SEASONAL VARIATION OF AIR POLLUTION STRESSES IN CONIFERS

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Introduction

Total peroxidase activity has been established as one of the most sensitive indicators of air pollution induces stress effects (Horsman and Wellburn 1975, 1977). The changes in total peroxidase activity have also been related to many other stress factors, e.g. pathogens, nutrient status and wintering. Peroxidases have several functions within the plant cell and their metabolic functions may vary with their subcellular location. Changes in the activity or the isozyme composition of peroxidases are not a specific reaction of the plant to a pathogen infection or an air pollution effect, rather they are an accompanying characteristic of the altered metabolic activity of the plant cell under the influence of various exogenous and endogenous factors. The role of peroxidases in resistance or susceptibility has been summarized in a number of reviews (Frič 1976). Seasonal changes in peroxidase patterns have been studied specially in many woody plants (Keller 1974, Esterbauer et al. 1978, Huttunen 1979). In preliminary studies, no significant difference in normal seasonal wintering peroxidase patterns was found between unpolluted and polluted samples (Huttunen 1979). In more recent studies, air pollution induced stress has been found to increase even during the winter months. The normal seasonal stress increases under air pollution influence (Huttunen et al. 1979a, 1980, Huttunen 1980).

In this paper some of the results of the air pollution induced stress project carried out in Finland during the years 1977-1980 are discussed.

As an introductory background for the study, we might mention that one of the aims was to investigate the role of air pollutants as additional stress factors under winter climate - the methods used for measurement should be suitable to whole-year monitoring. The oxidative processes of plant cells were thought to be among of the most suitable parameter for such studies. The other methods used were electron microscopy, transmission electron microscopy, buffering capacity studies, water potential assays, etc.

Material and methods

The peroxidase activity of Picea abies and Pinus silvestris needles were analyzed in several industrial, urban and rural areas in Finland. A standardized mixed sample of several trees and several needles in the middle part of the tree crown were used. The stress monitoring was carried out during the different seasons, and the air pollution induced stress was compared with the air pollutant dispersion and the ambient air concentrations. The total peroxidase activity was also compared with the photosynthetic activity and injury development in urban and industrial areas. For the sake of comparison, the leaves and buds of Betula pubescens were used to indicate the stress in broadleaved trees. The study areas are shown in figure 1. The method presented by Keller and Schwager (1971) was used with some modifications.

Results and discussion

Soon after needle flushing both pine and spruce needles had a high peroxidase activity. The activity decreased some days after the most active flushing period, and after that the peroxidase activity continued to increase towards the autumn. The highest values were observed at mid-winter. The changes from November till February exhibited statistically significant differences when compared with each other. The normal seasonal fluctuations clearly revealed the changes induced by such factors as temperature, etc. The most obvious natural stress situation was water deficiency induced stress in the late winter conditions and the peak values of peroxidases due to the coldest months (fig. 2).

In industrial areas high relative peroxidase activity values were observed almost throughout the year. The relative peroxidase activities were highly variable as compared with the control needles: the relative activity varied within 150 % ... over 1000 %. The stress was most obvious in areas with combined SO_2 and NO_2 pollution, but the areas with SO_2 pollution alone had almost similar stress effects. The highest peroxidase activities were recorded soon after the highest pollutant concentrations. After short-time high concentrations, development of acute injuries was observed. The development of injuries impaired the peroxidase indication due to cell injuries. The acute needle injuries outside the industrial areas caused a situation in which the highest stress values were often observable outside the acute injury zone. Bioindication with peroxidases together with a microscopic inventory was useful even in industrial areas.

On a regional scale, the seasonal development of chronic stress was always easily observed. The gradual development of stress started soon after the needle flushing and was clearly seen in industrial and urban areas three - four weeks afterwards. During the summer, the normal development of needles was seen to be more rapid in town areas with some "urban pressure", such as temperature effects. This naturally caused some disturbances in the stress indication, but the differences passed in some weeks and only pertained to the most active needle elongation period. The development of needle stress was most rapid during the autumn and early winter months, and the stress often continued to increase until February. The region where the stress effects were observable increased in size during the autumn and winter months because of the increasing dispersion of air borne pollution. The stress dispersion correlated well with the pollutant dispersion (Huttunen et al. 1980), figs. 3 and 4. The stress was most obvious in the areas where no acute injuries were visible, but where the chronic stress often reached an injurious level and new chronic injuries were developing. The development of injuries could be related to injuries in the membranes of the chloroplasts. As it was earlier observed, these chronic injuries are associated with the accumulation of pollutants in needle tissues (Huttunen 1975, 1979). Pollutant toxicity to membranes during the wintering period is the most obvious reason for injuries. The increase in oxidative capacity, the lowest buffer capacity and many other factors explain this type of injury. As it has been shown earlier in my papers, the seasonal differences in air pollution effects can be measured. The mechanism of the injurious effects is different during the different seasons (Huttunen 1974, 1975, 1978, 1979).

When the peroxidase indication of stress is compared with the photosynthetic activity of needles in summer, the stress is related to depressed photosynthesis in the areas with air-borne sulphur compounds and to increased respiration in areas with combined effects of nitrogen dioxide and sulphur dioxide. In summer, the photosynthetic decrease was most evident in areas with some short-time concentrations. The decrease more or less resembled acceleration of the photosynthetic capacity. During summer, stress values of 150 ... 200 % were related to a 25 - 50 % photosyntetic inhibition and, correspondingly, stress values of 150 ... 200 % were related to a 25 percent increase in stress respiration (Huttunen et al. 1980). The areal correlation between peroxidase stress and stress respiration was not so clear as the correlation between photosynthesis and peroxidase activity.

When the stress values of pines and spruces were compared, it occasionally appeared that similar concentrations had somewhat greater effects on the spruce than on the pine in the case of sulphur compound pollution, but in some cases the effects on the pine were greater than those on the spruce. The explanation for these results must lie in the local soil conditions, the variation of concentrations in the different parts of the forest, etc. When the stress values of coniferous were compared with the stress values of birch leaves, almost similar results were obtained. The stress persisted in the buds of the birch, and the buds had some new stress effects during the spring (Huttunen 1980).

Many regional stress and air pollutant dispersion maps showed the influence of higher stacks as maximum dispersion areas outside the urban areas. In many cases the maximum of stress effects was measured several kilometres outside the urban area.

The influence of human activity was seen even in the profiles made in northern Finland with sparse population and small villages (Huttunen et al. 1980).
The stress effects were variable due to different seasonal air pollution conditions. When the sulphur dioxide concentrations and the stress effects were compared, annual mean values of 20 - 30 ug m^{-3} SO_2 were responsible for relative stress values of 200 ... 200 percent. In birch leaves a mean summer month value of 50 ug m^{-3} was observed to show stress values over 200 percent.

The difficulties of comparind the fluctuations of ambient air pollutant concentration from day to day and month to month showed that some special indexes, like the summing up of the concentrations (doses), must be used. In all cases the ambient air concentrations of Finnish towns and industrial areas influenced their surroundings (Table 1.).

Table 1. Air pollution induced stress effects and air quality in some urban forest areas in Finland (air quality according to the reports of the Finnish meteorological institute).

Oulu	monitoring 1977 1980	
	SO_2 monthly means	
	summer 19 23 $\mu g\ m^{-3}$	
	winter 27 47 $\mu g\ m^{-3}$	
	annual mean values	town area and surroundings
	24 35 $\mu g\ m^{-3}$	150 400 %
	short-time concentrations	
	over 100 $\mu g\ m^{-3}$ about 2 %	industrial areas stress
	mostly in January - March	of 150 1000 %
	NO_2 peak value 1/2 h	
	518 $\mu g\ m^{-3}$ (30.4.1978)	
	annual means	
	20 27 $\mu g\ m^{-3}$	
Valkeakoski	monitoring 1978	
	SO_2 daily concentrations	industrial areas with many
	over 100 $\mu g\ m^{-3}$ about 9 %	acute needle injuries
	summer 29 62.5 $\mu g\ m^{-3}$	
	winter 45 76 $\mu g\ m^{-3}$	surroundings with needle
	annual mean 51 $\mu g\ m^{-3}$	stress of about 200 500 %
Pori	monitoring 1979	
	SO_2 summer mean 50 $\mu g\ m^{-3}$	industrial areas with some
		injuries and stress effects
		about 200 400 %
		(birch leaves)
		surroundings with stress
		effects of about 150 200 %

The stress effect monitoring during the different seasons was easier to relate to the ambient air concentrations than to one single mapping of injuries or stress effects.

More information is needed for correlating the stress effects to the growth of trees. But the air pollution effects must also be considered on a seasonal time scale because of the numerous disturbances in timing the natural seasonal processes, etc., which may cause secondary injuries.

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Fig. 1. Study areas in which the effects of air pollution on forest ecosystems were studied during the years 1977 ... 1980. The large dots are the main study areas, the small dots are supplementary and control sample areas. The background of the map shows the subareas of the boreal forest region.

Fig. 2. Normal total peroxidase activity of Pinus silvestris L. needles during the winter months from November 1979 till March 1980 in the control area (Alavuotto ($65^{o}02$'N, $26^{o}25$'E). The changes in the needle total peroxidase pattern are remarkable even during the winter months due to changes in the normal wintering conditions, a = ▲5 min 1978 needles, b = ▲5 min 1979 needles, c = ▲10 min 1978 needles, and d = ▲10 min 1979 needles (14^{o}C).

Fig. 3. Relative peroxidase activity of pine needles in urban and surrounding rural areas in Oulu. On the left the distribution maps of sulphur and on the right the distribution of stress. In the stress map of May 1978 the absolute scale is shown, while in the others a relative scale against the normal control forest samples is given. The needles of 1977 were used in May 1978, the needles of 1978 in February 1979, and the needles of June 1979 in July.

Fig. 4. Relative peroxidase activity of pine and spruce needles in industrial and urban areas of Kemi ($65^{o}44$' N, $24^{o}34$' E). On the left the situation in November 1978 as compared with the control area in Simo, on the right the situation in February 1979 (the needles of 1978 were obtained).

Figure 1

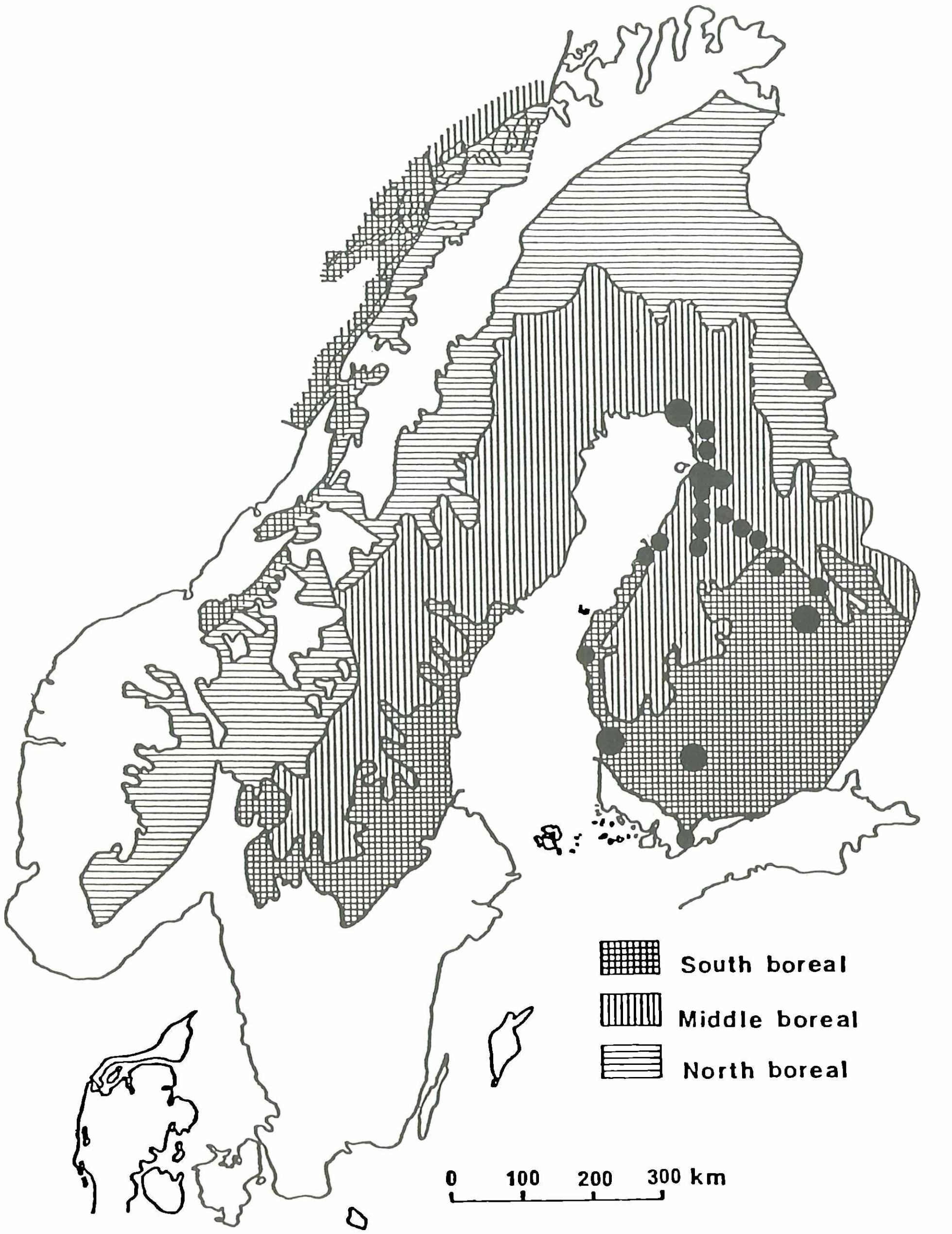

South boreal
Middle boreal
North boreal
0 100 200 300 km
Source: Naturgeografisk regionindelning av Norden
NU B 1977:34

Figure 2

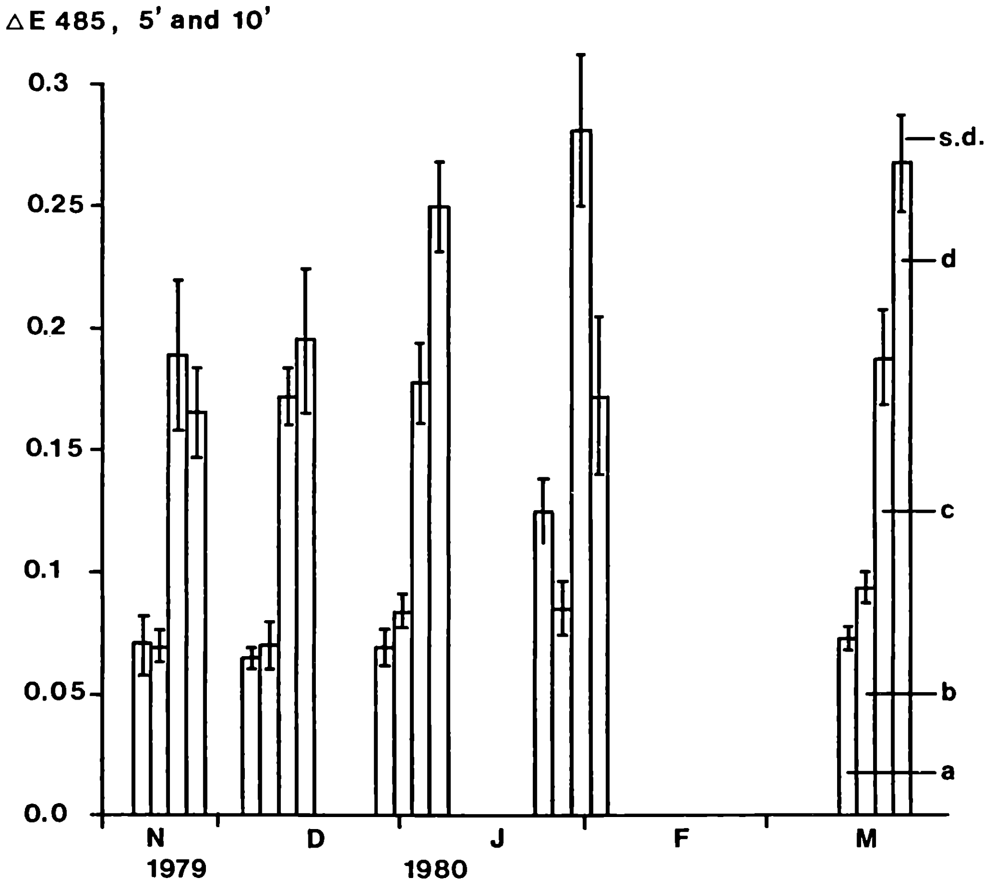
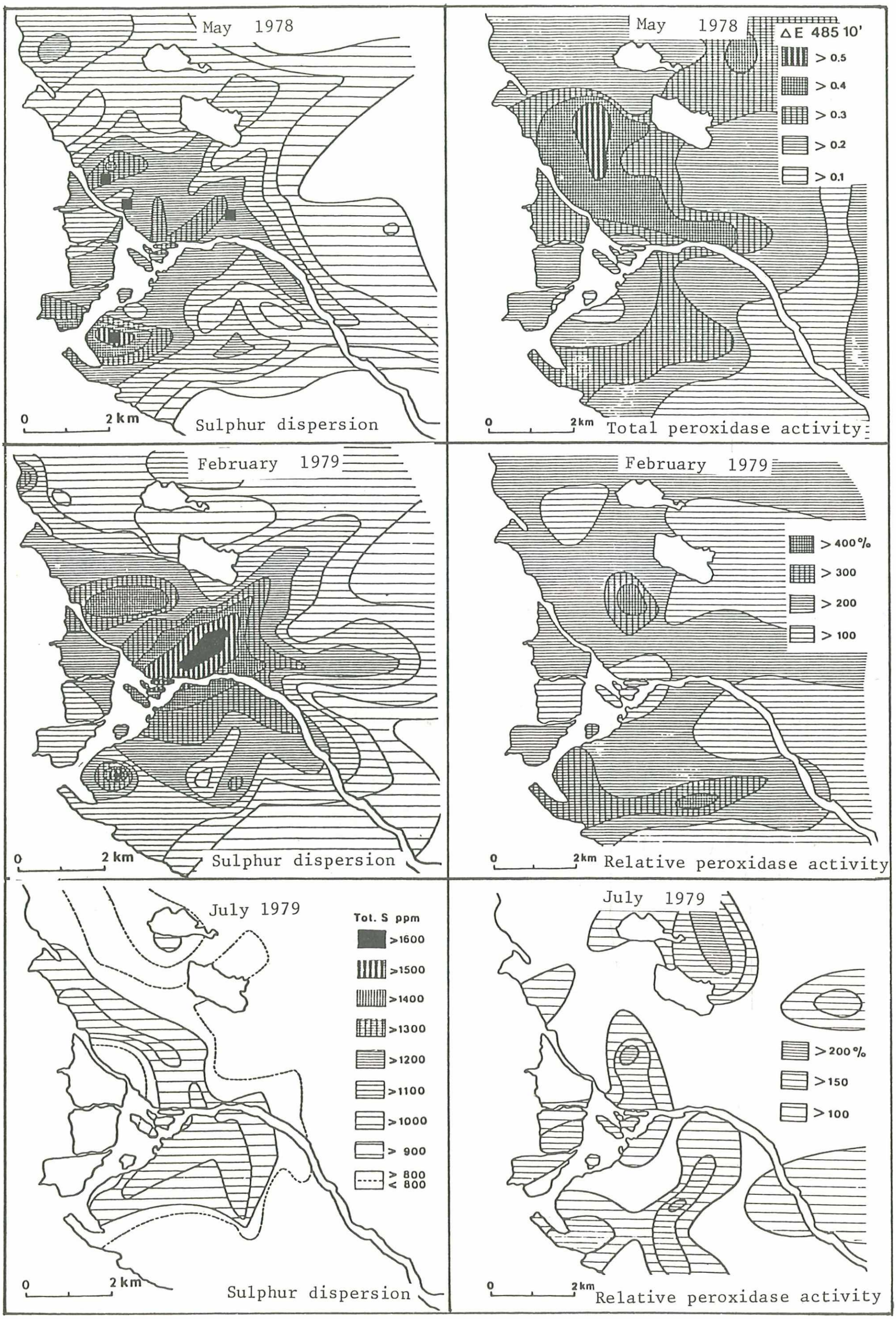


Figure 3


May 1978
0 2 km
Sulphur dispersion
May 1978
ΔE 485 10'
> 0.5
> 0.4
> 0.3
> 0.2
> 0.1
0 2 km
Total peroxidase activity
February 1979
0 2 km
Sulphur dispersion
February 1979
> 400 %
> 300
> 200
> 100
0 2 km
Relative peroxidase activity
July 1979
Tot. S ppm
>1600
>1500
>1400
>1300
>1200
>1100
>1000
> 900
> 800 < 800
0 2 km
Sulphur dispersion
July 1979
> 200 %
> 150
> 100
0 2 km
Relative peroxidase activity

KEMI 65°44'00"N 24°34'30" E

Figure 4