Forest Decline and Acid Rain — Some Facts and Fallacies

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ABSTRACT

The acid rain controversy and forest decline in Europe are reviewed. Although forest damage is extensive, there are suggestions that much of it may be due to factors other than changes in atmospheric chemistry. A combination of elevated ozone levels, acid mists, fogs and frosts, following drought years, seems the most plausible hypothesis in areas worst affected. Low soil fertility may accentuate the problem. Rainfall acidity is less in Ireland compared with the rest of Europe and projected emissions of sulphur dioxide from generating stations appear to be of little consequence for Irish forests.

INTRODUCTION

The concern in recent years over acid rain and its alleged association with forest decline or dieback stems from alarming German survey figures in the early 1980s on the extent of forest damage in the Federal Republic, the high amenity value associated with areas such as the Black Forest and problems over the future availability of wood for industry in Europe where already there are major supply deficits. Irish foresters might perhaps feel justifiably uneasy. Our proximity to Britain, echoes of Sellafield and Chernobyl, the concentration on monocultures of exotic species, and the establishment of Ireland's largest generating station at Moneypoint in Co. Clare, based on coal, are seen by some as a combined threat to what is often referred to as the most productive forest estate in Europe.

The purpose of this review is to consider the nature and status of forest decline within the European context. Secondly, to outline the main factors, including acid rain, that are considered to be contributing to the problem and finally, to comment on their significance for Irish forestry, particularly in the context of Moneypoint.

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FOREST DECLINE

Forest decline is by no means a new phenomenon in Europe. Binns and Redfern (1983), for instance, point out that silver fir (*abies alba*) dieback has been known for more than two centuries, the species having reached its maximum extent about 1600. Several episodes of fir dieback have been reported since then. It is the recent outbreaks, however, dating from 1972, and the drought year of 1976, and their extension to Norway spruce, now the most important tree in Germany, that has caused alarm.

Surveys in Germany in 1982 suggested that 8 percent of the forest area was damaged. The estimate rose to 34 percent (2.5m ha) in 1983 and 50 percent in 1984 (Anon). Since then the rate of increase in damage appears to have decreased, the 1985 figure being 52 percent (Anon, 1985). The survey results recently published for 1986 suggest a significant reduction in the area showing damage, particularly for conifers (Anon, 1986). Although the figures are high, they must be interpreted with caution. Firstly, there are no data for damage prior to 1982 and secondly, as has been pointed out by Binns *et al* (1984), the statistics are presented in terms of hectares of damaged forest whereas in fact the areas represent the sum of small areas occupied by individual trees. Thus the 1984 German survey report gives an area of 11,000 ha of dead trees but points out that these were usually individual trees scattered over a wide area. Apart from a few limited cases, it was not possible to find any groups of dying trees.

Damage has also been reported from other European countries: France, Belgium, the Netherlands, Switzerland, northern Italy and southern Sweden. Reports cite 15-40 percent damage in broad-leaved and coniferous forests but again there are difficulties in interpreting data due to differences in methodology, presentation, and on what constitutes "damage". There appears to be a consensus that the damage is of a new kind, termed "novel forest decline" by Krause *et al* (1985), and not something that can be attributed to straightforward pollution or a soil nutrient deficiency. Much of the dieback in the German Democratic Republic, Poland and Czechoslovakia does appear to be due to sulphur dioxide damage and differs from that being experienced in West Germany and other central European countries. Damage has also been observed in some of the eastern States of North America; Johnston *et al* (1983) report on growth decline in red spruce (*Picea rubens*), pitch pine (*Pinus rigida*) and shortleaf pine (*Pinus enchinata*) but fail to establish whether the problems relate to pollution or a series of dry summers or a combination of both. Widespread damage to Ponderosa pine (*Pinus ponderosa*) due to high concentrations of ozone in the San Bernadino Mountains east of Los Angeles is reported by Davis (1983).

Because of the general concern over forest decline, uncertainties relating to what constitutes "damage" and differences in survey methodologies etc., the EEC introduced in November 1986 a Regulation on the protection of forests against acid depositions. This will help clear up some of the ambiguities, particularly in relation to methods used to assess and report statistics on damage.

FOREST DAMAGE SYMPTOMS

Damage symptoms most widely reported for the two species mainly affected are listed in Table 1.

Table 1: Damage symptoms reported from West Germany for silver fir and Norway spruce affected by forest decline. (Based on Krause *et al*, 1985).

Silver Fir	Norway Spruce
— Chlorosis and yellowing of needles, mainly on upper side.	— Yellowing of older needles, mainly on upper side. Typical magnesium deficiency.
— Premature loss of needles.	— Premature loss of needles.
— Premature reduction in height growth — resulting in "storks nest formation".	— Drooping of branches and twigs.
— Reduction in fine roots and mycorrhiza.	— Reduction in fine roots and mycorrhiza.
— Injury first observed on exposed and dominant trees.	— Injury first observed on exposed and dominant trees.

Because of the yellowing, and its association with magnesium deficiency, much of the research has involved an evaluation of magnesium status and the response of trees to magnesium and lime application (Huttl, 1984). However, needle analysis from healthy and damaged trees do not always show distinct differences in nutrient levels.

Damage has also been recorded in Scots pine, beech and oak, but to a lesser extent. Again dominant trees are first affected and the yellowing of the foliage is the most characteristic symptom.

Possible causes of forest decline

Besides being influenced by atmospheric chemistry, tree growth is also affected by a range of climatic and edaphic factors. Small shifts in climate, particularly in marginal situations, as in the case of silver fir in central Europe over the last two decades, may result in changes or stress in species (Baumgartner, 1979). Climate also influences diseases and pests. A good example is the association between the outbreaks of *Elatobium abietinum* and mild winters in Britain and Ireland. Rehfuess (1985) cites the extensive occurrence of attacks of needle caste fungi, *Lophodermium spp.* and *Rhizosphaera kalkhoffii* in Norway spruce in southern Germany in 1982/83 and their relationship with frost shocks as another example. The resulting defoliation contributed in no small way to the high figures reached for needle loss in subsequent forest damage surveys.

Exposure can also be a major constraint, and where extreme, can result in atmospheric drought, characterised by drying out and browning of the needles. Much of the forest damage in central Europe is associated with high elevation sites greater than 600 metres above sea level. Growth is also affected by the supply of a number of major and minor soil elements. Some elements are both essential and potentially injurious. The classic examples are sulphur and nitrogen, both of which are required for photosynthesis. Gaseous sulphur and nitrous oxides can, as pointed out below, be damaging if present in sufficiently high concentrations. Similarly, excess amounts of some trace elements can be harmful. Aluminium is the most abundant potentially toxic element in soils and its availability is strongly influenced by acidity and in turn by the occurrence of acid rain. Finally, the long life span of forest trees, and their known capacity to scavenge and absorb nutrients from the athmosphere (Miller & Miller, 1980) makes them sensitive not only to pollution but to all sorts of environmental stress and change. With age, they also become less adapted by their mere increase in size to environmental change. Much of the forest damage reported in Europe is confined to trees over 80 years of age (Binns & Redfern, 1983).

Air pollution hypothesis and forest decline

Air pollution influences on tree growth can be subdivided into two main categories:

(i) Direct effects through the leaf stomata of gaseous pollutants such as sulphur dioxide and nitrous oxides, including interaction with wet deposition on above ground parts of trees, followed by indirect effects on the root system.

(ii) Indirect effects on above ground and below ground parts of trees due to the accumulation of wet and dry deposited substances in soils.

Sulphur dioxide:

Sulphur dioxide (SO_2) is the classical air pollutant and when present in high concentrations is known to adversely affect the health and growth of trees. The gas is emitted from many sources, but mostly from the burning of coal and also from refining and smelting plants and from industries that manufacture or use sulphuric acid. The worst example of tree damage by SO_2 in Ireland occurred in the early 1970s at Shelton Abbey in Co. Wicklow where it was found that about 40 ha of the forest surrounding the N.E.T. fertiliser factory were severely damaged (McAree, D., unpublished: Forest and Wildlife Service). This coincided with regular recordings of 500 micrograms m^{-3} (ug m^{-3}) of SO_2 in the area. Mean annual levels at the Valentia meteorological station in Co. Kerry in 1981 were 0.8 ug m^{-3} (McCaffrey, F., personal communication). Dublin city in 1981 had a mean annual concentration of 62 ug m^{-3}.

One of the difficulties in establishing a relationship between SO_2 levels and forest decline is that emissions have tended to fall in Europe since 1970 (Sartorious, 1984) during a period when damage to forests appeared to increase. Another difficulty relates to establishing threshold levels for SO_2 damage. Controlled environment experiments have attempted to establish such relationships but their relevance to field conditions where concentrations fluctuate daily and seasonally, and where episodic extreme concentrations may be more important is questionable (Last, 1982). According to Mukammal (1976), threshold levels for acute injury are about 850 ug m^{-3} and about 140 ug m^{-3} for chronic injury. Below these levels he considers SO_2 to be generally non injurious to forest trees in the sense of producing visible evidence of damage. Keller (1984) on the other hand showed that carbon dioxide uptake by Norway spruce could be reduced by up to 50 per cent when exposed to continuous concentrations of SO_2 of 260 ug m^{-3} even though there were no *visible* signs of injury. Anderson (1983) suggests that growth decreases can be expected at yearly concentrations of 25-50 ug m^{-3} of SO_2. This is in agreement with results from studies carried out by Soikkeli (1981) in industrial areas of Finland. In contrast to this a major summary report (I.E.R.E., 1981) suggests that the long term threshold concentration for yield reduction in trees lies between 100 and 150 ug m^{-3} with the possibility of a lower threshold in regions with extreme climatic conditions.

Following a review of ambient SO_2 levels in areas affected by forest decline, Krause *et al* (1985) concluded that the gas could be eliminated as an overall cause of the problem. This is not to say that SO_2 cannot directly result in forest damage in countries such as Czechoslovakia where peak levels of 1800 ug m^{-3} can occur. The fact is however that damage has been reported from areas with SO_2 concentrations as low as 2-3 ug m^{-3}, in Switzerland for example (Bucher, 1985b).

Nitrous oxide:

Gaseous nitrogen compounds are less toxic than SO_2 and any effects on growth resulting from increased nitrogen deposition are likely to be indirect through the soil rather than directly on tree foliage. In parts of southern Sweden total nitrogen deposition in precipitation has reached 70 kg/ha/annum (Nihlgärd, 1985) a figure seven times greater than that recently measured at Avondhu Forest in Co. Cork (Carey, *et al,* 1986). About half of this originates from nitrous oxide emissions and other combustion processes, the remaining portion from volatilisation of ammonia from the agricultural sector. Such "oversaturation" of the soil with ammoniacal nitrogen, Nihlgärd, argues, rather speculatively, adversely affects the forest ecosystem through enhanced leaching of nutrients, increased susceptibility to frost and pathogens and decreased soil microbial activity. Many scientists do not share this view.

Ozone:

Ozone is a secondary air pollutant formed under the influence of reactions between ultra violet light — bright sunshine — and nitrous oxides and hydrocarbons. The gas occurs naturally in the stratosphere some 25 km from the earth but elevated levels can occur near ground level if conditions are favourable for its formation. It is considered the most phytotoxic air pollutant in the United States (Davis, 1983) where the high concentration of automobiles and weather conditions in areas such as California combine to provide ideal conditions for its formation. There are no data available for levels in Ireland.

Krause *et al* (1985) reports increases in ozone concentrations, particularly in rural parts of West Germany, and suggests that peak value years (over 500 ug m^{-3}) correspond more or less to the increase in observed forest injury. The primary site of ozone attack is the cell membrane. This leads to enhanced leaching of foliage nutrients, including magnesium causing yellowing of foliage, and increased susceptibility to pathogen attack.

Acid rain

Because of the presence of carbonic acid the pH of unpolluted rain is about 5.6 and acid rain has come to mean precipitation (rain, fog, dew, snow) containing sufficient amounts of acidic air pollutants to produce a pH less than this figure. Sulphur dioxide and nitrous oxides are the main gases responsible for a lowering of the pH in polluted atmospheres.

Rainfall acidity has increased in industrial countries since the

1950s due to the increased combustion of fossil fuels. It has been estimated hat 90 percent of all sulphur falling on northern Europe is derived from man-made sources (Overrein 1983). In Ireland the proportion is less due to the lower industrial base and our proximity to seawater.

Rainfall acidity has also increased in Ireland since the early 1960s (Matthews *et al,* (1981). In 1985 fifty four percent of the samples collected had a pH less than 5.6. Recent studies by An Foras Forbharta in the Dublin region gave a mean pH of 4.7 for five collection stations, some of the lowest values being associated with the Glencree Valley (Bailey *et al* 1986). The study also showed lowest pH readings and highest SO_2 concentrations occurred when winds came from an easterly direction. Recent studies by the Forest and Wildlife Service at Avondhu Forest in Co. Cork gave a mean pH of 5.6 over a two year period (Carey *et al op. cit*). The pH of rainfall in substantial areas of Britain and Europe has a pH of 4.4 or less. The mean value for Norway and Sweden is about 4.2. Because pH is expressed on a logarithimic scale, rainfall with a pH of 4.4 contains 10 times more hydrogen ions than that with a pH of 5.4.

Although potential direct effects of acid rain on trees have been listed, Morrison (1976) concluded that visible damage was unlikely to occur unless the pH of the rain was 3.00 or less when lesions of the leaves could be expected.

Most of the interest in acid rain has centred on its indirect effects on the release of soil cations such as calcium and magnesium and, in particular, the potentially toxic aluminium. Chief protagonist has been Ulrich (1983) who suggests that the resulting solubilised aluminium damages tree roots and ultimately causes dieback. Other German scientists disagree (e.g. Rehfuess *et al,* 1983) and Alexander and Miller (1985) report satisfactory growth of seedlings at higher aluminium concentrations than those found in Ulrich's studies. Furthermore, forest decline has been reported from areas in Germany with low levels of soil aluminium. In Norway and Sweden the dying off of fishstocks in thousands of lakes is attributed to the release of soil aluminium by acid rain into streams and rivers. Despite this evidence, the damage to forests appears far less than in central Europe and tree ring studies have failed to establish any relationship between growth and acid rain (Jonsson and Svenssen, 1972).

Moneypoint

The main concern expressed about the new 900 MW electricity generating station at Moneypoint in Co. Clare relates to the emission of SO_2 following the combustion of some 2 million tonnes of coal annually in a plant where no desulphurisation equipment has been fitted. Studies by the Electricity Supply Board, (Lawlor, 1978) suggest that in the area of maximum impact — some 10 km from the plant — annual means of 12-14 ug m^{-3}, monthly means of 30-60 ug m^{-3} and daily mean maxima in the order of 100 ug m^{-3}, can be expected. Outside this zone, levels will fall off sharply. Mangan (1985) predicts a figure of 1 ug m^{-3} for the Burren area. Assuming these estimates to be reasonably correct, it would appear that it is most unlikely that direct visible damage to trees will occur, particularly in the context of the suggested threshold levels mentioned earlier. Overall the increased deposition of SO_2 is predicted to be approximately 50,000 tonnes/annum. This compares with a total national figure for SO_2 emissions of 155,000 tonnes in 1984 and 234,000 tonnes for 1979 (Bailey, 1984). Thus when the station is working to capacity, total emissions for the country will be 12 percent less than the figure for 1979 before the commencement of the change over to natural gas. Big changes in rainfall acidity are therefore most unlikely. If changes do occur, they are likely to be small and of little if any consequence for tree growth. However, the evidence would seem to suggest that there may be a greater tendency for soil acidification to be enhanced as a result of forest growth (Likens and Bornmann, 1974). There is increasing evidence of such long term changes in Britain, particularly in parts of Wales, where concern has been expressed over the increased levels of aluminium in some water courses. However, the current total generating capacity for the UK based on coal is some 35,000 MW, many individual stations having a capacity of 2,000 MW. When looked at in this context Moneypoint (900 MW) would appear to be of little environmental concern, particularly when it is borne in mind that the Forestry Commission in Britain have so far found no relationship between forest health and rainfall acidity or sulphur deposition (Binns *et al* 1984). However, it may well be that ecosystems other than forest, for example certain aquatic systems, are more sensitive to small changes in atmospheric chemistry. It is also possible that organisms other than the trees within the forest ecosystem, for example certain mirco-organisms, could be adversely affected by minor changes which have so far gone undetected.

As part of their environmental programme the ESB have installed a number of monitoring stations for measuring SO_2 and rainfall acidity. These are sited at Kilrush, the Burren and in a Forest and Wildlife Service plantation in the Slieve Bloom Mountains. The Forest and Wildlife Service has also established a series of forest health plots nationwide which will be monitored annually.

Discussion and Conclusions

The available evidence suggests that a number of factors are responsible for the dieback and decline of European forests. There are some suggestions that the problem may have been overstated somewhat and there is certainly still a large degree of uncertainty in relation to what constitutes "damage". Air pollution due to high concentrations of SO_2 has been killing trees locally for centuries and is currently responsible for extensive forest dieback in countries such as Czechoslovakia and Poland but it is a long way short of explaining the forest decline phenomena reported from Europe in recent years. Neither is acid rain directly responsible, although indirectly it may accentuate stress on infertile soils of low base status. The most plausible theory currently advanced is that the drought years of 1976, 1982 and 1983 put trees under stress on a wide scale and that elevated ozone levels and, in some instances, acid mists and fogs at high elevations, are responsible for the damage. These weaken cell membranes and accelerate the leaching of calcium and magnesium from foliage, increasing its susceptibility to frost damage. In areas where the rainfall is strongly acid, the calcium and magnesium are eventually leached from the soil resulting in foliage yellowing. Lime, magnesium and potassium applications are now being tested as remedial treatments in a number of countries. There are a number of examples of unhealthy trees and plantations in Ireland but these can invariably be related to poor soils or incorrect choice of species rather than acid rain or pollution. Projected emissions from generating stations such a Moneypoint would appear to be far below what are considered potentially damaging although areas within 10 km of the plant might be expected to show some indirect effects in the long term, the significance of which remains conjecture at this point in time. According to Last (1982) Norway spruce and Scots pine are amongst the most pollution sensitive conifers. Sitka spruce is susceptible but less sensitive than Norway spruce. Lodgepole pine and western red cedar are considered the most tolerant species.

A positive aspect of the current debate is the large injection of funds that have been made into European forestry research programmes. Although these may not necessarily solve or contain the problem of dieback, they will provide an insight into what the key stress factors are and ultimately the basis for improved productivity and stability in forest ecosystems.

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