Fire Regimes, Fire Ecology, and Fire Management in Mexico

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I propose several broad fire regimes and provide an analysis of fire ecology for the principal vegetation types in Mexico. Forty percent of Mexican ecosystems are fire-dependent (pine forests, several oak forests, grasslands, several shrublands, savannas, palm lands, wet prairies, "popal" and "tular" swamps), 50% are fire-sensitive (tropical rain forests and tropical seasonal forests, tropical cloud forests, mangrove, fir forests, several oak forests, and several shrublands), and the remaining 10% fall into fire-influenced (such as several gallery forests) and fire-independent categories (shrublands in most xeric environments, very high-altitude prairies). I also present an analysis of current fire-management trends, highlighting the trend toward integral fire management, which merges prevention and control, community-based fire management, and ecological fire management.

INTRODUCTION

Mexico is characterized by megabiodiversity. For instance, it hosts more pine, oak, agave, and cacti species than any other country in the world (1). It ranks fifth in the number of vascular plant species (26 000 spp.), fourth in amphibians (284 spp.), second in reptiles (717 spp.), and fifth in mammals (450 spp.) (2). It also represents the limit between the biogeographic neoarctic and neotropical zones and hosts diverse tropical, temperate, and semiarid ecosystems, covering 141 745 168 ha (3, 4). It should be noted that Mexican biodiversity is due in part to the coincidence of both neoarctic and neotropical zones.

Forest fires are a common disturbance in such ecosystems, mostly due to anthropogenic causes (approximately 90% of recorded fires), but also to natural causes, the latter of which occur principally in northern Mexico (5). The most important cause, representing almost 50%, is the use of fire related to agriculture and cattle-raising activities. Campfires and smokers also are an important cause of forest fires (6). For the period 1998–2006, a mean of 8727 recorded forest fires affected an average of 287 281 ha per year. The worst fire season Mexico has ever experienced was 1998, with 14 445 forest fires on >850 000 ha (7). It has been estimated that global climatic change will facilitate more wildfires in North America (8).

The agriculture-related causes have their roots in poverty, such as the lack of: alternative productive opportunities, forest culture, and better fire-management options. Since poverty is still a major problem, poverty-related fire causes are also expected to drive more fires in the middle term. However, some communities have good community-based fire management, such as La Sepultura Reserve, Chiapas, where specific fire use helps to maintain its *Pinus oocarpa* forests, among other objectives (9). Similarly, in Venezuela, the Pemones use fire to maintain the savanna and to prevent fires of higher magnitude, among other objectives (10). As in other parts of the world, the use of fire for agricultural purposes has ancient roots in Mexico. For example, 3000 years ago, a shifting cultivation system for the tropics was designed by the Olmec culture (11). This agroforestry system, which includes fire, was widely utilized by the Mayas. However, presently, because of the increase of population and a significant reduction of the fallow period, this system has become one of the factors contributing to the reduction of tropical forests.

FIRE REGIMES IN MEXICAN ECOSYSTEMS

For this section and those to follow, I follow the vegetation classification given by Rzedowsky (12), with slight modifications in some "subtypes" that are fire-dependent. In the following subsections, primary types of vegetation were considered rather than secondary or induced types. The causes of the fires that shape the fire regimes are not separated into human and natural causes in this work, as this is very difficult to do so. Throughout the document, the terms vegetation type and ecosystem are used interchangeably.

In Mexico, conifer forests (mostly pine forests) are principally established in temperate montane systems throughout the country (6 300 278 ha), as are conifer-broadleaf forests (mostly pine-oak associations, 14 199 659 ha). Broadleaf forests (mainly oaks) have a similar distribution (9 570 705 ha). The fir forests have small ranges on mountains in several parts of temperate Mexico. There are many types of shrublands, mostly in arid and semiarid regions on both mountains and flat areas, principally in northern and central Mexico (58 472 398 ha). The tropical rain forest is found mainly in southeastern Mexico and also in the western and eastern coastal areas (5 793 910 ha). A similar but larger range corresponds to the seasonal rain forest (10 948 862 ha). Other tropical vegetation types include palmetto lands, savannas, and the tropical cloud forest (9 697 289 ha). Hydrophytic vegetation, including mangrove and wet prairies ("tular" swamp, with *Typha* species, and "popal" swamp, with *Pistia* species, among others), covers 1 115 203 ha of coastal tropical Mexico (4).

A fire regime refers to the long-term nature of fire in an ecosystem and the prominent effects of fire that characterize such an ecosystem (13). Fire regimes are defined according to frequency, severity, season, duration, extent, spatial distribution, depth of burn, and type of fire (14, 15).

Several fire-regime classifications fit well with the Mexican ecosystems, particularly those outlined by TNC (The Nature Conservancy) (16) and Myers (17) (both actually correspond to the relationship between the ecosystems and fire-regime characteristics), and that of Barney et al. (18). The first classification includes: *i*) fire-dependent ecosystems, *ii*) fire-sensitive ecosystems, *iii*) fire-influenced ecosystems (an intermediate category between the two previous ones), and *iv*) fire-independent ecosystems. The second classification system considers three types: *i*) frequent, low-intensity surface fires, *ii*) infrequent, high-intensity crown fires, *iii*) relatively frequent, high-intensity fires (an intermediate category), and an added category *iv*) no fire regime.

Based on a literature review, synthesized in the section Fire Ecology in Mexican Ecosystems, field trips, and observations, I propose the classification of fire regimes of Mexican vegetation as shown in the following list and Figure 1. In Figure 1, the temperature and mean annual precipitation represent the typical conditions for each type of vegetation, but the area of each oval is not in proportion to the hectares that such

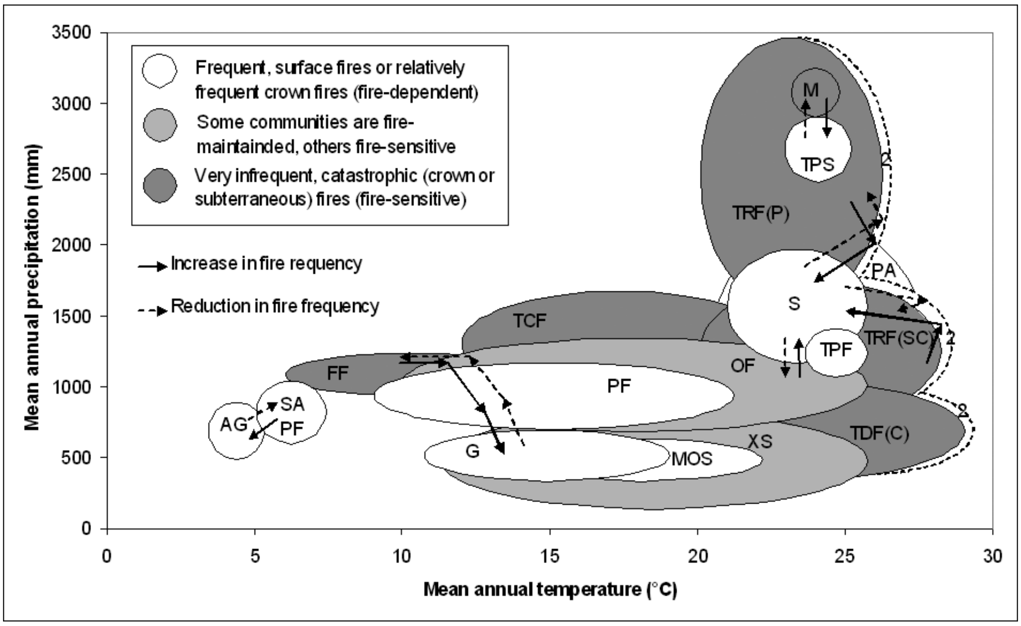


Figure 1. Fire regimes for most extensive vegetation types in Mexico. AG = alpine grasslands, FF = fir forests, G = grasslands, M = mangrove, MOS = Mediterranean and other shrublands, OF = oak forests, PA = palm lands, PF = pine forests, S = savanna, SAPF = subalpine pine forests, TCF = tropical cloud forests, TDF(C) = tropical seasonal forests (deciduous), TFR(P) = tropical rain forests (evergreen), TPF = tropical pine forests, TPS = wet prairies ("tular" and "popal" swamps), TRF(SC) = tropical rain forests (subdeciduous), XS = xerophytic shrublands, 2 = secondary vegetation. Arrows show some successional trends.

vegetation type covers. Also, the succession trends are symbolic, because they correspond to areas with the same temperature and precipitation, although, in Figure 1, the arrows span across different temperatures and precipitation values.

Frequent, low-intensity surface fires or relatively frequent and high-intensity fires (fire-dependent)

- Most pine forests and pine-oak forests
- Several oak forests, mostly those corresponding to initial successional stages
- Several shrublands, such as the Mediterranean shrubland in Baja California (relatively frequent and high-intensity fires)
- Grasslands
- Savannas
- Wet prairies (tular swamps and popal swamps)
- Palm lands

Infrequent high-intensity fires (fire-sensitive)

- Fir forests
- Several oak forests, principally from middle to advanced successional stages
- Several xerophytic shrublands
- Tropical rain forest (perennial, subperennial, and subdeciduous)
- Tropical seasonal forest (deciduous)
- Cloud forest
- Mangrove

Infrequent, high-intensity fires (fire-influenced)

- Several gallery forests

No fire regime (fire-independent)

- Arid shrublands
- Highest altitude alpine prairies

Using such fire regime classifications, and the area covered by vegetation type (3), I estimate that 40% of the area of all ecosystems together in Mexico have frequent, low-intensity surface fires (frequency of some years, approximately 15 or less) and some relatively frequent crown fires (fire-dependent, frequency of decades); 50% correspond to very infrequent (return period of decades or centuries) high-intensity crown, or subterraneous, fires (fire-sensitive ecosystems, including some fire-influenced); and 10% correspond to no fire regime (fire-independent). Considering the areas that are not highly disturbed, fire-dependent ecosystems include 17.7 million ha of temperate areas (58.3%), 26.6 million ha (45.5%) of semiarid areas, 1.7 million ha (6.4%) of tropical regions, and 2.3 million ha (54.8%) of hydrophytic and halophytic ecosystems, for a total of 48.3 million ha (40.4%). It should be mentioned that anthropogenically influenced fire regimes have helped both to preserve and to degrade fire-dependent ecosystems, such as pine forests, via an appropriate fire regime for the former case, or due to an excess of fire or the lack of it with eventual very intense and severe fires for the latter case (altered fire regime). Fragmentation has also been produced in part by altered fire regimes, such as in the case of tropical forests, and it also contributes to the alteration of fire regimes by reducing the area a fire may reach into a fire-dependent ecosystem.

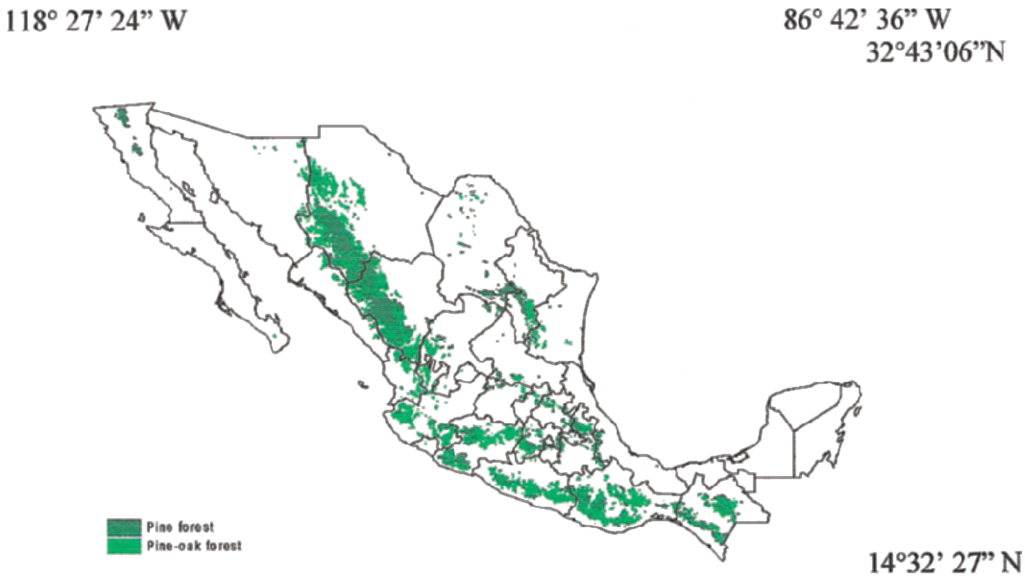
In the neoarctic biogeographic zone, 75% of ecosystems are fire-dependent, while in the neotropic realm, 63% of ecosystems are fire-sensitive, and 25% fire-dependent (19). Regarding the alteration level of fire regimes for the major habitat types worldwide, 38% of the fire regimes of temperate coniferous forests are considered intact, as well as 38% of flooded grasslands and savannas. In counterpart, 79% of fire regimes of tropical and subtropical dry broadleaf forests, 75% of tropical and subtropical moist broadleaf forests, and 70% of fire regimes of tropical and subtropical grasslands, savannas, and shrublands are degraded or very degraded (19).

Among the factors that have affected fire regimes in Mexico are livestock farming and ranching, fire excess and fire suppression, rural and urban development, agriculture, conflicts with traditional use of fire, global climatic change, logging, transportation infrastructure, and invasive species (19).

FIRE ECOLOGY IN MEXICAN ECOSYSTEMS

Fire-dependent Ecosystems

Pine Forests. Mexico hosts 47 pine species and 20 infraspecific taxa (20) (Fig. 2). Eight fire traits for 35 taxa of Mexican pines have been reported (5), and the list keeps growing. Five species have five or even six of such traits. The tropical high-altitude pine *Pinus hartwegii* regenerates well on fire-created beds; it has thick bark, self-pruning capacity, as well as the capacity to restore its scorched crown, it resprouts when young, and it exhibits the grass stage. *P. oocarpa*, the Mexican



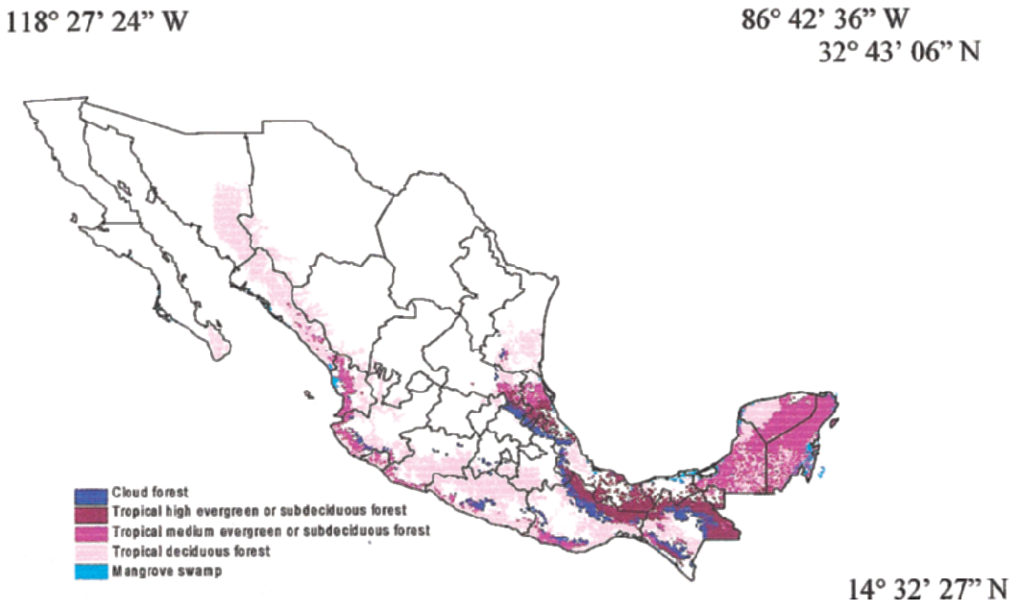


Figure 2. Top: Distribution of pine and pine-oak forests. The vast majority of these forests are fire-dependent. The southern states include tropical pines and oaks. Bottom: Distribution of tropical fire-sensitive vegetation. (Distribution of vegetation types based on 65.)

tropical pine with the broadest range, has serotine cones, regenerates well in burned areas, has thick bark, resprouts, and presents self-pruning capacity. The other pines with five fire traits are *Pinus leiophylla*, *Pinus montezumae*, and *Pinus patula* (5). Regeneration of 8000 seedlings ha^{-1} two years after crown fires has been reported for *Pinus douglasiana*, *Pinus herrerae* and *P. oocarpa* in Jalisco (21).

The tropical high-altitude *Pinus hartwegii* is found in 17 states in Mexico. It spans from 2800 to 4300 meters above sea level (22), making the highest altitude pine worldwide. Fire frequency in this ecosystem is estimated at 3–15 y. Fire favors the regeneration of this pine because it opens growing space among grasses for seed germination, and seedlings benefit from the ashes. The grass stage present in the seedlings represents a fire trait. Also, if the shoot of a young tree is destroyed or killed by fire, it may resprout. It should be noted that the intensity of both the grass stage and resprouting ability varies among populations. In adult trees, a thick bark protects the cambium from lethal temperatures and restores its scorched crown (23). Fire intensity, fire season, the influence of the density of the stand on the fuel complex, and tree size, all affect tree survival differentially. The first year probability of mortality for a 3 cm diameter to the breast height (dbh) tree is 0.95 for a high-intensity prescribed burn conducted at the peak of the fire season on dense juvenile stands (900 to 2500 trees ha^{-1}); probability is reduced to 0.03 for the same tree size under a low-intensity prescribed burn conducted early in the season in an open (300 to 700 trees ha^{-1}) young stand. In all cases, the higher is the tree dbh, the lower is the probability of mortality (24). Higher mortality in dense stands is related to the higher release of heat by the burning of needle litter, in comparison to grasses in open stands, close to the superficial tree roots (24). Furthermore, some cases of fire promoting tree growth have been documented for this species. Due to the elimination of older and lower productive branches with foliage that is less efficient photosynthetically, and also due to fertilization with ashes (25), low crown scorch, no higher than one-third of the crown height, increased the width of the tree ring by 34% the following year in comparison to the unburned control. Relative tree height growth (height increment of the year divided by the tree height) was promoted by mid-season low-intensity prescribed burns in comparison to the unburned control and to higher-intensity treatments (26). Higher understory species richness (almost 100% increase) and diversity have been recorded after prescribed burns (27), in comparison to unburned controls, with such an effect lasting 3 y (28) (Fig. 3). In *Pinus pseudostrobus*, *Pinus teocote*, *Quercus canby*, *Quercus laeta*, *Quercus laseyi*, *Quercus polymorpha*, *Quercus rhizophylla*, and *Quercus virginiana* forests of NE Mexico, the diversity increases in young postfire cohorts, decreases again in two intermediate successional stages, and increases again in old stands (29). Therefore, fire contributes to maintaining a high diversity in most pine forests and pine-oak forests.

With respect to pinyon pines, fires and hurricanes are responsible for a light-wave–like age distribution for *Pinus lagunae* (endemic and rare species) in Baja California Sur (30). Some pinyon pines seem to be fire-sensitive. In Tamaulipas, the area covered by the pinyon pines *Pinus cembroides* and *Pinus nelsoni* was reduced by the 1998 fires (31). However, good regeneration has been found in *Pinus cembroides* stands after fires (32); therefore, fire regimes need further study in Mexican pinyon pines. In general, fire frequency is high in pine forests in all of Mexico; it is estimated at 1 to 20 y, or 3 to 15 y in most cases. For instance, a fire frequency of 3.8 y was found for *Pinus durangensis* and *Pinus engelmannii* forests in Sonora (33). In addition, a mean fire interval of 3.9–5.2 y was found in studies of *Pinus ayacahuite*, *Pinus durangensis*, and *Pseudotsuga menziesii* stands in Chihuahua (34). Pine forests that are burned too frequently become degraded. Pine forests under fire exclusion eventually burn with a much higher intensity, causing effects that are far more severe.

Other pine forests exhibit longer fire return periods. In stands dominated by *Pinus jeffreyi*, in Sierra de San Pedro Mártir, Baja California, open stands (65–145 trees ha^{-1}) are due to infrequent intense surface fires with a rotation period of 52 y, similar to Californian mixed-conifer forests before the imposition of fire-suppression policy (35). Other authors (36) consider that if fire-suppression activities are maintained or expanded in this region, fire hazards and associated problems with forest sustainability will increase.

Oak Forests. Mexico hosts 150 to 200 oak species (37), including tropical oaks such as *Quercus oleoides*. Fire ecology in Mexican oaks has been studied far less than in pines. Apparently, tree oaks corresponding to early successional stages are more adapted to fire (and fire-dependent) and exhibit resprouting capacity as a dominant fire trait, while oaks from advanced successional stages may be less fire-adapted (fire-sensitive).

Oaks with small acorns regenerate well on burned sites, while oaks with large acorns do not (37). Oak species related to frequent fires include *Quercus crassifolia*, *Quercus crassipes*, *Quercus laeta*, *Quercus microphylla*, and *Quercus obtusata* (37). In the state of Guerrero, studies have found that *Quercus liebmanii* and *Quercus magnoliifolia* tolerate surface fires (38). Fire helps to maintain a high diversity in many oak forests, but apparently not in all of them.

Pines and oaks form complex associations, and the succession of so many species is poorly understood. In many cases, oaks follow pines during ecological succession, and fire (during the growing season) impedes oaks from taking over pines; in other cases, the contrary happens. For example, in the Sierra de los Ajos Reserve, Sonora, a crown fire affected a stand of *Pinus leiophylla* var. *chihuahuana*, *Quercus arizonica*, and *Quercus hypoleucoides*. After the fire, the pines died, but many trees of both oak species resprouted, and 14 y later, they dominated the stand (D.A. Rodríguez-Trejo unpubl. data). Similarly, in the Chiricahua Mountains, Arizona, surface fire favors pines (*P. arizonica*, *P. leiophylla*, *P. engelmannii*), and resprouting allows oaks (*Q. arizonica*, *Q. emoryi*, *Q. hypoleucoides*) to rebound. Presettlement surface fires maintained open stands, with a high pine:oak ratio, and excluded less fire-resistant species. A century of reduced fire due to fire prevention and firefighting has led to anomalous stand-replacing crown fires, where most oaks have resprouted, but pine establishment has been scant (39).

Figure 3. Top: Low-intensity prescribed burn recently conducted in an experimental area at the Ajusco volcano, southern Mexico City. The treatment was applied in March 2006. Bottom: Initial responses of the understory by the rainy season (September) of the same year. (Photos: D. A. Rodríguez Trejo)

Grasslands. Most of the native grasslands have coexisted with fire (40), which has also helped to maintain a high diversity; thus, they are fire-dependent, and Mexican grasslands are not the exception. In the southern US, burned *Bouteloua aristidoides* grasslands increase their production during wet years, and reduce it during dry years (41). Such grasslands extend into northern Mexico. In central Mexico, *Festuca tolucensis* and *Muhlenbergia macroura* grasslands associated with *Pinus hartwegii* advance the timing of flowering and produce more flowers in burned areas than in unburned areas (42).

Shrublands. There are many types of shrublands in Mexico, some fire-maintained, some fire-sensitive. Among the former are the chaparral and the *Acacia* and *Prosopis* shrublands, in northern Mexico. In central Mexico, oak shrublands (*Quercus frutex*, *Q. microphylla*, *Quercus repanda*) are fire-dependent too; in a shrubland of the former species, there were 1 530 000 oak resprouts 16 mo after a forest fire (23). In Baja California, there is a vigorous resprouting of shrubs after fires. Some of the species present are *Adenostoma fasciculatum*, *Arctostaphylos* spp., and *Ceanothus* spp. (12). In this type of shrubland, fire is one factor that helps to keep a high diversity.

In an evergreen, sclerophyllous shrubland in the Tehuacan Valley, central Mexico, a comparison was made between species of different origin, Mediterranean and neotropical. The species with neotropical origin were less able to regenerate after fire, and the resprouting feature of several species (with Mediterranean origin) was similar to that of fire-prone Mediterranean-type ecosystems (43).

A comparison was also made between the size of fires in shrublands on both sides of the border of the US and Mexico; larger fires were found in Southern California with respect to northern Baja California. The author mentions that the highest efficiency and resource level for fighting the fires in California over decades produced higher fuel accumulations than in Mexico, inducing such phenomena (44). The younger shrublands are less flammable (44).

Among the most sensitive shrublands are desert shrublands. For instance, when affected by forest fires, the giant cacti *Carnegia gigantea* shrubland suffers high mortality (45).

Savannas. Fire may convert tropical forests into savannas. However, savannas may also originate from edaphic factors, flooding, or by human perturbation (12, 46). The tall grasses present in Mexican savannas, such as *Andropogon*, *Imperata*, *Paspalum*, and *Trichachne* are resilient to periodic burns (47), and they are fire-dependent, with fire contributing to the maintenance of the savanna's diversity. Among the typical savanna-trees, *Byrsonima crassifolia*, *Coccoloba barbadensis*, *Crescentia alata*, *Crescentia cujete*, and *Curatella Americana* are adapted to fire. The seeds of *Crescentia americana* and *C. cujete* germinate better after being heated from a surface fire (46).

Wet Prairies. Main genera include *Typha* spp. and *Pistia* spp. (47), and fire propagates readily on them. The plants resprout vigorously after burning. Depending on the season in which fire occurs, swamp animal wildlife may be affected at different levels. Studies are needed on this topic. Under anthropogenic influence tular swamps (*Typha*) may burn twice during one year (Edmundo Aguilar pers. comm., Subdirector, La Encrucijada Reserve, Chiapas) (Fig. 4).

Palm Lands. Palm lands with species such as *Acrocomia mexicana*, *Brahea dulcis*, *Scheelea liebmannii*, *Sabal mexicana*, and *S. yucatanica*, among others, are adapted to fire. They resprout vigorously after burning (12, 46).

Figure 4. Neighbor vegetation types with different fire effects. The tular swamp resprouted well after fire (top). The red mangrove trees (*Rhizophora mangle*) affected by fire on the border died (bottom). (Photos: D. A. Rodríguez Trejo)

Fire-sensitive and Fire-influenced Ecosystems

Fir Forests. Fir forests (mostly *Abies religiosa*) correspond to a fire-sensitive ecosystem. Although some populations under low-intensity fire can resprout foliage after the crown is slightly scorched, fire generally causes high mortality to the species. Moreover, their regeneration is shade-tolerant. During wet years, fir forests offer a natural barrier to fire in central Mexico. In dry years, crown fires may occur in this forest, particularly if high fuel loads are also present, as in the case of the Parque Desierto de los Leones, a 1529 ha National Park in central Mexico. This forest has been affected by forest decline, mainly due to pollution from the end of the 1970s to the present. There, adult tree mortality has averaged 51.5%, in some areas reaching 100%, and resulted in a very scant presence of seed and tree regeneration (48). Fuel accumulation was huge, reaching up to 160 Mg ha^{-1} (49). By 1998, a crown fire affected more than 1000 ha, 400 ha into the park, causing almost total tree mortality.

Tropical Rain Forests. Tropical rain forests host the highest diversity among forest ecosystems worldwide (Fig. 5), but fire can degrade them (50) and reduce such diversity. Fires are rare without human influence. When coupled with severe drought, an ignition may initiate extensive and destructive forest fires. In 1998, 22 000 ha of tropical forests in the Selva el Ocote Reserve, Mexico, were affected (Reserva de la Biosfera Selva el Ocote unpubl. data). Also, a complex of 20 fires in Campeche affected >20 000 ha of tropical vegetation during the 2003 fire season (Universidad Autónoma Chapingo [UACH]-Comisión Nacional Forestal [CONAFOR] unpubl. data).

Normally, this forest represents a natural barrier for fire. However, during dry years, it burns. After burning, a tropical forest is even more flammable because more radiation penetrates to the soil, drying the remnant forest fuels and increasing the fire danger. Moreover, ferns colonize many of the burned areas, making the restoration of the tropical forest more difficult. Such ferns (e.g., *Pteridium aquilinum*) are very flammable (Fig. 5).

Hurricane impacts leave large amounts of forest fuels on a tropical forest. According to UACH-CONAFOR (unpubl. data), Hurricane Dean left loads as high as 179 Mg ha^{-1} of woody forest fuels. After Hurricanes Janet (1959) and Gilbert (1988), large fires followed in the affected areas. During the megafires in 1989, which burned on the fuels accumulated by Hurricane Gilbert (1988), 119 233 ha in southern Mexico were affected. The tree survival was 70% in hurricane-affected areas after Gilbert. However, such survival was reduced to 9–26% in areas affected by both hurricane and forest fires (51). Seven years after the big fires of 1998 on the Selva el Ocote Reserve,

Figure 5. Top: Near Calakmul Reserve, Campeche, a road served as a fire break and prevented burning of this tropical rain forest. The burned side (bottom) exhibits residual fuels and almost total incidence of direct solar radiation, increasing the fire danger along with invasive ferns. (Photos: D. A. Rodríguez Trejo)

Chiapas, 45 tree species were found in nonburned areas, 27 tree species were found in areas affected by the 1998 fires, and 13 tree species were found in areas affected by both the 1998 and the 2003 fires. The densities found were 325, 163, and 53 trees ha^{-1}, respectively (52). For the fire-perturbed areas, the same authors also found that species typical of secondary, savanna-like or savanna vegetation dominated the forest (*Bursera simaruba*, *Byrsonima crassifolia*, *Cecropia obtusifolia*, *Cedrela odorata*, *Cordia alliodora*, *Heliocarpus donnell-smithii*, *Lysiloma acapulcensi*s, *Piscidia piscipula*, *Tabebuia rosea*, and *Zuelania guidonia*).

Some tropical rain forest tree species respond well to fire. For instance, in southern Mexico, fire promotes the presence of *Swietenia macrophylla* and other associated species (53). However, it must be taken into account that the vast majority of tree species in tropical forests are fire-sensitive.

In the past years, fire has not been considered to be among the principal menaces for tropical rain forests in the management plan of the Selva el Ocote, Chiapas. Currently, it is considered the most important threat. In the past, lightning originated fires of some tens or hundreds of square meters before the rains controlled them. However, presently, some lightning is not accompanied by rain and is starting to cause more extensive fires (J. Velázquez pers. comm.). An example of man as the factor most closely associated with the increase of fire frequency in tropical forests is illustrated by the relationship between road density and surface affected by fires in reserves in the state of Chiapas (54).

Tropical Seasonal Forests. It is observed that the neotropical deciduous forest is susceptible to fire (55). Slashing and burning dramatically reduced both the seed density and the number of species germinating from the seed bank (30 species before and 13 species after a burn) (56). Fire seems to limit the extent and diversity of the tropical deciduous forest in several places. For instance, at La Sepultura Reserve, Chiapas, fire has contributed to the presence of savannas, in relation to historic and apparently also ecological time frames: more fire extends savanna while reducing the tropical deciduous forest, whereas fire exclusion extends such forests, reducing savanna.

There are several types of tropical deciduous forests, and *Metopium brownei*, a species present in tropical seasonal and tropical rain forests, resists fire and tends to dominate when fire reduces tree density and acts in the conversion of tropical forests to savannas (46).

Cloud Forests. This is an ecosystem with high levels of humidity, which makes combustion difficult. However, similar to tropical forests, during severe droughts, it burns catastrophically, as in 1998 at the El Triunfo Reserve, Chiapas. Also during 1998, in the cloud forest of Los Chimalapas, Oaxaca, fire affected some 38 000 ha. The tree mortality after these fires reached 80% (57). For the same place, losses of aerial biomass from 82% to 88% were reported, as well as live fine root biomass 49% lower in metamorphic substrates and 79% lower in sedimentary substrates in comparison to unburned areas (58). The fires reduced diversity.

Mangroves. The most common Mexican trees in the mangrove are *Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemosa*, and *Conocarpus erectus*. Frequently, mangroves are adjacent to tular swamps, and the tular swamp ecosystem may burn frequently, transmitting fire to the edge mangroves, thus killing them.

Some mangrove species may resprout after a top fire kills the trees (59). Lightning damage is common in the mangrove trees, and under very dry conditions, lightning may initiate some wildfires. In absence of fire, the mangrove extends and displaces the tular swamps (Fig. 4). Apparently, fire reduces the diversity of the mangroves.

Gallery Forests. Some components of central Mexico gallery forests, such as *Taxodium mucronatum*, may resprout after some damage by fires. In northern Mexico, there are gallery forests containing both fire-dependent and fire-sensitive species.

Comments on Ecological Succession

There is a trend of higher surface fuel loads as succession advances in many successional series, such as the following in central Mexico: grasslands (mean fuel load = 8.0 Mg ha^{-1}, maximum fuel load = 10.4 Mg ha^{-1}), pine or pine-broadleaf forests (23.3 Mg ha^{-1}, 76.4 Mg ha^{-1}), broadleaf forests (mainly oaks, 13.3 Mg ha^{-1}, 19.0 Mg ha^{-1}), fir forest (27.2 Mg ha^{-1}, 109.9 Mg ha^{-1}) (49). Such successional trends are inversely related to fire frequency and directly related to fire intensity. As succession advances, fire regime tends to be less frequent with fires that are more intense and severe (e.g., crown fire in fir forest). In contrast, the initial successional stages have frequent surface fires with low to medium intensity and severity (e.g., grasslands and pine forests into the fir range). Similarly, higher surface fuel loads were described (21) as succession advanced in the State of Jalisco from pine forest (*Pinus douglasiana*, *P. herrerae*, *P. oocarpa*) (49 Mg ha^{-1}) to mixed pine-hardwood stands (96 Mg ha^{-1}). However, from this point, fuel diminished as stands matured to cloud forests (25 Mg ha^{-1}).

FIRE MANAGEMENT

Traditionally, Mexico has carried out a fire-exclusion fire-management policy. The lead firefighting and normative agency is the CONAFOR (Comisión Nacional Forestal). It has nearly 2000 core trained and experienced firefighters. However, the number rises to 10 000 when the resources of several state governments, other organizations, and volunteers are included. States that have the most trained human resources include the Distrito Federal, the State de México, and Chiapas, among others. The CONANP (Comisión Nacional de Áreas Naturales Protegidas), in charge of Mexican Reserves, has been increasing its fire-management capabilities since the historic 1998 fire season in Mexico (UACH-CONAFOR unpubl. data).

Material and infrastructure resources include 800 vehicles from all the organizations, 31 fire engines, the regular rent of 10 helicopters each year, plus the participation of aircraft from the Mexican army, CONAFOR, and government. Also in Mexico, there are 156 detection towers, and 206 fire stations. Detection via satellites has been provided by the CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad) and the Universidad de Colima.

The efficiency of the Mexican program has been proven in economic and environmental terms. For instance, in an analysis of the 2003 fire season, it was estimated that thanks to firefighting efforts, burning of 5 312 714 ha was avoided (the affected area was 322 448 ha by 8211 fires that year); the economic losses by such fires (wood, firewood, reforestation on affected natural regeneration and forest plantations) reached US$379 302 097, but the avoided economic losses were estimated at US$8 570 420 667. The CONAFOR investment in fire protection that year was US$14 288 909. The emissions of seven pollutants by these fires reached 6 159 655 Mg (mostly CO_2), while 131 249 780 Mg of avoided emissions were estimated (UACH-CONAFOR unpubl. data).

Some organizations are lobbying for the beginning of a new fire management policy, recently named integrated fire management. The normative and operative leading organization for such a trend is CONAFOR itself. In 2005, a nationwide meeting, organized and headed by the CONAFOR, reunited the normative-operative federal and state fire management areas, the CONANP, related national and international nongovernment organizations, and the academic-research area, among others.

In that meeting, a list was made that served as basis for the formulation of a national diagnostic and a new national fire-management plan, including an analysis to strategically and gradually begin integrated fire management. Such material has been formulated with the participation of several organizations, headed by the UACH and CONAFOR.

Some of the key players in the overall process are universities such as the UACH (e.g., the Ajusco Project researching fire ecology, restoration of burned areas, integrated fire management, and the installation of small demonstrative areas, which started in 2000), the U. de G. (Universidad de Guadalajara; research projects on fire ecology, restoration of burned areas, and integrated fire management), the University of Washington (UW) and the US Department of Agriculture (USDA) Forest Service (FS) (both mentoring U. de G. and UAAAN (Universidad Autónoma Agraria Antonio Narro) for the development of forest fuels stereoscopic photoseries for the Sierra de Manantlán, Jalisco, and the Sierra de Arteaga, Coahuila). The FMCN (Fondo Mexicano para la Conservación de la Naturaleza) has been supporting projects nationwide on generation of capabilities for firefighting and on integrated fire management and fire ecology, with funding from US Agency for International Development (AID).

The global fire initiative of The Nature Conservation (TNC) started working in Mexico in the year 2000 by organizing workshops, first to evaluate the forest fire situation in Mexico and then toward ecological use of fire, which later evolved to integrated fire management, with the participation of speakers from TNC, USDA FS, UACH, U. de G., UAAAN, and INIFAP (Instituto Nacional de Investigaciones Forestales y Agropecuarias). TNC and FMCN played a key role in introducing the participation of CONANP (Comisión Nacional de Áreas Naturales Protegidas), a strong member of the initial integrated fire-management community. TNC has been one of the key generators and promoters of integrated fire management in Mexico, Latin America, and throughout the world.

The need for prescribed burning in Mexico, with ecological and silvicultural objectives coupled to the reduction of fire danger, and also to satisfy the needs of rural people (campesinos) who use fire (and who frequently initiate forest fires), in order to prevent such fires, presently named integrated fire management, was identified years ago in Mexico (60, 61). However, the meaning of integrated fire management has several interpretations (17). For instance, (integrated) fire management is also defined as the activities that a country, state, or region carry out to prevent and fight forest fires; to understand how, when, and the objectives of the rural communities that have been using fire historically in the different ecological regions; to regulate the use of fire so it may serve with goods and services from forest ecosystems, both the rural and urban societies, without adversely affecting the forest ecosystems; to research fire ecology and fire effects, and in general to use fire science and to apply new fire-knowledge in forest ecosystems management; to use fire for the administration of ecosystems in order to preserve, restore, or to make them productive (silviculture, traditional uses); and to educate and to inform the users of fire and the public opinion on this matter. All this is in a context of maximizing positive fire impacts (diversity, regeneration, tree growth, nutrient and organic matter recycling, wildlife habitat, food for cattle, *etc.*) and minimizing the negative effects of fire (risk for firefighters, people, and property, deforestation, erosion, pollution, tree and wildlife mortality, catastrophic fire danger, extremely frequent fires, economic impacts, *etc.*), according to a fire regime (anthropogenic and/or natural) that is convenient from several points of view, such as: ecological, political, social, anthropological, legal, economic, normative, and operational (62, 63). Additional information on integrated fire management is available in several references listed herein (17, 62, 64).

Mexico is giving other clear signals of starting to move toward integrated fire management with projects that have started in some sites, such as Selva El Ocote and La Sepultura Reserves, Chiapas; additionally, these reserves have elaborated their integrated fire management plan, along with el Triunfo and la Encrucijada Reserves, Chiapas, and Calakmul Reserve, Campeche, despite the lack of sufficient financial resources. Interestingly, the forest office of Chiapas has expressed an interest in such an approach through the organization of workshops. The CORENA (Comisión de Recursos Naturales) of the Mexico City Government, agrees with prescribed burning with campesinos, naming this strategy integrated fire management, although the connection with ecological objectives is still pending.

Also in review is a new version of the Mexican Official Norm for the Use of Fire NOM-015, which incorporates the participation of CONAFOR, the SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales), TNC, UACH, and the Mexican Association of Forestry Professionals, and several more. This version introduces the concepts of fire regimes (first in its class for a Forestry-Mexican Official Norm), perceives and tries to regulate better the need of the campesinos for use of fire and prescribed burning, and seeks to increase the participation of municipalities, governments of states, and reserves, among other issues.

The trend keeps increasing slowly, but it still has a long way to go. One obstacle is the lack of sufficient human, material, and financial resources. However, the approach that is being followed is to conduct operative or research pilot projects, such as those at Sierra de Manantlán (U. de G., UW), la Sepultura Reserve (CONANP, TNC, and the University of Colorado), and the Ajusco Project (UACH).

Fire ecology and topics of integrated fire management are included in graduate and undergraduate courses at the UACH and U. de G. Also, the most reputed nationwide operative training courses organized by CONAFOR, with the collaboration of USDA, FS, and, more recently, TNC, have included both themes, not to mention the TNC workshops in Mexico and Central America. The USDA, FS, and TNC also have trained Mexican and Central American personnel on prescribed burning. So, for new generations of professionals and firefighters, this issue is not rare. In the future, the trend that Mexico finally takes on fire management will be known. Presently, a new generation of fire managers, researchers, heads of national and international nongovernmental organizations, and heads of reserves are sharing the goal of achieving integral fire management, for the sake of Mexican biodiversity and the well-being of the population.

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