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Forest decline in Norway: monitoring results, international links and hypotheses

Norwegian Agricultural Advisory Centre, Ås, Norway

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CONTENT

Introduction

In the late 1970s forestry people (including scientists) in the Federal Republic of Germany became aware of phenomena which were later to be named «neuartige Waldschäden», the novel forest disease or forest decline. Reports on forest decline of this new type soon appeared extensively in the media as well as in scientific journals. Air pollution was immediately blamed as a causal factor, but very few scientific facts could support this view. Immission damage near industrial centres has been recognized for some time now, but in the early 1980s it became obvious that this new forest decline was of a more complex nature. Somewhat similar symptoms were found in many other European countries, even in forests far from local emissions. However, differences in decline symptoms occurred in various regions (Fig. 1). In the most severely affected parts of central Europe, extensive forest dieback was recorded over tens of thousands of hectares, while in western and northern forests, only minor defoliation of living trees was apparent.

Figure 1. Severely defoliated Norway spruce

Forest decline in Europe

CLASSIFICATION OF FOREST DECLINE IN EUROPE

Today damage is classified within two major groups: the classical forest diseases and the novel forest disease.

The classical forest diseases

Forest damage of traditional types has always prevailed: fungal and bark beetle attacks are well known in Europe. Immision damage caused by different gases, sulphur dioxide and hydrogen fluoride are also well known, producing typical symptoms. Climatic conditions, such as frost, drought, flooding or salt spray, can cause severe damage. Strong winds and heavy storms can affect forests and result in severe damage with heavy economic losses. Forests growing on poor soil with low nutrient status may show different signs of poor health, e.g. yellowing of needles. Typical symptoms are caused by deficiency of nutrient elements such as potassium, magnesium, nitrogen and phosphorus. However, none of these types of damage belong to the «novel forest disease» concept.

The novel forest disease

The concept of the novel forest disease is characterized by several diffuse symptoms of decline resulting in a disease syndrome, hierto unknown (Schütt et al. 1983).

A simultaneous and rapid decrease in the health and vigour of both softwood and hardwood forests has affected many species of trees growing under a wide range of soil, site and climatic conditions. The syndrome differs from ordinary tree diseases in that many affected forest ecosystems are likely to be destroyed. The symptoms are of two general types, according to Schütt & Cowling (1985):

(1) Growth reducing symptoms include loss of foliar biomass, loss of feeder root biomass, decrease in height and diameter increment, chlorosis, premature senescence and death of older needles and leaves, increased susceptibility to secondary root and foliar pathogens, death of affected trees and change in ground vegetation.

(2) Abnormal growth symptoms include abscission of green leaves and green shoots, altered branching habits (lametta syndrome) and abundant production of adventitious (secondary) shoots, altered morphology of leaves, repeated abnormal crops of seeds and cones and changed allocation of photosynthetic products.

German scientists have recognized five different types of forest decline (FBW 1986):

– Needle yellowing at higher elevations in the German «Mittelgebirge». This decline type is characterized by chlorosis of needles and loss of older needles. Magnesium deficiency may be an associated factor (Zöttl & Hüttl 1985, Rehfuess 1987).

– Thinning of tree crowns at medium-high altitudes in the German «Mittelgebirge». This decline type is also characterized by loss of needles, but without discoloration.

– Needle reddening in older stands in southern Germany. This decline type is associated with the needle fungi *Lophodermium piceae, L. macrosporum* and *Rhizosphaera kalkhoffii* (Rehfuess & Rodenkirchen 1984).

– Chlorosis of needles at higher elevations in the Bavarian Alps, mainly caused by potassium and magnesium deficiencies (Rehfuess 1983). Chlorosis of needles and loss of younger needles are the symptoms.

– Thinning of tree crowns in northern coastal areas. Loss of needles and reduced growth characterize this decline type.

One or several of these German types of forest decline can be found almost throughout Europe. The ultimate symptoms for several of these types are needle discoloration and needle loss; therefore, further investigations have concentrated on the study of causal factors leading to such symptoms. These symptoms have also been the two major criteria recorded in nation-wide surveys. Yield and death rates of stands are also criteria of increasing interest. Most countries in Europe have been alerted by the German findings and are now seriously concerned about the future health development of their forests, looking out for symptoms that may indicate early warning signals of any type of forest decline.

ORGANIZATION OF FOREST DECLINE MONITORING AND RESEARCH IN EUROPE

European activities on forest damage assessment and monitoring

The widely known threat caused by air pollution and the evolution of the new forest decline has forced European governments to initiate annual, nationwide and standardized forest damage surveys. The Geneva agreement of the United Nations Economic Commission for Europe (UNECE) to reduce sulphur emissions was presented at the Convention on Long-Range Transboundary Air Pollution in 1979.

In July 1985, the executive body for the Convention decided to launch an International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The purpose of this programme is to facilitate the collection, on a national level, of comprehensive and comparable data on changes in forests related to actual environmental conditions (in particular air pollution, including acidifying depositions) in order to improve evaluation of trends in damage resulting from pollution and to establish a better understanding of dose-response relationships. The executive body also decided to establish a programme task force with the Federal Republic of Germany as the leading country.

Two programme co-ordinating centres, one in Czechoslovakia for the eastern countries and one in the Federal Republic of Germany for the western countries, are responsible for collecting data from countries taking part in the programme and for compiling annual reports on the national surveys of forest damage.

The structure of the ICP is based on national focal centres, i.e. institutions or laboratories in the participating countries which submit information to one of the two programme co-ordinating centres for processing, evaluation and reporting.

A Manual on Methodologies and Criteria for Harmonized Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests (hereafter referred to as the ECE Manual) was adopted in 1986. Furthermore the programme task force decided that, starting in 1986, parties to the Convention should conduct large-scale representative forest damage surveys based on the guidelines laid down in the ECE Manual.

Survey results were reported to the programme co-ordinating centres following the format defined in the ECE Manual. These surveys describe the actual state of vitality of forests based on an assessment of the tree crowns. The survey results do not, however, permit the drawing of conclusions as to causal factors. The cause-effect relationships will be investigated on the basis of long-term observations on permanent plots and by forest ecosystem analysis, two essential elements of the future activities of the ICP.

Reports have been published for the years 1986, 1987 and 1988 (GEMS 1987, 1988, 1990), and these deal mainly with the two principal international criteria on forest decline, defoliation and crown colour (see below), as recorded in large-scale, nation-wide or regional surveys.

Other European activities under the Convention and other programmes dealing with air pollution effects

The executive body for the Convention on Long-Range Transboundary Air Pollution has approved six other international cooperative programmes, three of which deal with the effects of air pollution on materials, rivers and lakes, and agricultural crops. The ICPs on integrated monitoring and on mapping critical levels and loads are the most important programmes with regard to terrestrial ecosystems, although EMEP and other programmes are of interest.

The European countries have agreed on the Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP), which aims at characterizing the transboundary transport of air pollution. The monitoring of air and precipitation qualities is the primary objective in this programme, which was launched in 1979 and is part of the UNEP-ECE activity (NORD 1988). The EMEP system of air pollution measuring stations is well established across Europe.

In addition to the internationally coordinated programmes under UNECE, a large number of investigations are being carried out individually by university units and research institutes. Summarized information and discussions of results from a selection of these investigations dealing with problems linked to forest decline are presented by Schmidt-Vogt (1989). More information on the status of European countries within the framework of UNECE is being gathered in the spring of 1990; however, this information is not yet available.

METHODS OF ASSESSMENT

The UNECE ICP Forests programme has three main levels of activity in monitoring forest vitality:

1. Large-scale representative surveys and assessment
2. Intensive studies on permanent plots
3. Special forest ecosystem analysis

Large-scale representative surveys and assessment

The ECE Manual for the assessment of forest decline symptoms in Europe has applied four main assessment criteria: crown defoliation (or density), crown colour (yellowing), yield (increment) and volume (death rates).

Assessment of crown density (or needle biomass)

The assessment of crown density (defoliation or crown thinning) is a subjective estimation based on visual observation. A description of the method is given in the ECE Manual. To obtain optimum results, observers have to follow certain simple rules:

– Observers must have a satisfactory view of the tree from several observation angles. At ground level, the optimal view is obtained at a distance equal to the tree height. On slopes, trees should be observed at a point above the tree or at least at the same level.

– Assessment should be carried out by two trained observers using binoculars.

– Assessment should be carried out in full daylight.

The ECE Manual does not state which parts of the tree crown should be assessed. However, the Nordic countries have observed only the upper half in spruce and the upper two-thirds in pine. Although not indicated in the Manual, this method appears to be very similar to the usual procedure applied by other European countries. Normal and natural damage to the crown is not taken into account (whipping, broken branches and so on).

The crown density (defoliation) has, until now, been estimated in classes of 10% or 5% relative to a tree with full foliage. The reference tree should be a healthy tree in the vicinity. For the survey in 1990 and thereafter the class stages will be at 5% in all countries belonging to the European Community (EC). A few countries are applying other classes (e.g. Norway: 1% classes). The percentage of defoliation is transformed by data processing into the international defoliation classes 0-4 (Table 1, Fig. 2). Class 1 is now often called the «early warning stage».

Table 1. The ECE defoliation (crown density) classes

Class	Defoliation %	Crown density %	Explanation
0	0 - 10	90 - 100	Not defoliated, healthy
1	11 - 25	75 - 89	Slightly defoliated
2	26 - 60	40 - 74	Moderately defoliated
3	> 60	< 40	Severely defoliated
4	Dead tree	Dead tree	Dead tree

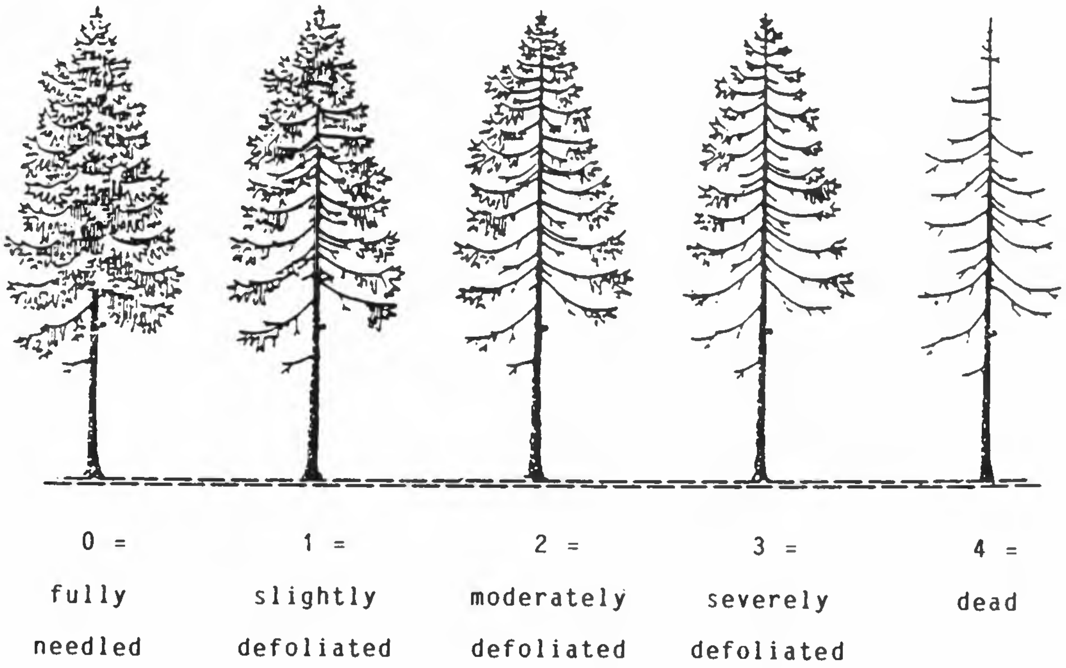


Figure 2. Different defoliation classes (from the ECE Manual)

Additional information about tree vitality may lie in the different patterns of defoliation and branching types. These additional variables are summarized below and in Fig. 3. Four different types of defoliation of Norway spruce can be recognized:

– Larch type: A more or less even defoliation of the whole crown results in a larch-like appearance. The lower crown is the most seriously affected part, whereas the top appears normal. Spruces with comb-like branching are particularly conspicuous when damaged because the absence of needles produces the limply hanging form of the second or higher order branches. Spruces with comb-like or brush-like branching drop branches of second and higher order when defoliation is severe.

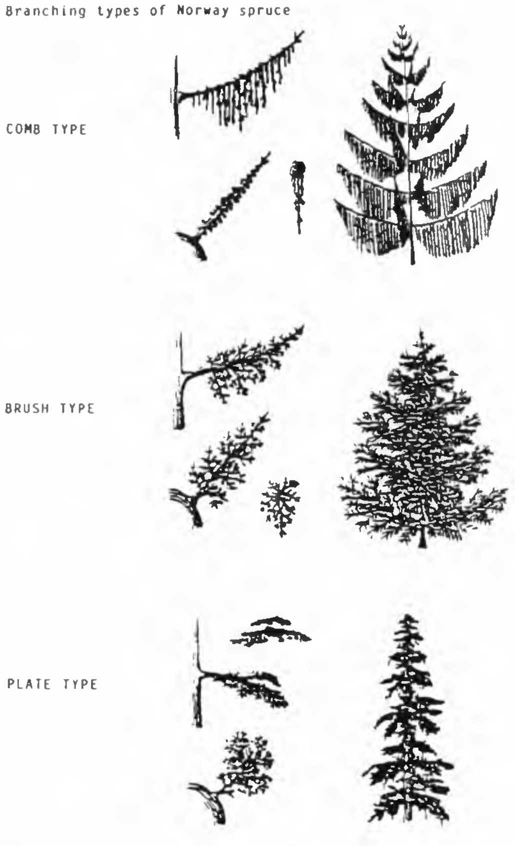


Figure 3. Different branching types (from the ECE Manual)

– Sub-top dying type: «Window-like» defoliation appears just below the fully foliated top, regardless of the branching type. In the lower parts of the crown the foliage remains denser, but in severely damaged trees defoliation extends over the entire crown, blurring the distinction between this and the larch-type defoliation.

– Top dying type: Defoliation in the part of the crown that is exposed to light is more severe than in shaded parts of the crown. In the advanced state, the top dies and a lower branch may take over as the leader.

– Peripheral defoliation type: Defoliation occurs evenly throughout the crown from the outside towards the interior.

Assessment of discoloration of the foliage

Discoloration of the foliage is also assessed visually on the upper parts of the crown. From 1990 on there will be five classes of discoloration (Table 2), where the fifth class includes dead trees. The criteria for discoloration are obviously indistinct and ill-defined, lying somewhere between the amount of discolored needles or leaves and the quality of their colour (usually yellowing).

Table 2. The ECE discoloration classes

Class	Needles / leaves discolored %	Discoloration
0	0 - 10	None
1	11 - 25	Slight
2	26 - 60	Moderate
3	> 60	Severe
4	Dead tree	Dead tree

Assessment of yield and volume

Growth, increment and yield as well as volume estimations of stands and their death rates are also to be monitored, according to the ECE Manual. This part of the programme has not been completed yet, but it is in progress in several European countries.

Intensive studies on permanent plots

Activities concerning the second level of the international co-operative programme are connected with a large number of permanent plots within each country. In addition to the variables mentioned above, a number of other parameters are included as recommended in the ECE Manual. Among these are soil and vegetation analyses. However, in our opinion, many of these parameters are too complex to elaborate at this level, and might therefore be transferred to and achieved in the third level of the programme. Few results have been reported from these activities to date.

Special forest ecosystem analysis

Studies carried out as part of a special forest ecosystem analysis on permanent plots are less co-ordinated than the large-scale surveys, though the ECE Manual prescribes routines for such studies.

Despite the fact that many forest ecosystem studies are in operation in Europe, very few appear to have a national representative perspective. The present report explains the Norwegian national system of permanent plots for special forest ecosystem analysis, which has a national representative perspective, in order to demonstrate types of data that can be extracted from such a system.

Plot system

The locations of the intensive study plots for special forest ecosystem analysis in Norway are shown in Fig. 4. (The plots, with codes PR, NO, BI, NA and HL, are considered later in this report.) The most important criteria for selecting the plots were: (1) About 80 to 100-year-old Norway spruce forest of the blueberry type (Eu-Piceetum myrtilletosum, which is the most common forest type in Norway), (2) moderate slope, (3) homogeneous soil properties, and (4) a specific moderate stand density. The plots are conserved for at least 10 years. There is at least one plot in each of the 19 counties in Norway. This has given a dispersal of plots over the whole country which is approximately proportional to the distribution of forest land.

Parameters

When the plots were established, the parameter set was not quite fully established. Some parameters were recommended in the ECE Manual, and some ideas were taken from other studies running at the Norwegian Forest Research Institute, mainly from the Integrated Forest Study (IFS) funded by the Electric Power Research Institute (EPRI), USA. In addition, a few parameters were included from other sources. Many of these were not previously exactly described (equipment, size, number, etc.), so it was necessary to develop some of the methods further. The set of chosen parameters provided a promising link with other systems of plots. The Norwegian system is probably one of only a few European systems for special forest ecosystem analysis operating today that can be linked to both the UNECE monitoring programme and a larger research programme on forest ecosystem nutrient cycling, e.g. the IFS.

So far it has not been possible to apply all the desirable variables in the monitoring programme. The most important deficiency is probably the dry deposition analysis. Physical and chemical analyses of shrubs and of whole trees are also missing.

The most important additions to other forest ecosystem studies are the assessment of trees according to the ECE Manual (crown density, crown colour, forest increment and volume) and the recording of epiphytic lichen flora on branches and trunks. The epiphytic lichen flora is being investigated because of its traditional value as a bioindicator of sulphur dioxide pollution. A mycorrhiza and root biology study is also in progress.

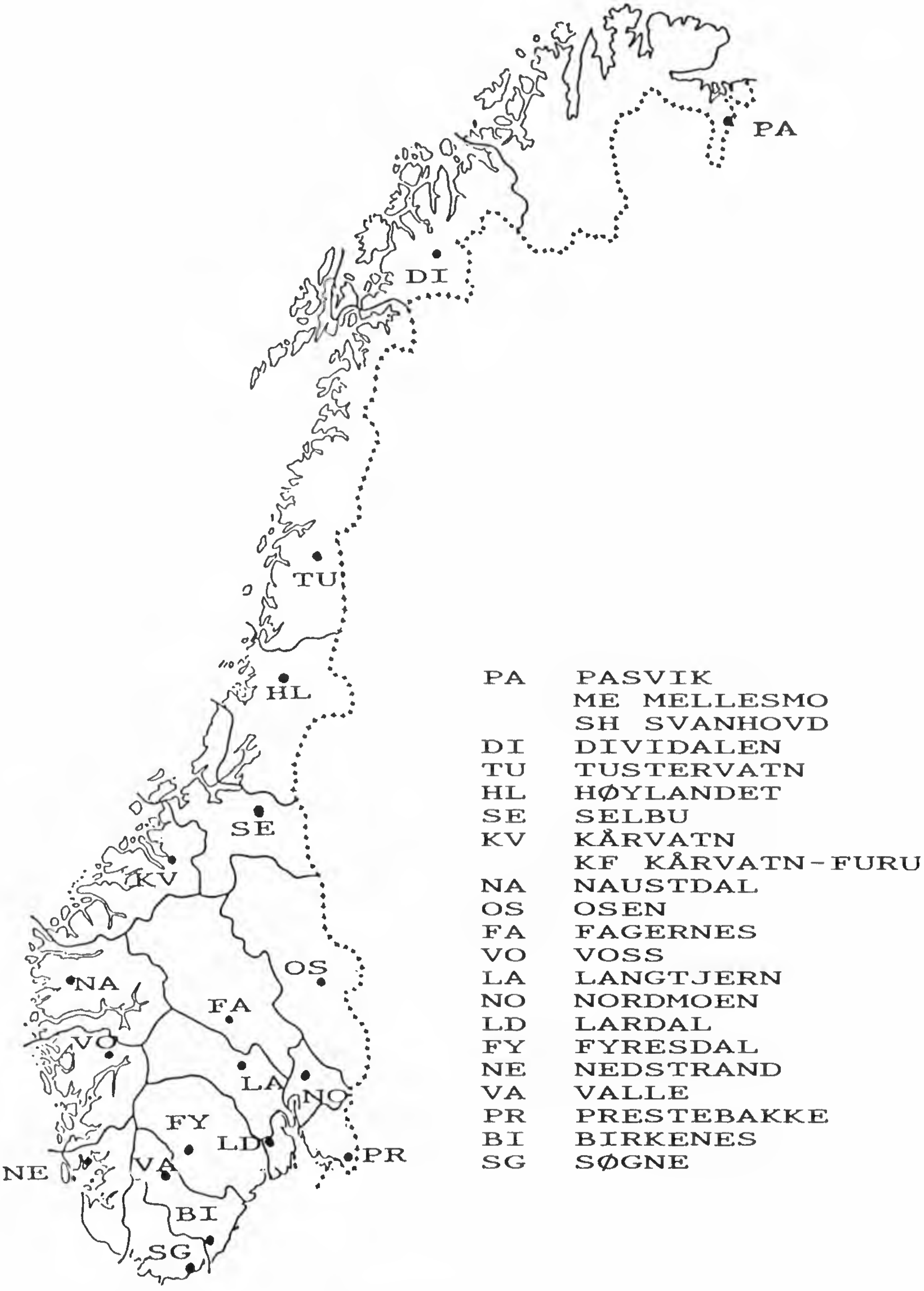


Figure 4. Locations of the intensive study plots for special forest ecosystem analysis in Norway. (The plots with codes PR, NO, BI, NA and HL are treated further in this chapter.)

Forest decline - extent and trends in Europe

LARGE-SCALE REPRESENTATIVE SURVEYS

Air pollution in Europe in general

The concentrations of air pollutants in Europe, estimated according to the EMEP system, are demonstrated by air pollution maps (Schaug et al. 1989). The figures display some spatial trends in air pollution levels in Europe. As expected, there are very high concentrations of sulphur dioxide (Fig. 5) in central-eastern parts of Europe, mainly originating from coal-based power plants and heavy industry. Nitrogen emissions are more common in the western parts of Europe.

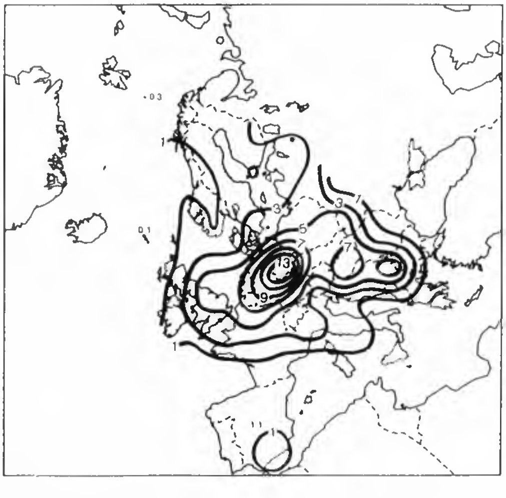


Figure 5. Sulphur dioxide in rural areas in 1987. Annual mean concentrations (µg S/m^3) (from EMEP 1989)

Crown assessment - defoliation

The ECE report stated that, of 161 million hectares of forest in Europe (excluding most of the forests in the USSR), around 108 million, or roughly 65%, were covered in the 1988 survey (GEMS 1990). Over 990,000 trees were assessed on 53,000 sample plots. Areas not yet entirely covered by the survey include parts of some broad-leaved forests, mostly in Scandinavia, and the low broad-leaved evergreens (maquis) in the Mediterranean countries, where they contribute to the total forest area.

The major species observed are Norway spruce, Scots pine, white fir, beech and oak. Many other species of conifers and broad-leaves are monitored in some countries. The results on defoliation from the survey year 1988 are given in Fig. 6.

It is possible to conclude from the figures and tables extracted from the 1988 European forest damage survey that:

- Despite considerable differences in forest structure, species composition, levels and types of air pollution, surveys of forest health based on commonly agreed methods are now being conducted in 25 countries across Europe.
- Forest damage, expressed as a loss of needles or leaves, has been observed in all of the 25 countries.
- In many regions, forests at higher elevations and forests older than 60 years are considerably more defoliated than younger stands and forests at lower elevation.
- Old spruce, fir and oak are currently the most affected species.

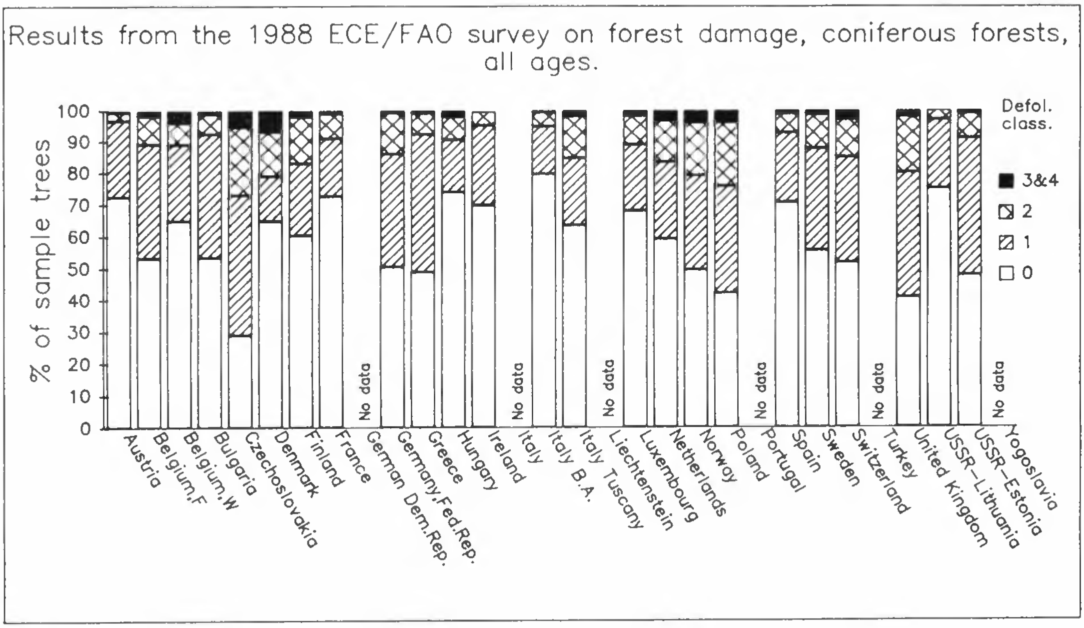


Figure 6. Results from the survey year 1988 on defoliation, alphabetically arranged (data from GEMS 1990)

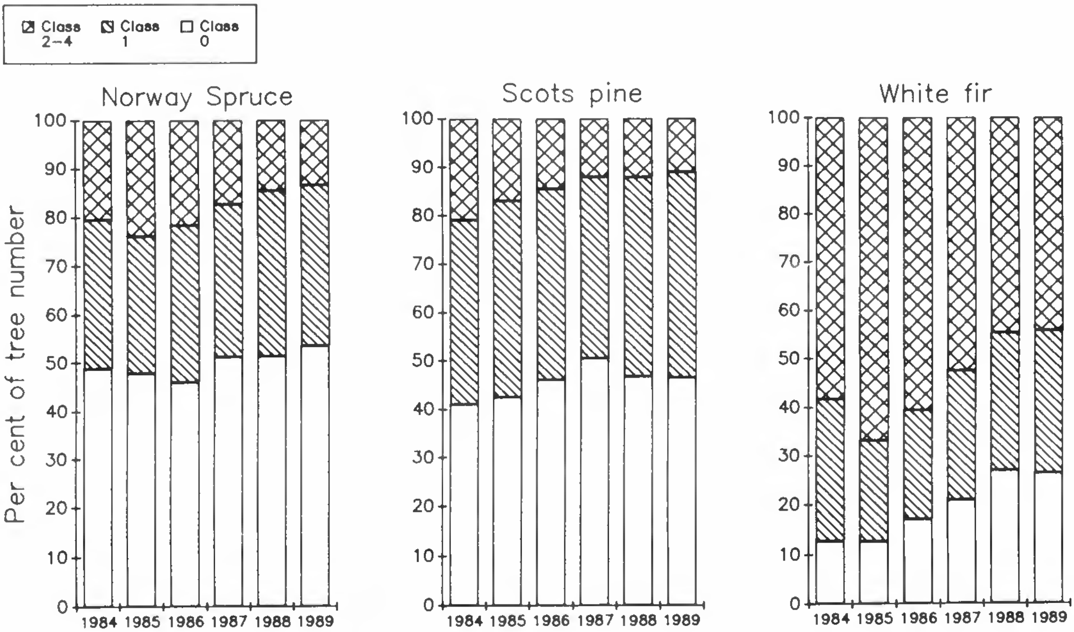


Figure 7. Trends in the Federal Republic of Germany from 1984 to 1989 for Norway spruce, Scots pine and white fir (data from Anon. 1989)

– Nordic coniferous forests are shown to be as defoliated as many central European forests.

Trends

The co-ordinated, official monitoring of forest health (mostly conifers) in Europe began in 1986. However, in the Federal Republic of Germany preliminary surveys were conducted as early as 1982. The first two surveys (1982 and 1983) are not quite comparable with later surveys because of differences in methodology. In 1984, the annual and standardized nation-wide surveys were started in the Federal Republic of Germany and a few other European countries. The methodology used in these surveys later became the basis for the methodology adopted by the UNECE system, as described in the ECE Manual. Fig. 7 gives the trends in defoliation in the Federal Republic of Germany for Norway spruce, Scots pine and white fir (Anon. 1989). In Table 3 the changes in defoliation for a selected group of countries during the period up to 1988 are summarized. There seems to have been a slight decrease in defoliation during these years. In our opinion the changes might be real where the methods are comparable.

Assessment and monitoring of deciduous trees have taken place for only a few years in most of the European countries. Typical results from Austria are given in Fig. 8. We recognize a certain increase in defoliation in the earlier years and then a decreasing level of defoliation.

Crown assessment - discoloration

Assessment and monitoring of discoloration have taken place mostly for coniferous species, mainly Norway spruce, Scots pine and white fir, but also for larch and Douglas fir. Though this part of the programme has been measured and is still an important, ongoing parameter in

Table 3. Changes in the degree of defoliation for some countries during the period 1986 to 1988. Data from GEMS 1990

Country	Defoliation classes 2-4 1986	1987	1988	% change last two years (+/-)
Austria	4.5	3.5	3.3	-0.2
Belgium-Flanders	-	4.7	10.8	+6.1
Bulgaria	4.7	3.8	7.6	+3.8
Czechoslovakia	16.4	15.6	27.0	+11.4
Denmark	-	24.0	21.0	-3.0
Finland	-	13.5	17.0	+3.5
France	12.5	12.0	9.1	-2.9
Germany, Fed.Rep. of	19.5	15.9	14.0	-1.9
Italy-Bolzano	-	3.1	5.2	+2.1
Liechtenstein	22.0	27.0	23.0	-4.0
Luxembourg	4.2	3.8	11.1	+7.3
Netherlands	28.9	18.7	14.5	-4.2
Norway	7.0(*)		20.8	+13.8(**)
Spain	18.2	10.7	7.3	-3.4
Sweden	11.1	5.6	12.3	+6.7
Switzerland	16.0	14.0	15.0	+1.0
United Kingdom	-	23.0	20.0	-3.0
Yugoslavia(***)	23.0	16.1	17.5	+1.4
USSR-Lithuania	-	14.8	3.0	-11.8

(*) regional survey in 1984/85
(**) change 1984/85-1988
(***) regional survey in 1988

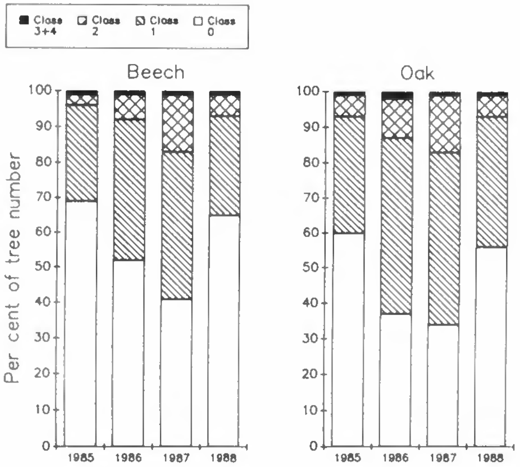


Figure 8. Defoliation of beech and oak in Austria 1985 - 1988 (from Sanasilva 1988)

the European countries, it has not yet been reported regularly by the ECE.

Yield and volume

Forest growth and increment are compiled in some countries by tentatively applying standardized methodology (e.g. Kramer 1986). The ECE Manual has prescribed some preliminary methods, but the investigation periods are still too short to produce adequate yield data. However, crown density has been shown to be correlated with growth parameters in some regions (Horntvedt & Tveite 1986, Björkdal & Eriksson 1989). Tree-ring analyses have been carried out, e.g. for parts of Norway (B. Tveite pers. comm.), and in these instances no obvious relationships between air pollution levels and tree-ring widths were found.

It is important to note that the areas with totally dead forest (damage class 4) have not increased during this period. In the Federal Republic of Germany dead forest covered 7360 hectares in 1988, which is 0.1-0.2% of the total forest area (Kandler 1989).

INTENSIVE STUDIES ON PERMANENT PLOTS AND SPECIAL FOREST ECOSYSTEM ANALYSIS

General site data and air pollution

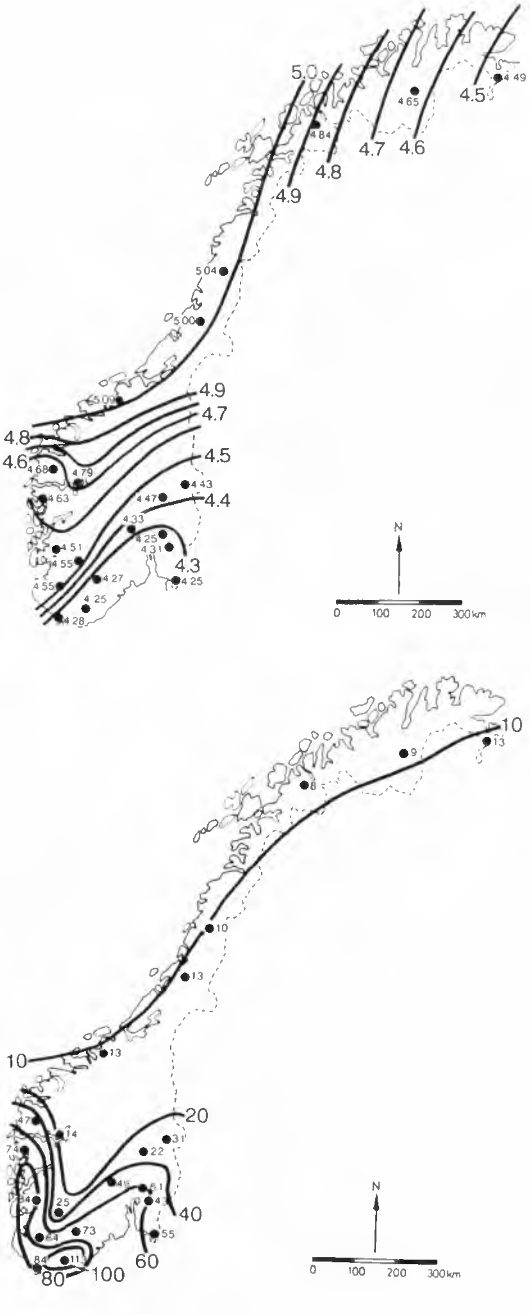
The monitoring of air and precipitation quality in Norway is performed by the Norwegian Institute for Air Research (NILU). The 1988 results (SFT 1989) quite clearly demonstrate the pollution levels of the country. The pH of precipitation is given in Fig. 9a, which shows a pattern with clear gradients of precipitation acidity. The greatest acid precipitation (pH 4.3) is found in the southern and southeastern regions. However, the pH is not directly correlated to the deposition of strong acids (H^+) as a result of great differences in the amount of precipitation. This aspect is reflected in Fig. 9b.

There is a similar pattern for sulphate-sulphur and nitrogen compounds in 1988. The deposition of sulphate-sulphur varies from 1.6 g S/m^2 in the southern regions to less than 0.2 g S/m^2 in the northern regions. The deposition of nitrogen compounds varies from 2.3 g N/m^2 in the southern regions to less than 0.2 g N /m2 in the northern regions (SFT 1989).

The crown density on 9 of the 19 permanent plots has been monitored since 1986. The results, given in Fig. 10, indicate that mean crown density has been quite stable during this period (OPS 1990). Although there may be some changes, this is probably within the range of errors of the method itself. The crown colour on the same plots has also been quite stable throughout these four years.

Selected plots along a pollution gradient

Concerning permanent plots (Fig. 4.), one of the aims is to run a programme for nutrient cycling data. Five plots coded PR, NO, BI, NA and HL will be further discussed. These are selected plots located along a decreasing pollution gradient from south to north. This feature can be



Figures 9a and b. pH and H^+ depositions in Norway 1988 (from SFT 1989)

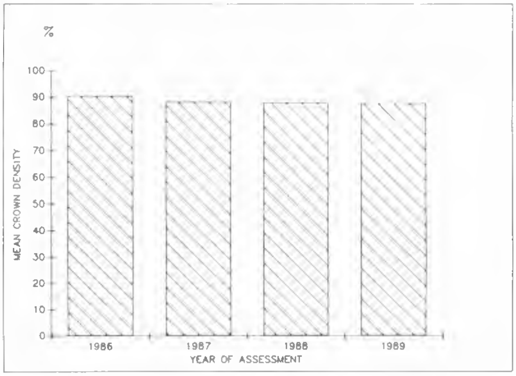


Figure 10. Mean crown density of nine permanent plots for special forest ecosystem analysis followed from 1986 in Norway (from OPS 1990)

observed when comparing Fig. 4 and Figs 9a and 9b. Table 4 provides the general site information concerning these five monitoring plots.

Soil chemistry

The general conifer forest soil type in the Norwegian monitoring plots is «Gleyed Humo-Ferric Podzol» (OPS 1988a, b, 1989), according to the Canadian soil classification system (Canada Soil Survey Committee 1978).

Soil profile chemistry and representative soil sampling.

The nutrient capacity varies from plot to plot depending on age, relief, vegetation climate, soil parent material and other conditions. The soil descriptions are based on one profile from each plot. The soil chemistry for each plot is based on a network of soil auger cores from a grid inside the plot corresponding to 1200 subsamples per hectare. The cores are composited into four parallel series. In Table 5 the results for the five plots referred to in this report are presented (OPS 1988a, b, 1989).

As the tables show, the soil is acid in these plots. The magnesium and calcium contents of the soil have not reached deficit levels, but increasing nitrogen de-

Table 4. General site information for five monitoring plots located along a gradient from south to north in Norway. Data from OPS data bank

Plot code	Latitude (N)	Location Longitude (E)	Altitude m a.s.l.	Main tree species	Stand age(*)	Stand density (**)
BI	58°23'	8°15'	210	Norway spruce	95	1333
PR	59°00'	11°32'	135	Norway spruce	77	924
NO	60°16'	11°06'	205	Norway spruce	76	727
NA	61°34'	5°53'	70	Norway spruce	37	2166
HL	64°39'	12°19'	120	Norway spruce	142	1210

(*) mean age at 1.3 m above the ground
(**) tree number per hectare

Table 5. Chemical properties of soil samples in five monitoring plots located along a gradient from south to north in Norway. Data from OPS data bank

Plot	Horizon	pH (H_2O)	CEC	BS	Ca	K	Mg	N	C:N	Soil
code	(*)		(**)	%	<-----	mmol/kg	------>			classification
BI	LFH	3.6	334	53	58	17	19	1033	32	Gleyed Eluviated
	Ae/Ahe	3.9	28	15	1.0	0.9	0.4	51	28	Dystric Brunisol
	AB	4.0	34	9	0.6	0.6	0.2	40	30	
	B	4.4	41	9	0.6	0.8	0.2	116	32	
PR	LFH	3.7	315	49	54	18	13	988	32	Gleyed Humo-
	Ae/Ahe	3.8	50	10	1.1	1.3	0.4	96	28	Ferric Podzol
	Bh	4.2	68	7	0.9	1.2	0.4	164	25	
	Bf(20cm)	4.5	30	7	0.5	0.6	0.1	120	25	
	Bf(15cm)	4.5	20	7	0.3	0.2	0.1	87	26	
NO	LFH	3.7	305	51	56	22	10	1045	29	Eluviated
	Ae	3.8	100	4	1.2	0.7	0.5	77	31	Dystric
	B(10cm)	4.4	52	3	0.3	0.5	0.2	49	29	Brunisol
	B(10-20cm)	4.6	22	5	0.2	0.5	0.04	35	31	
	B(20-35cm)	4.7	12	8	0.1	0.4	0.04	26	33	
	B/BC(35-50cm)	4.7	8	11	0.1	0.3	0.04	19	36	
NA	LFH	4.0	326	55	41	19	35	1270	25	Gleyed Humo-
	Ahe	4.0	79	18	1.5	3.3	3.1	446	16	Ferric Podzol
	AB	4.1	58	12	0.7	1.7	1.2	265	17	
	Bf(15cm)	4.4	48	8	0.6	0.7	0.5	169	23	
	Bf(15cm)	4.5	40	8	0.6	0.7	0.3	120	27	
HL	LFH	4.0	421	74	84	28	50	1104	32	Gleyed Ferro
	Ae/Ahe	4.2	37	29	2.2	1.0	1.7	54	30	Humic Podzol
	Bhf/Bf(10cm)	4.6	98	16	3.6	1.6	2.2	198	34	
	Bf/Bm(15cm)	4.7	53	18	2.2	1.3	0.9	151	36	

(*) After the Canadian System of Soil Classification
(**) mmol(c)/kg

position might accelerate the demand for these two elements.

These results probably reflect quite well the chemical and physical properties of Norwegian forest soil in spruce forests of blueberry type. Revision of the soil auger sampling is planned at five-year intervals. It is hoped that this sampling programme will provide information pertaining to possible acceleration in soil acidification and on whether nutrients are being leached or toxic elements accumulated.

Soil water chemistry

The five permanent plots referred to in this report have Alundum tension lysimeter plates installed at different depths and they are operated at a constant suction of 10 kPa. For practical reasons soil solution is collected only in the frost-free period of the year. Results from the first three years are given in Table 6. No unusual trends are seen, though the southernmost plot (PR) has the highest aluminium concentrations found in the Norwegian plots (Table 6).

Nutrient status based on needle analysis

According to type 1 forest decline damage, nutrient imbalance appears to be of major importance in several regions of Europe, e.g. the Black Forest, the Bavarian Alps and the Harz area (FBW 1986). Optimal nutrient conditions are essential for good forest vitality and growth. However, the optimal nutrient concentration for forest growth will be different for different areas with various soil properties, nutrient levels and air pollution input. This feature might be of great importance in the analysis of forest damage in relation to deviant nutrient cycling.

Table 6. pH and weighted concentrations of sulphate- sulphur, nitrate-nitrogen, ammonium-nitrogen and total aluminium in soil water for the sampling period 1986-1988 in five monitoring plots located along a gradient from south to north in Norway. Data from OPS data bank

Plot	Horizon	pH			SO_4-S			NO_3-N			NH_4-N			tot-Al		
code					< - - - - - - - - - -			µmol(c)/l			- - - - - - - - - - >			<- - µmol/l - - >		
Year		1986	1987	1988	1986	1987	1988	1986	1987	1988	1986	1987	1988	1986	1987	1988
BI	H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ae	4.45	4.37	4.32	87	66	83	2	2	4	4	5	1	22	25	24
	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PR	H	6.81	5.44	4.16	145	149	141	8	4	5	13	9	7	12	48	64
	Ae	4.38	4.59	4.26	161	150	125	3	6	4	26	9	3	42	58	79
	B	4.50	4.48	4.49	303	287	251	3	13	16	4	6	1	39	48	53
NO	H	4.92	4.31	4.11	77	53	72	25	3	7	14	9	4	14	25	26
	Ae	5.30	4.81	4.94	115	95	82	d	d	4	7	11	2	3	8	9
	B	5.43	5.45	5.16	96	102	92	d	2	4	7	13	3	2	2	1
NA	H	4.64	4.17	4.15	38	36	42	3	445	5	4	4	5	9	15	16
	Ae	4.64	4.64	4.59	46	43	50	9	2	4	3	5	3	16	18	19
	B	5.02	5.12	4.85	47	72	55	d	12	2	2	6	2	5	4	7
HL	H	-	4.20	4.11	-	35	31	-	2	2	-	2	2	-	9	9
	Ae	-	4.66	4.63	-	76	43	-	9	4	-	5	4	-	26	46
	B	-	5.86	5.84	-	42	31	-	4	4	-	6	4	-	3	6

d : detection limit (NO_3-N = 0.02)

- : not in operation

Table 7. Concentrations of sulphur, nitrogen, magnesium, calcium and potassium in the current year's needles of Norway spruce in five monitoring plots located along a gradient from south to north in Norway. Year of sampling in parentheses. Data from OPS data bank

Plot	Sample year	S	N	Mg	Ca	K	P	Zn
		<------ mmol kg^{-1} ------>						
BI	(1986)	28	857	49	68	166	42	0.6120
PR	(1986)	28	929	37	53	179	65	0.4587
NO	(1986)	28	857	37	78	176	71	0.6116
NA	(1986)	28	1000	53	45	166	55	0.3058
HL	(1987)	28	857	49	83	192	48	0.6116

According to some European authors (e.g. Hüttl 1985), different levels of chemical elements have been listed as deficiency levels. However, many of the nutrient elements would be below this threshold if these guidelines where to apply to Norway. The concentrations of some important elements in the current year's needles found in the selected monitoring plots in Norway are given in Table 7 (OPS 1988a, b, 1989). All data are from healthy Norway spruce (= full crown density and normal colour). These concentrations are mostly low (cf. Binns et al. 1980, Hüttl 1985), but the Norwegian trees have probably adjusted their nutrient requirements to this level, restricted by the soil and the climate of Norway.

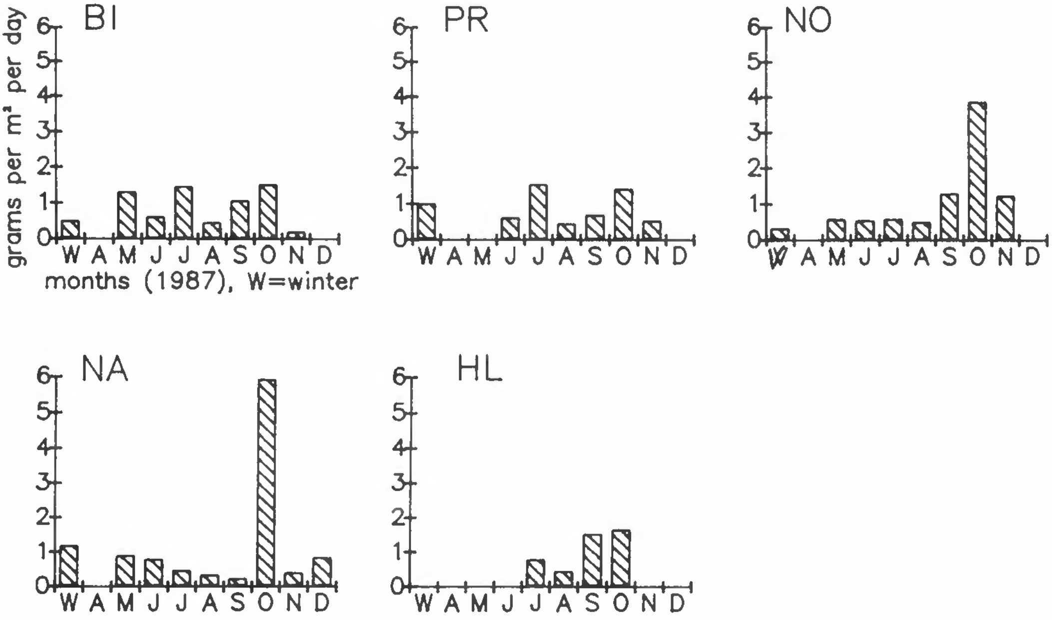


Figure 11. Litterfall from five monitoring plots located along a gradient from south to north in Norway. Values in grams per square metre per day, air dried, 20°C. Data from OPS data bank

Litterfall

Litterfall from trees is an important parameter in the nutrient cycle. The litter from trees on the plots is collected monthly during the snow-free time of the year. For practical reasons, only one collection of litter is carried out in the snowy season. Snow depths can reach more than two metres during the winter.

The 1987 litterfall amounts from the plots are shown in Fig. 11. The variation between months is clearly expressed in the figure. Much of this variation can be related to strong wind episodes. In October 1987 it was very stormy in southern Norway, causing heavy litterfall. Surprisingly, the crown density evaluations in the succeeding year did not show any decrease in crown density. We believe that the reason for this is the rapid buildup of the needle biomass after the storm in October 1987 and before the assessment of crown density in September 1988.

The mean amount of total litterfall per day is approximately one gram per square metre (air dried, 20°C). The variation lies between 0.2 and 5.9 g per day, where the maximum amount is measured after the storm in October 1987. There is significant variation between the different plots and years. So far, we believe that the annual variation in the amount of litterfall depends mainly on differences in climatic conditions, such as strong winds, frost and desiccation. There are also important site factors and variations in tree age and stand density which will have some influence on litterfall.

The chemical content of litterfall from the monitoring plots is being analysed and is not yet available.

Precipitation within the stand and free-falling precipitation

Nutrient input from the atmosphere is monitored using precipitation collectors placed randomly within each plot. The precipitation is collected as bulk and throughfall, separately. Since 1989, there have been weekly collections throughout the year. Bulk precipitation has been collected in an open area close to the stand.

Typical examples of the flux and concentrations of some elements in the throughfall and free-falling precipitation are given in Table 8. The results are from 1988, but are representative of other years. Volume weighted mean pH in bulk and throughfall precipitation for the gro-

Table 8. Depositions and concentrations (in parentheses) of sulphate-sulphur, nitrate-nitrogen and ammonium-nitrogen in bulk and throughfall precipitation in the June-October period in 1988 in five monitoring plots located along a gradient from south to north in Norway. Deposition in mmol(c) m^{-2} and concentration (weighted means) in µmol(c) l^{-1}. Data from OPS data bank

Plot code	SO_4-S		N (total)		NH_4-N		NO_3-N	
	Bulk	Throughfall	Bulk	Throughfall	Bulk	Throughfall	Bulk	Throughfall
BI	28 (58)	35 (93)	67	45	31 (32)	21 (29)	37 (39)	23 (31)
PR	11 (51)	16 (118)	15	18	6 (14)	10 (36)	9 (19)	7 (26)
NO	12 (48)	19 (88)	18	17	7 (15)	9 (19)	10 (21)	8 (19)
NA	7 (29)	5 (34)	9	6	3 (6)	3 (11)	6 (12)	2 (7)
HL	4 (24)	6 (34)	5	4	2 (5)	1 (4)	3 (9)	2 (7)

Table 9. Volume-weighted mean pH from the collecting seasons 1986-1988 for bulk and throughfall precipitation in five monitoring plots located along a gradient from south to north in Norway. Data from OPS data bank

Plot code	1986 bulk	1986 throughfall	1987 bulk	1987 throughfall	1988 bulk	1988 throughfall
BI	4.37	4.20	4.40	4.30	4.30	4.27
PR	4.33	4.04	4.39	4.23	4.37	4.23
NO	4.30	4.17	4.39	4.31	4.36	4.33
NA	4.81	4.90	4.60	5.00	4.70	5.00
HL	-	-	4.68	4.72	4.92	4.75

wing season for the years 1986-1988 are given in Table 9.

The main result from these data is a verification of the well-known pattern of air pollution in Norway, where the most polluted areas are in the southeastern and southern parts of the country. It is also an important fact that some of the nitrogen input is absorbed in the tree crowns. We recognize this as a certain uptake of nitrogen compounds by the foliage, and conclude that it might indicate a non-saturated condition of nitrogen in the forests.

Though it lies north of the PR plot, the NO plot seems to have a higher input of airborne pollutants. The reason for this is the slightly higher amounts of precipitation at the NO plot. Also, the relatively high inputs at the NA plot are caused by large amounts of precipitation.

Perspectives for special forest ecosystem analysis

The first compilation of data from parts of level 2 and level 3 of the ICP Forests programme is being prepared during the spring 1990 as an «interim report on cause-effect relationships». Some data are available from these two levels already, mostly published in separate reports from various national programmes. Examples are the «Sanasilva» programme in Switzerland (Sanasilva 1989), «Monitoring Programme for Forest Damage» («Overvåkingsprogram for skogskader») in Norway (OPS 1988a, b, 1989), the «Höhenprofil Zillertal» in Austria (e.g. articles in Phyton Vol. 29, 1989) and studies in the Federal Republic of Germany, e.g. «Das Forschungsprogramm Waldschäden am Standort Poststurm» (Bauch & Michaelis 1988) and the ecosystem study in Lange Bramke (Hauhs 1989).

However, many countries lack data. The results presented in this report are examples from the Norwegian system of plots for special forest ecosystem analysis (level 3), which we hope will demonstrate that it is possible to run a national network of stations where the recorded parameters are important inputs to a model based on nutrient cycling.

A nutrient cycling model is not yet fully developed, but we believe that collected data from monitoring plots can be useful, e.g. in the model which has been developed and tested during the IFS project. We assume that this and other models have to be adapted in some way so that they can be used for the different climatic conditions found in various regions. Such adaption procedures are already planned to take place in new research projects.

Causes of forest decline in Europe

ACCEPTED EXPLANATIONS

The forest decline in Europe has led to the formulation of several hypotheses, and numerous experiments have been carried out to test them. Most of the published information is well summarized in Schmidt-Vogt (1989).

The report of the 1988 forest damage survey in Europe (GEMS 1990) points out that differences in the spatial and temporal development of forest damage have become particularly evident in 1988. These features support the opinion of many scientists that forest decline can best be described as a process of high causal complexity, involving both abiotic and biotic factors.

In Austria, Belgium-Wallonia, Czechoslovakia, the German Democratic Republic, the Federal Republic of Germany, Italy-Tuscany, Liechtenstein, Poland, Switzerland and Yugoslavia, air pollution is considered an *essential* factor when determining of the quality of forest stands. Forest ecosystems are negatively affected by depositions of sulphur dioxide, nitrogen compounds and their atmospheric transformation products, acids and ozone. Forest management decisions are strongly influenced by air pollution risks.

Air pollution is regarded as one of the factors contributing to weakening of forest health in Belgium-Flanders, Bulgaria, the Netherlands, Denmark, Finland, France, Hungary, Italy-Bolzano, Sweden and the United Kingdom. In Hungary, biotic and abiotic causes are considered to be the main damaging factors, but the effects of air pollution cannot be ignored. In Greece, biotic and abiotic factors and inadequate management practices are considered to be the main parameters determining forest health. As for Norway, we assume that air pollution is a possible predisposing factor.

The novel forest decline damage in Europe is being intensively studied in the light of new and old observations and experimental results. Most scientists agree that no single hypothesis can explain all the recorded facts. However, the following presentation of the complex relationships involved demonstrates how a monocausal (partial) hypothesis may be integrated into a basic multiple stress model.

Air pollutants, such as sulphur dioxide and nitrogen oxides, may produce acid precipitation which leads to soil acidification. Sulphate and nitrate ions passing through the soil horizons cause leaching of base cations, thus progressively decreasing the buffering capacity and depleting the soil of nutrient elements such as magnesium, calcium, potassium and others. With a lowered pH, metal ions are freed, some of which may be toxic to tree roots (e.g. aluminium species) or to mycorrhizal fungi (Ulrich 1984, 1986). To what degree these processes are counteracted by weathering partly depends on inter alia edaphic and climatic conditions at the site. If net leaching takes place, the result over time may be the reduced availability and reduced uptake of nutrient elements important for tree growth, which will lead to deficiency symptoms, reduced crown and root growth and finally, to decline symptoms (Schulze 1989). At the same time the acid precipitation may accelerate the natural leaching of ions from the foliage, thus exacerbating a possible deficiency in leaves (Ulrich & Matzner 1983).

Air pollutants such as nitrogen compounds, carbon dioxide and some other gases (e.g. methane), may possibly contribute to global heating. Increasing levels and loads of these pollutants will result in increased plant production and tree growth, which in turn create greater demand for some of the leached nutrient elements, and cause further acidification of the soil by increased uptake of base cations. Accelerated development of deficiency symptoms and growth reductions may arise. Increased nitrogen deposition may affect the natural development and physiology of the trees, rendering them vulnerable to frost, drought, parasites and insects, and may exert a negative influence upon the mycorrhizae (Nihlgård 1985, Göbl 1986).

Air pollutants, such as ozone and other photo-oxidants, cause damage to cell membranes in living tissues. They may also interfere with physiological processes, rendering trees susceptible to frost, and they may accelerate senescence of needles and leaves. These effects increase the degree of multiple stress accumulated in the forest ecosystem (Arndt 1985a, b, Krause & Prinz 1986).

Air pollutants, such as heavy metals, may also cause inhibition of nutrient uptake mainly by their negative effects upon mycorrhizae and the soil microbiology (Glatzel 1985, Göbl & Mutsch 1985).

HYPOTHESES

A few basic hypotheses have governed the type of approach taken when searching for causal explanations of the new type of forest decline. The discussion has gone beyond the stage of monocausal explanations, although Koch's postulate (Last et al. 1984) is still most useful and, we believe, also necessary in elucidating etiological relationships. Today, a range of multiple stress hypotheses have gained solid support. These are being extensively accepted as the bases for explaining how interactions between predisposing, inciting and contributing factors lead to the decline and death of a tree (or a forest). This is aptly described as the decline disease-spiral by Manion (1981).

In a second hypothesis it is assumed that the total stress loaded onto a forest ecosystem is decisive in its response to a new additional stress impact (Schütt et al. 1983, Schütt 1988). This idea is analogous to the situation where a barrel will overflow by the addition of only a single drop of water - if the barrel is already filled to the brim. The consequence of this hypothesis is that even a slight reduction in air pollution loads may be enough to bring the total amount of stress below a certain damaging or lethal threshold. If this is true, one will have to admit that removal of this stress, regardless of which category of factors it belongs to, is of the utmost importance, even though it may quantitatively be of minor magnitude compared with the other (natural) stresses involved.

This view must be borne in mind when evaluating statements made by various countries on the significance of air pollutants in the forest decline etiology.

In our opinion, a third hypothesis will be needed in order to explain more of the forest decline phenomena that have been reported from Europe. We claim that predisposing factors cause a latent susceptibility to inciting factors. This latent susceptibility then increases under sustained stress, which leads to a higher degree of predisposition that is only revealed by the impact of inciting factors.

The forest ecosystem may be compared to an exposed but undeveloped photographic film. Nobody can see the picture until it is developed. The developer incites a sudden and profound change in the film. The information hidden in the exposed picture is revealed, and strong relationships become evident between the intensity of the exposing light and the resulting colours of the film.

When predisposing, inciting, and contributing factors act in sequence, it is commonly presumed that the resultant responses in a forest ecosystem will develop gradually. The expected response may be explained as a continuous, linear or curved relationship expressing a direct correlation to the impact of factors in action. However, we claim that most of the existing reports of forest decline in central Europe and elsewhere indicate discontinuity in damage development. Sudden changes in forest health status have been observed in several countries. In the Federal Republic of Germany, the German Democratic Republic, Poland and Czechoslovakia, vast areas of coniferous forest, mainly Norway spruce, have died suddenly or have started to decline rapidly shortly after experiencing abrupt temperature variations in midwinter or spring, severe insect attacks during summer, summer frost or early frosts during autumn, severe droughts, winds or winter storms (Bosch & Rehfuess 1988). These are all typical inciting factors. Their impact upon the forest ecosystem depends upon the degree of predisposition already present in the system, i.e. the accumulated effect of the predisposing factors in action at earlier stages. This level of predisposition may be linked in a continuous way to the level of these predisposing factors. However, to date there is no direct method for displaying and recording this level of predisposition, unless the system is challenged by a sufficiently strong inciting factor.

In a forest ecosystem, various predisposing factors may have been in action for many years, e.g. in cases of displaced species or ecotypes of trees, severe climate during certain periods, or constant immissions of air pollutants at subtoxic levels. Over time, increasing levels of predisposition may develop. We presume that the accumulating degree of predisposition is a function of the total predisposing load. After development of symptoms or damage caused by some inciting factor(s), this level of predisposition is revealed and may then show strong correlations to levels of impact of the predisposing factors, as well as to the inciting ones.

If this hypothesis is true, it must lead to a change in our concept of the present forest decline situation and its progress in various regions. Primarily, one should not interpret stability in levels of symptoms or damage as an absence of threatening factors. Only after the activation by the inciting factors will the true situation become evident. Secondly, predisposing factors should be focused on in order to milden the impact of inciting factors, which are often inevitable occurrences of natural phenomena.

Areas bordering natural tree limits (boreal, alpine or oceanic) constitute a substantial part of the forested land in northern Europe, e.g. in Scandinavia. Severe natural climatic stresses prevail in these regions. According to our hypothesis, such conditions would only allow for the slightest margin of additional (anthropogenic) stress to the forest ecosystem before the maximum thresholds would be reached.

Conclusion

It is widely accepted that forest decline is a multiple syndrome and that there is less synchrony in its incidence than was previously thought. There are also some doubts as to the «novelty» of some kinds of damage, e.g. magnesium deficiency and damage associated with needle fungi. Nevertheless, the appearance of so many ailments in the forest at roughly the same time suggests that there are linking and triggering factors.

The large-scale surveys of forest damage are useful and very important for identifying and quantifying the problems with novel forest decline, but the scientific quest for its causes can probably be carried out only through detailed work in long-term studies of forest ecosystems. Models of nutrient cycling are necessary tools for revealing the true status of health in our forests. A continuation of the present pollution loads for extended periods of time or an increase in pollution levels may threaten the vitality of forests over large areas of Europe. A reduction in air pollution loads would improve the condition of our forests and postpone a possible expansion of forest decline. The important role of forests and the threat of global warming as a result of the possible greenhouse effect support the need for further measures to reduce air pollution.

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