AIR POLLUTION AND FOREST DECLINE NEAR MEXICO CITY *

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Abstract. The forests of *Abies religiosa* Schl. *et* Cham. in the north and the northeast slopes of the mountains of the southwestern region of the Valley of Mexico are in an acute process of decline, particularly the fir forest of the Cultural and Recreational Park Desierto de los Leones. The mortality of the trees began in 1981, and by 1987 30% of the trees of the Park had died; the mortality continues. The surviving trees are in a very poor crown condition, having thin crowns with many dead branches. in the light of current knowledge air pollution, in particular the oxidant gases (ozone), are the primary cause of decline, but other conditions or agents (age of the trees and diseases) could be contributing factors in the dying of the trees.

1. Introduction

Forests of *Abies religiosa* Schl. *et* Cham. ('oyamel' in Spanish, 'sacred fir' in English), are found higher than 2700 m above sea level on the northeast and north slopes of the mountains of the south of Valley of Mexico, were until a few years ago very dense forests, offering many places for recreation to hundreds of thousands of inhabitants of Mexico City. Unexpectedly, a few years ago, an acute process of decline has been present that had not been seen before; hundreds of thousands of trees have died since 1981 when the first signal of decline was registered. In the Cultural and Recreational Park Desierto de los Leones alone Flores Arellano (1987) [1] has reported a volume of dead wood of 278 000 m^3, up to 1987. The causes of decline of the trees have hardly begun to be understood and it is foreseen that it will be the result of a complex of interacting factors. In the present paper, the situation that exists in the Desierto de los Leones Park is described, since that is where the decline has been studied in more detail. However, death is also present in other woods of the same slopes.

Initially we describe the process of decline. Following that, the results of the investigation on the causes of decline are discussed.

The Park is located to the southwest of Mexico City, occupying an area of 1539 ha, in a range of altitudes of 2700–3790 m above sea level. It has a polygonal shape whose axes follow a northeast-southwest direction. The climate is temperate, cool and humid with rains in summer, the precipitation being about 1200 mm yr^{-1}. There are 67 days with freezing on average per year. The geomorphology is abrupt with an

[1] Flores Arellano, (1987), pers. com., Jefatura del Programa Forestal en el D.F.

* Contribution from 'Fourth World Wilderness Congress – Acid Rain Symposium, Denver (Estes Park), Colorado', September 11–18, 1987.

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average slope of 25.95%. The oyamel forest used to cover, before the declination process set in, more than 70% of this area, the rest being occupied by pine, oak and other broad leaf trees (Trigo Boix *et al.*, 1985).

2. The Forest Fir Decline

Death of trees in the Park was noticed very clearly in 1981. The trees began to die in small groups and the groups increased in size up to 1983, when they were so big that it was necessary to compile an inventory to determine the volume of standing dead trees. The results of the inventory [1] show that there was a volume of 103 000 m^3 of wood from dead standing trees. These groups of dead trees were called a 'cemetery' and were located on a northeast exposure that faces Mexico City. These groups of trees of cemeteries were present along the gullies, the mortality of the trees following a pattern from the center of the gullies to both hill slopes. By 1985 the Comisión Coordinadora de Desarrollo Rural del Departamento del Distrito Federal, present manager of the Park, obtained permission to cut and log the dead standing trees. This work was initiated in 1986, but by this time the dead standing trees had reached a volume of 223 540 m^3, and in the first half of 1987 a volume of 270 775 m^3 was attained. This number represented 36% of the total volume of *Abies religiosa*, which was 753 000 m^3 in the 1983 inventory. In order to identify the mortality pattern of the trees, the Dirección de Sanidad Forestal of the Secretaría de Agricultura y Recursos Hidráulicos, performed two flights over the park in order to take color infrared photographs. The first flight was performed in October 1985 and the second one in June 1987. The advance of the tree mortality is very obvious in the interval between the two flights. Using the aerial photographs of both flights it is intended to analyze the growth of the dead tree areas.

2.1. Symptoms of Decline of the Surviving Trees

Since 1983 it has been recognized that many of the green trees show symptoms of decline, and several researchers have attempted to identify the pattern of decline. In the División de Ciencias Forestales de Chapingo, a study of the physiognomy of crowns with different degrees of affectation has been carried out. The key that was followed was a modification of the one generated by Ferrell in 1980. With it, data from 399 trees with live foliage had been rated, with 20 variables being registered for each tree. These are under analysis with the purpose of generating a rating system of risk. In this work we describe only some of the physiognomic characteristics that are considered to be more important evidence of symptoms. These characteristics are: percent of dead branches in the crown, needle retention, foliage color and shape of crown, particularly the top.

[1] Internal Memorandum dated 15–VIII–83 from Jefatura de Programa Forestal to the Subsecretario Forestal.

TABLE I

Percent of dead branches in 399 trees from the damaged area in the Desierto de los Leones Park

Percent	Number of trees
0–10	4
11–20	21
21–30	37
31–40	37
41–50	61
51–60	92
61–70	64
71–80	44
81–90	15
91–100	24

2.1.1. *Percent of Dead Branches in the Crown*

In the 399 trees it was found that more than 60% of them have more than 50% of dead branches in the crown. In Table I it is seen that the trees have lost many of their branches. In analyzing the disposition of the dead branches it was found that the majority of them were below the top. Thus, a pattern of death was identified that goes from the bottom to the top of the tree, the top of the crown being the last part to die.

2.1.2. *Needle Retention*

In order to register this variable the top was divided into two parts, the upper half crown of most of the trees was graded as transparent while the lower half was graded as very transparent. The results are shown in Table II.

Alvarado Rosales *et al.* (1985) checked the foliage of 103 trees, finding on them needles 1, 2 and occasionally 3 yr old. When they measured the needle retention in other areas they found needles 1, 2, 3, 4 and occasionally 5 yr old.

TABLE II

Needle retention in 399 trees from the damaged area in the Desierto de los Leones Park (1986)

Condition of needles retention	Number of trees (lower half crown)	Number of trees (upper half crown)
normal (4–5 yr)	2	2
transparent (2–3 yr)	56	214
very transparent (1–2 yr)	221	103
absence	120	39

2.1.3. *Foliage Color*

The crown was divided into two parts. The foliage of the upper half was greener than the lower half, which in general was yellowish green. The results are shown in Table III.

TABLE III

Foliage color of 399 trees from the damaged area in the Desierto de los Leones Park, August 1986

Needle color	Number of trees (lower half crown)	Number of trees (upper half crown)
green normal	111	248
green yellowish	149	102
orange-brown	52	10
dark brown	87	39

Alvarado Rosales *et al.* (1985) studied the damage that is observed in the needles. They mention that, initially, whitish spots are present which afterwards change into a brown color and become coalescent, until the needles acquire, on the upper side, a uniform brown coloration. In transversal cuts a disintegration of the pallisade cells located on the upper side is observed.

2.1.4. *Top Condition*

The trees show rounded tops with no evident point, in many instances, 63% of the all 399 trees, the top was observed to be flat or rounded. We summarize the results in Table IV.

TABLE IV

Top condition in 299 trees from the damaged area in the Desierto de los Leones Park (1986)

Top condition	Number of trees
Pointed	38
Flat or rounded	252
Dead with regrowth	41
Dead without regrowth	52
Recently dead	16

From the observations about the condition of the top it may be concluded that the trees have lost a great quantity of foliage, many of the branches have died and the vigor has decreased considerably.

2.2. Growth of fir trees in the damaged area

Another variable related to the strength of the trees is the growth of their diameter, which can be expressed as a current annual increment by diameter category or by the growth time necessary to reach the next diameter category. Both variables were calculated for groups of trees from the affected area, from the exposure opposite to the affected area (on the other side of the mountains) and from the area which is found in the mountains of the East of the Valley of Mexico (this was at the University of Chapingo Forest Experimental Station in Zoquiapan, México). From these studies we can recognize that the trees of the affected zone are older trees. From 127 measured trees an average age of 96 yr was obtained with an ingrowth time of 29 yr in order to reach the next diameter category (the next 10 cm of diameter). Trees of the same diameter category from the other two areas were much younger, those from the south exposure (opposite the damaged area) had an average age of 60 yr and an ingrowth time of 19 yr. Finally, the trees from the Forest Experiment station in Zoquiapan were 43 yr old and they had an ingrowth time of only 7 yr. The results obtained are shown in Table V.

TABLE V

Age and diameter of groups of dominant trees of *Abies religiosa* from two localities in the mountains of Valley of Mexico (1987)

	Zoquiapan Exposition		Desierto de Los Leones Exposition	
	North	South	North	South
Number of trees	24	24	127	24
Mean diameter (DBH) cm	52.83	51.5	54.00	53.5
Mean age (years)	47.7	43.25	96.08	61.4

On comparing the current annual increase for the last 36 years, in intervals of 5 years, between trees from the Desierto de los Leones and the Zoquiapan trees, a strong difference was found between both localities. However it must be remembered that these populations were of different ages. Even though the dendrocronological analysis is incomplete, it can be said that the trees growing in the damaged area are mature trees, or maybe overmature trees, and they grow more slowly than the ones from the other observed areas.

3. Causes of Death of Sacred Fir

In the declining forest it is difficult to diagnose the causes of death since different factors interact in a very complex manner. First, we will consider the role that pollution of the air in Mexico City plays as a factor that influences the strees of the trees. Second, we will consider other contributing factors such as diseases and insect pests.

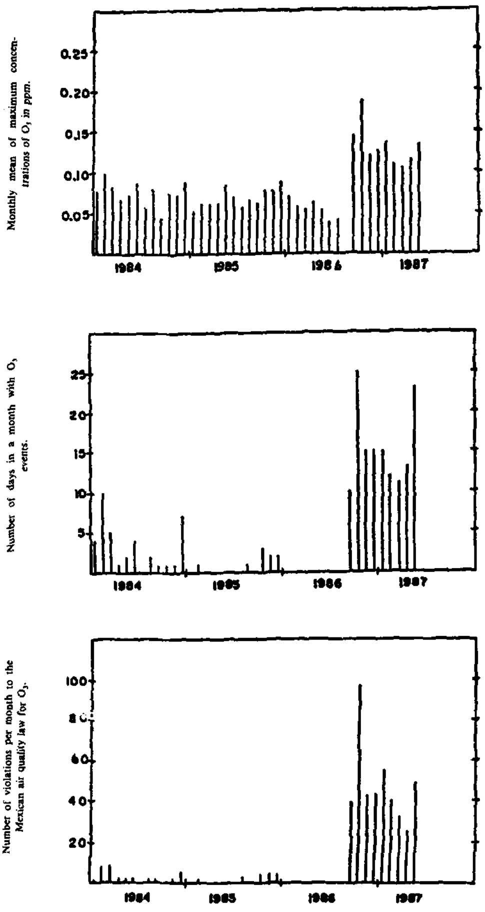

Fig. 1. Monthly mean of maximum concentrations of O_3 in ppm, number of days in a month with events of O_3, number of violations per month of the Mexican limit for O_3, registered in the south of the city (1984–1987) taken from Bravo *et al.* (1987).

3.1. The air pollutants of Mexico City

In the metropolitan area of the city 25 000 industries are located (30% of the industry in the country), 70 of them being of very large. However, the principal sources of air pollutants are the vehicles. Nearly 3 000 000 of them circulate in the abridged road system of the city. The principal kind of vehicle is the car. The accelerated growth of the city, now containing about 17 000 000 inhabitants, has frustrated an adequate planning of the road system. For this reason, it is very common to see slow traffic or congested roads.

In 1981, the total inventory of emmisions in the Valley of Mexico gave 3 780 000 ton of pollutants emitted to the air, of which 68% was carbon monoxide, 15%

unburned hydrocarbons, 10% was sulfur dioxide and 3.5% were particles and nitrogen oxides (Giron Hurtado, 1986).

Bravo *et al.* (1987) presented a set of new data for vehicle emmisions only. They said that of the 11 000 tons day^{-1} that are emitted to the atmosphere (4 000 000 tons yr^{-1} 89% was carbon manoxide, 9.5% hydrocarbons, 0.9% nitrogen oxides, 0.3% sulfur oxides and 0.4% were particles. These authors attached major importance to the second and third pollutants since they are the generating force for photochemical air pollutants. Also they said that ozone is now the main pollutant, and many times during the year its concentration rises above the levels set for it by the Mexican authorities. The permitted limit is no more than 0.11 ppm on average per hour. The impact of this pollutant has risen since September, 1986, when a new gasoline was introduced by Pemex. This new gasoline was introduced in order to reduce the high levels of lead in the suspended particles of the air. Figure 1 shows the average per month of maximum concentrations of ozone, the number of days in a month with O_3 events, and the number of hours per month in which this pollutant is above the Mexican limit. Other oxidants (PAN and aldehydes) are also formed, but they have been considered to be of lesser importance than ozone.

The highest concentrations of another very important air pollutant, SO_2, are located in the north and northeast regions of the city. Because the industrial sources are established there, the concentrations that reach the Park Desierto de los Leones is rather low.

3.2. Meteorological considerations in the transport of air pollutants

The location of Mexico City on the Southwestern part of the Valley of Mexico places it in a protected position from the wind. For this reason ventilation is not sufficient so that frequently one can observe at noon how the pollutant layer expands vertically, to be later carried away to the south and southwest by the wind.

The circulation of superficial winds has a daily behavior that is different from 6 a.m. to 2 p.m. Also there are some differences during the drought season from October to April and the rainy season from the end of May to the beginning of October. The behavior of the air is presented in Figure 2. Notice that the corresponding flow at 2 p.m. is similar for both seasons of the year because the wind is from north to south. That is why at this time it is transported to the south and southwest. In the late afternoon and at night, a catabatical wind flow is established that comes down from the hill slopes west and south of the city. These winds are found in combination with the ones which blow from north downwards from other mountain systems (Serrania de Guadalupe). The result is a horizontal convergence of air during the night and in the early hours of the morning. This flow convergence reinforces the convergent circulation which is generated by the 'heat island' of the city. The city/country thermal contrast is more accentuated during the winter. Then, the convergent flow is stronger during the first hours of the mornings when the maximum

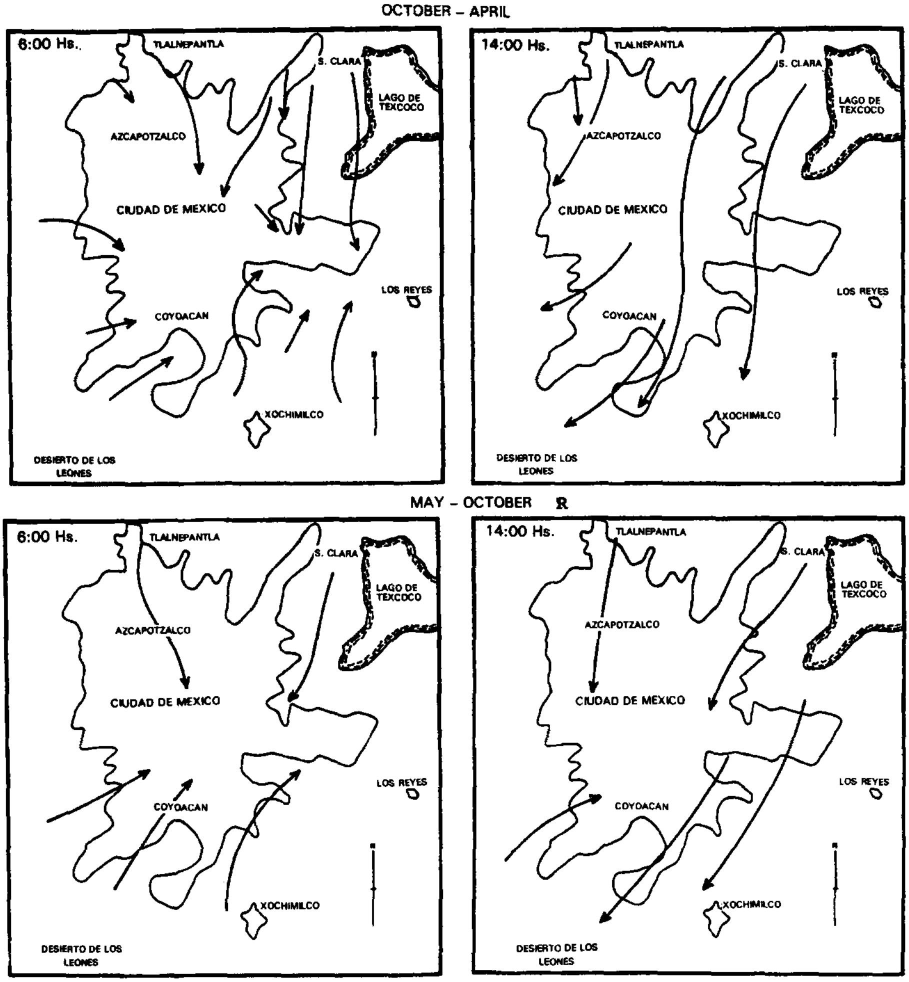

Fig. 2. Superficial air flow with the most frequent wind in Mexico City.

concentrations of some pollutants are reached, coinciding with maximum vehicle emmisions.

Besides this ordinary pattern of superficial flow, one of the greatest meteorological problems that the city experiences is the presence of thermal inversions. In the Valley at least two types of inversions are present. One occurs by the cooling of the surface and the other by the dripping of cool air from the mountains. The thermal inversions which are present regularly in the winter (67 days of 90 possible days) can also occur in the summer and the fall. Generally they are a few hours in duration, diluting as the hours of the morning go by.

4. Identification of the Damage to Conifers by Air Pollutants

Phytotoxic concentrations of pollutants have been registered since 1971. In that year, Bauer (1972) exposed indicator plants in different places of the city, finding evidence that damage by ozone was present. In 1980 and 1981 Hernández Tejeda *et al.* (1982), made observations in forests of *Pinus hartwegii* from the south of Mexico City (Sierra del Ajusco). The evaluated pines presented chlorosis and premature fall of the needles. In the needles they observed the classical symptoms of oxidant damage – bandig and mottling. The most drastic damage was observed by the end of the spring and the beginning of the summer. Hernández Tejeda and Bauer (1984) installed chambers with activated carbon filters. After a year they compared the foliage of exposed versus protected plants and observed that the exposed needles showed endoderm damage and collapsed tranfusion tissues and floem. The same authors compared the content of chlorophyll in the exposed needles with the those from the chambers with filters. The changes in the chlorophyll content was related to the observed changes in the affected leaves. The chlorophyll lost was 31.8% in comparison to the quantity of chlorophyll of the protected needles. The same authors observed the same type of damage, but with greater intensity, in the *P. hartwegii* forest, which is above the sacred fir forest in the Desierto de los Leones Park.

The evidence of oxidant damage in pine, the behavior of the superficial air flow and the high concentrations of ozone in the air that flows to the southwest, suggest that the sacred firs at the Desierto de los Leones Park are receiving large quantities of ozone, which is in agreement with the view of the majority of the researchers that are working in this subject in Mexico.

5. Importance of the Insects and Diseases in the Mortality of Firs in the Desierto de los Leones Park

The bark beetle *Pseudohylesinus variegatus* was ultimately responsible for the death of the trees. However, in the División de Ciencias Forestales de la Universidad de Chapingo, a study was performed (it is still in progress) concerning the role played by the bark beetles in the death of the trees. It was found that 98% of 420 trees with green foliage where bark samples were taken had experienced unsuccesful attacks by new adults. The insects only got to the floem and there they died, absorbed by the resin. Succesful attacks were registered on trees that have brown foliage or that completely lack foliage. The larvae were found in trees which had died several months previously. In one experiment, several logs were installed in a very damaged sacred fir stand in order to define the biological cycle of the bark beetles. The unattacked logs were sited in May (1986) and the beetles became successfully stablished by the following May (1987), which suggests that the insects are secondary to another stress.

A rot fungus was found in the big roots of several trees with green foliage from the affected zone. Its identification is still in progress. The symptom in the recently dead roots is the change of color of the xylem. In roots with a more advanced rotting a miceliar fan has been noted. This fan is similar to the one produced by *Fomes annosus*, but nevertheless it has not been possible to obtain reproductive structures. In the roots with very advanced rot, a deterioration of the sapwood is observed, they had miceliar areas among the wood tissues. The role of these fungi in the death of the trees is as yet unknown. However, in the few observed trees, it has been consistently found.

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