EXPERIENTIA

Volume 41/No. 3 Pages 285–425 15 March 1985

Reviews

'Waldsterben': Our Dying Forests

Part I

Editorial Preface

Perhaps the only incontrovertible result of the 'Waldsterben' research which has been carried out to date over several continents is the certainty that we are dealing with a disease syndrome far more complex than had been imagined even a year or two ago. Research that generates as many questions as it answers is not ready to be reined into the rigid confines of a comprehensive review. And yet, facts which *are* emerging – even if they are single pieces of the complex puzzle whose pattern is not yet clear – should, we feel, be disseminated as rapidly as possible. We have decided, therefore, to depart from our usual Multi-author Review format and with this issue of EXPERIENTIA introduce a new series of research reports on the Waldsterben crisis. Further papers on all aspects of this topic (including critical perspectives on areas which thus far have received insufficient attention, such as the connection between forest decay and radioactivity) will appear henceforth in free succession.

We wish to extend special thanks to Dr J. B. Bucher who has lent invaluable advice during the organization and preparation of this new series.

H. M.

Introductory Remarks

In the opinion of many scientists, the effects of air pollution are now posing the most serious threat to forests in the temperate zone. Forest damage has already spread to an alarming extent throughout Central Europe. In the Federal Republic of Germany, where the scientific and public community is highly aware of the ravages of forest decay, the phenomenon is better known as 'Waldsterben', a term which is now in current use internationally. Since much of the investigation into Waldsterben originates from and concentrates on this country, research reports have been written primarily in German. One of the goals of EXPERIENTIA's new interdisciplinary review series is therefore to bring this problem to the immediate attention of a concerned international public.

A few years ago, many researchers felt that acidic deposition was the main cause of forest decay. Later, it was discovered that other causes (for example, oxidant pollution and pathogens of various kinds) might be playing key roles as well. The increasingly rapid deterioration of the forests (in 1982, 7% of the forests in the Federal Republic were afflicted; by 1984 the figure had jumped to 50%) indicated that reassessment of old hypotheses and new problem approaches were urgently necessary. The present series will make no attempt to establish a consensus about the causes of forest decay; instead, EXPERIENTIA wishes to provide a forum for lively scientific debate.

The first contributions to this series are devoted to background information. *J. Fuhrer* discusses the formation of secondary air pollutants and their occurrence over Europe. He shows that the formation of atmospheric acidity is interrelated in a complex manner with the processes leading to the accumulation of ozone and other oxidants, which finally may have eco-toxicological consequences to forests. It is still difficult to prove these effects in the field, although under controlled conditions the uptake and the effects of gaseous air pollutants can easily be shown. The biochemical and physiological effects of fumigation experiments on trees are analyzed by *W. Landolt* and *Th. Keller*, For several years, now, a general depression of forest growth has been observed over wide regions in the northern hemisphere. This growth depression is most pronounced in regions afflicted by Waldsterben. The article by *S. B. McLaughlin* and *O. Bräker* deals with methods for evaluating and predicting forest growth responses to air pollution. The authors also highlight general methodologies in studying forest decline in Europe and the United States. Finally, *J.-Ph. Schütz* describes the few silvicultural measures available to control forest decay in a polluted environment.

In a syndrome as complex as Waldsterben, predisposing, inciting and contributing factors all play important roles in the death of an individual tree. Some of these factors will be assessed in the second part of this review series which will include articles by *B. Ulrich* and *E. Matzner* ('Implications of the chemical soil conditions for forest decline'), *A. Hütterman* ('The effects of acid deposition on the physiology of forest ecosystems'), *E.F. Elstner, W. Osswald* and *R.J. Youngman* ('Basic mechanisms of pigment bleaching and loss of structural resistance in spruce needles: advances in phytomedical diagnostics'), and *F. Nienhaus* ('Infectious diseases in forest trees caused by viruses, mycoplasm-like organisms and primitive bacteria'). Further parts of the series are in preparation.

J.B. Bucher
Birmensdorf

Formation of secondary air pollutants and their occurrence in Europe

J. Fuhrer

Institute of Plant Physiology, University of Bern, Altenbergrain 21, CH-3013 Bern (Switzerland)

Key words. Forest decay; air pollution; acid deposition; photochemical oxidants; ozone; peroxyacetyl.

1. Introduction

Primary air pollutants are removed from the atmosphere by sink processes such as wet and dry deposition or chemical and photochemical conversion. The latter processes lead to the formation of secondary air pollutants. Among them, photochemical oxidants, primarily ozone and peroxyacetyl nitrate (PAN), and strong acids are of major concern because of their occurrence in long-range transported air masses and their biological and ecological impact.

Photochemical oxidants have attracted research and public interest since the 1940s, when substantial damage to crop plants and forest trees started to occur in southern California. Apparently, the problem has now spread over the entire United States, and ambient ozone concentrations at present reduce the yield of crop plants in all areas recently investigated[78]. Symptoms of severe ozone damage to forest trees can be observed at the present time at lower elevations on the western slopes of the Sierra Nevada Mountains[162], and, most strikingly, oxidant gas impact on successional plants has appeared in remote areas in the Blue Ridge Mountains[41]. Such an oxidant threat to plant life is also expected in other parts of the world, particularly in many countries of Europe. An involvement of oxidant gas (especially of ozone) in the process leading to the present forest dieback has been suggested for areas in Bavaria (higher elevations)[122], southern Germany and Nordrhein-Westfalen[121], and also in Switzerland[19, 47]. This presentation attempts to describe the processes possibly involved in the formation of oxidant gases in the atmosphere and to summarize some of the data available on ozone and PAN occurrence in Europe (mainly northwestern Europe). Although nitrogen dioxide (NO_2) is also considered to be one of the photochemical oxidant gases, it is only included here as it takes part in atmospheric transformations leading to ozone and PAN or nitric acid.

In recent years, another form of secondary air pollution has become an important scientific and political issue, namely that of 'acid rain'. This term refers to wet deposition in the form of rain, mist, snow, hail or intercepted fog and cloud water containing amounts of strong acids (sulfuric and nitric acid) in excess of what can be expected from the natural biogeochemical cycles of sulfur and nitrogen. Hence the phenomenon of acid rain reflects the disturbance of hydrochemical cycles[145]. Since acid or acid-forming substances can also be introduced into ecosystems by dry deposition, it is more appropriate to apply the term 'acid deposition'. This includes all deposition processes to be considered, i.e. 1) wet deposition by rain- or snowfall, etc., and dry deposition by sedimentation of particles *(= precipitation deposition)*, and 2) impactation of aerosols and mist, fog or cloud droplets together with the absorption of gases on wet surfaces or inside the stomata of leaves and needles *(= interception deposition)*[150]. The deposited acids can interfere with processes in aquatic[40] and forest ecosystems[52] and can affect agricultural crop productivity[44]. Acid deposition is believed to be the dominant factor leading to destabilization and forest dieback in Central Europe[149]. Continent-wide precipitation sampling networks in Europe and North America have provided us with a general picture of the widespread occurrence and the increasing frequency of highly acidic precipitation events[86, 87, 107, 113–115]. The formation of atmospheric acidity is largely driven by photochemistry and is therefore closely related to the formation of oxidant gases. In this review, mechanisms involved in the formation of atmospheric acidity are therefore considered together with those leading to secondary oxidant gases. Furthermore, the factors which may influence the free acidity of wet precipitation and fog are summarized, and a rough picture of the occurrence of strong acids in precipitation over Europe is given.