetation communities other than those considered here.

Vegetation communities		Crown fire	Surface fire	Ground fire (mixed)	Without fire type information	Total
Rainforest communities	Number fires	4 (3.8%)	58 (55.8%)	37 (35.6%)	5 (4.8%)	104
	Total area (ha)	29275* (55%)	8861 (17%)	14352 (27%)	517 (1%)	53005
	Arboreal area	15165* (59%)	1357 (5.3%)	8963 (35%)	111 (0.7%)	25596
Pine-oak communities	Number fires	211 (19.8%)	838 (78.6%)	8 (0.75%)	9 (0.8%)	1066
	Total area	74315.5 (42%)	95174.5 (54%)	553 (0.3%)	6505 (3.7%)	176548
	Arboreal area	12781 (33.8%)	24429 (66%)	57 (0.2%)	7 (0.02%)	37274
Evergreen cloud forest com.	Number fires	1 (20%)	4 (80%)	0	0	5
	Total area (ha)	20 (1%)	2364 (99%)	0	0	2384
	Arboreal area	20 (8%)	230 (92%)	0	0	250
Pine-oak-rainforest	Number fires	7 (9.6%)	56 (76.7%)	1 (1.4%)	9 (12.3%)	73
	Total area	5998 (15.2%)	31555.5 (80%)	350 (0.9%)	1498 (3.8%)	39402
	Arboreal area	740 (13.6%)	4183 (76.8%)	0	613 (11.2%)	5446
Total	Number fires	223	956	46	23	1248
	Total area	109609	137955	15255	8520	271339
	Arboreal area	28706	30199	9020	731	68566

vegetation during the 1998-El Niño year were also concentrated in pine-oak communities (65% of the incidences, 39.4% of the total burned area, i.e. 69187 ha), and rainforests (13% of the incidents, 27.4% of the total burned area, i.e. 48014ha). However, when focusing on the arboreal layers, the most affected communities were rainforests (55% versus 1.3% in the non-El Niño years) while pine-oak communities were less affected than in non El Niño years (18% versus 87% in the non-El Niño years). This suggests a dual impact trend, depending on whether it is an El Niño or a non-El Niño year.

Regarding the structural socio-economic causes that frame fire trends in this tropical State, land tenure plays an important role. In Chiapas, land distribution has been -and still is- the reason for disputes among communities and private owners, and communities themselves (Collier 1994 in Ramírez-Marcial et al. 2000). In the last five decades, there have been transformations of several private properties into communal lands *or ejidos* -especially intensified by the Zapatista movement-, whose vegetation communities have received and intensified human pressures (Ramírez-Marcial et al. 2000). In terms of fire trends, during the period 1993-1999, e*jidal* lands had the highest values of fire incidence (52% of cases), followed by private properties, communal lands and national lands (Table 4). Percentages for the total area burned followed the same trends as incidence: *ejidos* (47%), private property (15%), communal lands (9.7%) and national lands (8.6%). Mixed tenures that included national lands (not included in the previous group) were responsible for another 11.8% of the area burned, which, combined with strictly national areas affected by fire, amounted to 20% of the total area burned. Annual variations of land tenures were higher when dealing with areas than when dealing with incidences. *Ejidal* lands and private properties were both responsible for half of the burned area each year. When these values were standardized by the area occupied by each type of tenure, these trends were modified (Table 4). Regarding the number of fires, *ejidal* lands still presented the highest incidence, but national areas, private properties and communal lands presented similar incidence values. The main difference appeared in terms of area burned, because national lands were the most affected tenures, with 7.6% of the total national land affected by fires, followed by *ejidal* lands (4.7%), communal lands (3%) and private properties (1.8%).

It has been debated which land tenure is the one that offers the highest resource protection. It is frequently considered that private properties are the best way to obtain higher stability and sustainable management (Tucker 1999).On the contrary, common properties and *ejidos* are considered a way of degrading natural resources, because they are supposedly not submitted to extraction restrictions and are frequently considered to be over-exploited as a result of this lack of control (Runge 1986; Tucker 1999). In Chiapas, this pattern is somehow confirmed when standardizing the affected areas by the State areas occupied by the four land tenures considered. Thus, private properties were the least affected, followed by communal and *ejidal* lands. Exclusively national lands were the most affected, requiring special attention, as they were created with the idea of biodiversity preservation (WWW4) and they supposedly present a higher degree of protection.

Finally, among the activities that directly or indirectly lead to forest fires, known as immediate causality, negligence and deliberate burning were the most important, indicating an important human component in Chiapas fires (Table 5).

Table 4. Land tenure impact in Chiapas during the period 1993-1999. For each tenure, the percentages of the number of fires and area burned are given in the first two columns. The last two columns show the standardized values of the number of fires and area burned of each tenure related to the areas occupied by these tenures in the State. As any combination of two different land tenures is considered a mixed tenure, no reference values are defined to standardize the values obtained in this last tenure category.

Land tenures	Number of fires of each tenure . Total number of fires^{-1} (%)	Area burned in each tenure . Total area burned^{-1} (%)	Number of fires in each tenure/ Area of each tenure in the State (number of fires/ha)	Area burned in each tenure/ Area of each tenure in the State (ha/ha)
Ejidal land	52.3	47	0.025	4.7
Common land	10.6	9.7	0.016	3.0
National land	4.0	8.6	0.017	7.6
Private property	28.0	14.9	0.016	1.8
Mixed tenure	5.2	19.9	-	-

These trends are also observed in the rest of the Mexican Republic (Rodríguez 1996), as well as in other tropical areas (Goldammer 1993; Nepstad 1999).Thus, negligence was the most important cause, being responsible for 51% of the incidents (±11%) (during the period 1993-1999), mainly related to the non-application of compulsory security measures. The main negligent causes include agrarian and farming activities (mainly field cleaning and pasture regrowth burns), which accounted for 46% of the total causality. They were responsible for (56±12%) of the total area burned in the State in that period. Deliberate burning (arson, illegal hunting and fights among communities) were responsible for 33% (±14%) of the incidents and 21% (±11%) of the total area burned. Moreover, an inter-annual analysis of these causalities revealed that the proportion of fires caused by negligence and deliberate burning was not related to the variation in the annual number of incidents, and their combined percentage remained more or less stable around 70-80% each year, including the El Niño 1998 episode. In Central America and other tropical areas, it is difficult to determine where negligence ends and where intentional fires start. Fire is sometimes the result of deliberate negligence, with the objective of weakening woods in order to obtain forest cutting authorisations or land use changes (Vélez 1986).

Table 5. Percentages of immediate fire causalities in Chiapas, understood as those causes that directly or indirectly provoke fires. Other causes include railways, electric lines, military training activities and vehicles.

Years	Negligence	Deliberate	Unknown	Meteorological	Other causes
93	53.7	37.2	6.6	0.8	1.6
94	45.8	42.4	11.0	0	0.8
95	40.0	48.7	10.7	0	0.7
96	36.5	44.7	18.8	0	0
97	54.8	23.1	22.0	0	0
98	56.4	22.1	21.5	0	0
99	68.7	9.6	18.2	1.5	2
Mean± SD	50.8±11	32.5±14	15.6±6	0.33±0.6	0.73±0.8
Years	Negligence	Deliberate	Unknown	Meteorological	Other causes
93	70.1	15.4	4.5	1.4	2.38
94	67.5	22.7	7.2	0.0	0.04
95	44.4	41.9	7.7	0.0	0.03
96	42.8	27.2	18.3	0.0	0.00
97	55.1	12.4	16.1	0.0	0.00
98	66.8	7.8	8.3	0.0	0.00
99	54.8	19.5	23.9	0.7	0.22
Mean± SD	57.4±11	21±11	12.3±7	0.3±0.6	0.4±0.9

Little is known about the role of fire as a disturbing agent or the relationship between fire and ecosystem structure and functioning in many tropical ecosystems, as is the case of the Chiapas forests. This situation is also true for other Mexican areas, and increased fire ecology research has repeatedly been requested in

Mexico (see review in Fule and Covington 1997). Moreover, as tropical vegetation is an active agent controlling global climate and warming processes, the biome that contains the worlds major biodiversity levels, and the provider of many ecological services, further research needs to be done in order to correctly identify, monitor and diminish future risks in these areas. Among these risks, environmental degradation related to soil erosion, nutrient leaching and ecological services decrease will reduce soil fertility and prevent successful long term agrarian practices in many of the burned areas (Malingreau et al. 1985), forcing the application of external inputs that will have their own ecological impact.

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WWW1: SEMARNAT, Secretaria de Medio Ambiente y Recursos Naturales de México. Mexican States with larger burned areas during 1995-2000. http://www.semarnat.gob.mx/incendios/ estadisticas_incendios /mapa_incendios.shtml

WWW2: SMN. Servicio Meteorológico Nacional de México. http://smn.cna.gob.mx

WWW3: SOI. NOAA. Southern Oscillation Index. http://www.cpc.ncep.noaa.gov/data/indices/

WWW4: CONABIO. Comisión Nacional para la Conservación de la Naturaleza. www.conabio.gob.mx

WWW5: SEMARNAT. Priority municipalities in terms of forest fires in Chiapas. http://www.semarnat.gob.mx/ incendios/municipales/chis.jpg.

WWW6 : SMN Servicio Meteorológico Nacional de México. http://smn.cna.gob.mx/productos/map-lluv/hmproduc.html