Advances in Integrated Fire Management in Central Mexico

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Abstract

This paper reports on the research and operational results of efforts made by some rural communities, the National Forestry Commission (CONAFOR), the Universidad Autónoma Chapingo (UACH) and other organizations to achieve integrated fire management in central Mexico. The research includes the latest results obtained by UACH's Ajusco Project on the subject, in both fire-maintained and fire-sensitive ecosystems. Operationally, the paper reports on the holding of workshops, meetings and prescribed burns oriented towards this type of fire management in Mexico City and the states of Mexico, Puebla and Tlaxcala, organized with producers by CONAFOR and UACH. It is a joint effort involving farmers, government organizations at the federal and state levels, and a teaching and research institution. It seeks to contribute to this management alternative, through the merger of the ecological use of fire, its judicious and low-impact use by rural communities, and the prevention and fighting of forest fires, promoting all kinds of positive impacts and reducing the negative ones.

Introduction

Despite its small area of almost 150,000 ha, Mexico City, also known as the Federal District, is a federal entity with the biggest human population in the country. The largest number of fires also occurs there. In fact, it is not uncommon to have more than 1,000 fires per year. However, most are small, as the National Forest Commission (a federal government agency) and the Natural Resources Commission (an agency of the Mexico City government) have the human resources, materials and specialized equipment to perform fire management tasks. Over 40 % of the causes are agricultural. Farmers burn open grasslands or in the forest to promote the emergence of new sprouts, called "pelillo" in Mexico, which they use to supplement the diet of their animals during the dry season. Escapes from the burning of crop residues, used to clear the ground, fertilize it with ashes and reduce potential pests, are also part of such agricultural causes. About 25 % of the causes include bonfires

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and still-lit matches and cigarette butts tossed onto the ground by passers-by and fieldworkers (CONAFOR, 2012; CORENA, 2012).

Rural areas in the southern part of Mexico City cover almost 89,000 ha, and include some 50,000 ha with forest vegetation. The latter includes both fire-maintained and fire-sensitive and -influenced vegetation. The first group includes pine forests, oak forests, matorrales (shrublands) and zacatonales, while in the second group a few patches of cloud forest and sacred fir forest can be mentioned. The latter is considered moderately adapted to fire by recent research.

The forests in the south of Mexico City, which are in wildland-urban interface areas, provide many environmental services to the city, such as control of dust clouds, water and carbon capture, recreation and leisure sites and ecotourism, among others.

As is the case elsewhere in the country and in many parts of the world, a large number of fires in this area are linked to agricultural causes, which are based on poverty and the needs of rural people, but also on a lack of information. But they are also superimposed on extensive ecosystems requiring fire to stay healthy, such as those mentioned; moreover, the smoke produced from fires further contaminates what is already one of the most polluted cities in the world.

It has also been estimated that climate change, globally and in Mexico, is expanding dry areas and thus resulting in increased fire hazard. This, coupled with a still far-off solution to poverty, lets us see near-future, medium-term and long-term scenarios of more forest fires, which must be managed from their social and ecological components, in addition to preventing and fighting fires that will remain an important part of management efforts.

The above is the challenge facing fire management in Mexico City and the country as a whole, which will only be properly met when fire is used for ecological, management and conservation purposes in ecosystems that need it, and when people who use fire in the traditional way minimize escapes, follow the existing regulations and stop conducting uncontrolled burns, so that the positive effects of fire are maximized and the negative ones (such as air pollution and erosion) minimized. All this should be promoted and validated by research carried out by universities and research centers, which have also taken a very active role in Mexico. This is called integrated fire management.

In the year 2000, the University of Chapingo initiated the Ajusco Project, which is focused on fire ecology, integrated fire management and restoration of burned areas. The project's goals, in addition to those set forth in the previous paragraph, are to promote fire research, increase the number of postgraduate students delving into the subject, train more people in the area of forest fires, provide feedback to courses with the information generated and participate in national and international

workshops and conferences, such as this one, to disseminate the results. The aim of this paper is to give a summary overview of what has been achieved so far by the project and its impact.

Work regions and partnerships

Although the project team started its research in the cold-temperate area of central Mexico, it is now also at work in tropical and semi-arid areas. In total the project team has worked or is working in Mexico City and 11 states of the country: State of Mexico, Tlaxcala, Hidalgo, Puebla, Guerrero, Oaxaca, Chiapas, Quintana Roo, Campeche, Sonora and Coahuila.

In various forms, it has worked with international institutions and organizations such as: the University of Arizona, Northern Arizona University, the University of Colorado, the U.S. Forest Service, the Fire Sciences Laboratory in Missoula, Montana, Natural Resources Canada, the Nature Conservancy, the University of Lleida, Spain and the University of Jaén, Spain. Nationally, partnerships have been formed with CONAFOR, CONAFOR-Mexico City, CORENA, CONAFOR-Puebla, Colegio de Postgraduados, Universidad Autónoma de Guerrero, Universidad Autonoma de Hidalgo, and CONANP. Some of the contributions made by the project are cited below. The references correspond to members of the work team.

Including professors' work, theses, articles derived from both and published in international or national journals, books, book chapters and presentations at events, from regional to international, there have been more than 60 publications. Some more are in progress and several of those already published are mentioned below.

Contributions to the ecological component of IFM

Basic information

In this regard the work team has contributed, along with other organizations, including the federal government, to the acceptance of the ecological role of fire in the regulatory and operational areas of fire management in the country. This has been promoted through conferences, work meetings, workshops, scientific papers and presentations at workshops. In this particular area, the public has been farmers, children, middle school to graduate students, fire management operational and regulatory staff, professors and researchers. It has also helped to determine the level of relationship between fire and the various types of vegetation in the country.

Mexico is the country with the highest number of species of pine (47 taxa) and oak (167 species) worldwide (Farjon and Styles, 1998; Zavala, 2007), and its forests

cover large areas. Through adaptations to fire such as thick bark, grass stage, regeneration in burned areas, rapid growth, recovery of crown foliage that was dried or scorched, most Mexican pine species show adaptations to fire. Among the pines with the most adaptations to this ecological factor and that have wide distribution are: *Pinus hartwegii*, *P. montezumae*, *P. patula*, *P. greggii*, *P. oocarpa*, and *P. michoacan*, among others. The least adapted include the pinyon group, such as *P. cembroides* (Rodríguez and Fulé, 2003) (Figure 1). Regarding oaks, of 73 species analyzed and reviewed, the majority also showed adaptations to fire. Morphological indications that reveal such adaptations in different species include: resprouting capacity, thick crust, regeneration in burned sites, small nut and deciduous habit. In general, oaks in cloud forests and tropical forests (except those forming savannas) are fire-sensitive, for example *Q. insignis*. Among the tree species adapted to fire in Mexico are: *Quercus rugosa, Q. crassifolia, Q. crassipes, Q. magnoliifolia, Q. hypoleucoides* and *Q. arizonica*. Shrubs include: *Q. frutex, Q. repanda, P. potosina* and *Q. microphylla*, among many others (Rodríguez and Myers, 2010).

Fire-sensitive ecosystems have also been evaluated, such as the tropical forests of the Selva El Ocote Biosphere Reserve, Chiapas, after 23,000 ha were affected by fires in 1998. Seven years after the fires, the number of tree species and their diversity based on the Simpson index (D), in samples from different conditions studied, was: unburned forest (45 species, D=0.96), areas only burned in 1998 (27, D=0.86), areas burned in 1998 and restored with direct seeding (13, D=0.73), others burned in 1998 that were restored but were burned again in 2003 (10, D=0.58), and others burned in 1998 and 2003 (13, D=0.69). The control area presents a slight gradation in the values of importance among the abundant species in the unburned area. On the other hand, a few species, typical of savannah, dominate the lower richness present in the affected areas (Maldonado *and others*, 2009). Sacred fir (*Abies religiosa*) forest, the type of climax vegetation in the temperate areas of the entity, has been considered as moderately adapted to fire. Prone to crown fires in dry years, such as 1998 and 2011, one of these fires affected 200 ha in the community of Topilejo, Mexico City, in 2011. A 73.1% mortality rate was determined, and logistic models were used to estimate the probability of tree mortality. Structure variables, namely height ($p<0.0001$), diameter at breast height ($p=0.028$), crown length ($p<0.0001$) and height to the base of the crown ($p>0.0001$), explained, with an inverse relationship, the mortality. By contrast, a direct relationship was found with the severity variables: fatal height ($p<0.0001$) and crown scorch percent ($p<0.0001$) (Temiño and others, in process) (Figure 2).

The avifauna of burned areas was studied in a *Quercus crassifolia* forest in Chignahuapan, Puebla. This research found that a hummingbird, *Hylocharis leucotis*, prefers severely burned areas where it finds the species *Bouvardia ternifolia,* which

has a tubular flower where the nectar is obtained (Ponce *and others*, 2011). A general proposal for fire regimes and fire ecology for Mexican vegetation was also developed (Rodriguez, 2008).

Figure 1—Stand of *P. hartwegii*, in central Mexico, where low intensity and severity prescribed burning was conducted seven months earlier. Photo by Dante A. Rodríguez Trejo (2006).

Figure 2—Effects of a crown fire in central Mexico on sacred fir (*Abies religiosa*) forests six months later. Photo by Dante A. Rodríguez Trejo (2011).

Applications

In this case, besides better understanding the fire ecology in species and regions of interest, the strategy is to have applications and guidelines that are useful when performing prescribed burns and that help to maximize the beneficial effects and minimize the negative impacts of fire. For example, Rodríguez *and others* (2007) point out from logistic models that low-intensity prescribed burns (early morning, against the wind and slope), conducted no later than mid-season, cause virtually no mortality in *P. hartwegii* saplings, while an intense burn (afternoon, and with the wind and slope), which simulates a fire, eliminates more than 80 % of individuals. In probabilistic terms, at lower diameter at breast height (DBH), all treatments have a greater probability of mortality, but this is much more pronounced in the late-season treatments conducted at high intensity (with the slope and wind, with burning in the afternoon) and in dense stands. For example, a tree with a 10-cm DBH has a < 1 % probability of mortality if a prescribed burn is carried out in mid-season, in the morning and at low intensity (against slope and wind) in open stands. By contrast, a

tree of the same diameter burned with the intense treatment, in dense stands and in May will have a 50 % probability of mortality. These results are considered to be applicable to most temperate-cold climate pines in the country. The resulting model was:

$$P = 1 / (1 + \exp - (-2.3145 + 2.2619X1 + 2.00528X2 + 2.0343X3 - 0.4119X4))$$

Where: X1 is time of year (0=March, 1=May), X2=intensity (0=low, 1=high), X3=density (0=low, 1=high), X4=DBH (cm).

P. hartwegii is fire resistant, but *Q. crassifolia* is tolerant. For the latter species, in areas burnt with high severity, Juarez *and others* (2012) suggest that the probability of mortality for the above-ground part of an oak also with 10-cm DBH is 30 %. However, the probability for the entire individual (including the root) is only 5 %, as it is able to resprout. According to these authors, the probability of resprouting increases with lethal height (since by affecting buds containing auxins these phytohormones are eliminated and with them the inhibition to activate basal buds) and decreases with the diameter of the trees (the juveniles are more vigorous). On the other hand, according to Temiño *and others* (in process), for the species moderately adapted to fire, *Abies religiosa*, in an area affected by a crown fire 6 months before, a tree with a 10-cm DBH has an 80 % probability of mortality.

As part of the ecological responses in pine forests, there is greater species richness and diversity in the understory. Hernández and Rodríguez (2008), Espinosa *and others* (2008) and Islas (in press) show that one year after burning that richness increases by approximately 40 %, compared with the control, reaches 60 % by the end of the second year and falls to an additional 50 % by the end of the third. Another contribution lies in the estimation of total load (TL) or the load of certain types of forest fuels, e.g. woody fuels, from models using explanatory variables of the stand structure, such as basal area (BA), as proposed by Rodríguez *and others* (2009):

$$TL = 2.462 + 9.5553 \ln BA$$

Applications in the fire prevention and suppression component of IFM

Studies carried out in this regard include that of Carrillo *and others* (2011) and those of UACH-CONAFOR (2008) and Rodríguez *and others* (2011) on the impact and fire hazard resulting from Hurricane Dean. In the first, fire hazard areas were identified in the state of Puebla, as detailed in the following section. In the last two,

fuel loads felled by Hurricane Dean in 2007 and their spatial distribution were determined, along with hazard areas requiring priority attention based on fuel loads and distance to agricultural areas.

Another study conducted by UACH-CONAFOR (2011) establishes that, given the particular characteristics of Mexico City in terms of fire, which combine the same rural pressure found elsewhere in the country with the pressure of Mexico City, by not fighting fires, almost 58,000 wooded hectares of the federal entity would be affected by fire each year.

Contributions to the social component of IFM

Human dimensions and fire

For Puebla, Carrillo *and others* (2012) modeled the effect of both environmental (precipitation and exposure) and anthropogenic (number of branch roads and proximity to rural communities) variables, which influence the probability of fire in the entity. In this case, there tends to be more fires in areas with higher rainfall (where more fuels accumulate) on southern exposures (drier), in areas with many branch roads and few communities.

Derived from a project undertaken by CONAFOR-UACH (2007), Rodríguez *and others* (2008) refer to an inverse relationship between various forest fire parameters and the human development index, and also a direct relationship with: surface area disturbed by man, number of farmers subsidized in the spring-summer cycle for agricultural production, and maximum wind speed.

Applications in the social component of IFM

In this case the intent is to: A) disseminate the information generated so that it reaches the rural communities and is useful to them, B) contribute to the application of controlled burns in order to achieve effects similar to those demonstrated experimentally, and C) maximize the benefits derived from fire and contrast the negative effects of prescribed burns and wildfires. With regard to the latter, the aim is to discourage the indiscriminate use of fire and promote its correct rural use in communities where there is no empirical knowledge of this type. To this end, some efforts have been made with rural communities, with farmers or community fire brigade members, such as:

Workshop on fire and prescribed burns with ejidatarios in Chignahuapan, Pue., 2000, sponsored by the Technical Forest Services of Sierra Norte de Puebla.

Training Workshop on forest fires with Puebla state firefighters in

Huauchinango, Pue., in 2001, sponsored by INIFAP.

Training Workshop on forest fires with Puebla state firefighters in Chignahuapan, Pue., in 2003, sponsored by CONAFOR-Puebla and Puebla's Ministry of Environment.

Intoductory workshop on IFM in Villas de Santa Clara, Talxcala, 2009, sponsored by CONAFOR.

Participation in meeting on research and community experiences in the Tlalpan borough, sponsored by CORENA, Mexico City government, in 2012.

In this component, Chavarría (2009) and Ortiz (2009) analyzed grazing practices in central Mexico, the yield and carrying capacity of grassland in *P. hartwegii* forests and the precise objectives of fire use by livestock farmers.

In the workshops mentioned above and others, some of the available information has been disseminated in the form of lectures and practices, with feedback from farmers. One recent effort was to conduct an extensive prescribed burn on land with a high incidence of fire, which is summarized in the sub-section entitled "Application of prescribed burns towards IFM."

Establishment of demonstration areas

As a result of research or workshops, several demonstration areas have been established. They have been visited by farmers, students and researchers, who were able to see the benefits of prescribed burns. In most of them, there is continuing research on fire ecology and medium-term fire effects. The following list of demonstration areas includes information on their location, size and year of establishment (Figures 3 and 4):

Chignahuapan, Pue. (1 ha, 2000)

Ajusco National Park, Mexico City (4 plots, each with 1 ha, 2002)

Ajusco National Park, Mexico City (4 plots, each with 1 ha, 2006)

Villas de Santa Clara, Tlaxcala (1 ha, 2009).

Ajusco, Mexico City (12 ha, 2012).

Efforts in other forums

In order to disseminate the project's advances, information has been presented at events like World Fire 2003, 2007 and 2011 in Sydney (Australia), Seville (Spain) and Sun City (South Africa), respectively, and at the 4th International Fire Ecology and Management Congress in Savannah, Georgia (USA, 2009). See, for example, Rodríguez (2010, 2011).

Figure 3—Prescribed burn carried out with ejidatarios in Chignahuapan, Pue. Photo by Dante A. Rodríguez Trejo 2000.

Figure 4—Prescribed burn conducted with communities in Villas de Santa Clara, Taxcala. Photo by Dante A. Rodríguez Trejo, 2009.

The project has also been involved with The Nature Conservancy (TNC) in various workshops held in Central America between 2002 and 2006 and focused on fire ecology and integrated fire management, as well as with CONAFOR (several Forest Expos, state events), CORENA (events in Mexico City), and other government organizations, NGOs, and universities (UNAM, Universidad Autónoma de Guerrero, Universidad Autónoma de Puebla, Universidad de Hidalgo).

Application of prescribed burns towards IFM

Prescribed burns carried out in workshops are intended to promote integrated fire management. Next, a prescribed burn, the last and largest conducted by the project in central Mexico, is detailed. This prescribed burn, oriented to IFM, was held at a site belonging to a community, with its permission and the participation of firefighters belonging to it. An area with a high incidence of forest fires, as well as difficult terrain, was chosen. Such difficulties lie in areas with abundant hills, which imply uneven terrain. At the site, almost all year winds blow from different directions throughout the day and with different speeds, tending to increase as the day progresses. Fuels are mainly grasses, but with young trees in patches in different areas. Adult trees (*Pinus hartwegii*) are present at medium to low density.

The prescribed 12-ha burn was directed and conducted by CONAFOR and UACH staff. The objectives were:

- Reduce forest fuels to abate the fire hazard and protect young trees from fire.
- Produce forage for the livestock of herders, who often start fires in the area without causing significant damage to the trees.
- Contribute to maintaining wildlife habitat and the fulfillment of the ecological role of forest.
- Find a synenergy with farmers to burn at low intensity and gradually discourage the generation of forest fires.
- Obtain, on a large scale, experimentally determined benefits, such as: minimum mortality of trees, including juveniles, little damage to tree crowns, promotion of understory species diversity and reduction of forest fuels.

In March and April 2012, the experimental prescribed burn was carried out in two stages, with the participation of 30 firefighters at different times. The first stage was to burn a wide 2-ha band, located on a very steep slope and towards which winds often blow. It served as a safe area to treat the rest of the site. The second stage was the extensive burn.

The topographic and wind variation make it infeasible to apply a traditional technique, because the fire would eventually find a favorable wind and/or upslope on which it would develop more intensely, negatively affecting the young trees and, to some extent, also the adult trees.

For this reason an adaptation between chevron and backing fire techniques was made, since the fire was begun in a slightly irregular strip, starting on the ridgeline of the hills, in order to treat the latter always against the slope and with or against the wind, or perpendicular therewith, according to the case. Before the fire began to climb other slopes, burning began on the next line starting from the next ridgeline, so that it was roughly working on lines. Over most of the site, it was possible to have low intensity and severity.

In accordance with the prescription, it was generally possible to burn with flame lengths of 0.5 to 1 m, particularly around the perimeter of the site. In some small interior sectors flame length was greater. In such cases the burning of fuels in the direction of the fire's advance was done earlier to reduce the intensity. The advance by lines from the ridgeline was always maintained (Figures 5-8).

Figure 5—Prescribed burn in progress in Ajusco, Mexico City. Photo by Dante A. Rodríguez Trejo, 2011.

Figure 6—Prescribed burn in progress. Photo by A. Rodríguez Trejo, 2011.

Figure 7—Completed prescribed burn. Photo by Dante A. Rodríguez Trejo, 2011.

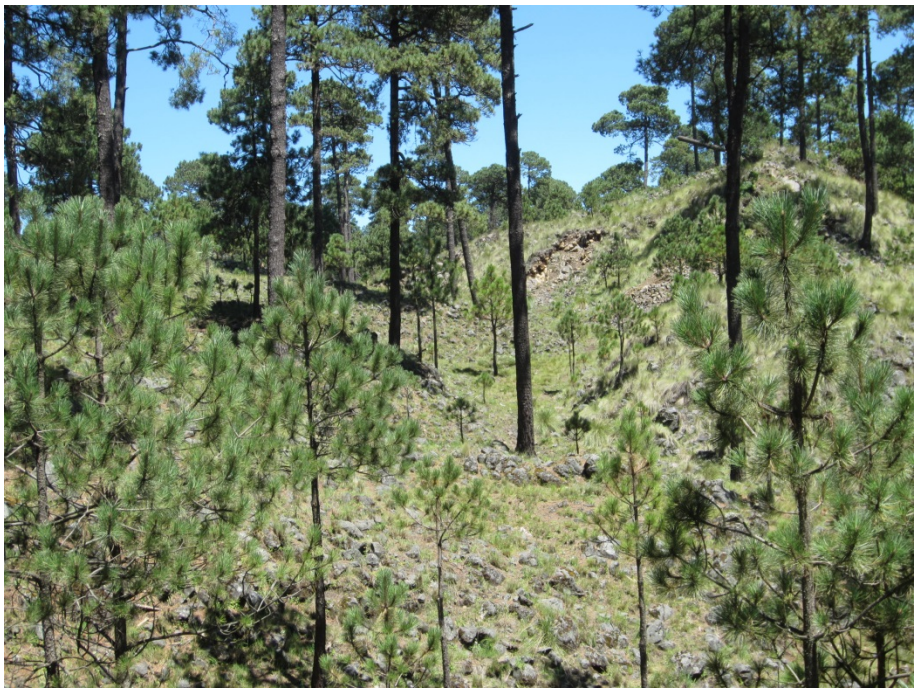

Figure 8—The prescribed burn area (left half of photo) 6 months later. Photo by Dante A. Rodríguez Trejo, 2011.

Figure 9—The work crew. Photo by Dante A. Rodríguez Trejo, 2012.

Today the area is monitored in terms of research (for example, studying the effect of the fire on height growth and resprouting in young trees) and its use by members of the community (qualitatively). It also serves as a demonstration area and, in the future, more prescribed burns are planned to help reduce fires and maximize various types of fire benefits in these forests that need them as an ecological factor. These forests are heavily used by the inhabitants of these rural areas, where due to the influence of city dwellers (tossed cigarette butts, bonfires) fires are also produced. All of the above is within the context of Mexico City, one of the biggest and most polluted cities in the world, and which requires the services of these forests.

Conclusions

The project has been one of the efforts that have helped increase information about fire ecology and fire use in the country, and one of the pioneering initiatives in integrated fire management. The strategy of thesis research has proven to be effective and contributes to the training of more professionals in the field of forest fires. The challenge is to continue contributing in this direction, but with new topics, while continuing to contribute to the social component.

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