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Waldsterben in the Forests of Central Europe and Eastern North America: Fantasy or Reality?

The reported decline and death of forests, initially termed "Waldsterben" and subsequently "neuartige Waldschäden," has aroused the concerns of scientists, policy makers, and the general public alike. The level of press coverage has been almost unprecedented for an environmental issue. Photographs of dead trees created a strong impact, particularly in those countries where trees and forests form an important part of the national psyche. Within the English-language literature, much of the concern can be traced to a widely read paper published in 1985 by Schütt and Cowling (116). Their paper, in turn, seems to be based on the earlier predictions by Ulrich et al (136) of an impending general forest decline. Since the publication of the article by Schütt and Cowling, a large volume of research has been undertaken on the general problem of Waldsterben.

In this paper, we consider some of the statements by Schütt and Cowling (116). While it is always easier to work with hindsight, some of the statements made were clearly unsubstantiated at the time of publication. We examine their claims that an unprecedented, widespread decline of various forest species occurred in the late 1970s and early 1980s associated with damage by air pollution. Several reasons why Waldsterben might seem attractive to so many are examined at the end of our paper.

Origins of the Concept

Schütt and Cowling (116) describe Waldsterben as "a collective term for the widespread and substantial decline in growth and change in behavior of many softwood and hardwood forest ecosystems in central Europe." In their 1985 article, Schütt and Cowling refer to Waldsterben as a disease. Later, Schütt (115) stated "Waldsterben to be explained as a disease of forest ecosystems," preferring this basic philosophy of causality over an alternative suggestion that Waldsterben could also be distinguished as "a number of single well-known tree diseases which simultaneously occur at the same locations by chance." Schütt and Cowling further suggested that the geographic extent of individual species' declines and their sudden common occurrence in the late 1970s and early 1980s be considered an unparalleled new disease phenomenon within the forest pathology literature. "Never before have so many different soil, site, and climatic conditions shown so markedly similar and serious effects" (116).

Ulrich (134) argued that he and colleagues had first proposed a "hypothesis of a general forest decline occurring within the coming years" (136). Most of the subsequent concepts proposed by individual scientists seem to stem from this perception of a general forest decline. Concurrent to the early publications about a new forest decline, several major international excursions and their associated reports enhanced the development of the concepts of Waldsterben elaborated on by Schütt and Cowling (116). Tours were led into the high-elevation stands of Fraser fir (*Abies fraseri* (Pursh.) Poir.), balsam fir (*Abies balsamea* (L.) Mill.), and red spruce (*Picea rubens* Sarg.) of the northern and southern Appalachian Mountains in the eastern United States (82). Comparable numbers of declining and dead trees were observed with symptoms purported to closely match those seen in European forests. In addition, numerous other efforts were made to reinforce the concept of a general decline in both European and North American forests (69, 109,114,137,144,156). A major function of the excursions was to build a consensus on the reality of the phenomenon.

As monitoring of atmospheric depositions (popularly termed "acid rain") increased, reports of suspected direct effects to forests in the United States and Canada began to emerge in the literature (e.g., 8,34,88,90,101,108,146,148). Several newspapers and popular periodicals further expanded public awareness of the purported direct effects of acidic depositions (e.g., 6,9,10,14,17,46,85,130), as did several state level reports (e.g., 7,20). These citations were selected from wide-ranging sources to illustrate the importance of the media in promoting the role of air pollutants (i.e., acid rain) in alleged forest declines.

Several reported species declines (note: not forest declines) were used to exemplify possible relationships to acid rain. In North America, two received particular attention: sugar maple across much of its range in south central and eastern Canada and throughout much of the northeastern United States (e.g., 21,30, 33,97), and high-elevation spruce-fir forests of the Appalachian Mountains from Maine to Georgia (69,82,91).

The decline of spruce and fir forests in the eastern United States was suggested as a new and unexplained phenomenon of unprecedented proportions; air pollutants were high on the lists of direct and/or indirect causes. Woodman and Cowling (156) reported the suspicion that airborne chemicals might be involved, based mainly on a correlation between observed altitudinal gradients in symptoms with known altitudinal gradients in atmospheric pollutants. They noted, however, that "none of Koch's postulates (78) has been satisfied."

Elsewhere, numerous photographs of dying trees were published suggesting a unique devastation of forests across all of Europe and North America (Fig. 1). The public, as well as many colleagues in related fields of forest biology, were repeatedly given the suggestion of air pollutant involvement in the ill-defined concept of Waldsterben (115,116).

The trend moved into the scientific literature. In the introductory remarks of many papers, unsupported assertions were made about declines. For example, while citing LeBlanc et al (87), Mehlhorn et al (98) stated that, "Analyses of tree ring growth patterns indicate that recent forest decline, currently affecting many trees throughout Central Europe and North America, started between 20 and 30 years ago. Because research activity has so far failed to isolate pathogens that may be responsible for this disease, most scientists are now inclined to the view that a non-biological cause is responsible for the problem. Atmospheric pollution

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has emerged as the most likely primary cause."

Similarly, Cape et al (25) began with, "There has been increasing concern over the past decade about the declining health of some forests in central Europe and eastern North America. Although many hypotheses have been suggested to explain this decline, it is widely accepted that air pollutants (such as sulphur dioxide, nitrogen oxides and ozone, acid rain and mist, etc.) might affect forest health by directly damaging foliage, or indirectly by increasing soil acidity." In contrast to this carefully worded introduction, van Dijk et al (147) stated that "Air pollution is generally accepted as a major cause of forest dieback in Europe and North America." In another example, Ulrich (135) claimed, "The realization, at the start of the 1980s, that forests remote from industrial areas were suffering environmental stress on a massive scale, due to atmospheric pollution, has sharpened our eyes for damage symptoms on trees." In the same book, Hanisch and Kilz (48) stated that, "Airborne pollutants have been suggested as the main causal agent of the recent coordinated and widespread forest declines." In most cases (there are many more), the existence of a Waldsterben-like forest decline is taken for granted, although authors vary in their willingness to directly pinpoint air pollution as the cause.

With the strong emphasis placed on 1) the existence of forest decline and 2) the role of air pollution as a cause, it is hardly surprising that so many people have accepted both conjectures as fact.

Examining the Evidence

Waldsterben, as described by Schütt and Cowling (116) and Schütt (115), includes a simultaneous and rapid decline in the health and vigor of both coniferous and broad-leaved forests beginning in 1979 or 1980, with symptoms classified as growth-decreasing, abnormal-growth, and water-stress. These works further suggested that unknown causal stress factors were involved, but stated that atmospheric deposition was known to be involved. They listed six basic hypotheses, including acidification–aluminum toxicity, ozone effects, magnesium deficiency, general disturbance of physiological function, excess nutrients, and air transport of growth-altering organic substances, all put forward as explanations for particular portions of the syndrome. It was proposed that many forest ecosystems would likely be destroyed.

Problems with forest decline. One of the most critical aspects of the argument put forward was that a simultaneous, widespread, and rapid decline in forests was occurring in Europe and North America (116). For Europe, the injury data presented by Schütt and Cowling (116) related to the percent forest area in West Germany with more than 10% defoliation. Since 1985, the threshold for damage has been raised from 11 to 26% defoliation, a change which resulted in a reduction of the damaged area of forest from approximately half to less than 20% (18). In practice, it is difficult to see how these figures are calculated, since the German assessment procedure is based on a fixed number of trees per plot, a procedure that generates data that cannot be related to forest area (102). Despite this, German reports (36–44) frequently refer to the several thousands of hectares of dead forest in the Mittelgebirge (midaltitude mountains).

The development of Waldsterben has been monitored in Europe in national inventories of forest condition performed under the auspices of the United Nations Economic Commission for Europe (UNECE) and the Commission of the European Communities. These programs (combined in 1991) assess the extent of defoliation and discoloration in trees throughout Europe. A critical point is that these surveys did not begin until the 1980s, and relatively consistent surveys did not begin in most countries until the mid- to late-1980s. After the completion of the first survey, a country would report the condition of its forests. The results were always presented as the percentage of trees affected by Waldsterben, i.e., with defoliation. Neither of these general surveys involved a detailed diagnostic investigation of individual trees.

The annual reports produced by the UNECE have received widespread attention. These reports stressed a number of aspects of the surveys. First, they argued that the surveys were undertaken in a consistent and standardized fashion, thus enabling the results from different countries to be compared. Although subsequent studies (67; L. Bouhot, G. Landmann, and J. C. Pierrat, *unpublished*) indicated that major differences exist among the operating standards used by different countries, the UNECE reports have continued to compare results. In recent years, a proviso has been added to the base of comparative

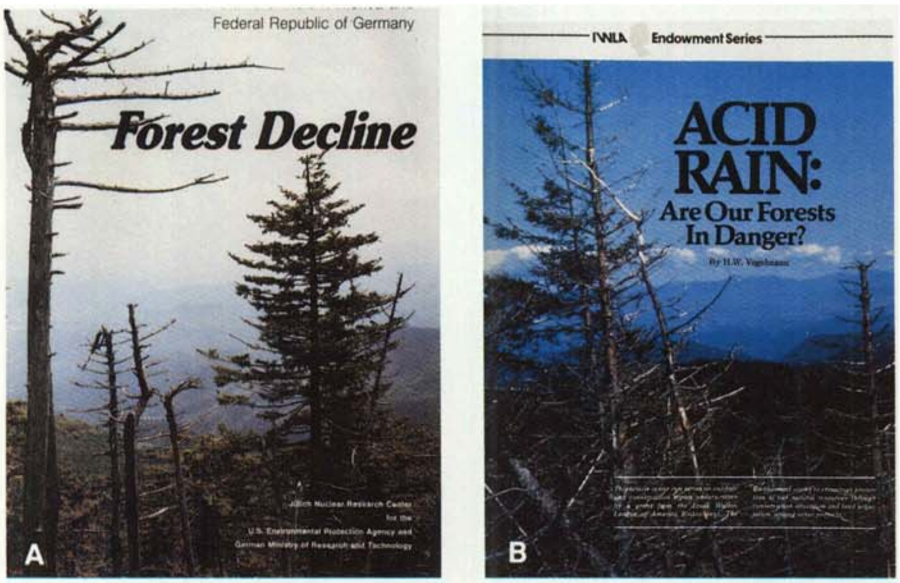

Fig. 1. Scenes of forest devastation offered as part of the early evidence of cause–effect relationships involving acid rain or air pollution in general while building the case for Waldsterben. (A) Krahl-Urban et al (82); (B) Vogelmann (148).

Symptoms of Waldsterben by Schütt and Cowling, 1985

Growth-decreasing symptoms
- Discoloration and loss of foliar biomass
- Loss of feeder root biomass
- Decreased annual increment
- Premature senescence of older needles in conifers
- Increased susceptibility to secondary root and foliar pathogens
- Death of affected trees
- Death of herbaceous vegetation

Abnormal-growth symptoms
- Active casting of green leaves and green shoots
- Stork's nest formation in white fir
- Altered branching habit and greater-than-normal production of adventitious shoots
- Altered morphology of leaves
- Altered allocation of photosynthate
- Excessive seed and cone production

Water-stress symptoms
- Altered water balance

tables indicating that "comparisons between countries should be made with caution," despite the clear evidence that such comparisons are meaningless. The results, collected over the last 2–7 years, do not suggest a significant increase in mortality, although the proportion of trees with thin crowns has increased.

The novelty of the symptoms that Schütt and Cowling (116) attributed to Waldsterben must be seriously questioned. Although they referred to earlier records of silver fir decline, for every individual symptom there are good documentary records for the previous existence of the same symptom not associated with decline. For example, what is meant by "excessive seed and cone production" (116) as an abnormal growth symptom? Seed and cone production was certainly very high in some areas in some years (e.g., 31,62,66), but this variation is well-known. In European beech, the relationship between cupule production and summer temperature has been known since the time of Carl Linnaeus (89), well before any possibility of regionally dispersed air pollution and drought interactions. Substantial interannual variations in flowering and fruit production are widely documented (e.g., 65,81,93). Similarly, rapid leaf abscission is a well-known response to drought (35). The symptoms were not always seen on the same tree, but the list of Schütt and Cowling also refers to a variety of species. It is important to recognize that they do not document a single site where all the symptoms they describe can be found together.

Because the symptoms of Waldsterben have always been present in our forests (49,52) and the changes in growth and/or crown condition of trees currently classed as damaged can be traced, in some cases, to events over 100 years ago (45,71,119, and many others), we must question the argument that symptom onset was rapid. The alleged rapid spread of Waldsterben implies a spatial advance of the phenomenon (115,116); this is also unsupported by field evidence (71,73). Defoliated trees were already present in individual countries when each of the surveys of forest damage began. There is no indication of a spread of damage across individual countries; rather, the supposed spread reflects the disjointed starts of surveys in different countries.

The symptoms on species other than Norway spruce and silver fir, particularly those leading to mortality, are less clear. Extensive mortality of European beech (*Fagus sylvatica* L.) occurred over the last 20 years, mainly following periods of drought and related (possibly) *Nectria* damage. Scots pine (*Pinus sylvestris* L.) was alleged to show similar symptoms of decline, but these are not widespread. A detailed study of mortality of Scots pine in the Lubben forest area of Germany (53) indicated that annual mortality of Scots pine is extremely variable, with the peak years being 1976, 1983, and 1985–1986; these were years with low rainfall. In Switzerland (one of the few European countries with a genuinely representative inventory of forest condition), no consistent change in mortality rates of all species occurred in 1985–1993, a fact that cannot be linked to selective felling of sick trees, as removals have not been significantly biased towards defoliated trees (66).

Examples of incomplete literature reviews leading to misdirection in suggested etiological agents (i.e., air pollutants) involved in species declines have been published (e.g., 5,20,117). In more comprehensive reviews (e.g., 29,51,70–74, 83,84,100), very different conclusions were reached, with the symptoms reported in the 1980s found to be the same or similar to those seen in earlier periods. These symptoms are associated with factors such as the extensive planting of pure spruce stands on unsuitable sites outside the species' natural range, root and stem damage, and the effects of adverse climatic conditions. Similarly, detailed examination of old records indicated numerous similarities between the declines in the 1980s and earlier declines (e.g., 110). Norway spruce decline occurred on the central plateau of Switzerland in 1893, 1900, 1904, 1906, 1908, 1911, 1917, 1919, and 1921 (111). Although no similar reports of forest damage in the neighboring Black Forest of Germany occurred, other than the report by Hiβ (54), it seems dangerous to suggest that the similar damage seen in the 1980s was unprecedented, particularly in view of numerous other reports of Norway spruce decline in Germany (e.g., 118,150,154). The many historical records of Norway spruce and silver fir declines were reviewed (29,63,71–74,155).

Published literature on previously identified etiological agents (and/or reputable causal complexes of combined agents) of specific declines was also overlooked, while air pollutants were identified as a more likely and a sometimes directly cited most likely cause. The article by Woodmann and Cowling (156), after a limited description of visible injury and mortality among sugar maples (*Acer saccharum* Marsh.) and other hardwood tree species in Canadian and northeastern United States forests, concluded with the statement, "Air pollution is believed to be a primary or contributing causal factor because no other more plausible explanation has been suggested."

In marked contrast, scores of authors (e.g., 55,56,58,59,86,121,153) had previously described the symptoms and numerous causal agents and complexes associated with maple blight, dieback, decline, and mortality occurring over the span of their investigations. A review by Walker et al (152) details a list of citations dealing with problems of sugar maple in eastern Canada, some dated as early as 1944 (107). Millers et al (100) also provided a long list of studies of sugar maple decline, some from the early 1900s (1,50). This extensive literature was not cited by Woodman and Cowling (156), who presented circumstantial evidence lead-

Fig. 2. The 12 June 1988 "Mark Trail" comic strip as it appeared in Sunday papers across the United States. It depicts the devastating effects of the balsam woolly adelgid to the fir forests on Mount Mitchell. ©1988 by North America Syndicate, Inc. World rights reserved. Reprinted with special permission of North America Syndicate.

ing to air pollutants as "the most plausible explanation" of causality.

The most recent report of the USDA Forest Service and Forestry Canada North American Maple Project (NAMP) concluded that more than 90% of the sugar maples surveyed across southeastern Canada and several New England states were considered healthy (99). About 7,000 upper-canopy trees were evaluated. The report further concluded that approximately 86% of the 10% symptomatic trees (>50% dieback) had major bole and root damage. Thus, one must seriously doubt the claims of a widespread dieback and decline of sugar maples from Quebec to Ontario, New England, New York, and Pennsylvania (10,156). Most causes were diagnosed on a site-specific basis, such as the more recent invasion of pear thrips (*Taeniothrips inconsequens* (Uzel)) in Pennsylvania stands (129). Kolb and McCormick (79) further implicated the 1988 drought as part of a continuing stress complex for sugar maple in Pennsylvania. Two recently published diagnostic manuals provide additional detailed descriptions of the various stressors of sugar maple in natural stands and sugarbushes of the northeastern United States and Canada (57,126).

A major pest of fir forests in the eastern United States was overlooked while several researchers attempted to link air pollutants to observed symptoms in high-elevation spruce-fir forests in this region. Infestations of the balsam woolly adelgid (*Adelges piceae* (Ratzeburg)) have occurred across much of the current range of Fraser and balsam fir in the eastern United States (32). Although the adelgid was already identified as a destructive pest in the southern Appalachian spruce-fir forests (3,4,27), no hint of the insect's presence was offered by Woodman and Cowling (156).

Bruck reported on surveys of disease and insect presence on Fraser fir and red spruce (23), and Bruck and Robarge (24) reported on changes in the structure of the southern Appalachian forests. However, after detailing the occurrence of pests and pathogens, Bruck (23) states, "With the exception of damage to Fraser fir inflicted by the baslam woolly adelgid, little significant pathology or insect infestation was noted." Yet Bruck and Robarge (24) further speculate that numerous insults of meteorological, natural biotic, and/or man-made origin have impacted the boreal montane forests for quite some time. They then suggest that "The high deposition of acidic, nutrient and toxic substances principally due to cloud deposition may also be a predisposing or contributing factor, to the apparent increased rate of stand deterioration" (citing Schütt and Cowling, 116). The final line of their summary states, "No conclusions can be drawn at this time regarding the reasons for spruce/fir deterioration in the southern Appalachian Mountains, however, the future of the ecosystem is uncertain at best." It is difficult to understand how the readily available literature on the importance of the balsam woolly adelgid could have been omitted in these and several follow-on papers concerning the spruce-fir forests of the southern Appalachians, as illustrated by several reports, in which only the characteristics of atmospheric deposition are discussed in relation to impact on forest decline (5,70,112). An additional report of severe ice damage to spruce and fir in the Mount Mitchell area during the winter of 1986-87 (103) was likewise often missed. A 1937 report of devastating fire and overcutting across much of the high-elevation red spruce range was also ignored (80). It is notable that even the "Mark Trail" comic strip of 12 June 1988 recognized the role of the introduced balsam woolly "aphid" in causing the devastation to the forests on Mount Mitchell (Fig. 2). Just 5 weeks later, a New York Times article (113) quotes Bruck as "90 percent certain that manmade air pollutants traveling from the Ohio and Tennessee Valleys, particularly low-level ozone and acidic moisture in clouds, was combining with natural stresses, high temperatures and drought, to create an environment in which the trees cannot survive." Bruck also made comparisons of the Mount Mitchell scene to the "early stages of mass destruction of forests in recent years in central Europe." No mention was made of the adelgid.

Scores of references both in the scientific and in the more popular literature and press continued to ignore the important presence and independent capacity of the balsam woolly adelgid to cause 95% of the mortality of Fraser fir in the Black Mountains (Mount Mitchell) and the Great Smoky Mountains National Park (32,104) (Fig. 3). We have been inundated with photographs of these now-famous forest decline sites in articles that do not mention the presence of the balsam woolly adelgid (91). An example of this tactic appeared most recently during the preparation of this article. The front cover of the August 1993 *Journal of the Air and Waste Management Association* displayed a photograph of dead Fraser fir atop Mount Mitchell with the cover photo description noting, "A complex interaction of a variety of biotic and abiotic stress factors, including air pollution, is responsible for the disease and injury to forest trees." Readers are then referred to a journal article (5) that describes in considerable detail the cloud chemistry of Mount Mitchell; unfortunately, there is no mention whatsoever of a link between the cover photo, its description, and the content of the article.

Many similar publications have appeared in Europe. As in North America, there were situations with clear evidence of species-specific, site-specific declines. In the mountains of eastern Europe, large areas of Norway spruce died, and it was generally accepted that air pollution was the cause. Why, then, did beech survive in these forests (Fig. 4)? Why was the decline concentrated at high altitudes, while the nearby forests at lower altitudes (and closer to pollution sources) remained largely unaffected? Why did the reports fail to mention the importance of rime ice events in these forests or the extensive, documented damage on Norway spruce by the larch bud moth (*Zeiraphera dininiana* Gn.) (12)? The UNECE was quite categorical

Fig. 3. A view of Mount Mitchell, North Carolina, taken in 1987. The forest to the left of the mountain crest was unprotected from balsam woolly adelgid attacks, while the forest to the right was sprayed with insecticide until 1974. The effects of the slowly advancing attack are evident.

on the cause of the damage: "research results obtained so far clearly indicate that air pollution is an essential, causal factor in the de-stabilization of forests" (137). Unfortunately, the UNECE failed to provide any supporting documentary evidence for this statement (138–140).

If our interpretations are correct, we as a scientific community have been intentionally led to believe that a dramatic and unexplained decline of many major species has taken place. Thus, we should have been able to easily find large expanses of dead and dying forests by traveling to forested areas. (Land in 30% of the former Federal Republic of Germany, 11% of Great Britain, 27% of Switzerland, and 59% of Pennsylvania is forested.) However, for many who subsequently traveled through the Black Forest of southern Germany, the expansive forests of the eastern United States, or the more limited forests of Great Britain and Switzerland, Waldsterben-like disturbances were not easily and quickly discovered. Indeed, one must very often pass through expansive symptomless and/or otherwise normal forested areas before arriving at very site-specific (and often well-defined) areas of species and cohort-species declines (Fig. 5). Often, very healthy and beautiful forests are the norm on excursions to the well-known areas of so-called forest decline (Fig. 6). Experiences were similar in the forests of Poland, the Czech Republic, and the former East Germany, where excursions literally traverse kilometers of asymptomatic forests of spruce, fir, beech, oak, and other mixed species en route to high-elevation, site-specific loci of specific tree species in decline (125). To date, there are no reputable reports of unexplained general massive forest declines from anywhere across the North American continent (13) or Europe (62–64).

Blaming air pollution. Schütt (115) clearly stated that, "Waldsterben is explained with air pollutant effects although 'classical pollutants' cannot be the primary causes." Unfortunately, no empirical evidence of cause–effect relationships could be cited because of the lack of sufficient air pollutant monitoring and/or knowledge of pollutant exposure–response thresholds for each species. Notwithstanding the lack of clear scientific evidence, the link between air pollutants and these multiple and varied symptoms easily found its way into the literature. In the press and therefore in the public perception in European countries, the United States, and Canada, the link was clearly established between air pollutants (particularly acid rain) and the purported forest declines.

A number of national and international review groups interpreted descriptive reports in the so-called scientific literature as evidence of the reality of Waldsterben. These reports also suggested a prominent causal role for air pollutants. It is surprising that so many pathologists, entomologists, physiological ecologists, and other forestry "experts" were ready to accept such a claim. Even more surprising is the widespread acceptance of the belief that air pollution is causing major losses to forests in Europe (excluding the European part of CIS and Spain) of 82.5 million cubic meters per year between 1985 and 2085, representing a value of $29 billion per year (105). This work, sponsored by the Timber Committee of the UNECE and the FAO European Forestry Commission, is also presented in official reports (e.g., 144,145) that, among other assertions, claim that defoliation in excess of 10% in hardwoods and 25% in conifers can only be caused by air pollution.

As recently as 1992, a working group of the International Union of Forest Research Organizations published a resolution that in part states, "IUFRO P2.05-00 resolves that only a rapid decrease in emissions of traffic can ensure the health and welfare of forests and other natural ecosystems. The policy towards this goal should be urgently created by governments" (68). In looking at such a claim, one wonders why the results of more than 100 years of research on causal agents that clearly threaten forest and ecosystem health were ignored.

The survey undertaken by the Commission of the European Communities contains a section on the possible causes of any observed defoliation or discoloration. One of the eight possible causes permitted on the assessment forms is damage by air pollution. Of the 77,435 trees assessed in 1991, defoliation or discoloration was only attributed to air pollution on 0.1% of the trees (143). This detail appears to have escaped the notice of the authors, who in the first sentence of the introduction state, "There is increasing evidence of the effects of air pollution on forest ecosystems."

The reports of the UNECE also stressed the role of air pollution. The report for 1990 (141) states, "A continuation of the present pollution load for extended periods of time or an increase in pollution levels will threaten the vitality of forests over large areas of Europe. If the present concentrations of air pollutants and the deposition loads

Fig. 4. European beech surviving with virtually no symptoms of decline in an area of the Ore Mountains showing severe death of coniferous species from drought and subsequent bark beetle attacks.

Fig. 5. A high-elevation stand of Norway spruce and silver fir in the Hochsgarten area of southern Germany's Black Forest showing typical symptoms of magnesium deficiency and the effects of previous droughts. Note the recovery of the silver fir, as indicated by new shoots emerging from the top of the crown and along the main stem.

of noxious compounds to forests are not reduced, the sustainability of forest management cannot be guaranteed in the future. A reduction of the air pollution load would improve the condition of these forests and postpone a possible expansion of forest decline." These statements were published despite a panel of experts from the same task force (142) concluding that, "Levels of crown defoliation and discoloration reported on a national basis do not give sufficient information to draw any conclusions about the effects of air pollution on forest condition."

Reevaluating the Research

Quiet but very important studies have been conducted over recent years in the spruce-fir decline areas in the high-elevation stands of the northern Appalachians. As in the southern spruce-fir studies, numerous suggestions of a role of acidic precipitation in the observed symptoms were popularly expounded in the earlier literature and popular press (69,77,149,156). Careful and detailed excavation of the root systems of spruce and fir with varying disease symptoms revealed a probable role of the conifer swift moth, also known as the ghost moth (*Hepialus gracilis* Crote) (47,151), in the decline symptoms. Additional work by Bergdahl et al (15) further implicates root disease fungi entering through the wounds made by *H. gracilis* in furthering the decline symptoms.

Perhaps if more careful diagnostics had been employed earlier in this decline and a more comprehensive review had been made of the scores of papers on known pathological and insect pest attacks of spruce and fir, the proper diagnosis would have directly followed. Peart et al (106) published a concise description of the most recent stand conditions of high-elevation red spruce in the northern and southern Appalachians using nearly 200 citations. Six broad conclusions were offered for the stand conditions and related causes for those areas having some difficulties. No mention was made of acidic depositions or air pollutants in general, but spruce bark beetle, episodic winter injury, chronic wind stress, conifer swift moth, adelgid-caused fir mortality, and the sudden exposure of residual spruce to numerous environmental stresses, ice damage, and site deterioration due to land use history were all noted as playing some role on a site-by-site basis.

Millers et al (100) clearly demonstrated that all declines of eastern U.S. hardwoods had periods of overlap, affected many species, and were widespread geographically. The authors summarized declines of 65 species of trees using 415 citations dating from as early as 1856, with 36 major insect pests, 18 diseases, and long lists of abiotic (drought, frost, etc.) stress factors cited as causal agents. Numerous declines and diebacks were noted as having multiple complexes of causal agents. For just the declines of *Quercus* spp., they listed 57 reports of decline involving 11 species of oak across the eastern United States. They list 14 major defoliating insects, stem and branch cankers, root rot disease fungi, and six abiotic stressors directly and/or interactively bringing about the noted declines. All of this spanned 130 years of available reports (1856–1986). During this same period, major site-specific declines and diebacks of maple (*Acer*), ash (*Fraxinus*), birch (*Betula*), beech (*Fagus grandifolia* Ehrh.), aspen (*Populus*), hickory (*Carya*), sweet gum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.), and dozens of other eastern forest tree species were occurring throughout their own natural ranges. Had someone decided to look collectively at the declines of these multiple species in the 1930s, the concepts of Waldsterben might have enjoyed a much earlier origin.

Much the same applies in Europe. In a compilation of declines recorded in central Europe, Cramer (29) lists 66 declines of silver fir (*Abies alba* Mill.) occurring between 1800 and 1980. He documents 24 instances of Norway spruce decline between 1800 and 1980 and notes historical records of declines of Scots pine, European beech, alder, oak, and ash. Since these records refer only to damage with symptoms similar to those associated with Waldsterben, a much greater list could be compiled if all causes of decline were included. Numerous other declines are reported in the literature and can easily be found by browsing through back issues of European forestry journals, many of which extend into the last century.

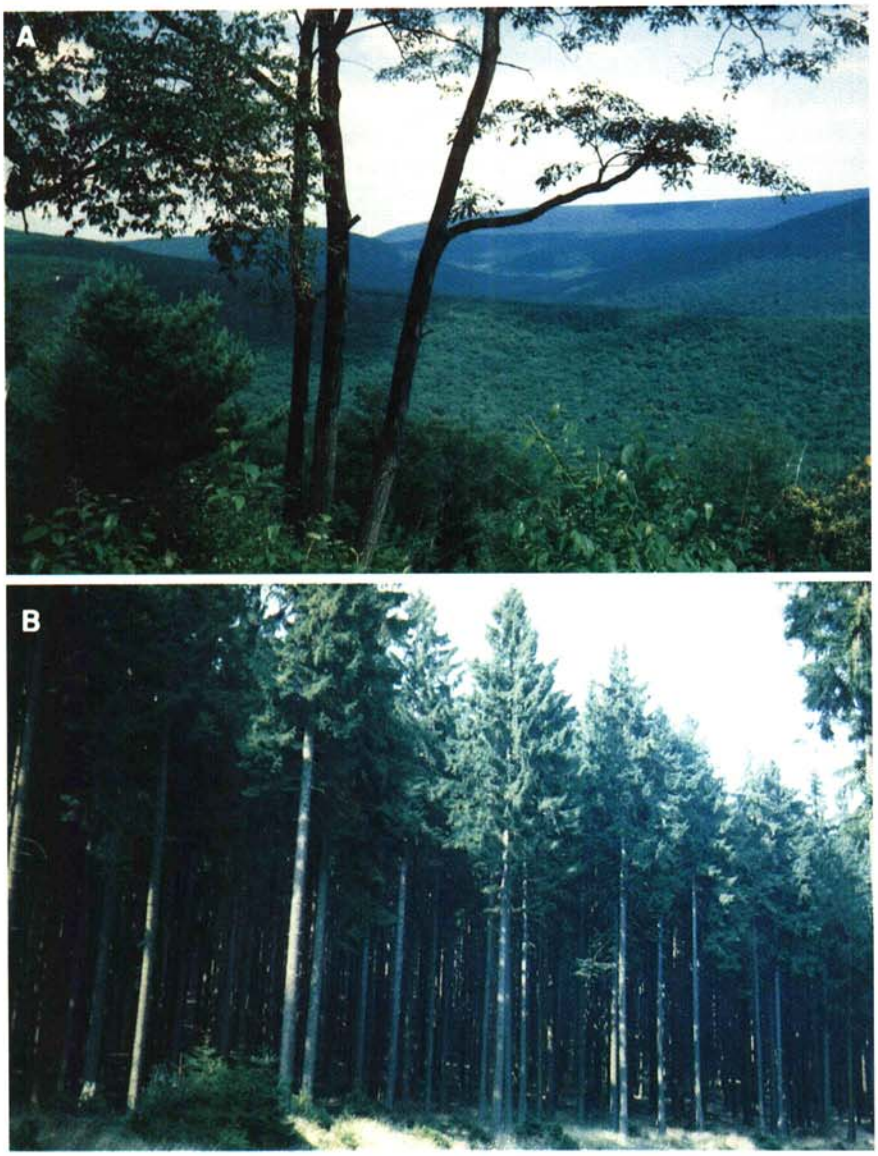

Fig. 6. Typical scenes (A) in central Pennsylvania and (B) in the Black Forest of southern Germany showing normal forests. Forests such as these are often casually seen while traversing to the far less prominent scenes of forest devastation.

Waldsterben: Fantasy or Reality?

The evidence that scientists, politicians, and the general public accepted the concept of Waldsterben uncritically is compelling. But why did they? There are several possibilities. One is that the debate over Waldsterben coincided with a growing interest in environmental issues, a fact that has been examined by Boehmer-Christianson (19). During the 1980s, environmental pressure groups became increasingly vociferous and powerful in terms of their financial resources. Inevitably, in the current context, our central goal has become to reduce pollution. However, connecting air pollution with the diverse symptoms of supposed forest declines over the last several decades is unjustified.

A second motivation lies in the funding structure of modern science. The research is often of very high quality and contributes greatly to our understanding of trees and forests, but its relevance in determining the connections of air pollutants to Waldsterben is questionable. However, it is clear that research that demonstrates "no effect" will not generate further funding to investigate air pollutants.

What is the reality? Declines occurred in a number of tree species during the 1980s. However, similar declines were extensively documented in the past. These previously described declines often occurred simultaneously in different parts of the world, and this is not, as has been alleged, a new phenomenon. The declines involved single species, very often growing under highly specific site conditions (100). Each species decline was characterized by a specific suite of symptoms. However, because the number of symptoms a tree can express is limited, there was considerable overlap. The variety of symptoms and causes of forest tree injuries should never have been grouped under one term, such as Waldsterben, Waldschäden, and/or neuartige Waldschäden. Furthermore, the implied uniqueness of the spatial and temporal patterns of symptoms, i.e., the suddenness of symptom expression and the never-before-seen geographic distribution of the Waldsterben phenomenon is in serious disregard of pre-Waldsterben forest pathological and entomological knowledge (e.g., 22,28,52). In particular, crown transparency, the most widely used index of forest health in surveys, is nonetiologically specific (Fig. 7). Consequently, the finding that transparency levels fluctuate from year to year, species to species, and region to region is entirely predictable (62).

On the other hand, there is evidence that air pollution can affect trees, both under experimental conditions and in the forest. There is a large body of literature on the effects of pollution from point sources; a number of case studies are reviewed by Smith (128) and Innes (62). While the most severe effects were associated with the highest exposures (e.g., Sudbury, Norilsk, etc.), increasing numbers of studies demonstrate that regional exposures of ambient levels of pollution (tropospheric ozone) in some areas are capable of affecting young or even mature trees (26,94,120,127). Such effects not only include changes in physiological mechanisms, but may also include direct and visible injury to the foliage of sensitive species (Fig. 8). In addition to the direct effects described above, changes in forest soils have been attributed to acidification (e.g., 131,133). While such changes may well be associated with changes in the health of tree roots, to make a direct connection between acidification caused by air pollution and changes in tree health, as influenced by changes in root condition, is more difficult. Such associations have been claimed for the Solling area (95,96,132) (Fig. 9), but there is general agreement that such results cannot be readily extrapolated to different soil types and different pollution types and/or loadings.

Consequently, while we accept that air pollution can and does influence tree health under certain circumstances, we cannot accept that Waldsterben as a phenomenon exists or that it can be attributed to air pollution. That there is continued reference to the phenomenon in the literature, either as Waldsterben or as (new) forest decline or forest damage, concerns us.

A New Consensus

One of the themes of this paper is that much effort has been expended to build a consensus on the role of air pollution in forest decline. Ashmore et al (11) stated, for example, that "the only general consensus at the present time is that this (forest decline) is a complex problem involving a range of stress factors, including pollution, but that no single hypothesis can explain the forest

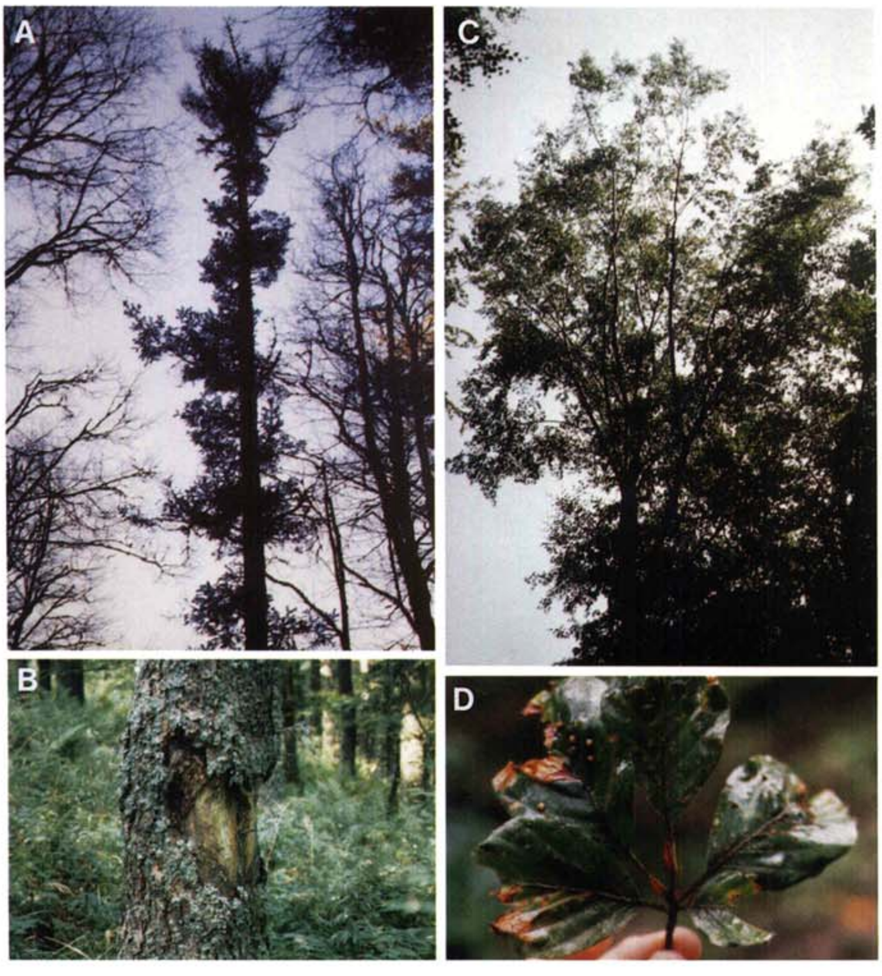

Fig. 7. (A) A silver fir in a forest health survey plot of the State of Badenwurttemberg, Germany, photographed in fall 1989. Note the severe crown symptoms of dieback, and also note (B) the lower bole injury from a old logging wound not recorded in the data set on an annual basis. (C) European beech near Rhinefelden, Germany, evaluated at 35% crown thinning without the causes noted on the tally sheets. There was no sampling of the upper crown. A specially removed branchlet (D) shows leaves injured by several insects and diseases, with powdery mildew also evident on the underside.

decline phenomena observed in different locations on different species." Note the assertions that it is a single distinct problem (not many), that pollution is involved, that it is widespread, and that it supposedly involves many species.

Despite the enormous publicity surrounding Waldsterben, there has been a continuous undercurrent of dissention. Binns and Redfern (16), who were among the early skeptics, stated, "There is undoubtedly an element of neurosis involved in the readiness of many foresters and some workers to attribute any decline or dieback in forest tree species to the combined effects of atmospheric pollution and acid rain without adequate critical investigation." Subsequently, a number of scientists seriously questioned aspects or the totality of the Waldsterben concept (60–64,71–74,76,122–125). This perhaps culminated in the statement from Manion and Lachance (92) that "Classic 'Waldsterben' as perceived by the general public does not exist." As time passes, it becomes increasingly clear that the forests of Europe are not dying. Indeed, recent reports of increased growth and productivity exist for formerly described Waldsterben-prone forests, e.g., the Black Forest (76). Still other reports argued that the annual forest increment in Europe is higher than ever before (75). The proposed phenomenon of massive dying of forests has not increased or spread as suggested in earlier papers (115,116). Current surveys report, for example, that basal area growth increment is increasing for all major timber species in Pennsylvania (2).

Consequently, we seem to be returning to the pre-Waldsterben consensus on forest health. It is very rare for all trees in a forest to decline simultaneously. Instead, individual species decline due to specific factors. In some circumstances, several stresses may interact to cause the decline of a few susceptible species at a particular site. Air pollution may be involved in a few cases, but the evidence for such an involvement away from known sources of pollution is extremely limited. The concept of a general forest decline, as described by Schütt and Cowling (116), is untenable.

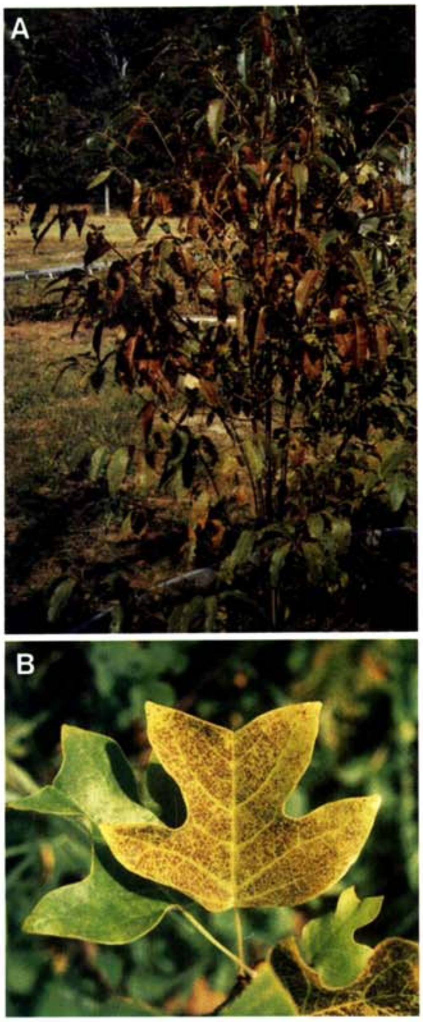

Fig. 8. (A) A black cherry sapling of open-pollinated family R-12, an ozone-sensitive family, in the Moshannon State Forest in north central Pennsylvania showing stippling, premature reddening, and defoliation from ambient ozone exposures, and (B) leaf of yellow-poplar in the Shenandoah National Park in Virginia showing typical ozone-induced upper surface stipple.

The Future

We invite young scientists to carefully examine their areas of forests (in research and survey efforts) for current health status and overall condition. If, indeed, their observations suggest that some unexplained problem may exist, we urge them to look for all possible causes of the symptoms and to delve deeply into the background of the situation, including previous records of possible causal agents and historical records of land-use and forest-management practices.

We join our colleagues who promote the concepts of Waldsterben in inviting our young colleagues in forest science to join the fray—this work is truly exciting. But we also urge caution, more careful diagnostics, and the use of your total knowledge of the fields of forest pathology, entomology, stress physiology, silviculture, and the like, as related to all other aspects of forestry sciences, before reaching too many conclusions from your observations. Proof of causality is not as easily achieved as we have been led to believe in the case of air pollutants and the purported existence of the cataclysmic forebodings of Waldsterben.

We are concerned to see that some of the same errors made in the Waldsterben debate are being repeated in the latest bandwagon concept: global warming, i.e., climate change. The concepts and predictions of Waldsterben caused many casualties in the scientific community; it would be a pity if the reputation of forest pathology as a whole were to suffer.

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Fig. 9. A view across the top of the Harz Mountains in central Germany where a major windstorm occurred on 13 November 1972 (G. Hartmann, Forest Research Station, Gottingen, *personal communication*). Numerous excursions have been led to this site of supposedly severe acidification. Note standing trees in the background and numerous seedlings and saplings emerging from the grass cover. Most uprooted root systems (then stumps) within the defined area were aligned in the same direction, indicating a blowdown.

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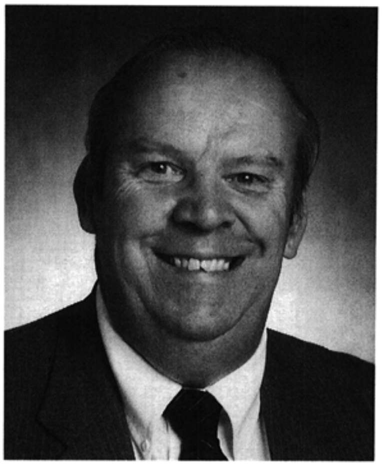
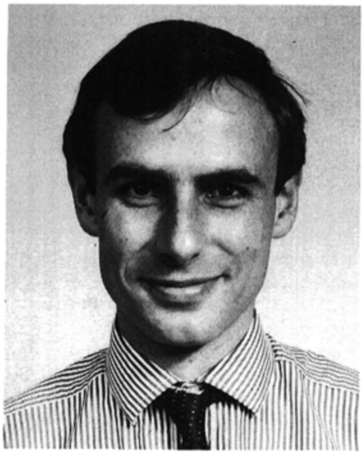


John M. Skelly

Dr. Skelly is a professor in the Department of Plant Pathology and a faculty member in the Environmental Resources Research Institute at the Pennsylvania State University, University Park. He received his B.S. in Forestry (1962) and M.S. (1964) and Ph.D. (1968) in plant pathology all from Penn State University. He rose through the professorial ranks at Virginia Polytechnic Institute and State University from 1968 to 1982, becoming Director of the Laboratory for Air Pollution Impacts to Agriculture and Forests in 1980. He then became head of the Department of Plant Pathology at Penn State from 1982 to 1985. He currently is involved in teaching one graduate course in the topical area of air pollution effects on terrestrial systems; research programs address air pollution effects on eastern forest tree species, with special emphasis on determining foliar injury and exposure-response relationships leading to changes in whole-tree physiology and productivity. Cooperative programs of study are also current with programs in Switzerland, Poland, and Mexico. He has served as an author and/or as a member of review panels for the USEPA inclusive of those dealing with the preparation of the Air Quality Criteria Documents for ozone, sulfur dioxide, particulates, and nitrogen oxides. His recent interest in the correct diagnosis of the numerous causal factors in forest health assessments developed while on Sabbatical leave to Albert Ludwig's Universitat in Frieburg, Germany in 1989.



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Dr. Innes is section leader of the Forest Health Inventory and Intensive Monitoring Group at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) in Birmensdorf, Switzerland. He received his B.A. (1979) and Ph.D. (1983) in geography from the University of Cambridge, England. After working as a research fellow on the impact of environmental change in upland environments, he joined the British Forestry Commission in 1986, where he was responsible for annual surveys of forest health. This work involved the development of a suite of indicators to characterize tree health, as well as the training and checking of field crews and the analysis and publication of the results of the surveys. In 1992, he joined WSL, with an assignment to review the annual forest health survey and develop a program to monitor the condition of forest ecosystems in Switzerland. With a detailed knowledge of the condition of forests over much of Europe, he is interested in ensuring that international reports accurately reflect the condition of forests, through both an improved standardization of field observations and the elimination of speculative or unsupported assertions from scientific reports.

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