G.J. Heij and J.W. Erisman (Editors). Acid Rain Research: Do we have enough answers?

Forest condition in Europe and North America: What have we learnt over the past ten years?

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Abstract

Due to alarming signals of forest decline in Europe and the U.S.A., a number of research activities started around 1984 to find the causes and to quantify the role of air pollution. Now, in the year 1994, the topic of "acid rain" has faded into the background. Studying the literature of the past ten years, this action seems justified. Little proof can be found for causal relations between forest condition and any form of pollution. Exceptions are the declines occurring when gaseous concentrations are far beyond critical levels. Here, harmful effects are directly observable. However, appearances may be deceptive when concentrations are low. Soil acidification and its subsequent effect on the functioning of roots appears to be the dominant mechanism of injury in this case. Acidification is a cumulating phenomenon and it will not stop when deposition levels decrease. Therefore, the quality of soils has to be carefully monitored in the future. Further development of the concept of critical loads will be an important topic in the forthcoming years.

1. INTRODUCTION

During the 1980s, considerable concern about the condition of trees developed in many parts of the world. Visitors to forests saw dead and dying trees and foresters described the increasing necessity to fell trees prematurely in order to prevent the spread of insects. The story was picked up by the increasingly environmentally aware media and by politicians. As a result, the issue of forest decline rapidly became one of the most widely discussed environmental topics of the 1980s. Since then, public interest in the subject has waned and it no longer draws the same level of political interest. This was partly because of an improvement in the health of forests in the late 1980s ([1]).

The central issue in the debate about forest decline has been the detrimental effect of air pollution. The seeming absence of any long-term, large-scale decline in the overall condition of forests does not preclude any adverse effects of air pollution. Whereas acute injury is usually easy to diagnose, chronic effects are much more difficult to identify. This has not prevented some from making such statements about air pollution as e.g. "in recent years forest damage has increased in country X because of air pollution, possibly in combination with climatic effects". As with other such claims, the evidence supporting this assertion is limited in many cases.

In the following sections, three questions will be answered. First, what body of evidence is sufficient to prove causal relations? Second, what scientific knowledge has been gained over the past ten years? Third, what are the implications for future research?

2. CAUSALITY

2.1 Criteria

It is important to clarify which body of evidence is sufficient to prove causal relations. Innes in his textbook on forest decline ([1]), recalls criteria from [2]: (i) the infecting agent must be present in all patients showing symptoms of the disease, (ii) the infecting agent must be isolated from the patient and (iii) the infecting agent must produce the disease under controlled laboratory conditions. These criteria were expanded by the Committee on Biologic Markers of Air Pollution Damage in Trees [3]. Their five primary criteria for establishing cause-effect relationships were:

- strong correlation;
- plausibility of mechanism;
- responsiveness or experimental replication;
- temporality and
- weight of evidence.

These criteria speak for themselves. However, many claims in literature do not satisfy all of these requirements. E.g., the presence of a correlation alone is a poor indication of a cause-effect relationship. A correlation does not necessarily imply causation; see the example in §2.2. Thus it is necessary to include other evidence. As for experimental replication, a major criticism of most experimental studies of 'forest decline' is that there has been a tendency to generate symptoms under laboratory conditions and then to look for these symptoms in the field (the reverse process should be applied). Temporality means that the timing of decline should coincide with changes in air pollution levels. However, the evidence of such temporal associations is very weak in general ([1]).

2.2 Examples

An example of the problems associated with a lack of temporal association is described by [1]. Rehfuess re-examined data presented by Ulrich et al. in 1980, who proposed that the fine root biomass of trees in the Solling area of Germany had decreased in parallel with an increase in the aluminium concentration of the soil solution. Rehfuess, however, showed that the decline of the fine root biomass had occurred *before* the rise in aluminium concentrations and that moisture stress was the primary cause of the decline.

A second example is given by [4,6]. There is vast literature on the dying of silver fir in Europe, known as "Tannensterben". Visser and Molenaar analyzed ring-width data of declining silver firs in the Bavarian forest (south of Germany). They conclude from correlative statistical inferences that the drastic drop in wood production since the 1960s and the subsequent recovery in the 1980s cannot be explained by meteorological conditions. See Figure 1. They conclude that the significant correlation between filtered ring widths and an index for SO_2 emissions points to a relation between tree growth and pollution. However, Kandler ([5]) questions their conclusions. He states that these results are due to the use of an inadequate measure of the degree of air pollution and a

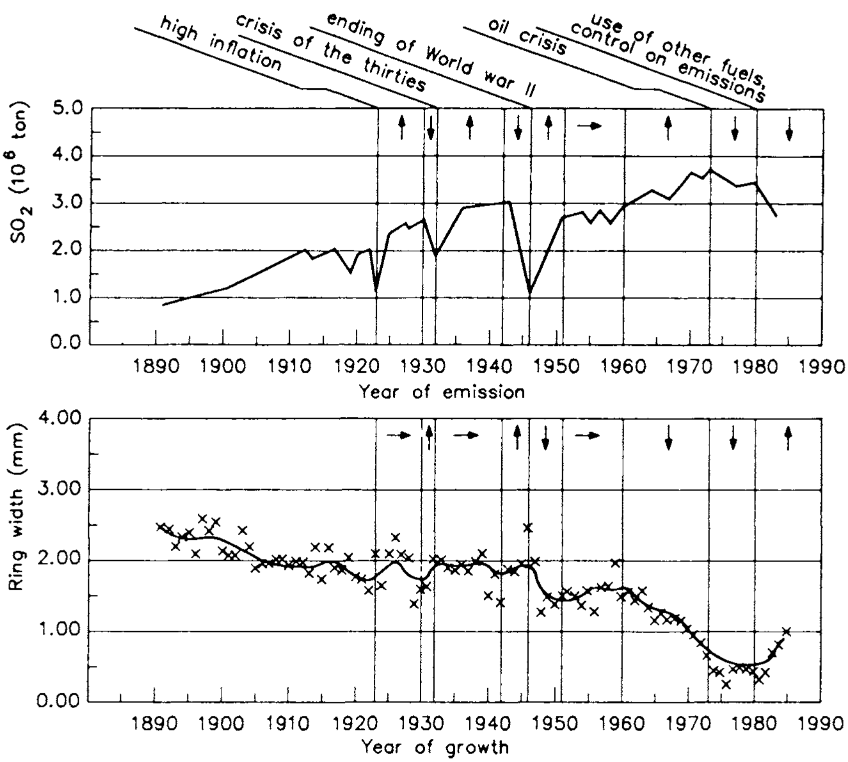

Figure 1. SO_2 emissions in the former F.R.G. are shown in the graph at the top The lower graph shows a ring-width curve of four silver fir stands in the Bavarian forest (solid line). The curve has been filtered for weather influences. An increase or decrease during specific periods is indicated by arrows. Periods of economic events are marked by vertical lines (from [8]).

biased set of tree-ring data. On the other hand, Elling ([7)] analyzed silver fir in the same region and found high values of Sulphur in needles as well as a large number of missing rings at many sites. Finally, silver fir is known to be very sensitive to SO_2.

There is no definite proof in the light of the criteria stated in §2.1. There is a (strong) correlation, temporality is more or less fullfilled and the mechanism is plausible. However, there is no experimental replication and the weight of evidence is not complete satisfactory (no consensus between researchers).

3. FOREST CONDITION AND ACIDIFICATION

Summarizing the scientific knowledge on forest decline and air pollution, the criteria listed in §2.1 have been taken into account. The conclusions are listed concisely and point by point. Main references are [1], [9], [10], [11] and [12].

3.1. Forest decline

- The term 'forest decline' is misleading. First, many types of decline can exist within individual species. Second, most signs of decline are limited to one or two species within a specific forest. A better term would be: tree decline.
- There are many documented cases of *natural* forest decline. Sometimes the dieback can be attributed to a single pathogen, i.e. severe insect defoliation or drought. Often the reasons for decline are unclear.
- If concentrations of pollutants are high (in the order of mg/m^3), *direct* above-ground effects on trees are likely to occur. There are numerous examples of direct injury around emission sources in the past. A well-known example is the triangle Bohemia, southern Poland and the south of the former German Democratic Republic. Here, the atmospheric concentrations of SO_2 are far beyond critical levels. Another example is the high Ammonia emission from bio-industry in the Netherlands. The detrimental effects are clearly observable in the vicinity of farmlands. An example in Central America is the metropolitan district of Mexico City with nearby forests and other nature reserve areas. It is an area of 800 km^2 within a basin surrounded by mountains, where photochemical oxidants reach high values. An example in North America is the west coast of the U.S.A., where in some parts extreme ozone concentrations occur (maximum hourly concentrations 200-300 ppb).
- Apart from examples such as those given above, no other instances of widespread, large-scale forest decline in Europe and North America have been demonstrated at the present time. There are few instances of *tree* decline in which air pollution plays a dominant role, as in the decline of pines in the San Bernadino Mountains (U.S.A.).

3.2. Surveys of forest condition

- The concept of vitality classes (loss and discoloration of foliage) has generally been chosen as an indicator for forest condition. Since 1984, nation-wide surveys have been performed annually. Since 1988 temporal and spatial patterns of damage classes in Europe have been analysed by the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) for UN/ECE. The 1993 report [12] is a cooperation with EEC. There are in total 34 participating countries.

• *Temporal* patterns of the distribution of trees in specific damage classes show statistically significant increases over the years 1988-1992 for many tree species. Data of four species, averaged for the whole of Europe, are shown in Figure 2. The upward trend in foliage loss for Scots pine, beech and Norway spruce is significant (α=0.05). There are no trends present in the discoloration data.

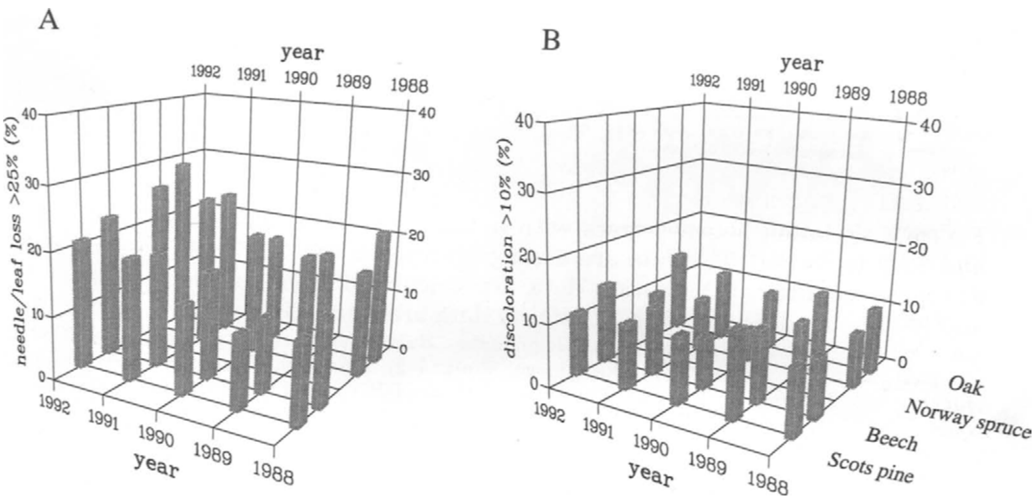

Figure 2. Percentage of trees in Europe with needle/leaf loss >25% (A) and with a discoloration >10% (B). Results of four species are shown. Data from [12].

• Figure 3A shows the result of a *spatial* comparison of the percentage of conifers with needle loss >25% and acid deposition. There appears to be a positive but statistically non-significant correlation between both variables (R= 0.36, tested with α=0.05). The same result is found for broadleaf trees (Figure 3B).

• ICP Forests concludes, among others, that vitality alone is not suitable to prove causal relations between tree condition and levels of acidification. Also, the usefullness of vitality as a representative indicator for forest condition is questioned by many (not however by ICP Forests): a tree cannot be classed as unhealthy simply because it has lost any of its foliage. Foliage loss is often the end-result of a series of changes in the tree's condition. Therefore, it is unclear what to conclude from Figures such as the ones shown here.

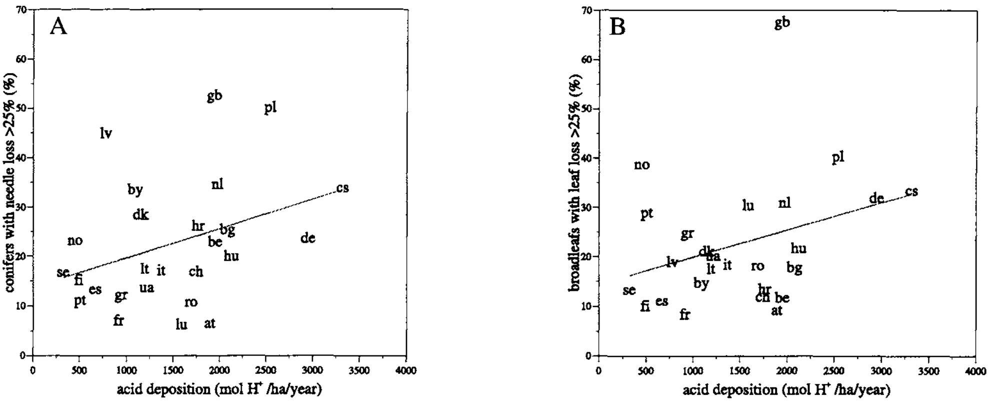

Figure 3. Relation between trees with needle loss (A) or leaf loss (B) over 25% and acid deposition. The data are average values for the year 1992 and cover 29 European countries. Deposition data are calculated from the deposition of S- and N-compounds, listed in [13]; vitality data are from [12].

Abbreviations: Albania=al, Austria=at, Belgium=be, Bulgaria=bg, Byelorussia=by, Croatia=hr, Czechia/Slovakia=cs, Denmark=dk, Estonia=ee, Finland=fi, France=fr, Germany=de, Greece=gr, Hungary=hu, Ireland=ie, Italy=it, Latvia=lv, Lithuania=lt, Luxembourg=lu, Netherlands=nl, Norway=no, Poland=pl, Portugal=pt, Romania=ro, Russia=ru, Spain=es, Sweden=se, Switzerland=ch, United Kingdom=gb, Ukraina=ua.

3.3 Multiple stress

- The weight of evidence for climate as having a major effect on trees and as being a cause of decline is overwhelming.
- Consequently, the idea that trees are affected by combinations of stresses with air pollution being one of them, has been generally recognized and accepted (multiple-stress hypothesis). Other factors are weather conditions, as mentioned above, insect attacks and silvicultural treatment. As for the Netherlands, the systematic lowering of groundwater levels should be mentioned.
- The global increase in carbon dioxide concentrations that has occurred over the past century, may have offset growth reductions attributable to pollution. The same holds for the deposition of N-compounds, which stimulates tree growth initially. Such enhanced growth behaviour has been detected by Briffa ([14]), who found increasing productivity in many western European conifers over the last century.

4. DO WE HAVE ALL THE ANSWERS?

The public fear of dying forests has proven to be groundless. However, from a scientific point of view, many questions remain unanswered, despite an enormous quantity of publications on the topic of "acid rain". The majority of researchers believe that acidification will harm trees through acidification of soils and the subsequent damage to roots and mycorrhiza. Because soil acidification is an *accumulating* process, the present decrease of deposition levels in many European countries will not stop the deterioration of soils. Therefore, forest condition and soil chemistry have to be monitored in the forthcoming years.

From these observations the following conclusions can be drawn:

- The concept of *critical loads* combines soil chemistry and its effects on the root system. Although calculations of critical loads and critical levels have drawbacks at present, it is a promising approach for the forthcoming years. See e.g. [15].
- There should be international agreement on what parameters are needed to *quantify* forest condition. Research shows that vitality should be monitored in conjunction with other indicators of forest condition: measurements of ring widths, nutritional status of soils, needle/leaf analyses and the quality of groundwater. Also, the selection criteria of forest stands should be formulated with care (see e.g. [16]).
- Experimental studies (i.e. open and closed top chambers) fail to reproduce symptoms and damage observed in the field. Such reproduction is essential for the assessment of causal relations. Further research is needed here.
- Improvement of silvicultural treatment and the right choices of species and provenances will better the condition of forests in the long term. However, to achieve this, economic gain should not be the main goal of forestry any longer.

As a final remark it should be noticed that of the entire forest ecosystem forest trees seem to be the *least sensitive part* to air pollution. They are less sensitive than forest ground vegetation, surface waters or crops [17].

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