

Tree pollen viability in areas subject to high pollutant deposition

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SUMMARY. The wet deposition process, including fog, is a major pathway of acidic pollutants from the atmosphere to the biosphere. Pollen grains are known to be sensitive biological indicators of pollution at this interface. In southern Québec, pollen viability of three hardwood species (sugar maple, white and yellow birch), was significantly reduced above the mean cloud base height (≈ 600 m) for two successive years (1987-1988) at two mountain sites (Roundtop and Tremblant). Ozone concentrations, fog water and precipitation pH values over the sampling periods are discussed.

Key words: Acid fog, mean cloud, base, pollen viability.

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INTRODUCTION

The mountains of southern Québec are the northern extension of the Appalachian Mountains. Peaks with elevation of ≈ 1000 m are found on both sides of the St. Lawrence River with the St. Lawrence lowlands forming a natural channel for low level air masses moving from air pollution source regions located to the southwest. One field site east of Montréal (Roundtop or Sutton Mountain, $45^{\circ} 04' 51''$ N, $72^{\circ} 32' 56''$ W) and one northwest of Montréal (Mount Tremblant, $46^{\circ} 12' 50''$ N, $74^{\circ} 33' 20''$ W) are used by Environment Canada's Chemistry of High Elevation Fog (CHEF) program (Schemenauer, 1986) to record meteorological

conditions, to analyze fog water chemistry, precipitation chemistry, and to measure ozone concentrations at altitudes up to 970 m. The measurements are being made in support of forest decline studies at higher elevations. This area of southern Québec is characterized by the highest precipitation acidity and major ion deposition from precipitation (Barrie and Hales, 1984) of any area in Canada except for southern Ontario. Provincial surveys (Ministry of Energy and Resources of the Government of Québec, 1987) of the health of hardwood tree species over the last 5 years have raised serious concerns about the health of forests and demonstrated the need for ecological studies in the area. This paper describes 1987 and 1988

measurements of the viability of white birch (*Betula papyrifera* Marsh.) pollen collected in the 350 m (550 m in 1987) to 850 m altitude range on Mount Tremblant and the viability of yellow birch (*Betula alleghaniensis* Britton) pollen collected in the 550 m to 800 m range on Roundtop Mountain. In addition, measurements of the viability of sugar maple (*Acer saccharum* Marsh) pollen were made at both mountains in 1988.

Dry pollen is generally hygroscopic and will absorb water, and pollutants dissolved in water droplets, and may be used as a sensitive biological indicator of pollution, especially during a short period prior to anthesis (Wolters and Martens, 1987). High elevation areas, such as the mountains of southern Québec, are immersed in fog as much as 40% of the time and also receive more rainfall than lower elevations (Schemenauer, 1986). The wet deposition due to impaction of fog droplets on foliage is a major pathway for the transfer of acidic pollutants from the atmosphere to the biosphere (Barrie and Schemenauer, 1986). The study presented here was designed to examine whether there is a vertical gradient in tree pollen viability associated with the increase in fog immersion time and altitude. It is known that pollutants, notably acidic aerosols, will affect pollen quality, as estimated by germination percentage and pollen tube growth (Ruffin *et al.*, 1983; Cox, 1984). Pollen of broad-leaved trees (maple, birch, aspen) has shown the highest sensitivity to acidic water droplets (Cox, 1983) and was chosen for examination at the Québec field sites.

MATERIALS AND METHODS

Pollen was collected in spring (from April 27th to May 13th in 1987; from April 27th to May 27th in 1988) along two altitudinal transects, one on the west slope of Mount Tremblant and the other on the north slope of a Roundtop Mountain (Fig. 1). Each transect site was

located in a moderate class of maple dieback (25-50% of trees with missing foliage at tree top). At approximately each 25 m of elevation, and when the selected species were present, 5 to 15 trees of each species were sampled. The trees were selected on the basis of the accessibility of their flowers, so sampled trees were not necessarily the same from year to year. Short branches with flowers were collected with a telescoping tree pruner 3 m in length, so that the maximum height of sampling was ~ 5 m. Flowers from the external and lower parts of trees were therefore overrepresented in our study.

A mix of fresh pollen from each tree was stained, directly in the field, with a 10% solution of 2,3,5-triphenyl tetrazolium chloride (TTC) diluted at the rate of 1 part to 10 parts of a 60% sucrose solution (Sarvella, 1964). Viability was then estimated by light red or dark red staining. Stained pollen were counted at 250x, and a minimum of 400 pollen grains were counted per slide. The results quoted below therefore represent measurements on 2000 or more pollen grains from each 25 m altitude step for each species. The fog water samples at the CHEF sites were collected with a Teflon string passive sampler of the type described by Mohnen and Kadlec (1989). The fog droplets impact on 340 Teflon filaments, each 50 cm long and 0.4 mm in diameter. The droplets bead up and run through a polyethylene funnel into a polyethylene sample bottle. Mohnen and Kadlec have shown that the collection efficiency of the filaments is above 50% for 5 µm diameter droplets for 5 m/s winds, above 80% for 10 µm droplets, and above 90% for 15 µm droplets. Thus, the larger droplets, which contain most of the fog liquid water, are very efficiently sampled and the composition of the samples should be representative of the water reaching foliage surfaces. The ozone measurements reported below were made with a TECO 45 u.v. photometric ozone analyser with calibrations traceable to NBS (USA) standards.

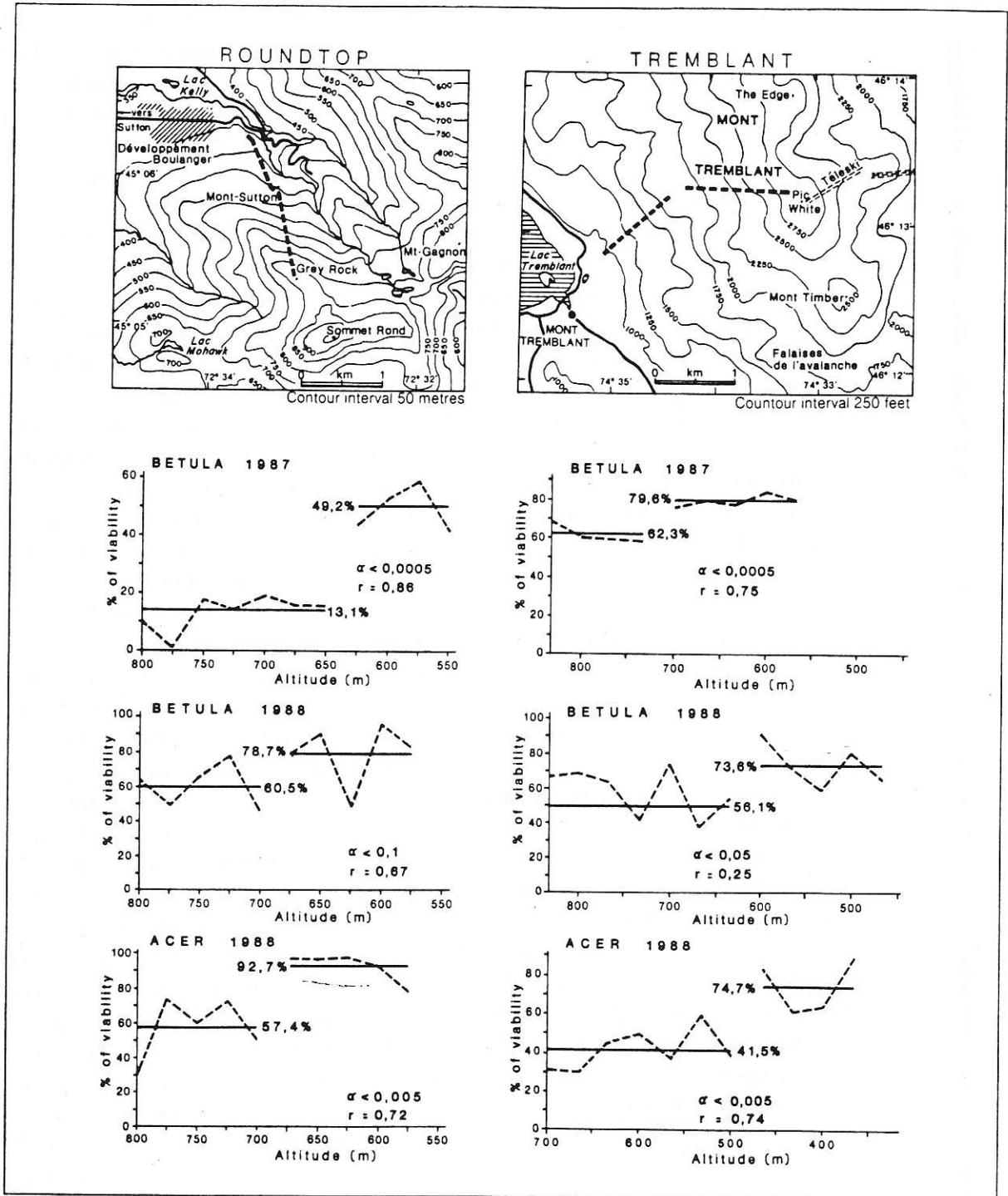


Figure 1. The locations of the 1987 and 1988 pollen transects on Roundtop Mountain and Mount Tremblant are shown at the top. Below each map the pollen viabilities of white birch (*Betula papyrifera*) at Tremblant, yellow birch (*Betula alleghaniensis*) at Roundtop, and maple (*Acer saccharum*) at both sites are given as a function of altitude. The percentage shown are the mean viabilities above and below the break point in the plot. « α » is the level of significance, and « r » the Pearson's coefficient of correlation between altitude and viability.

RESULTS

Results, expressed in percentage of viable pollen at each altitude, are shown in Fig. 1. Site to site pollen viability measurements are highly variable, ranging from 1.35% to 97.8%, however, a marked decrease of viability with altitude is evident. Correlation coefficients between altitude and pollen viability are, though, relatively low (from 0.25 to 0.86) and average 0.64. They were higher in 1987 ($r=0.80$) than in 1988 ($r=0.60$) and are higher for maple ($r=0.73$) than for birch ($r=0.63$). There was no difference between regions. The correlation coefficients are low because there is not a smooth decrease in viability with altitude, rather there seems to be a definite threshold between high and low viability stages. Indeed, if we group only the sampling sites on both sides of the highest decrease of viability (average number of 25 m altitude levels per group is 5; ranging from 3 to 7), the difference in mean viability is always significant ($0.005 < p < 0.1$) and the threshold is concentrated in an altitude range between 500 m and 725 m (mean = 638 m). In each of the six cases, marked decreases in viability take place over one sampling interval (25 m).

The mean viability percentage at lower elevations is 74.7% while it is only 47.9% at higher elevations, for a mean decrease of viability of 27%. This decrease was higher for maple (34%) and was higher in 1987 than in 1988 for both birch species. In addition, the standard deviation was four times lower in 1987 (4.21 vs 16.53), and the significance was increased by a factor of 10 to 200, depending on species and location.

DISCUSSION

The severity of damage to sugar maples and other hardwood tree species increases with altitude (Gagnon and Roy, 1989). This can be

caused by an increase in climatic stresses, poorer thinner soils or increased loads of pollutants. As the decreases in pollen viability were sharp rather than gradual, and were located at altitudes corresponding to the cloud base height for the site and season, we believe that atmospheric pollutants associated with the cloud cover on the mountain may have contributed to the decline of viability with altitude.

Schemenauer *et al.*, (1988) demonstrated that precipitation pH values from March - May, 1986 were constant (within 0,1 pH units) over the altitude range 250-850 m at Mount Tremblant. In June-September, 1986 precipitation pH values were again equivalent over the altitude range 665-970 m at Montmorency, north of Québec City (Schemenauer and Winston, 1988), and for a partial summer data set at Roundtop Mountain. Concentrations of the major acidifying ions, NO_3 and SO_4 , were also similar at the two measurement elevations at Montmorency. Though the precipitation amounts are higher at higher elevations on Roundtop Mountain (Schemenauer, 1986) and other locations such as Camel's Hump, Vermont (Vogelmann, 1980) there is no indication of major concentration changes in chemistry in the altitude range of interest in this paper. Precipitation measurements have only been made at two altitudes, but one would also expect that the precipitation amount would increase relatively smoothly with height, reflecting the fact that less water will be lost to evaporation as one approaches the cloud base. Thus, wet deposition associated with precipitation seems unlikely to be responsible for the sudden change in pollen viability observed at the sites in Québec.

The upper part of Roundtop Mountain is estimated to be in cloud 44% of the year with a maximum in late fall and winter and a minimum in late spring (Schemenauer, 1986). The actual percentages for April and May 1987 and 1988 are given in Tab. I. The percentage of time in

cloud at 0800 EST at 845 m was 26% and at 530 m it was 19%. Afternoon cloud immersion percentages are only slightly lower. Mean cloud base height for the 4 months was 655 m with a mean height lower (610 m) in 1987 than in 1988 (700 m). The fact that the mean cloud base height is similar to the mean height of the change in pollen viability (638 m) is not proof of a causal relationship, but the lower values of both parameters at Roundtop Mountain in 1987 with increases in both in 1988 is suggestive. The primary pathway by which pollutants enter a cloud is through cloud base (Barrie and Schemenauer, 1986). The lowest part of the cloud will, therefore, have the highest concentrations of pollutants. As clouds are advected over the mountains, they become by definition fog. Significant quantities of water can be deposited (Lovell, 1984; Joslin *et al.*, 1990) from these fogs. Fog water on Québec mountains has mean pH values of 3.7 to 3.9, about one-half a pH unit lower than for precipitation (Schemenauer, 1986; Schemenauer *et al.*, 1988; Schemenauer and Winston, 1988). This represents a threefold increase in H^+ concentration. The other major ions, NH_4 , NO_3 , SO_4 , are present in concentrations from 2 to 20 times higher in fog water (Schemenauer and Winston, 1988). In addition, events with extreme pH conditions have been recorded with pH values as low as 2.8 (Schemenauer and Winston, 1988). It is reasonable to postulate, based on the above, that because of higher frequency, longer duration and higher ion concentrations, acidic fog is more likely to have an effect on pollen than acidic precipitation is.

Anthesis period of deciduous trees is largely determined by the pace of the annual summation of heat units over $5^\circ C$. In the St. Lawrence lowlands, birch and maple pollinate in the days following 155 and 170 h respectively, with almost no variation since 1985 ($s=0.97$ to

1.40) (Comtois, unpublished data). The weather conditions at the end of April-beginning of May are therefore decisive in determining the sequence of pollination. The same synoptic weather patterns also influence pollutant transport and deposition.

In 1987, maximum temperatures over $20^\circ C$ at Roundtop Mountain and over $12^\circ C$ at Mount Tremblant a few days before anthesis seemed to trigger pollen emission. Minimum temperatures were $-3^\circ C$. Ozone showed maximum 1h average concentrations over 60 ppb one to three days prior to the mean pollination day at each site. The highest daily average ozone concentrations were 52 ppb at Roundtop Mountain and 49 ppb at Mount Tremblant in the week prior to anthesis. Monthly mean ozone concentrations for May 1985 were 40 ppb at Roundtop and 34 ppb at Mount Tremblant (Schemenauer and Anlauf, 1987). Thus neither the hourly maximum values nor the daily average ozone values were much in excess of previous monthly means. The lowest fog water or precipitation pH value recorded in the week prior to anthesis in 1987 at the two sites was 3.95. This occurred on a day at Mount Tremblant when the maximum hourly averaged ozone concentration was 62.3 ppb. It is unclear from the literature whether this pollutant combination constitutes an acute stress for pollen.

Table 1. Percentage of time in cloud and mean cloud base height at 0800 EST at Roundtop Mountain, Québec.

Year	Month	Summit 970 m	Ridge 845 m	Pipeline 530 m	Estimated Mean Cloud Base (m)
1987	April	33%	20%	17%	635
	May	29	29	23	540
1988	April	53	40	23	660
	May	35	16	13	740

In 1988, at Mount Tremblant, the final pollen sampling date was 27 May. Over the period 10 April to 27 May the minimum (1h) temperature was -8.6°C and the maximum (1h) was $+21.3^{\circ}\text{C}$. The maximum 1h average ozone concentration was 93 ppb. The highest daily average ozone concentration was 73 ppb. There were 11 fog samples (10 events) and 5 precipitation samples (5 events) with pH values <4.0 . The lowest pH (3.42) was measured in a fog water sample 6 days before the final pollen collection date on a day when the maximum hourly averaged ozone concentration was 59.5 ppb. From 10 April - 25 May, 1988 at Roundtop Mountain the temperature ranged from a minimum of -6.5°C to a maximum of $+21.2^{\circ}\text{C}$. The relationship between the daily mean ozone, maxi-

um hourly averaged ozone and fog water and precipitation pH values <4.0 is shown on Fig. 2. The lowest pH (3.23) was in a fog water sample collected 4 days before the final pollen collection date. It occurred on a day on Roundtop Mountain when the maximum hourly averaged ozone concentration was 59.7 ppb. This was the most severe event observed in the two pollination periods studies.

In a comparison of 1987 and 1988, spring-time in the latter year appears to have had the more severe pollutant regime. The 1988 ozone concentrations are higher and the extreme pH values are lower. The 1988 white birch viabilities follow this pattern and are somewhat lower at Mount Tremblant in 1988 than in 1987. However, the 1988 yellow birch via-

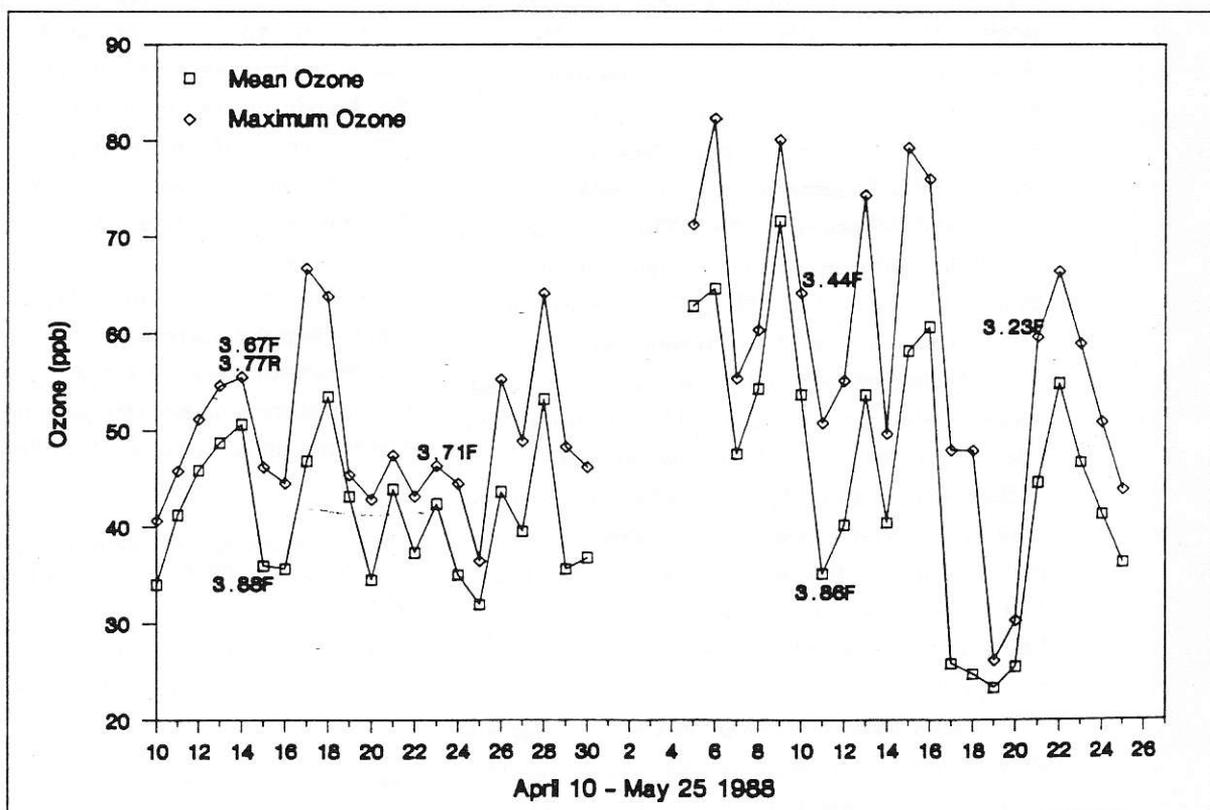


Figure 2. The mean daily, and maximum daily ozone concentrations at Roundtop Mountain, Québec, from 10 April to 25 May 1988. The fog water (F) and rainfall (R) pH values, for events with values below 4.0, are also plotted on the figure.

bilities are higher at Roundtop Mountain than in 1987. Thus, if singular events play a role in pollen viability, it appears that the exact timing of an event with high ozone and low pH may be critical, e.g. 6 days before anthesis there is little effect, whereas 4 days before there is a significant effect.

CONCLUSIONS

Statistically significant decreases in pollen viability with increasing altitude have been found for three tree species, at two sites in Québec in two successive years. Moreover, the change in viability occurs as a step function in a narrow altitude band (≈ 25 m). Without excluding population effects (changes in genetic structure, ploidy or hybridation) or solely climatic effects (mainly temperature), we believe that pollutant levels have an impact on the pollen viability of hardwood species at high elevations in southern Québec where acidic fog is frequent.

The mean altitude, for the 6 cases studied, at which the decrease in pollen viability occurs is 638 m (Fig. 1). The estimated mean cloud base height for April and May 1987 and 1988 (Tab. I) at Roundtop Mountain is 655 m. In 1987, the altitude corresponding to the change in viability was 638 m at Roundtop Mountain and the estimated mean cloud base was 610 m (April 680 m; May 540 m). In 1988, the pollen viability change occurred at 688 m and the cloud base was estimated at 700 m (April 660 m; May 740 m). The similarity of these altitudes is not proof of a cause and effect relationship between pollen viability and the presence of acidic fog, but it is suggestive of a linkage either through acidic deposition from fog or as a result of the extended periods of immersion in fog. Other weather related parameters such as precipitations and temperature are unlikely to have caused the phenomenon reported here. It

is possible that singular pollution events such as low pH fogs, high ozone concentrations or combinations of both can reduce pollen viability but the present data set is not large enough to draw conclusions in this area.

At this moment, we do not know if the observed mean decrease in viability of 27% is significant in the future evolution of the hardwood population structure at high elevation. It does seem to be in the same range as yearly variation at the same location. However, tree species have probably evolved towards an optimum pollen production, and years of low viability, induced by air pollution could lead to structural changes. Potentially, only those genotypes whose pollen is resistant to acidic fog will survive at higher elevations. Future work will try to look in more detail into pollen protein quality, actual pollen flow and pollen viability on ovules.

ACKNOWLEDGEMENTS

The authors would like to thank Carol Winston and Richard Tanabe for their work on the CHEF data, the operators at the two CHEF sites for their dedicated efforts in the sampling program, Dr. Louis Veilleux for the cloud frequency observations and Renée Lemieux and Nathalie Marois for the pollen counts.

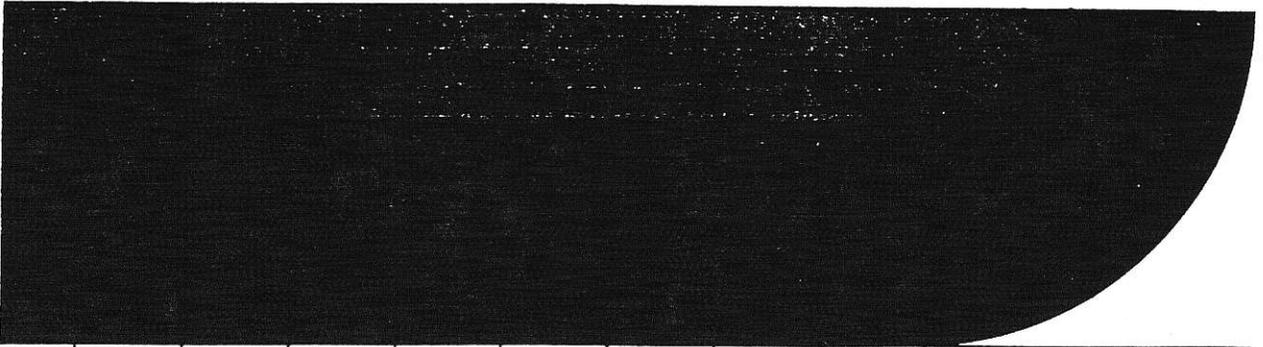
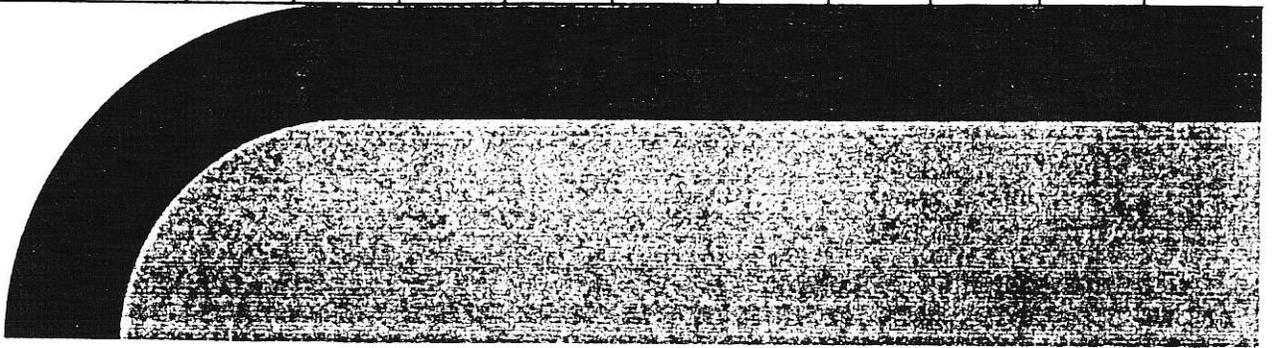
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The European Journal of Aerobiology

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The Journal of the Italian Association of Aerobiology

Volume 7 Number 2 December 1991