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AIR QUALITY: DIRECT EFFECTS OF SO_2 AND NO_X

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ABSTRACT

Due to the changes in the amount of SO_2 emissions and the changed conditions for their dispersion during the last 30-40 Years, the character of air pollution influence on the forests has also changed. From the analysis of the relations between the SO_2 concentrations and the reaction of sensitive tree species may be concluded that the threshold value is approximately 15 $\mu g.m^{-3}$ as long term average. At the prevailing background concentrations about 15-20 $\mu g.m^{-3}$ SO_2 in large areas. It is obvious, that this pollutant has regional importance. There are certain differences in the reaction of sensitive tree species on the impact especially the dependence of this reaction on other ecological conditions. Further pollutants can have additive, more than additive or less than additive effects.

INTRODUCTION

There are many theories to explain the vitality loss and large scale injury in European forests. Even though the prevailing cause according to the general opinion is the air pollution, there is no common agreement about the processes leading to injury and the contribution of individual air pollutants. Is is without doubt that the direct impact of air pollution still remains the main process causing injury in forests in some areas and to losses in forest production and in the social function of forests. The main question is what is the extent of the direct impact and what are the possibilities to distinguish between the direct impact and other forms and ways of air pollution impact in forest ecosystems.

Also the direct impact of gaseous pollutants on foliage and other parts of the trees is considered together with the direct influence of precipitation in various forms such as rain, mist, rime. Of main interest is the influence on coniferous forests, where there are major problems at

this time.

THE TREND OF AIR POLLUTION

In some cases in connection with the "new damage" in forests the direct impact has been excluded as the cause of injury from the point of view, that the direct impact can be only of local character. Further it was assumed, that there must be an immediate visible reaction of forests on elevated concentrations of air pollution. Both presumptions correspond to the trend of emissions and air pollution sources in the second part of the nineteenth century and in part till the middle of this century. But the development after this time changed markedly the character and amount of emissions and emission sources and the trend of air pollution not only in the surrounding of the industrial centers.

The first phase is characterized by relatively small amounts of emitted pollutants (mainly SO_2) from low stacks, therefore the dispersion of emissions was limited and very high short time concentrations occurred (with 10^5 $\mu g.m^{-3}$ SO_2 as a max. and 10^4 $\mu g.m^{-3}$ as a mean for a 30 min. period). Neverthless the long term average could remain relatively low.

The effort to reduce the ground concentrations using higher stacks, resulted also at higher amounts of emissions (up to 10^4 - 10^5 t SO_2 from one source), in a reduction of short term concentrations and peaks also at large distances from the source. The further increase of the stack heights up to 300 m and more makes this trend more expresive. The short time concentrations have been reduced to 10^2 - 10^3 μg $SO_2.m^{-3}$ as a peak and to 10^2 μg as an average over a 30 min. period. The background rose to 10^0 - 10^1 $\mu g.m^{-3}$ as long time average. There are distinct seasonal and yearly fluctuations in the near ground concentrations. The dispersion of large amounts of emitted SO_2 from one source influence the air quality over large areas.

Comparing it with the trend in SO_2 emissions, it is proable that the same can be said about accompanying substances as HF and organic substances, but not for NO_x where a substantial part is emitted from small mobile soures.

This development of emissions and their dispersion is very important for the characteristic on reactions of vegetation, especially of forest trees and forest ecosystems.

THE RESPONSE OF VEGETATION

The respons of vegetation to the air pollution due to emissions from small stacks with large fluctuations of near ground concentrations can be acute injuries found during the vegetation period. Broad leaf trees as well as conifers suffer under this influence. Due to a greater intensity of gaseous exchange the broad leaf trees can suffer from high peaks of pollutants more than e.g. spruce or pine. The conditions for the development of acute injury are concentrations of 10^{3} $Mg.m^{-3}$ SO_2 for 30 min. at least at a high intensity of physiological processes in the trees at high light intensities and at a high soil and air moisture content.

The acute injury nevertheless need not to be very dangerous, as the episodes occur seldom and mostly at the end of the vegetation period (temperature inversions in the late summer with high peaks of pollutants).

To the second area air pollution damage - the influence of low concentrations (up to 100 $\mu g.m^{-3}$ SO_2 as long term average) with seasonal and yearly fluctuations pertain the chronic injuries when no distinct symptoms on broad leaf trees occur but are very important for conifers. In broad leaf trees the chronic injury is mostly manifested by colour changes and premature leaf fall at the end of the vegetation period. Also in conifers the main damage is connected with a premature needle fall but this is a symptom, which is not specific enough because such a premature fall of needles can also be a result from water deficit or from a surplus of water in the soil, from extreme nutritional disorder or from fungal attack.

PHYSIOLOGICAL PROCESSES

The informations about the influence of air pollution on physiological processes can be summarized as follows:

- After a lasting impact on trees the photosynthesis is mostly limited, a short term influence, however,can stimulate the process.
- There is a distinct influence on water regime of the trees, but this is not an uniform trend. Dependent on outside conditions, stimulation or depression of transpiration can occur.
- There are distinct changes in mineral nutrition of trees. An increase of sulfur content in the needles is mostly accompanied with an increase of kalium, calcium or magnesium content.
- There are distinct changes in the amount of organic constituents

(starch, sugar, aminoacids).

MECHANISMS OF INJURY

The changes in the physiological processes are manifested by the following disturbances:

- Accelerated senescence. This is shown by premature leaf fall and the increase of silicium acid in the leaves.
- The "winter injury" of conifers. The absorption of SO_2 into the needles of conifers goes on also in winter. The increased sensitivity to frost can occur in strong winters or after a sharp drop of temperature. Very large was injury in European forests due to a temperature drop in the last days of 1978. The needles became red and in the spring a part of buds was killed and many trees died. A second example of winter influence is an injury that developes in late winter, when the soil is still frozen and strong radiation influences the trees. A disturbance in the regulation ability of stomata is a cause of needle damage.
- There is evidence that for the life of the trees also the disturbances in internal relations between the crown and the roots can be of importance. A direct impact of SO_2 can reduce the development of the roots more than the development of the crown and also the reduction of and changes in mycorrhiza can decrease the vitality of trees.

ECOLOGICAL DEPENDENCES

One of the characteristic features of air pollution injury to forests its development depending on ecological conditions. But in this respect there are differences between e.g. Norway spruce and Scotch pine.

In spruce forests there is a clear dependence of injury on altitude. It is not possible to decide the most important factor connected with the altitude; the wind velocity, the insolation, the temperature, or still other factors. But it is obvious, that the wind frequency and velocity is a very important factor. Stands on exposed sites, mountain ridges and stand edges are earlier damaged as are other parts of the forests.

A dependence of the intensity of the injury and its development on water content and on mineral nutrient reserves in the soil has also be proven. The dynamic of injury on oligotroph bogs and very moist soils is accelerated. In pine stands there is a clear negative correlation between the intensity of damage and the soil fertility. Therefore fertilization in these stands can give very good results in increasing the vitality and resistance of the pine forests.

Very important is the influence of factor "time" in relation to the influence of ecological factors. For assessment and evaluation of air pollution influence it is necessary to distinguish:

- the time between the start of the increase of air pollution level and the occurence of first visible symptoms
- the time between the beginning of air pollution effects and desintegration of the forest stand as a whole.

If we summarize the results of studies about the dispersion of emissions and the measurements of near ground concentrations of SO_2, it is obvious that the time of "latent" effect can be very long and the occurrence visible symptoms can be changed by other stress factors. Also at relatively high mean concentrations of SO_2 the time between the beginning of air pollution effects and the first visible symptoms can be some years.

The speed of damage development can be very different. We have forests with distinct symptoms of injury where during the last 30 years the damage has not clearly changed and where it is possible that these stands can reach their normal cutting age. But this is the case of forests growing under favourable conditions. Under present air pollution conditions a rapid development of the damage occurs with unfavourable ecological conditions or other stress factors.

SO_2 CONCENTRATIONS AND THE EFFECTS ON FORESTS

The reaction of stands of sensitive coniferous tree species to the SO_2 pollution shows, that it is not possible to characterise the relationship without reference to other ecological factors.

There are various possibililities to express the intensity of air pollution concentration. For pollutants such as SO_2, the arithmetical mean concentration seems to be a convenient way. The following values are of importance:

- the air pollution level at which no respons is occurring the threshold value
- the relationship between the average concentration and the reaction of forest stands

  For forest stands it is obvious, that it is not possible to gain answers on these relations under laboratory conditions, only long lasting experiments can bring results.

A convenient expression of the relation between the concentration of a certain pollutant and its effect is the time between the beginning of the effect and the desintegration of the stand (intensive mortality and the ioss of stand structure).

From the evaluation of results concentration measurements over long periods simultaneously with the assessment of forest stand injury it is possible to deduce that:

In spruce forests at higher elevations effects of air pollution can already be seen at longer term mean concentrations of 20 $\mu g.m^{-3}$ SO_2. Under extreme external conditions at this pollution level, serious damage can develop and an increased mortality occurs (Materna 1982, Wentzel 1982).

Table 1

The time between the beginning of air pollution effects and the desintegration of Norway spruce stands (in years)

SO_2 concentration	height above sea level (in m)			
$ug.m^{-3}$	up to 600	600-900	900-1050	higher then 1050
20				
20 - 30			30 - 40	20
30 - 50	50 - 60	20 - 30	20	
50 - 70	40 - 50	20	10	
70 - 90	30 - 40	10 - 15		
90+	20 - 30			

In stands of white fir, the threshold value is lower and already 15 $\mu g.m^{-3}$ SO_2 as a long term average can cause serious injuries.

In the pine forests visible symptoms of injury in older stands appear after some years with 25 - 30 $\mu g.m^{-3}$, at extreme external conditions already at 15 - 25 $\mu g.m^{-3}$ SO_2. A desintegration of stands results from long term concentrations of 70 - 80 $\mu g.m^{-3}$. (Huttunen 1980, Matterna 1981).

If we compare these figures with the background concentrations of SO_2 in large aeras of Europe, it is obvious, that it is not possible to consider the direct impact of SO_2 as a local problem, but as it is seen from the SO_2 trends, the direct impact has over-regional importance.

Dose-effect relationships are deduced mainly from measurements in the forests in regions where the air pollution is caused mainly through combustion processes. The SO_2 predominates but is not the single physiologicaly relevant substance. On the basis of leaf analysis it is possible to exclude the influence of HF, but not the influence of nitrogen oxides.

The concentrations of NO_2 in the forests we have measured are between 60 -100 % of the concentrations of SO_2. This can be one reason that there was a strong correlation between the S and N concentrations in the spruce needles in stands with various levels of air pollution (Materna 1981). Another possibility to explain this fact is that the increasing N content depends on the influence of SO_2 (Materna 1972).

It is not possible to single out the effect of NO_x on forest trees, as there is only a very limited data base on the NO_x effects. From various results it is possible to deduce that the toxicity of NO_x is substancially lower than SO_2 (Taylor et all. 1975, Mooi, 1983, Yang et all 1983). It is not probable that the present concentrations of NO_2 will cause injury to forest stands.

This does not exclude the possibility of synergistic effects of NO_x with SO_2 or with other constituents of polluted air. As an example the results of a study with various clones of white pine have demonstrated that a combination of SO_2 with NO_2 depending on external conditions can have an additive, more than additive or less than additive effect.

Beside the direct influence of gaseous pollutants it is possible to consider the direct influence of precipitation with varying chemical composition.

Results of intensive rainfall studies are avaible and also the direct effects of the polluted rain were studied. From these studies it is possible to deduce that only precipitation with a pH below 3 shows clear effects. Such acidity occurs only exceptionaly. In this respect an increased danger for forest stands is due to the fact, that high amounts of condensation nuclei in the atmospere increase the frequency and intensity of rime with high concentrations pollutants. This can cause necrosis of the needles during thawing.

IMPACT OF AMMONIA

Due to relatively high amounts emitted in some areas of Europe (*Buijsman et all. 1985*) it seems that ammonia must not be considered as a local problem only. Close to the sources the concentrations of nitrogen increase in the foliage of trees 2 - 3 times in comparison with the normal level and the concentration of inorganic nitrogen in the leaves increases even more. After the impact the concentration of chlorophyll increases, the imbalance in nutrition causes a premature needle fall. With respect to relatively high threshold value, probably at $10^2 - 10^3$ $\mu g.m^{-3}$, it is not likely, that the direct impact of ammonia will become a regional problem.

DIRECT AND INDIRECT IMPACTS

The reaction of the trees to the direct change in the mineral nutrition level, draws the attention on the possibility of increased danger to stands in which the mineral nutrition is unfavourably influenced by soil changes caused by acid deposition. It is possible to prove a deterioration of nutrition with Mg, K, Ca on regional scale. Such changes increase the sensitivity of forests to direct impact of pollutants and therefore it is possible that a combination of direct and indirect impact can influence the forests in very large areas.

It is possible to use leaf analysis to give evidence of direct impact of SO_2, HF, HCl if they are occurring in higher concentrations. The leaf analysis is well evaluated (Guderian 1970), and it is possible to estimate the level of SO_2 in the atmosphere from the concentration of sulfur in the spruce needles. (Materna 1981). Leaf analysis is also used to detect the area influenced by an increased level of SO_2 (Rudolph 1983). The small differences at low concentrations of sulfur dioxide are nevertheless

difficult to prove and therefore it is questionable whether with large individual variability of sulfur content in the needles of forest trees, it is possible to use this method with success over larger areas.

For nitrogen oxides it is only occasionally, for a short time after the occurrance of higher concentrations, possible to demonstrate the presence of NO_3^- in the foliage of spruce and pine. In the foliage of broad leaf trees these is normaly a relative high content of nitrates detectable and it is not possible to distinguish the increase due to pollution.

The direct impact of SO_2 alone and in combination with other pollutants decreases the increment of forest trees, increases the mortality in forests and has an unfavourable effect on the quality of wood produced.

Important is also the decrease in the resistance of forest stands to further stress factors - abiotic as well as insects and fungi.

For the future of the forests the reduction of fertility and the impoverishment of species is very dangerous.

Extremely endangered are the forests in extreme climatic conditions, especially mountain forests. This is also very important in respect to their social functions. It is possible to observe changes in water flow and water quality in damaged forested watersheds.

CONCLUSIONS

At the present level of air polllution on a regional scale, the direct impact of air pollution on forests has also a regional character. The forests are effected by sulfur dioxide and other pollutants. About the effects of some of the pollutants the information is very limited. Insufficient is also the information about the air pollution concentrations in forests.

Very great is the risk due to the loss of vitality and the decreased resistance of forests to other stress factors. Especially extreme climatic conditions can cause a significant increase of injuries in large areas.

A further threat is the disorder in the mineral nutrition as a consequence of soil changes due to acid deposition and the increased sensitivity of weakened forest tree species to the direct impact of air pollution.

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