THE EFFECTS OF ACIDIFYING AND OTHER AIR POLLUTANTS ON FORESTS

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RESUM

La pluja àcida no és l'única deposició nociva dels boscos, car, en principi, hi ha diversos tipus de contaminants i de deposicions que actuen alhora i gran quantitat de mecanismes que funcionen aïlladament i també sinèrgicament.

La recent deterioració dels boscos de l'Europa Central és deguda a les interaccions entre els factors biòtics, els antibiòtics i les tensions produïdes per la mà de l'home.

Per tant, per a aconseguir una protecció a llarg termini de la gran varietat de les funcions forestals, creiem que és indispensable una política de control dels contaminants de l'aire.

SUMMARY

Acid rain is not the only harmful deposition in the forests, but as a rule several kinds of pullutants and depositions are active at the same time, with a multitude of mechanisms acting alone as well as synergically.

Recent forest damage in Central Europe occurs due to interactions between antural biotic and abiotic factors and man-made stress.

Silvicultural measures may reduce the speed of damage development, but will be of extremely limited remedial use as long as air pollution stress continues. As natural factors largely escape the influence of man it is of primary importance to reduce the man-made stress.

Consequently, for a long term protection of the great variety of forest functions, a persistent air pollution control policy will be indispensable.

1. INTRODUCTION

In recent years forest damage of an extent previously not experienced has been observed in a number of countries in the northern hemisphere, particularly in some countries of Central Europe and predominantly in the central highlands.

A great variety of damage symptoms occurs in different tree species and in different locations. This can often not be explained solely by parasites and climatic damaging factors. The symptoms observed today have been known for more than a century from classical fume damage in forests in the immediate vicinity of large smokestacks industrial areas.

The centres of classical air pollution damage to forests in Europe are the Ruhr district, Saxony and Silesia as well as the Bohemian basin. The industrial region of the English Midlands is less relevant to forestry due to its modest forest cover.

The intensive recent forest damage, however, has been reported from a wide sphere around these industrial regions. The forest sites which have been affected recently are often remote from any factories and are remote from the classical fume damage sites.

Today the overwhelming majority of scientists believes that there exists a causal relationship between the recent forest damage and long-range transported air pollutants emitted by high stacks and transported by steady air currents over long distances.

The key role of acidifying compounds like for instance sulphur dioxide emitted into the air by industrial processes of combustion had been recognized already in connection with the classical fume damage. Today the responsibility for the observed increase in acidity of precipitation and soil in certain regions is generally attributed to sulphur dioxide and nitrogen oxides. Therefore, since the first observations of recent forest damage at the beginning of the eighties, acid rain ha been discussed as the main cause.

Besides the acidifying compounds stemming from the burning of great quantities of fossil fuels the atmosphere is polluted by the emission of heavy metals, halogen compounds and an enormous number of organic compounds. As far as recent forest damage is related to air pollution, also depositions of still unknown pollutants might play an important role.

2. SYMPTOMS AND EXTENT OF THE FOREST DAMAGE

The recent forest damage became obvious because of damage to the crowns of important tree species. Therefore the symptoms described in the following will refer mainly to the condition and the appearance of the crown.

The most important tree species of Central Europe have been most affected, such as Silver fir (*Abies alba* Mill.), Norway spruce (*Picea abies* [L] Karst.), Scotch pine (*Pinus sylvestris* L.), European beech (*Fagus sylvatica* L) and Penduncolate oak

(*Quercus robur* L.). Further tree species which are less important from a forestry point of view have also been affected.

At the beginning of the seventies Silver fir was the first tree species to show damage. Because a periodically appearing disease called Silver fir die-back had been known since the beginning of the last century, this more recent disease was perceived as alarming only because of its long duration, its wide spread occurrence, its great intensity and high death rate.

Characteristically the needles turn yellow and subsequently fall off. Needle-shedding, however, may even occur to green needles. This leads to a thinning of the crown, proceeding from the bottom to the top and from the centre to the outside. The development of the top shoot lags behind the development of branches and this leads already in young firs to the formation of a so called «storks nest crown». The high proportion of dead branches is striking. Apart from that, water sprouts arise. Damage to the roots and a pathologically extended wetwood in the lower part of the trunk accompany the disease.

At the beginning of the eighties the first symptoms appeared also on Norway spruce. The symptoms are similar to those observed on Silver fir, but show several peculiarities.

The needles or neddle tips turn yellow, especially if they are exposed to light and particularly on the upper, light exposed side. But also in the shaded parts of the crown discoloration occurs. The needles may also turn brown or red and older needles fall off prematurely. Hence there is a strong overthinning of the crown. Top drying and a higher proportion of dead branches is observed. As a consequence of the induced physiological weakness of the tree subsequent secondary damage by insects and fungi occurs. Finally, individual trees and grups of trees die.

Growth reductions, especially reductions of diameter growth, have been found particularly in the lower part of the trunk of both Silver fir and Norway spruce, at least in certain regions. This, however, will have to be treated later in connection with the effects on forest yield.

Within the last years also Scotch pine has shown increasing discolourations and thinning of the crown. Partial necrosis appears as well as a reduction of the needle lenght. The symptoms observed in Scotch pine may sitll be explainable by natural biotic and abiotic factors, but the increase in the extent of the damage is striking.

Until now the softwood species mentioned have been affected to a greater extent than hardwood species. As regards to hardwoods, damage is mainly reported on European beech. The leaves of the periphery of the crown begin to turn yellow and there is a crumpling and necrosis of leaves. The autumn leaves fall off prematurely and even green leaves are lost, predominantly at the top of the crown. Besides this process of defoliation and drying of the crown, also disturbed natural regeneration is observed.

The relations to the recent damage in conifer forests is not fully explained. This requires further research, because beech is the most important hardwood in Central Europe. In a number of localities it is considered as a suitable replacement for damaged species of coniferous trees.

The recent forest damage has been particularly thoroughly recorded in the Federal Republic of Germany and therefore some results of the latest damage assessments in this country will be presented in the following.

After an alarming increase in forest damage in areas remote from industry, a first damage assessment was carried out in 1982, identifying 8% of the total forest area as being injured by air pollution. In 1983 already 34% of the total forest area was found to be affected.

In 1984 the damaged part of the forest area was announced to be about 50%, this time, however, comprising not only air pollution damage, but both anthropogenic and natural forest decline.

Methodically the forest damage assessment, as conducted by the government, classifies the forest trees into five groups according to their percentage of leave or needle losses, the so called damage classes. Table 1 shows the damage classes 0 to 4, the corresponding percentage of needle losses as well as the percentage of the forest area for each damage class.

It can be seen in the table that 49.8% of the total forest area in West Germany belong to damage class 0 and do not show any significant symptoms of damage. The remaining 50.2% belong to classes 1 to 4, thus ranging from «slightly damaged» to «dead». The damage area of 50.2% is suspected to comprise an overwhelming part of air pollution damage. Classes 3 and 4 contain severely damaged or dead trees, but these represent only 1.5% of the total forested area.

Table 2 shows the area of each of the five most important tree species, expressed in millions of hectares as well as in percent of the total forest area. The tree species are arranged according to the sizes of their areas.

Among the five species, Norway spruce represents with 40% the greatest part of the forest area and Silver fir with only 2% the smallest portion. Whereas Norway spruce also represents 40% of the total damaged forest area, Silver fir constitutes only 4% of this due to its small foresta area. In contrast to this 87% of the Silver fir area are damaged, rendering Silver fir the species threatened most by air pollutants.

Distinguishing between forest damage caused primarily by acidifying and other air pollutants and damage of other origin is difficult because of the following reasons:

—recent damage cannot be separated from traditional damage based solely on its symptoms;

—latent damage is not recognized early enough;

—symptoms of damage caused by air pollutants can be hidden by secondary damage such us insects and fungi;

—trees damaged by natural stress factors may have been predisposed by air pollution stress;

—severely affected or dead trees removed by thinning operations escape recording.

The uncertainty about the true portion of forest damage caused by air pollution and the fact that at least in West Germany no significant deforestation has been recorded until now could lead to the opinion that the forests are not in great danger. It should be noted, however, that the damage has proceeded at an alarming rate and deforestation of large areas has been reported from e.g. Poland and Czechoslovakia.

Table 1.— Damage classes of the damage assessment in the Federal Republic of Germany*

Damage class	Needle-loss	% of total forest area
0 (without damage)	0-10%	49.8
1 (slightly damaged)	11-25%	32.9
2 (damaged)	26-60%	15.8
3 (severely damaged)	61-99%	1.5
4 (dead)	100%	

Table 2.— Tree species area and damaged area of the most important species in the Federal Republic of Germany*

Tree species	Area of tree species		Damage area of tree species	
	Millions ha	% of total forest area	% of tree species area	% of damage forest area
Norway spruce (Picea abies (L) Karst.)	2.886	40	51	40
Scotch pine (Pinus sylvestris L.)	1.470	20	59	23
European beech (Fagus sylvatica L.)	1.253	17	50	17
Pendunculate oak (Quercus robur L.)	0.620	8	43	7
Silver fir (Abies alba Mill.)	0.174	2	87	4
Others	0.967	13	31	8
Total	7.370	100		

*Adapted from «1984 Forest Damage Survey, Federal Ministry of Food, Agriculture and Forestry».

3. DAMAGE CAUSES AND RESPONSE MECHANISMS

Exact scientific proof that aire pollutants or particularly acid and acidifying compounds are the primary cause of the recent forest damage is still lacking in many areas. At present there are mainly plausible and indicative proofs, including the following elements:

—Insects and fungi can in general be ruled out as primary causes. Such disease agents play a role as parasites after previous damage by other factors.

—Viruses and mycoplasmas cannot be identified as damage causes, even where they are detected in forest trees. On the other the hypothesis that such factors are involved has not yet been falsified.

—Frost and drought may be excluded as primary causes, as the recent forest damage occurs on sites protected from frost as well as on humid sites.

—A connection with natural soil properties has not been established, as damage is observed on all soil types. Even the natural nutrient deficiency of many forest sites can be excluded, as it is not of recent origin and damage also occurs on nutrient-rich habitats.

—Misapplied silvicultural practices are out of the question, as damage is observed under all forms of forestry practice.

As natural factors alone cannot explain the extent of recent forest damage, especially those factors have to be considered, which are geographically widespread, which are harmful to different tree species and whose response mechanisms correspond with the observed symptoms. According to our current knowledge this applies oncly to phytotoxic air pollutants originating from man's indústrial activity. Moreover, it is striking that recent damage to forests has been reported predominantly from industrialized countries with high depositions of both domestic and imported air pollutants.

Acid precipitation is only a part of the forest injuring depositions. As the term «acid rain» is often used for the total deposition of pollutants, further specification is needed to understand the complex mechanisms leading to the forest decline. The deposition of air pollutants occurs in gaseous form or as dust particles, both of which is alles «dry deposition», or dissolved in water, which in turn is called «wet deposition». The wet deposition not only includes rain, but also snow fog carrying pollutants. Both wet and dry depositions may contain acid or acidifying compounds.

Because of their great aerodynamic roughness forests are especially exposed to both forms of deposition. Due to the great surface area of trees, they filter out the air pollutants effectively by wetting and absorption. Consequently, both kinds of deposition, dry and wet, are much higher in forests than over other surfaces. This explains partly why deciduous tree species have been injured to a smaller extent: the coniferous trees have a larger surface area and their needless are exposed all year round.

Moreover, the longevity of forest trees leads to an accumulation of pollutants. They may finnaly reach toxic concentrations in perennial plant organs such as he needles, the trunk wood, root wood and bark.

Depositions in the crown of the trees may also reach the soil by menas of washing off and leaf fall, in addition to the depositions passing the canopy unhindered.

It becomes obvious that forest ecosystems may be damaged by acid, acidifying or other air pollutants both directly through the plant organs above ground as well as indirectly via the soil an through the roots. In this respect particular attention has to be paid to soil acidification and its consequences for root growth and nutrient supply. As the complex mechanisms triggered by soil acidification has been discussed in great detail on the «Conference on Acid Rain» of May 24, 1985 at the ICEA in Barcelona, the indirect effects of acidifying air pollutants on the forests is not within the scope of this paper. Instead the direct effects on the plant organs above ground will be outlined in the following.

As already mentioned at the beginning, the responsibility for the observed increase in the acidity of precipitation and soil in certain regions is generally attributed to acidifying compounds in the atmosphere, particularly sulphur dioxide (SO_2) and nitrogen oxides (NO_x). In the air or on the surface of the plants these compounds undergo various chemical reactions. Sulphur dioxide reacts mainly with oxygen in the gas phase and with water droplets in the liquid phase, changing into sulphurous acid (H_2SO_3) and sulphuric (H_2SO_4). Ninety percent of the nitrogen oxides are emitted in the form of nitric oxide (NO) which is oxidized in the gas phase with oxygen or ozone (O_3) to nitrogen dioxide (NO_2) and with hydroxide radicals to nitric acid (HNO_3). Under UV-light a photolysis of nitrogen dioxide results in formation of nitric oxide and ozone as well as other photooxidants.

Sulphur dioxide affects the functioning of the guard cells of the stomata, and thereby the total gas exchange and the transpiration of the trees. The trees' metabolism will be disturbed by damage to the biomembranes of the cells and the cell organelles, which will lead to failures in their enzyme activity. The assimilation capacity will be reduced long before visual damage symptoms are discernable. The ageing of needles and leaves will be accelerated, which leads to premature shedding of leaves or to a reduced number of needle sets.

The reduced assimilation may be followed by growth reductions. The tree also becomes more susceptible towards natural stress factors and diseases.

This is in particular the case for a long term influence of low sulphur dioxide concentrations. A permanent maximum air concentration of 50 $\mu g\ SO_2/m^3$ is thought to be the upper limit to protect the forests at normal sites. At high altitudes and other critical sites an upper limit of 25 $\mu g\ SO_2/m^3$ has been recommended. These values are exceeded only in a few of the damaged stands. As damage still occurs, it may be concluded that eighter the limit values are too high, that cumulative effects over decades play a role, that additional pollutants are active or that there are unknown sudden high concentrations during short periods of time. There are indications of all these possibilities, but with different weights according to different sites.

Nitric oxide (NO) is dominant among the emissions of nitrogen oxides. It is, however, oxidized in the atmosphere to nitrogen dioxide (NO_2), which is more phytotoxic. The effects of nitrogen dioxide on trees are similar to those of sulphur dioxide. If it occurs alone, a maximum concentration of 35 $\mu g\ NO_2/m^3$ in the vegetation period seems to protect the forests. It is supposed that there are synergic effects of nitrogen dioxide and sulphur dioxide. The importance of nitrogen oxides lies primarily in its role for the formation of photo-oxidants under the influence of strong insolation, among which ozone is the characteristic substance.

A direct damage by photo-oxidants to forests has first been observed in the 1940's in a wide area around Los Angeles. Ozone changes the chemical structure of the wax layer of the cuticula, rendering the wax mores susceptible to erosion. Ozone must be considered as one of various causal factors for the recent forest damage, as the regions affeted partially coincide in time and space with increased ozone concentrations. Damaging effects may occur already with only small increase in the natural ozone concentrations (about 5 to 30 $\mu g\ O_3/m^3$). The typical symptoms of ozone damage, needle tip sized necroses on leaves and needles, are seldom observed. Greater attention is being paid to damage of the cuticula with subsequent erosion by acid precipitation. The activity of acidified precipitation on the leaves depends on the wetting properties of the leaf surface, which are determined by its chemical and morphological characteristics. In particular the proportion of wax in the cuticula and the presence of epicuticular wax determine the contact time of the moisture and thus the penetration of active ions through the epidermis layer and through the stomata.

During the evaporation of acidified water on the leaves, the pollutant concentration increases and the pH-value is lowered. At pH-values of 3 or less, erosion of the cuticular wax occurs, especially when it has already been attacked by ozone. Already before this stage the hydrogen ions in the acid precipitation may replace cations of the leaves, such as calcium, potassium, magnesium and manganese. The often observed magnesium deficiency in needles of damaged trees may be partly explained by this mechanism.

Heavy metals such as zinc, iron, cadmium, mercury and lead can act toxic to plants direcy via the plant surface. As the availability of heavy metals for the plant organs depends on their solubility, which increases with lower pH-values, high acidity of the precipitation will increase the toxic influence of the heavy metals. In particular heavy metals which have been transported in the atmosphere overy very long distances, which has to be supposed in connection with the recent forest damage, are finest particles and thus will be dissolved easily. The effects of heavy metals on the trees and their contribution to the recent forest damage are still largely unknown.

Very many organic compounds occur in the atmosphere and some of them are known to be highly toxic to plants. But their chemical reactions in the atmosphere as well as heir geographical distribution, accumulation and their effects on the forest ecosystems are not yet adequately known. There is also little knowledge about their connection with recent forest damage.

Regarding the response mechanisms outlined above the following conclusions may be drawn:

Acid rain represents only one way in which forest trees may be affected by acid and acidifying compounds. Moreover, acid and acidifying compounds are only a part of the phytotoxic air pollutants involved. Among the directly acting air pollutants none has been shown to be the main cause for forest damage. Neighter can the synergic effets of several substances alone explain all the damage symptoms observed on different tree species and under different site conditions. Of course, many of the damage symptoms will be explainable only in connection with the indirect effects via the soil, which have not been mentioned here. The key to the explanation of a variety of physiological processes in the tree will lie in the availability of nutrients in the soil and in the harmful effects of toxic ions causing damage to the roots.

It is obviously necessary to differentiate in the individual cases according to locally changing primary causes, and according to combined effects of anthropogenic and natural factors. A long term air quality stress can, even with low concentrations, reduce the resistance of trees against natural biotic and abiotic injuries. On the other hand, natural factors may increase the susceptibility of trees to air pollutants.

It is most important, however, that without anthropogenic air pollution there would be no forest damage to the present extent in Central Europe.

4. ECOLOGIC AND ECONOMIC CONSEQUENCES

The effects of pollutant stress alter the natural competition between the tree species. There may be a selection against taller trees, which are most exposed, as well as against more susceptible trees. This impoverishment of the genetic variation will render the forest ecosystem less adaptable to envorinmental conditions of all kind all will reduce its stability. This is of major importance for the diversified functions of the forests, especially where forests serve special protective functions.

The importance of certain threatened forest functions depends on the geographical region. Regarding water conservation, the regulation of runoff from precipitation and snow melt by the forests could be reduced. Loss of leaves, needles and roots will lower the water retention capacity of the forests, which is important for flood reduction and esorion protection.

A properly functioning forest ecosystem is indispensable for the filtering of pollutants in connection with drinking water supply. The leaching of accumulated pollutants into the ground water will even be enhanced by soil acidification. In some regions of Europe a lowering of pH-values and an increase in toxic metal ions has already been observed in spring water, as well as a tendency towards floods, particularly during springtime.

The soil erosion risk is specially pronounced in alpine regions, where irreversible damage can prevent reafforestation. Also in mountainous areas, forest decline leads to a drastic increase in avalanche risk. Already a slightly reduced number of trees per hectare could favor avalanche formation.

Forests have also a stabilizing effect on many climatic factors, such as wind speed, air humidity and temperature. As a result of deforestation a marked increase in wind velocity has already been observed in the Ore Mountains, which belong to the German Democratic Republic and Czechoslovakia. Usually this leads to enhanced evaporation. The consequences of local climatic alterations for agricultural land use are difficult to estimate.

The loss of the recreational value of the forest regions is of great importance in highly industrialized and urbanized areas. The recent forest damage in Central Europe, however, often occurs just in forests constituting important recreational regions. Apart from the harm to the people seeking recreation there, this also implies tourist business, which in those areas is a considerable source of income.

Among all the effects of continuing forest decline the alteration of the forest yield and its impact on the timber market is the most obvious economic consequence. Despite tree dying and growth reductions, an oversupply of high diameter classes is to be expected at the beginning, since the most damaged trees will hve to be removed from the stands at the right time to avoid secondary damage. Preliminary investigations have shown that the technological properties of wood from damaged trees are not impaired as long as secondary damage can be avoided this way.

In the Federal Republic of Germany for example forced felling of damaged trees would have amounted to a timber oversupply of about 10% in 1984, had not ordinary felling been restricted. If one assumes that within the comng ten years all stands older than 60 years would be cut by 10% annually, this would mean a multiple of regular felling. Apart from the severe impact on the timber market this would raise immense costs for keeping stocks of round wood and swan timber.

The extent of visible forest damage is so far not sufficiently known in all countries and the prognoses of the further development are uncertaini. It is therefore currently also impossible to estimate, how the forced felling of damaged wood will develop. Consequences for the timber market, from which the future development could be deduced, have not yet been evident.

5. CONSEQUENCES FOR THE FORESTRY AND FOREST SCIENCE

The multitude of effects of acid rain and other forms of air pollution damaging the forests is a challenge to foresters as well as scientitsts. The forestry measures to be taken mustaim.

1. at an accurate assessment of the damage and

2. at a reduction of existing forest damage as well as precautions against further decline.

An accurate assessment of the present extent of forest damage is necessary as a basis for research and for environmental politics. There is also a question of assessing which proportion of the redorded damage is really recent and which proportion of the recent damage has been caused by air pollution.

The methods being applied for this purpose are contained in the concepts of «monitoring» and «survey». While surveying uses statistical sample methodes, «monitoring» has its origin in satellite technology, refering to remote sensing to inspect large areas. In the context of forest damage assessment «monitoring» signifies a long term continuous observation of pollutant stress or the reaction of the forest ecosystem on external influences. In the case of active monitoring indicator plants are introduced into the ecosystem for observation. The observation of organisms already present in the ecosystem is called passive monitoring. In the forest ecosystems the trees themselves are available as bioindicators. The conspicious symptoms allow quick assessment of the extent of damage, but need not necessarily be connected to air pollution, and if so, are little pollutant specific.

Therefore for example aerial false colour photography is to be recommended for the estimation of the actual extent of recent forest damage, but is non specific for air pollution and thus needs support by terrestrial investigations. On the other hand, leaf and needle analyses are sufficiently specif indicators of pollutants. In particular perenniel conifer needles may be utilized as accumulating bioindicators. Especially in spruce the number of needle sets indicates acute air pollution stress. spruce needles therefore react as sensitive bioindicators, but it should be noted that natural stress factors may also influence the number of needle sets on the branch. Similarly the annual growth ring increment of a tree ring provides a mean of non specific sensitive bioindication. Tree ring analysis can greatly contribute to the damage assessment.

As an example the methodical basis of the current work of the author at the Institute for World Forestry in Hamburg will be outlined in the following along with first results.

The current research aims at the quantification of potential alterations of the yield of Douglas fir and Scotch pine in comparison with Norway spruce, which has already shown increment losses on certain sites due to the influence of air pollution.

Currently only 3% of the total forest area of the Federal Republic of Germany consist of Douglas fir, but this percentage is rising steadily, because Douglas fir is a vital, fast growing species and well suited for cultivation in Northern Germany. Actually a great number of Scotch pine stands destroyed by gale in 1972 have meanwhile been reafforested with Douglas fir. Until now there have been very few investigations regarding the growth of Douglas fir under air pollution stress, although this is very important, since Douglas fir is suspected to be less affected by recent forest damage.

The method employed to quantify increment alterations is based on tree ring and stem analysis. About 6 to 8 tree disks are cut from the stem at various heights and are prepared in the laboratory for tree ring measurements. From the disks 4 radial samples are cut at which the ring width measurements can be made to the nearest hundredth of a millimeter by means of an EKLUND-Tree Ring Measuring Device. The data aquisition, data processing and data storage are done by powerful computer programs.

The development of the volume of the trees cannot derived accurately from the annual diameter increment at breast height, because different increment at different tree heights due to air pollution damage may alter the bole shape. A stem analysis program permits the reconstruction of a lingitudinal growth ring pattern (resembling a scematic longitudinal section of the bole) and the calculation of the height and volume development, form factor alterations as well as alterations of the degree of slenderness. All the results can be displayed graphically on paper by means of a plotter.

Figure 1 shows the longitudinal growth ring pattern of a Doulas fir from a forest site 70 kilometers west of Hamburg, which has been known for some years to be affected by air pollution. Although the tree had been classified into damage calss 1 only according to its low amount of shed needles, severe growth reductions have occurred in recent years, especially in the lower part of the trunk. As a result, the bole shape has changed notably. The horizontal lines represent the disks cut out of the stem.

The annual volume increment of the same tree is shown in Figure 2. It may be derived from the graph that after vital growth until 1976 the annual increment was reduced by about 50%. The severe loss of increment of most of the sample trees in 1976 can be explained easily by the hot and dry summer of the same year. In contrast to other regions, however, at this site known to be exposed to air pollutants no recuperation has been observed for 9 years. It may be concluded that drought has triggered growth reductions and that continuing air pollution stress has prevented a recuperation of the physiologically weakened trees, thus leading to considerable losses in forest yield.

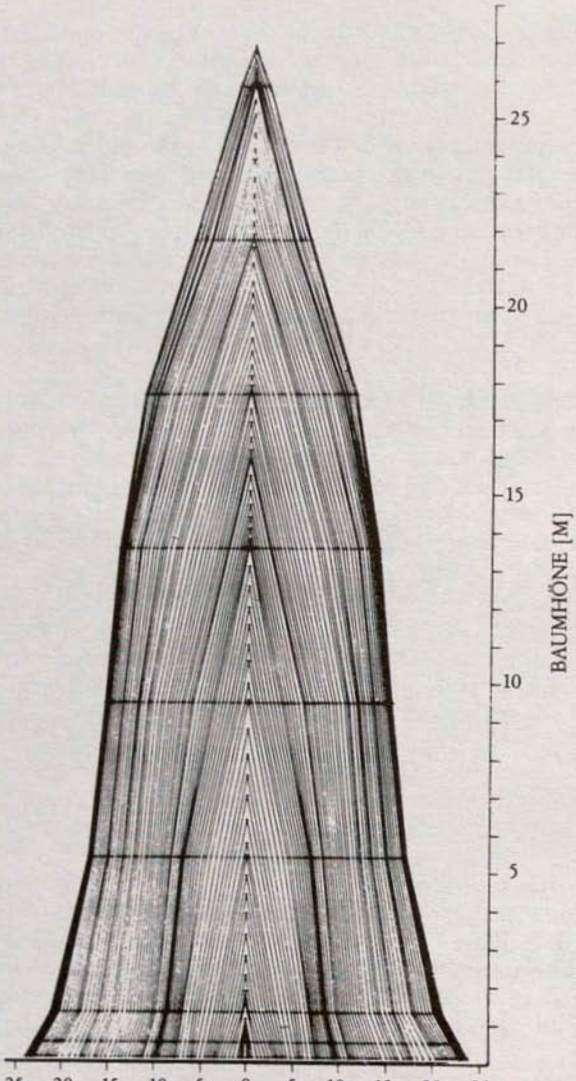

Figure 1.— Longitudinal growth ring pattern of a Douglas fir of damage class 1; age: 72 years.

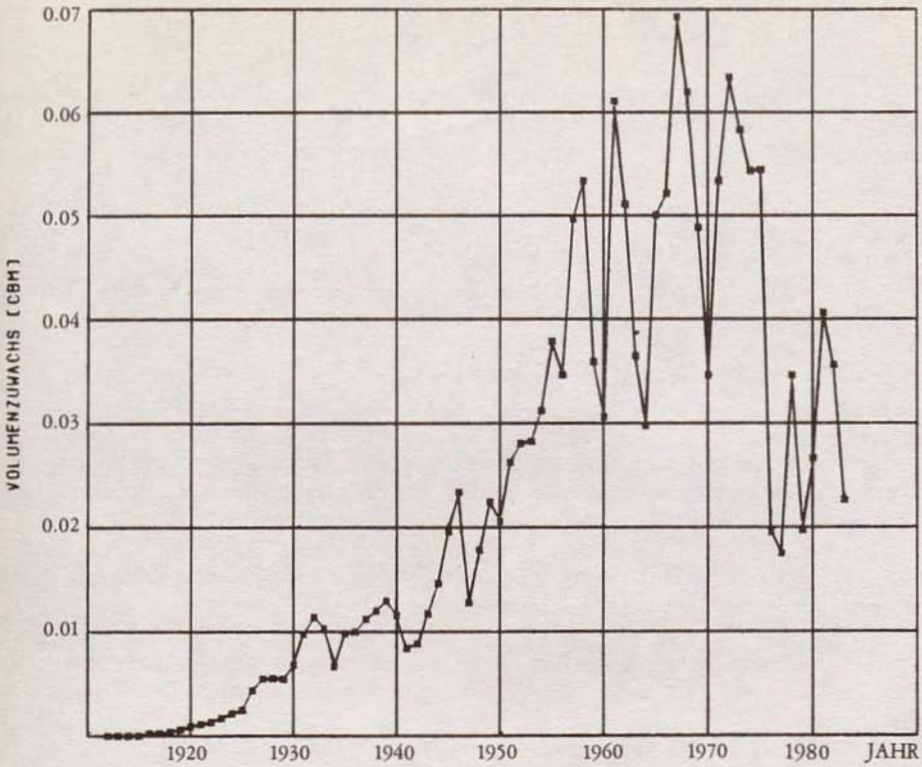

Figure 2.— Volume increment curve of the Douglas fir of damage class 1; severe losses of increment have occured after the dry year of 1976.

Despite this no correlation between the damage class and the growth of individual trees could be found in Douglas fir, Scotch pine and Norway spruce. At the beginning of the eighties a strong correlation between loss of needles and loss of increment had been found in Silver fir stands in Southern Germany. This applies to Norway spruce only at certain sites, whereas at many other sites any correlation is lacking. Therefore short term assessment of the crown condition does not necessarily permit conclusions regarding the long term physiological state of the trees affected by air pollutants.

This makes it so difficult to estimate the effects of acid, acidifying and other air pollutants on the forest yield. It has to be noted, however, that in many parts of our forests reductions of the yield must have been occuring for many years, eigther due to tree dying or due to increment losses in living trees. Alterations of the bole shape also have to be expected.

Forestry measures for reduction of damage may have three objectives: Prevention of damage in stands not affected, mititgation of damage in stands already affected and lastly the establishment of new more resistant forests in areas which have been deforested. The following measures may be applied primarily to avoid or reduce air pollution damage in presently growing stands:

—Fertilizing, aiming to compensate a determined deficiency, but only with careful considerations of possible disadvantages. The same applies to measures aiming to reverse a harmful lowering of soil pH, for example by liming.

—Silvicultural measures which aim to reduce the access by air pollutants, such as closing the canopy as well as the borders of the stand.

—Measures which aim to remove damaged trees at the right time to avoid secondary damage.

—Finally every forestry measure which increases the resistance of the forests stands.

Further general advice on practices to reduce damage cannot be given as damage occurs under all types of silviculture. For the establishmen of new stands and long term protection the following measures are recommended:

—Seed collection from suitable fructifying stands in order to ensure seeds as well as for establishing gene reserves.

—Fostering and protection of the natural reproduction by means of fencing and control of wildlife, as well as artificial reproduction of stands under cover.

Use of improved plant material with higher resistance will not be of short term success due to the long time needed for breeding measures and the control of breeding success. The results of breeding for resistance against classical pollutants are not transferable on recent forest damage and have remained insufficient despite decades of effort.

It is not yet clear, if e.g. Austrian black pine and Douglas fir, which so far have been preserved at various sites, constitute a long term alternative. Recently damage to Douglar fir has also been reported, though Douglas fir so far seemed to be more resistant.