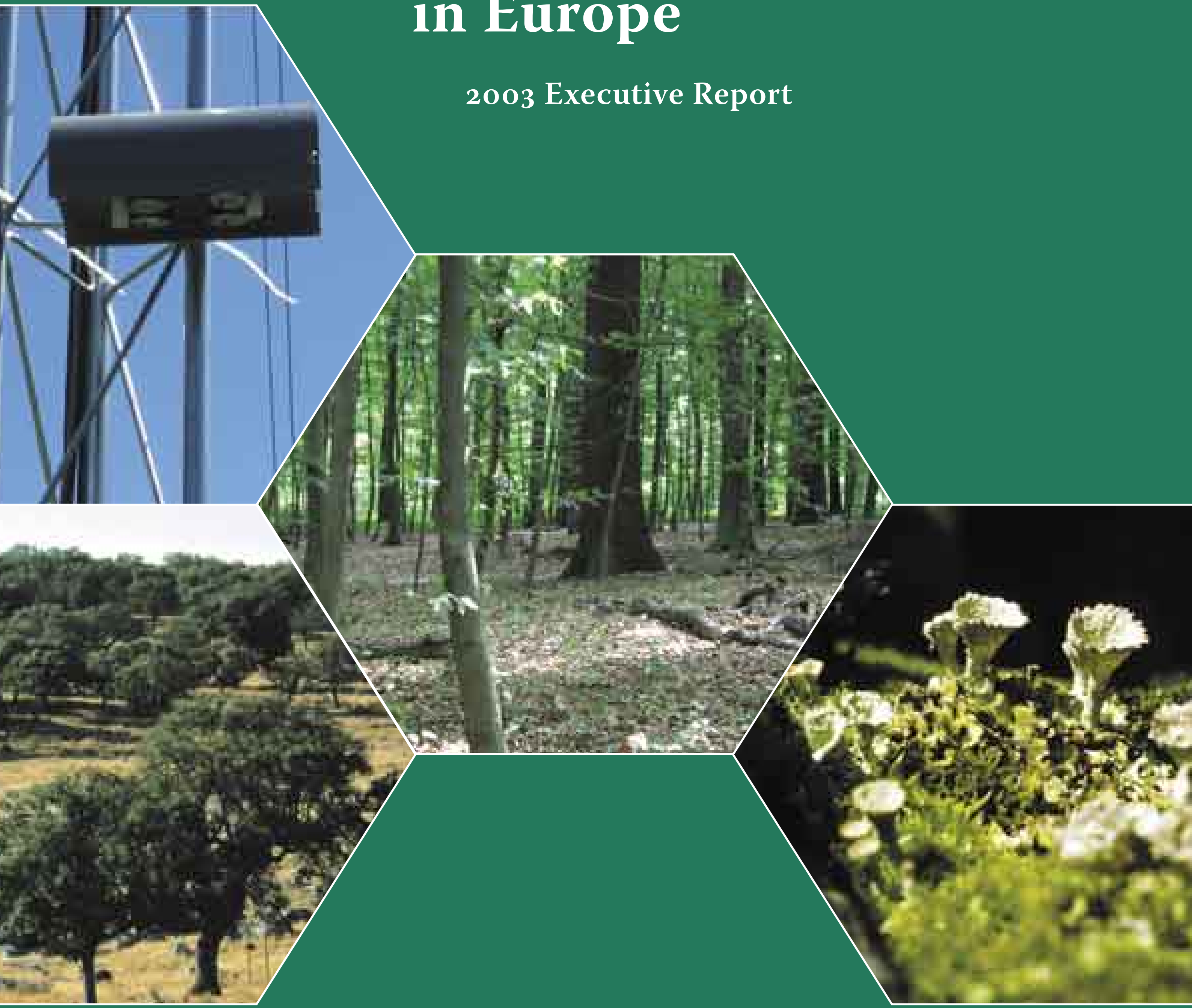
United Nations Economic
Commission for Europe

European Commission

The Condition of Forests in Europe

2003 Executive Report



Federal Research Centre
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The Condition of Forests in Europe

2003 Executive Report

Convention on Long-range Transboundary Air Pollution: International
Co-operative Programme on Assessment and Monitoring of Air
Pollution Effects on Forests

European Union Scheme
on the Protection of Forests against Atmospheric Pollution

United Nations
Economic Commission for Europe

European Commission

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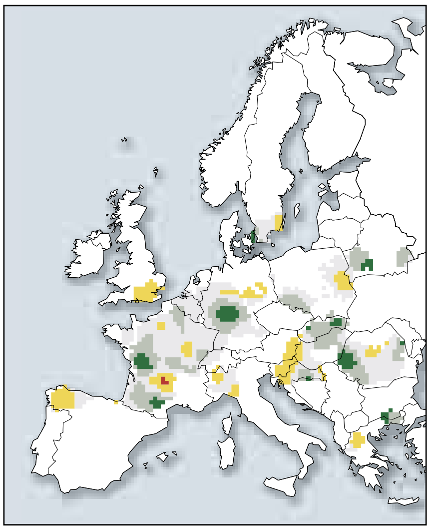
CONTENTS AND MAIN FINDINGS

The joint monitoring programme of the United Nations Economic Commission for Europe (UNECE) and the European Union (EU) is based on:

- 6 000 systematically selected Level I plots
- 860 Intensive Monitoring Plots (Level II)
- 39 participating countries



Five years development of oak defoliation

Annual assessments of over 17 years have revealed an overall deterioration with a transient recuperation in the mid 1990s. In 2002 about one fifth of more than 130 000 sample trees in Europe were classified as moderately or severely damaged.

Tree crown defoliation is influenced by tree age, weather extremes and biotic factors. Relationships between sulphur deposition and defoliation of the main tree species are substantiated. A reduction in sulphur emissions is reflected in the foliar chemistry of pine and spruce trees. Through changing dates of flushing, leaf colouration and leaf fall, trees are shown to react to climate change.

Simulation of nitrate concentrations

The highest nitrogen and sulphur depositions occur in the forest plots in central and western Europe. Scenario analyses for emission reductions according to international agreements show that sulphate concentrations in the soil solution will remain at the low level already reached in 2000 and that nitrate concentrations will decrease in most plots by 2010.

4. Ozone concentrations in forests. . . . . p. 26

Ozone concentrations were particularly high in southern Europe. Ozone injury is visible on the foliage of various tree species in Europe. The first results of an ozone test phase show the importance of continued monitoring activities within the programme.

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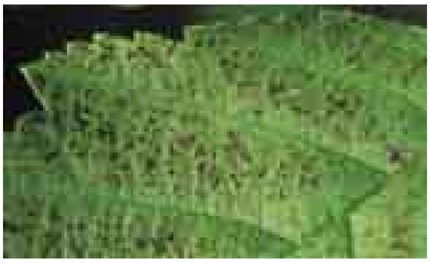

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Carbon uptake (sequestration) in forests can slow down the speed of climate change. Results show that current carbon uptake in European forests mainly occurs through an increase in standing biomass. Atmospheric nitrogen inputs accelerate tree growth, but their overall influence on carbon sequestration is rather small.

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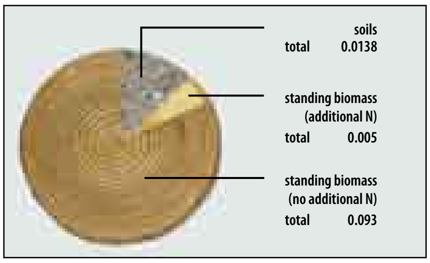

Annual net carbon sequestration in Gton/ha/yr

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The programme's database contains valuable information on many aspects of forest biological diversity, including ground vegetation, tree species and stand structure. *Galeopsis tetrahit* was e.g. a ground vegetation species occuring particularly on plots with high nitrogen depositions. A test phase has been launched for the development of additional assessments and more comprehensive indices.

7. Conclusions. . . . . p. 38

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Hemp-nettle (Galeopsis tetrahit)

Dr. Heinz-Detlef Gregor

PREFACE

It is a great pleasure to introduce you to the 2003 Executive Report on Forest Condition in Europe. Again this year, the report addresses significant elements for the work under the UNECE Convention on Long-range Transboundary Air Pollution and the European Commission with its unique network of scientific co-operation. Under the Convention the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was set up to monitor air pollution effects on forests by collecting comprehensive and comparable data on changes in forests under actual environmental conditions and to determine cause-effect relationships through research and monitoring. It is the largest programme under the Convention's Working Group on Effects and integrates the development of harmonized methods, training, the promotion of internal and external data exchange, quality assurance, scientific guidance and international partnership.

I appreciate greatly that the carefully planned and executed work programme of the EU/ICP Forests and its cooperation with the other five ICPs and the Joint Task Force on Health Effects provide the scientific evidence necessary to support effects-based environmental policies for Europe and the UNECE region, and increase the awareness of science, policy and the public of the effects of regional air pollution. At the same time I wish to acknowledge the generous support the Forest programme has received within the European Union Scheme on the Protection of Forests against Atmospheric Pollution.

The 2003 Executive Report builds on a 17 year time series of crown condition data, revealing an overall deterioration. The report substantiates relationships with air pollution and links phenological changes with climate change. At the same time it shows evidence that forest ecosystems´ recovery may be very slow.

Forest ecosystems are very complex. To understand their condition and assess their future development under the present, and predicted, environmental scenarios requires large data sets and continuous monitoring. This circumstance makes the existing wealth of data from contributions of 37 European countries and North-America also relevant for other regional or hemispherical programmes, such as the Acid Deposition Monitoring Network in East Asia (EANET) or the US Department of Agriculture Forest Service (USDA).

Activities under the Convention presently focus on preparations for the review process of the Multipollutant-Multi-Effect Protocol, once it enters into force, and other protocols expecting their entry into force within a few years. Time series like the ones collected within the joint EU and ICP Forests programme have their very special value, as they are the ones to trace trends in the condition of the monitored ecosystems as a consequence of the remarkable improvement of the 'pollution climate' in the ECE region.

In this respect, cooperation between individual ICPs is especially important. The Executive Report 2003 demonstrates the large scale cooperation of the programme with the other ICPs in the application of critical loads and dynamic modelling, in the field of cause-effect relationships, in the description of visible symptoms for ozone damage to forest trees, in support of the development of flux-based approaches for the assessment of ozone effects on forests, and in deposition model evaluation.

The future of the monitoring activities coordinated by all ICPs relies on the input from their National Focal Centres, the support from lead countries and voluntary contributions from the Parties in compliance with the work plan for the implementation of the Convention. The successful review of the protocols envisaged to continue in 2004 can only be conducted as planned if all programmes are able to deliver according to the work plan. Also, the timely fulfilment of all tasks calls for an agreement on a stable funding instrument for the effect-oriented activities under the Convention.

I wish to congratulate the EU/ICP Forests programme for the production of another excellent report. I hope that it will find its direct way to policy makers.

In the light of the multipollutant situation, future tasks for the programme will have to include deliberations on how to extend the use of data to perform cumulative risk assessments.

This way ICP Forests in cooperation with the European Commission will continue to be one of the main science-based and policy-oriented instruments for international cooperation in environmental monitoring, helping to solve common problems of transboundary air pollution.

Heinz-D. Gregor

River and forest landscape in Norway

Dr. Heinz-Detlef Gregor
Chairman of the Working Group on Effects of the
Convention on Long-range Transboundary Air Pollution

IMPACTS OF ENVIRONMENTAL STRESS FACTORS ON EUROPEAN FORESTS - RESULTS OF 17 YEARS OF FOREST CONDITION MONITORING

The condition of forests in Europe is subject to the impact of numerous environmental changes. These changes endanger sustainable forest management and hence the ecological, economic, social and cultural functions of forests. International environmental policies on preventive measures must have a sound scientific basis. A cornerstone of this scientific basis is long-term, large-scale and intensive monitoring of forest condition.

The monitoring system

Forest condition in Europe has been monitored over 17 years jointly by the United Nations Economic Commission for Europe (UNECE) and the European Union (EU). Large-scale variations of forest condition over space and time are assessed on 6 000 plots systematically spread across Europe in relation to natural and anthropogenic factors. This large-scale monitoring intensity is referred to as „Level I“. Causal relationships are studied in detail on 860 Intensive Monitoring Plots covering the most important forest ecosystems in Europe. This intensive monitoring is referred to as „Level II“. Both monitoring levels are complementary to one another. With its large number of plots and parameters and the participation of 39 countries, the programme operates one of the world’s largest biomonitoring networks.

Crown condition

Crown condition is used as a fast reacting indicator for numerous environmental factors affecting tree vitality. Annual assessments of crown condition over 17 years have revealed an overall deterioration with a transient recuperation in the mid 1990s. In 2002 about one fifth of more than 130 000 sample trees in Europe were classified as moderately or severely defoliated. The impact of the many factors on crown condition varies greatly over space and time. Relationships between trends in crown condition and the main anthropogenic factors are studied by means of multivariate statistics and geostatistical analyses. The results described in the present report confirm earlier findings of the programme which explained the variation in defoliation mainly as effects of tree age, weather extremes, biotic factors and air pollution. Effects of weather conditions are also revealed in changes in tree phenological development, i.e. changes in the dates of flushing, leaf colouration and leaf fall. With respect to air pollution, relationships between sulphur deposition and defoliation of the main tree species were substantiated.

“Montado / Dehesa“ open holm oak forest formation in Portugal

Air pollution

Corresponding with its political mandate, the programme pays particular attention to air pollution effects. Air pollution may detrimentally affect forest ecosystems well before the damage becomes visually obvious, for example as defoliation. Previous studies in the programme revealed relationships between the condition of forest soils and atmospheric deposition. Nitrogen depositions were found to be the dominant source of potential soil acidification. Deposition of acidity, nitrogen and heavy metals exceed critical loads at a large number of sites, indicating enhanced risks for forest ecosystems. In contrast, sulphur deposition decreased in recent years. The present report gives evidence of decreasing sulphur concentrations in needles of Norway spruce and Scots pine. This is a clear success of the drastic reductions of sulphur emissions in Europe under the Convention on Long-range Transboundary Air Pollution (CLRTAP) of UNECE. Under CLRTAP, eight legally binding agreements (protocols) have been adopted, setting national emission ceilings for all important air pollutants. The latest of these was signed in Gothenburg, Sweden, in 1999 (the „Gothenburg Protocol“) and aims at reducing sulphur emissions by at least 63% and NO_x emissions by 41% compared to 1990 levels.

A key issue is the types of benefit that can be expected from individual measures of emission control. For the first time the present report presents results of scenario analyses assuming future emission reductions according to the Gothenburg Protocol. This is achieved by means of dynamic models simulating reactions of soil chemistry to changing environmental conditions. Results indicate that the expected emission reductions result in a comparatively fast recovery of soil solution. Sulphate solution concentrations will remain at the low level already reached in 2000. Nitrate concentrations are predicted to decrease on most plots by 2010, particularly on plots with currently high nitrogen concentrations. The soil solid phase recovery will take considerably longer.

One of the main air pollutants affecting forests directly via the leaves and needles is tropospheric ozone. The first measurements carried out within the programme support knowledge that ozone concentrations are high especially in southern Europe. The programme’s visible ozone injury assessment will be developed further into the only effect monitoring system in forests on a European scale. Early results

Scots pine forest in Norway

reveal ozone injury also on common beech in Central Europe.

Carbon sequestration

Global warming is attributed to increasing concentrations of greenhouse gases in the atmosphere, especially of carbon dioxide (CO_2). The monitoring programme helps to inform on the degree to which carbon sequestration in forests can decrease the CO_2 concentration in the atmosphere. Results indicate that the current carbon storage in trees is 5-7 times as large as that in the soil. Extrapolations to the forest area of Europe, corrected for carbon removals by harvesting and forest fire, give an average rate of 0.1 Gigatons per year. Nitrogen depositions are shown to enhance carbon sequestration by around 5% through a stimulation of forest growth. It is considered that forest management has a pronounced effect on carbon sequestration.

Biodiversity

The existing monitoring activities provide data on many aspects of forest biodiversity. In last year's report, the influence of atmospheric deposition on ground vegetation was substantiated. This report focuses on stand structural information in the Level II database. Additional assessment methods and index calculations will be developed in an ICP Forests test phase starting in 2003.

Future directions

Forest monitoring in Europe will continue to provide a scientific basis for clean air policies under UNECE and EU. After first successes of clean air policies, the future tasks of the programme will comprise the verification of the effects of emission control. However, its well established infrastructure, its multidisciplinary monitoring approach and its comprehensive database will also permit significant contributions to other areas of environmental politics. The programme is already pursuing the objectives of several resolutions of the Ministerial Conference on the Protection of Forests in Europe (MCPFE) and provides information on some of MCPFE's indicators for sustainable forest management. It is also actively contributing to the United Nations Forum on Forests (UNFF). The expected results on forest biodiversity will be relevant for the implementation of the Convention on Biological Diversity (CBD) and contribute to the „Environment for Europe" Ministerial Process with the related Pan-European Biological and Landscape Diversity Strategy (PEBLDS).

With the possibility of contributing towards the assessment of carbon sequestration in forests, the programme will support the Kyoto Protocol under the Framework Convention on Climate Change. Moreover, the programme is receiving increasing attention from policy-making bodies and research institutions outside Europe. This is demonstrated by the recently launched cooperation with North American forest monitoring programmes in the field of critical loads assessments. Another example is the discussion of the applicability of European forest monitoring approaches to East Asian forests with the Acid Deposition Monitoring Network in East Asia (EANET).

Further information is available at:

http://www.icp-forests.org (ICP Forests)

http://europa.eu.int/comm/agriculture (European Commission)

http://www.fimci.nl (Forest Intensive Monitoring Co-ordinating Institute)

European mountain ash

1. The pan-European forest monitoring system

Introduction and background

Forests cover around one third of Europe's surface. Over large areas they are the most natural ecosystem on the continent. At the same time, European forests have high economic and social values which, in the common interest of the quality of life, have to be preserved.

The actual state of the forests is the result of continuous interactions between man and nature over centuries. International environmental policies as well as forest management rely upon a sound scientific basis for measures that will influence forest ecosystems in the future. A cornerstone of this scientific basis is long-term, large-scale and intensive monitoring of forest condition.

The origin of today's joint monitoring system dates back in the 1980s when a severe deterioration of forest condition was observed in large areas of Europe. As a response to growing concern about the role of air pollution in this decline, the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was established in 1985 under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). In 1986 the European Union (EU) adopted the Scheme on the Protection of Forests against Atmospheric Pollution and with Council Regulation (EEC) No. 3528/86, the legal basis for assessments was provided. Today, 39 countries participate in the pan-European monitoring programme.

Programme objectives

The objectives of the monitoring programme are:

- to provide a periodic overview on the spatial and temporal variation in forest condition in relation to anthropogenic and natural stress factors in a European and national large-scale systematic network (Level I);
- to contribute to a better understanding of the relationships between the condition of forest ecosystems and stress factors, in particular air pollution, through intensive monitoring in a number of selected permanent observation plots spread across Europe (Level II);
- to contribute to the calculation of critical levels, critical loads and their exceedances in forests;
- to collaborate with other environmental monitoring programmes in order to provide information on other important issues, such as climate change and biodiversity in forests and thus contribute to the sustainable management of European forests;

Surveys conducted	**Level I**		**Level II**	
Crown condition	annually	all plots	at least annually	all plots
Foliar chemistry	once until now	1497 plots	every 2 years	all plots
Soil chemistry	once until now	5289 plots	every 10 years	all plots
Soil solution chemistry			continuously	part of the plots
Tree growth			every 5 years	all plots
Ground vegetation			every 5 years	all plots
Atmospheric deposition			continuously	part of the plots
Ambient air quality			continuously	part of the plots
Meteorology			continuously	part of the plots
Phenology			several times per year	optional
Remote sensing			preferably at plot installation	optional

Table 1-1: Surveys carried out at Level I and Level II

- to compile information on forest ecosystem processes and to provide policy makers and the public with relevant information.

Monitoring design

To follow these main objectives, a systematic large scale monitoring network (Level I) and an Intensive Forest Monitoring Programme (Level II) have been set up (Tab. 1-1).

The strength of the Level I network is its representativity and the vast extent of its approximately 6 000 permanent plots, arranged in a 16 x 16 km grid, throughout Europe. Annual crown condition assessments are carried out at Level I. In addition, soil and/or foliage surveys have been conducted on many plots. A repetition of the soil survey is foreseen.

For intensive monitoring, more than 860 Level II plots have been selected in the most important forest ecosystems of the participating countries. A larger number of key factors are measured on these plots; the data collected enable case studies to be conducted for the most common combinations of tree species and sites. The latest amendments to ongoing surveys include test phases for ozone measurements and injury assessments, as well as for potential contributions to forest biodiversity assessments.

Healthy Norway spruce, Slovak Republic

2. LARGE SCALE FOREST CONDITION AND REACTIONS OF TREES TO CHANGING ENVIRONMENT

2.1 Crown condition in 2002 and past developments

Summary

- *More than 20% of 130 000 trees assessed in 2002 were classified as damaged. Trees that have been monitored since the start of the survey show continuous deterioration from 1986 to 1995. After a marked recuperation in the mid-1990s the deterioration resumed at a lower level.*
- *In-depth evaluations for Norway spruce and oak species show that there is no uniform trend of defoliation throughout Europe. Rather, they reveal changing conditions in different regions.*
- *High or low precipitation, insect and fungi attacks and air pollution are correlated with crown condition.*

Introduction

The programme provides a regular overview on forest condition in Europe through the 16 x 16 km systematic large scale monitoring grid. The annual crown condition survey is the main large scale activity of the programme. Within this survey, lack of foliage is described as defoliation for each sample tree. In 2002, more than 130 000 trees on approximately 6 000 permanent sample plots in 30 European countries were assessed following harmonized methods. In many countries additional assessments on denser grid nets were performed.

Defoliation responds to many stress factors and is therefore a valuable overall indicator for forest condition. Multivariate statistical techniques are used to reveal relations between stress factors and tree crown condition on a large scale. This report focuses on in-depth evaluations for Norway spruce and European and sessile oak following similar presentations for Scots pine and common beech in last year's report. The special focus on the condition of silver fir reflects the perspective and experience of national experts related to a specific tree species and continues a series which dealt with holm oak, Aleppo pine and common beech in earlier years.

Forests are complex ecosystems and environmental influences can be traced at various levels. This is clearly indicated by results of chemical foliar analyses and phenological observations.

Large scale results

21.3% of all trees assessed in 2002 were classified as moderately or severely defoliated or dead. Crown condition in the EU Member States was slightly better than in Europe

Methods

Analyses of temporal and spatial variation of Norway spruce and European and sessile oak are based on those Level I plots for which data on at least three spruce or oak trees were continuously reported from 1997 to 2002. Multiple influences were calculated for the evaluation period of 1994 to 1999 as later deposition data were not available.

Levels of defoliation: Defoliation field estimates throughout Europe are strongly influenced by stand age (older trees are usually more defoliated) and by the country in which the Level I plot is located (assessment methods sometimes vary between countries). The levels of defoliation presented were therefore evaluated as differences between field estimates and modelled plot values which take into account the variables 'stand age' and 'country' and hence compensate for their influence.

The development of defoliation was calculated as the plot-wise linear gradient of a regression through all annual mean plot values for the years 1997 to 2002. Age and country influences were negligible in the time trend evaluations.

The geostatistical method kriging was used to interpolate levels and trends of defoliation, based on the available Level I plots.

Multiple linear models were used to explain defoliation (1994 to 1999) caused by different environmental influences. External data were used for deposition and precipitation. A coincidence of high defoliation with certain stress factors can be interpreted as a probable damaging effect.

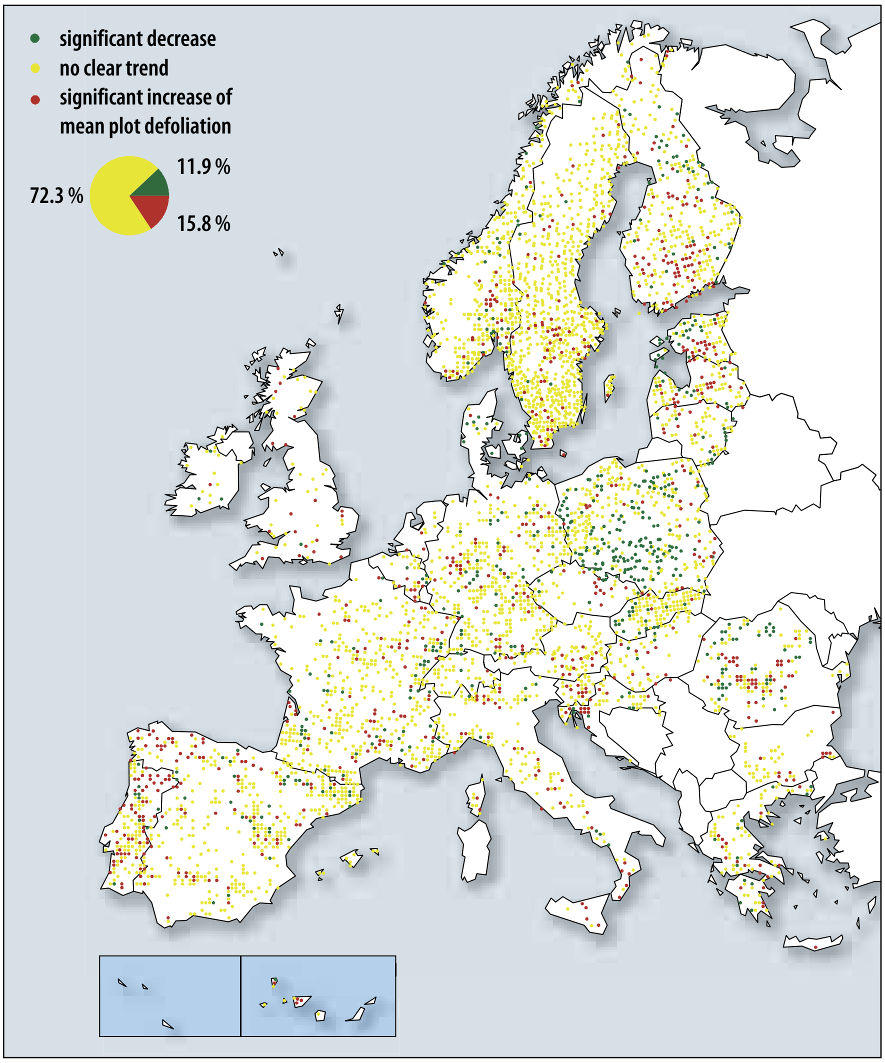


Figure 2-1: Development of defoliation for all tree species. Plot-wise linear trends for 1994 – 2002 were tested for significance. The evaluation period for France, Italy, and Sweden is 1997 – 2002.

International Cross-calibration Courses form part of the quality control programme for crown condition assessments. Here team leaders from different countries meet in the forests and assess the same sample of trees. Time consistency is checked by annually repeated assessments on photographs.

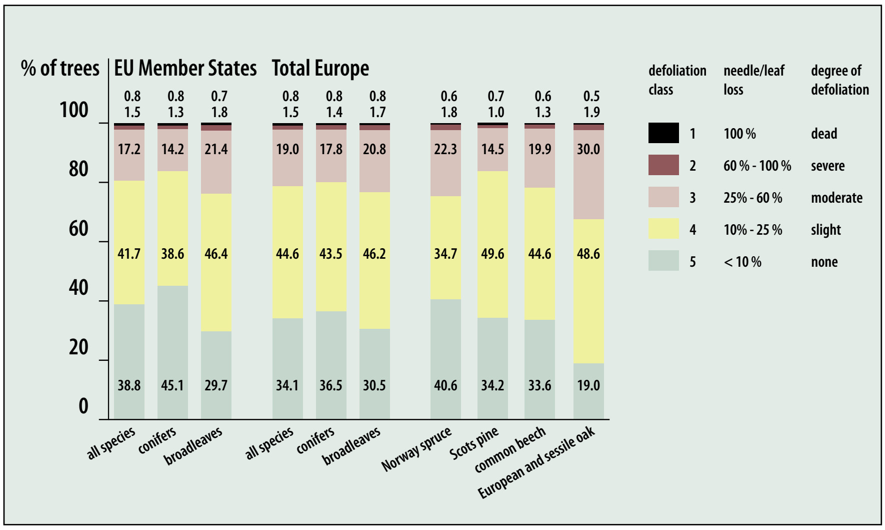


Figure 2-2: Percentage of trees in different defoliation classes for main tree species. Total Europe and EU, 2002

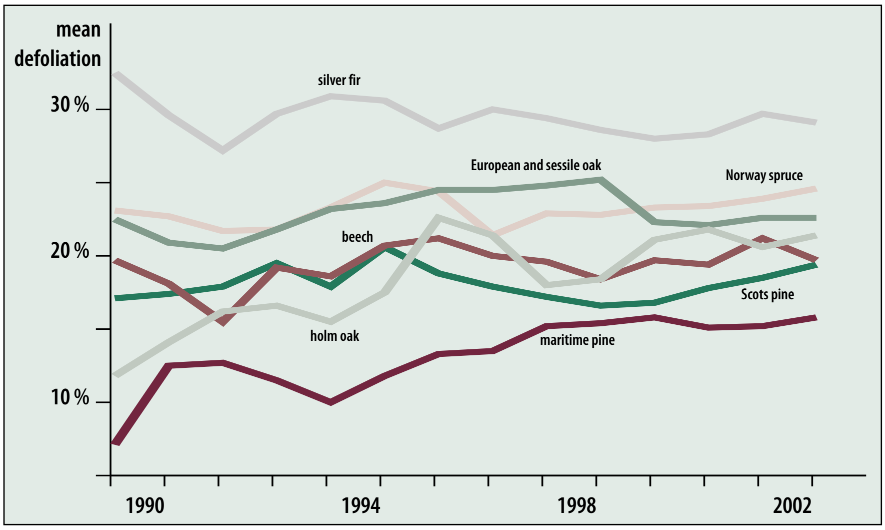


Figure 2-3: Trends for mean defoliation for European main tree species, calculated for continuously monitored trees. Sample sizes vary between 1 237 trees for European and sessile oak and 2 988 for spruce (silver fir: 289 trees)

as a whole. Of the four tree species most frequently occurring in the plots, European and sessile oak were the most severely defoliated species (Fig. 2-2).

The temporal development of defoliation was analysed for the sample of continuously monitored trees. The continuously monitored silver fir trees had the highest mean defoliation in all years. In general, mean defoliation values fluctuated considerably (Fig. 2-3). The proportion of damaged and dead trees (defoliation classes 2-4) of all species was highest in 1995 (25.6%) and decreased in the following two years (not depicted). Since then a steady but slow increase in damage has been recorded.

The plot-wise mapping of all tree species (Fig. 2-1) shows that the proportion of plots with a significant increase of mean plot defoliation from 1994 to 2002 was higher (15.8%) than the share of plots where mean defoliation decreased (11.9%). Plots with deteriorating crown condition are clustered along the northern and western coast of the Iberian peninsular, in southern Finland and Estonia, in the alpine region of Austria and in Slovenia and Croatia. Regions where plots are mainly improving are southern Poland and the coastline of Estonia.

Norway spruce

In Central Norway, mean defoliation of spruce is relatively high (Fig. 2-4 and 2-5). The situation is mainly explained by needle rust and root rot fungi. Damage was particularly high due to climatic stress. In the past five years the situation has slightly improved. In large regions of Sweden defoliation has increased since 1997, most likely due to similar causes as those for defoliation in Norway. In Belarus, an improvement was registered, but in the Baltic region and southern Germany there was a worsening of defoliation on most plots.

European and sessile oak

The deciduous oak trees showed a large variation in both mean defoliation and its temporal variation (Fig. 2-6 and 2-7). In some regions of France, the defoliation was rather high with improvements in the south and west of the country, but no country-wide uniform damage causes were identified. In Central Germany, the large scale improvement was explained by a recovery of oak trees after years of severe insect damage.

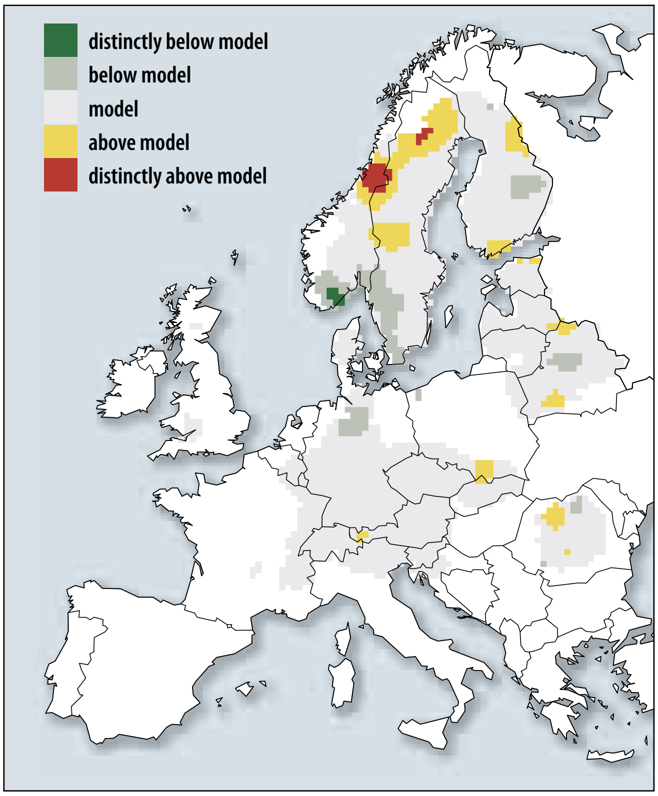


Figure 2-4: Defoliation of Norway spruce. Differences between medium term mean defoliation and model value. The interpolation is based on 1461 plots, which have been continuously assessed from 1997 to 2002.

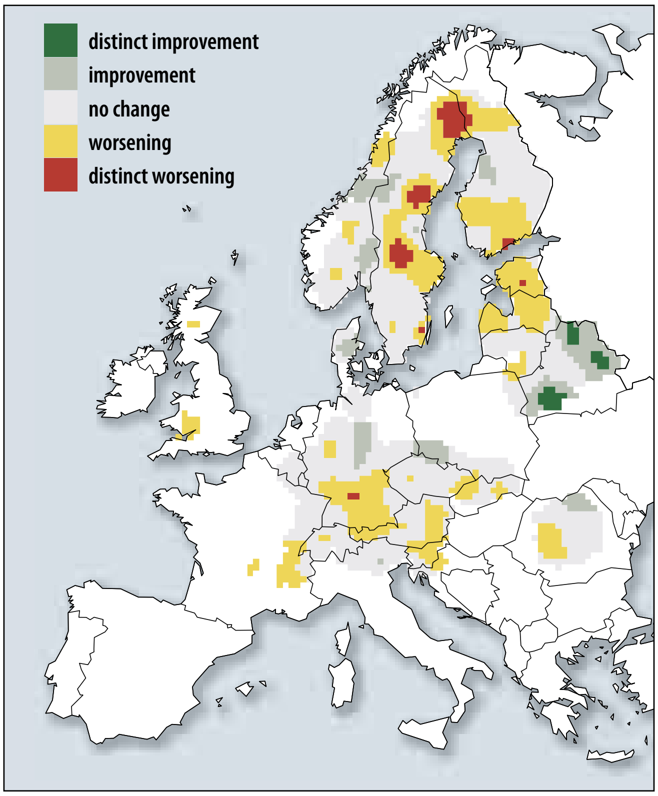


Figure 2-5: Mean defoliation trends over time of Norway spruce. The interpolation is based on 1461 plots, which have been continuously assessed from 1997 to 2002.

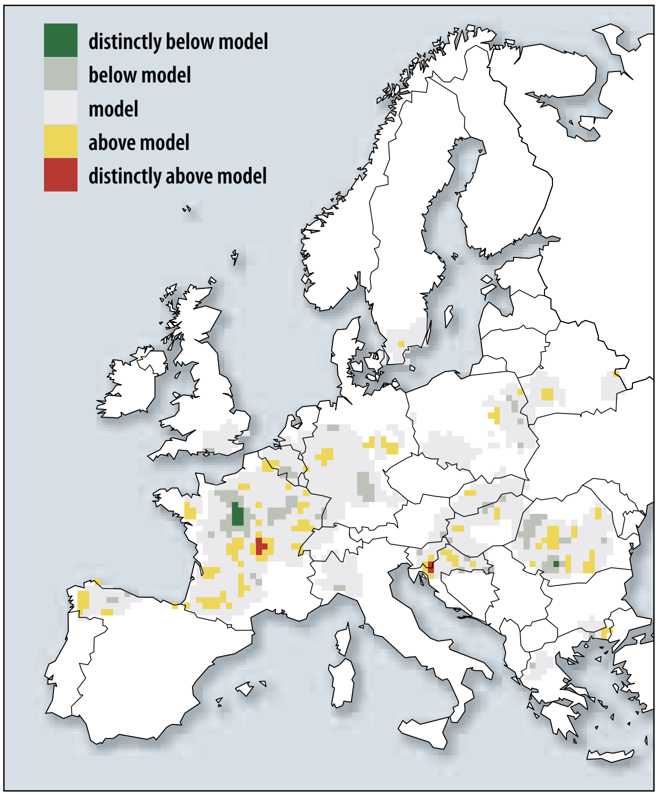


Figure 2-6: Defoliation of European and sessile oak. Differences between medium term mean defoliation and model value. The interpolation is based on 503 plots, which have been continuously assessed from 1997 to 2002.

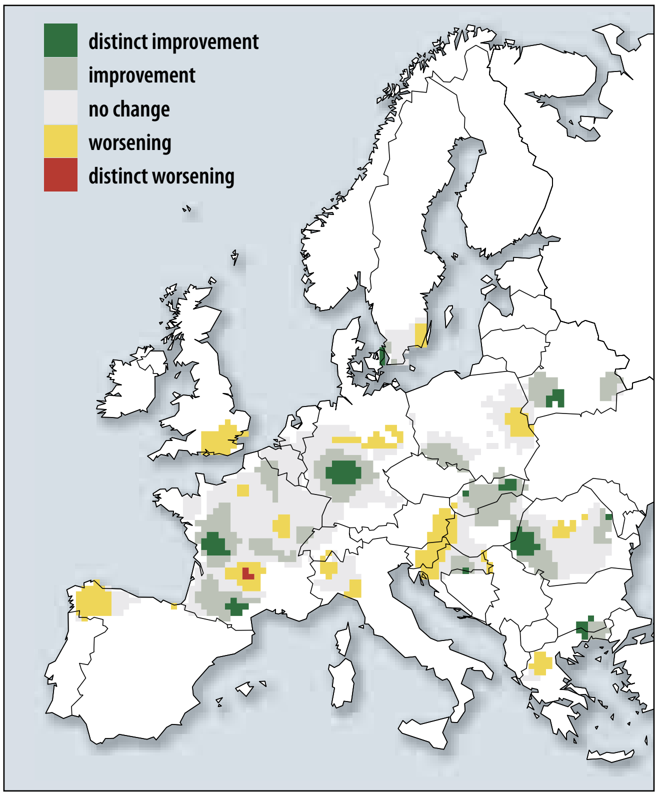


Figure 2-7: Mean defoliation trends over time of European and sessile oak. The interpolation is based on 503 plots, which have been continuously assessed from 1997 to 2002.

			Spatial variation		Temporal variaton	
			spruce	**oak**	**spruce**	**oak**
R-square			58.7	43.1	40.8	43.8
No. of plots			1046	291	1046	291
precip. actual year			-	-	-	-
precip. previous year					-	-
insect			+	++	+	+
fungi			+	--	-	+
deposition	S	actual year	+	+	+	+
	NH_4	actual year	+	-	-	+
	NO_3	actual year	--		+	+
	S	prev. year			-	+
	NH_4	prev. year			-	-
	NO_3	prev. year			-	+
year					0	0
age$_{\text{country corrected}}$			00	00		
country			00	00		

Table 2-1: Relations between temporal and spatial variation of defoliation of Norway spruce and European and sessile oak and various explaining variables as results of multiple linear regression analyses. The R^2 value indicates the percentage of variance explained by the model.

-	negative correlation
--	significant negative correlation
+	positive correlation
++	significant positive correlation
0	correlation
00	significant correlation

Multiple influences on crown condition

Multiple linear models confirmed that weather, insects and atmospheric deposition influence the condition of tree crowns in Europe (Tab. 2-1). The evaluations showed that a high precipitation level is related to relatively healthy tree crowns. These findings for spruce and deciduous oak support those reported for Scots pine and beech in last year's report. The influence of insect damage was also consistently reflected in the statistical evaluations for the four most frequently occurring tree species. Fungi showed varying relations. Sulphur (S) deposition of the current year was consistently related to high or increasing defoliation. A linear trend reflects a development statistically unexplained by the other predictor variables of the model. As can be shown on the maps, however, there was not a uniform Europe-wide trend, but varying conditions on different plots. Age and country were relevant causal factors explaining the spatial variation but did not influence time trend evaluations.

Silver fir dominated mixed mountain forest, Germany

The condition of silver fir (Abies alba)

Summary

- *Widespread damage on silver fir in the 1970s led to the installation of the first permanent monitoring plots. These were subsequently included in the current transnational forest condition monitoring grid.*
- *Silver fir is still among the most damaged tree species, with more than 40% of the continuously monitored trees affected and only a slight improvement in recent years.*
- *Many studies have shown its susceptibility to air pollution. Natural stress factors like drought periods also play an important role. A peculiarity is the infestation by mistletoe.*

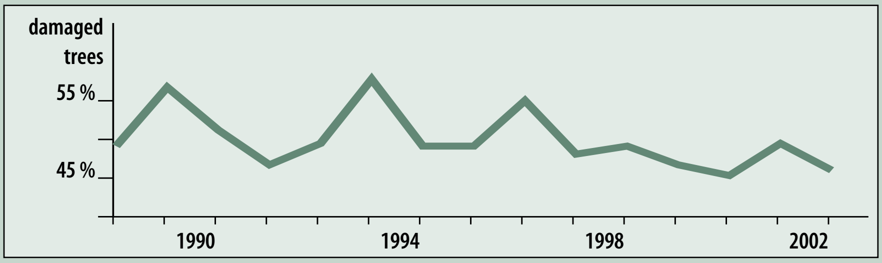
Introduction

Widespread damage of silver fir (*Abies alba*) was among the first recorded in the context of the so-called ‘Waldsterben’ (forest decline) in southern Germany and Central Europe in the 1970s. Originally the term ‘Tannensterben’ (fir decline) was used, but soon it became clear that more tree species were concerned. Due to this development, regional time series for silver fir crown condition are probably the longest ones available for a large number of plots.

The natural range of silver fir spreads across the humid mountain regions of central and southern Europe. The species is comparably shade tolerant and typically occurs in mixed mountain forests where it forms species-rich and structured stands in combination with Norway spruce, common beech and sycamore. In Central Europe the species occurs up to an altitude of 1 200 m. Only in southern regions like the Pyrenean Mountains can it be found above these altitudes. For optimum growth the species requires well drained sites with at least moderate nutrient supply. However, through a tap-root system it is also able to inhabit compacted and hydromorphic sites. Exceptionally it occurs on strongly acidified soils.

Historical development of silver fir damage

Detailed reports on silver fir damage, including specific symptom descriptions, were already made at the beginning of the 20th century. In the mid 1960s, deterioration was again observed, firstly in southern Germany, but subsequently in other European regions. Damage increased particularly in 1976, a year with extremely low precipitation. In the mid 1970s the highest sulphur dioxide emissions were also reported for these regions and for the first time a relationship between long-range air pollution and



Percentage of damaged silver fir (continuously assessed since 1988) on the Level I grid (defoliation classes 2-4, >25% defoliation)

crown condition deterioration was suspected.

The concern for decreasing ecosystem functioning led to the installation of permanent monitoring plots in order to document the development and to analyse the causes of the observed symptoms.

Monitoring results

At present more than 2 000 silver fir trees are recorded on the transnational large scale monitoring grid of the programme. France, Romania and Germany are the countries with the highest numbers of this species in the database. Since 1988, the species is among the most damaged ones with the percentage of damaged trees continuously above 45% (see also Fig. 2-3). The share was particularly high in 1989, 1993 and 1996. Since then a slight recovery has been observed. Regional time trends show even higher damage before 1988 with notable defoliation before 1986.

Stress factors and regeneration

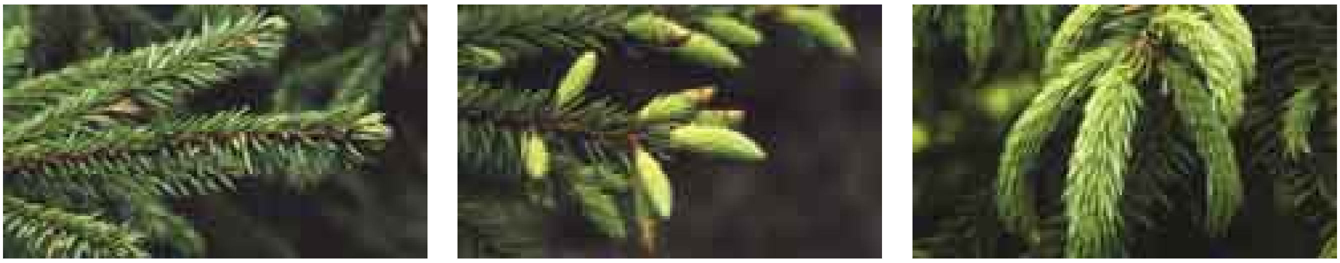
Regional trends are strikingly parallel on many plots regardless of their stand and site type. This suggests that the tree species' health status does not only depend on local influences but also on large scale stress factors. It has become clear that silver fir is susceptible to atmospheric sulphate inputs. Studies show that growth responds to the reduction of high sulphur dioxide emissions. Research in the 1980s also indicated damaging effects by soil fungi. In addition climatic factors like drought periods have been shown to be of importance for the health status of the tree species. Also too dense stands are more prone to decline.

There was also a clear relation between defoliation and the presence of mistletoe (Viscum album) infestation. Studies on infected firs show that mistletoe does not necessarily colonise highly damaged fir trees. The infection of comparably healthy tree crowns, however, leads to a continuous weakening.

Long term monitoring results from southern Germany revealed a relationship between mortality and mean defoliation. Die back was more likely for trees with a high mean defoliation. Damaged firs were also predisposed to secondary damage factors.

In contrast to many other species, silver fir is partly able to compensate for damage by forming secondary shoots. Severely damaged firs can thus survive for many years. In exceptional cases, a vital secondary crown can totally replace the weakened primary crown and thus may lead to complete regeneration.

Example of a severely damaged fir from 1985 to 2002 showing a distinct revitalisation.



Norway spruce at different phenological stages (before flushing, flushing, after flushing)

2.2 Phenology and environmental influences

Summary

- *The yearly phenological development stages of trees like flushing, leaf colouration and leaf fall showed relations to climatic influences and tree growth.*
- *The recently included phenological observations will be extended in future as they help in the analysis of environmental stress such as climate change. They also serve as a sensible early warning system.*

Introduction

Long-term assessments have shown that in Central Europe spring flushing currently occurs about two weeks earlier than half a century ago, and even four weeks earlier in northernmost Scandinavia. Since 2000, development stages of trees, such as flowering, flushing, leaf colouration and leaf fall, are recorded by phenological observations in a number of Intensive Monitoring Plots. Phenology is important in the study of effects of climate change on forest ecosystems, and it also provides an indication of genetic diversity and atmospheric deposition.

First results

In Finland and Germany flushing of Norway spruce was recorded on trees where the circumference was also continuously measured with girth bands. In general, earlier flushing and a longer growing period resulted in a larger diameter increment. (Fig 2-8, left) However, the meteorological condition during the particular growing season as well as single tree genetics and small scale site conditions may overlay these basic reactions (tree in Fig. 2-8, right).

At beech plots in Germany, Luxembourg and France, the length of the growing season (measured as the time between spring flushing and leaf discolouration in autumn) was closely related to temperature and geographic region.

Outlook

Phenological assessments have the potential of an early warning system for effects of climate change and are expected to be extended within the programme. The integration with other available data from the monitoring plots will support the analyses of cause-effect relationships. Longer time series, information from more plots and more trees per plot are required to improve the results.

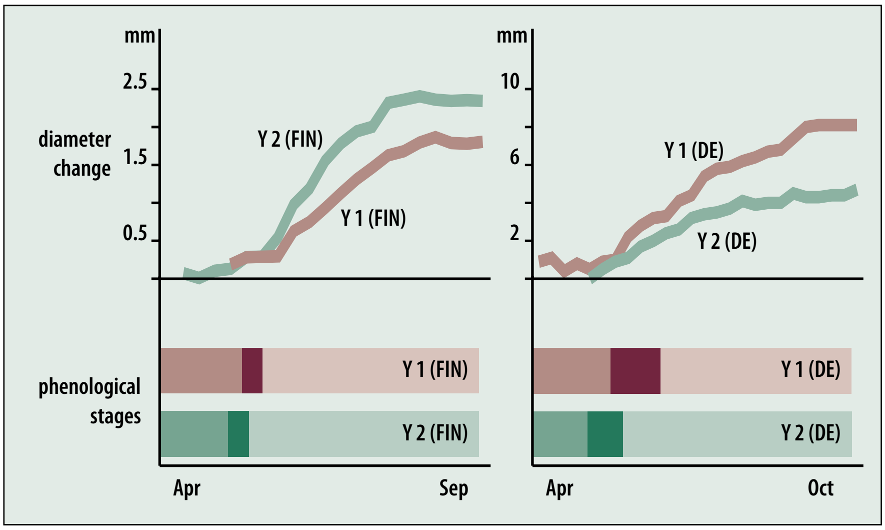


Figure 2-8: Diameter development and phenological observations at one spruce tree in Punkaharju (Finland, left) and one spruce tree in Sonthofen (Germany, right) in two different years.
upper graphs: girth band measurements.
lower graphs: flushing periods for the same trees in the two observation years (medium: before flushing; dark: flushing; light: after flushing).
Measurements in the same years are depicted in corresponding colours.

For more information see:
http://www.metla.fi/eu/icp/phenology/index.htm

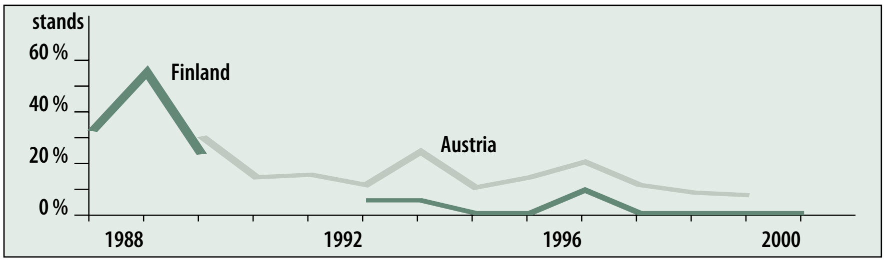


Figure 2-9: Proportion of stands with foliar sulphur concentrations above 1.1 mg S/g in Finland and Austria

2.3 Elemental foliar composition indicates environmental changes

Summary

- *The reduction of sulphur deposition is reflected in the chemical foliar condition of trees. This even applies to countries like Finland and Austria where sulphur concentrations in tree needles have been low during the last 15 years.*
- *Foliar nitrogen concentrations have remained low in both countries, but trends in some areas raise concern.*
- *In the monitored plots of both countries, nutrition was characterised by balanced nutrient ratios.*

Introduction

Chemical analyses of tree needles and leaves give valuable insights into tree nutrition which in turn reflects environmental change. Since 1987, the elemental foliar composition on 36 Finnish and 71 Austrian Level I plots has been determined annually. These countries were selected for evaluation because they have the most comprehensive foliar chemistry data sets.

Results

During the last 15 years, the needle sulphur concentrations have been low in both Austria and Finland. Even at this low level needle **sulphur** concentrations decreased (Fig. 2-9), reflecting the success of sulphur emission reduction programmes. In some remote areas in Finland the needle sulphur concentrations have dropped to a level normally found in pristine forests. In Austria, however, 7% of the sampled forests had concentrations above specific national thresholds.

Needle **nitrogen** concentrations in most parts of Finland and Austria have generally remained low. This is particularly true for Austrian forests located in alpine regions. Trees with higher needle nitrogen concentrations were often found close to agricultural and industrial areas. Taking into account the normal ageing effect of the monitored trees, a decrease in nitrogen concentrations would have been expected at constant input loads. Such a decrease has not been observed, so it is assumed that nitrogen is also becoming more available in remote areas. Increased availability of nitrogen can have adverse effects on forest ecosystems.

Needle sampling in Finnish (left) and Austrian forests (right)

Further reading:

Lorenz, M., V. Mues, G. Becher, C. Müller-Edzards, S. Luyssaert, H. Raitio, A. Fürst and D. Langouche, Forest Condition in Europe. Results of the 2002 Large-scale Survey. Technical Report. EC, UNECE 2003, Brussels, Geneva, 171 pp.

Lysimeters extract water from different soil layers

3. SIMULATION OF LONG-TERM IMPACTS OF ATMOSPHERIC DEPOSITION ON FOREST SOIL SOLUTION CHEMISTRY

Summary

- *If future emission reductions follow the Gothenburg Protocol, this will lead to rapid soil solution recovery according to applied models. On the other hand, recovery of the soil solid phase will take decades.*
- *Dynamic model calculations for around 200 Intensive Monitoring Plots show a very strong reduction in soil solution sulphate concentrations between 1980 and 2000 due to large reductions in sulphur emissions.*
- *The emission reduction scenario also predicts a decrease of soil nitrate concentrations for most plots by the year 2010 if the Gothenburg Protocol is fully implemented in all countries. Reductions are strongest for plots with high current nitrogen concentrations.*
- *Reductions of potentially toxic aluminium concentrations are mainly predicted for those plots where aluminium concentrations were high in the 1980s.*

Introduction

Air pollution is a crucial factor influencing forest condition in Europe. Under the Gothenburg Protocol countries have agreed to reduce significantly the emissions of sulphur, nitrogen oxides and other air pollutants. Sulphur emissions have been reduced considerably in the past decades (Fig. 3-1), but critical nitrogen and acidity loads are still exceeded on many plots, as was pointed out in last year's report. Time series for deposition of measured atmospheric pollutants are valuable tools of the programme with which to identify the success and further challenges for clean air policies in Europe.

The following chapter presents applications of a dynamic model, simulating future reactions of soils to deposition reductions. The evaluations were carried out in close cooperation with the LRTAP Convention partner programmes ICP on Modelling and Mapping and ICP on Integrated Monitoring. The results are a step towards the future goal of applying dynamic models not only on single plots but at a European scale.

Model application

At about 200 Intensive Monitoring Plots, both element input through deposition and element concentrations in the soil solution are measured regularly. At these plots a dynamic soil acidification model has been applied to see whether measured soil solution concentrations can be reproduced by the model. Existing data were used to optimise certain process parameters in the model. For most plots, the

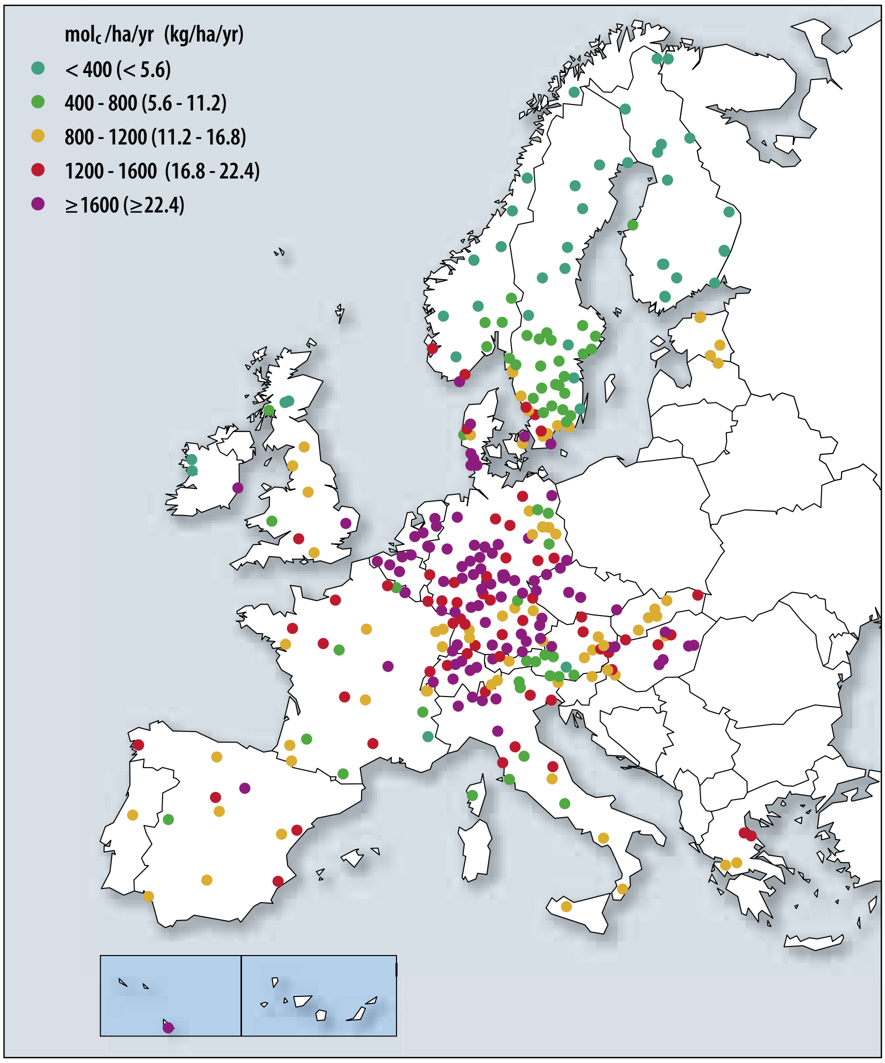


Figure 3-1: Total nitrogen deposition on Level II plots, 1998 - 2000. Nitrogen deposition was highest in Central Europe. Critical loads aiming at no further nitrogen accumulation in the soil are presently exceeded on 92% of the evaluated Level II plots. Critical loads taking into account effects on trees were exceeded on 45% of the plots. Due to interactions in the canopy, total deposition is modelled on throughfall measurements below the canopy and bulk deposition from nearby open fields.

agreement was reasonable to good (Fig. 3-2).

After optimisation of the model, impacts of expected deposition changes were simulated for the period 1970-2030. It is assumed that if the model is able to reproduce the soil solution measurements over a number of past years, it will also give plausible results for future simulations. The deposition scenario evaluated was based on the agreed emission reductions following the Gothenburg Protocol.

Results

The scenario analysis for all simulated Level II plots (Fig. 3-3) shows

Measurement equipment for the collection of wet deposition inputs in forest stands

Methods

Critical loads have already been presented in the 2002 Executive Report. They define the long-term load below which no significant harmful effects are expected. If deposition is greater than the critical load, there is an increased risk of damage to the ecosystem, and it is necessary to reduce the deposition to safeguard the ecosystem.

Steady state models are used to calculate critical loads. They do not take into account temporal changes in soil chemistry.

Dynamic models are used to simulate reactions of soil chemistry to changing environmental conditions. They are more complex as they integrate dynamic soil processes like cation exchange, sulphate adsorption and nitrogen retention.

Aluminium ions can damage plant roots. High concentrations particularly occur in acid soils, so their concentration in the soil solution is a key indicator for soil acidification.

Soil solution is the water that penetrates through the soil pores. Its chemical composition is influenced by deposition. It is also the basic medium for nutrient uptake of plant roots.

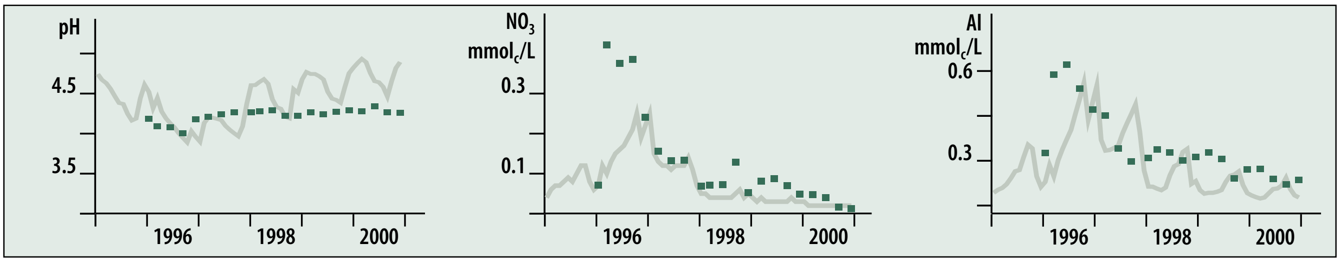


Figure 3-2: Example for measured (dots) and simulated (lines) pH, as well as nitrate (NO_3) and aluminium (Al) concentrations and in the soil solution of one Intensive Monitoring Plot. The specific simulation is good for aluminium, but less good for pH.

a sharp decrease in the median sulphate soil solution concentration caused by the strong reductions in sulphur emissions in Europe. It also shows that reductions in nitrogen emissions would lead to lower nitrate concentrations in the soil. Additional evaluations show that reductions will most probably occur on plots with high nitrate concentrations today. For some plots high nitrate values will remain in the future. The decrease in acid deposition leads to an improvement of the chemical status of the plots as pH increases and the accompanying aluminium concentrations decrease. It has to be taken into account that the results only reflect chemical reactions of the soil water. Reactions of the soil solid phase are always slower and will take decades or even centuries.

The geographical distribution of simulated sulphate concentrations in the soil solution of the modelled sites illustrates the strong decrease in 2030 compared to 1970 (Fig. 3-4). It also shows a high spatial variability in soil solution SO_4 concentration, with the highest values in Central Europe.

The geographical distribution of simulated aluminium concentrations mainly shows that plots with too high concentrations are strongly reduced over time (Fig. 3-5). Initially, aluminium concentrations were above a critical value of 0.2 mol_c/m^3 on about 20 % of the plots. Simulations show that in the future this percentage is considerably reduced to around 5 %.

Further reading:

De Vries, W., G.J. Reinds, M. Posch, M. J. Sanz, G.H.M. Krause, V. Calatayud, J.P. Renaud, J.L. Dupouey, H. Sterba, M. Dobbertin, P. Gundersen, J.C.H. Voogd and E.M. Vel, 2003. Intensive Monitoring of Forest Ecosystems in Europe. Technical Report. EC, UNECE 2003, Brussels, Geneva, 170 pp.

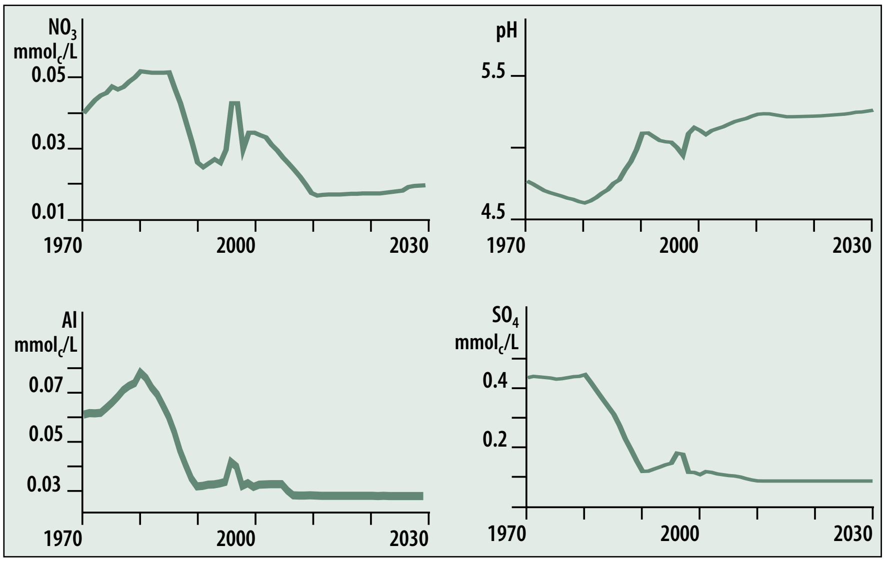


Figure 3-3: Simulation of median pH as well as sulphate (SO_4^{2-}), nitrate (NO_3^-), and aluminium (Al) concentrations in the soil solution of 200 Intensive Monitoring Plots for the years 1970 to 2030 under an emission scenario following the Gothenburg Protocol. The non-smooth behaviour of the lines between 1996 and 2000 reflects the use of year-specific data within this period, whereas for the other years average values were used.

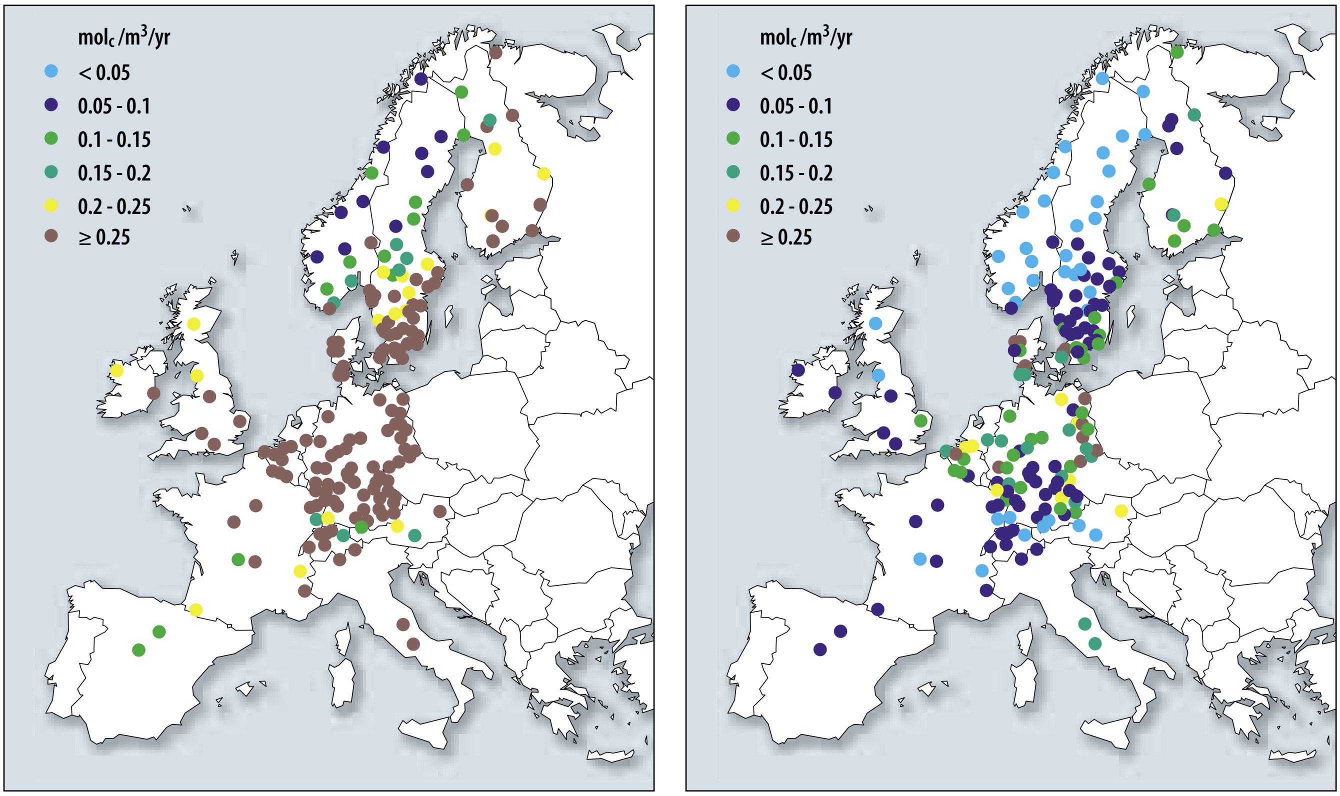


Figure 3-4: Simulated sulphate (SO$_4$) soil solution concentration on Level II plots in 1970 (left) and 2030 (right)

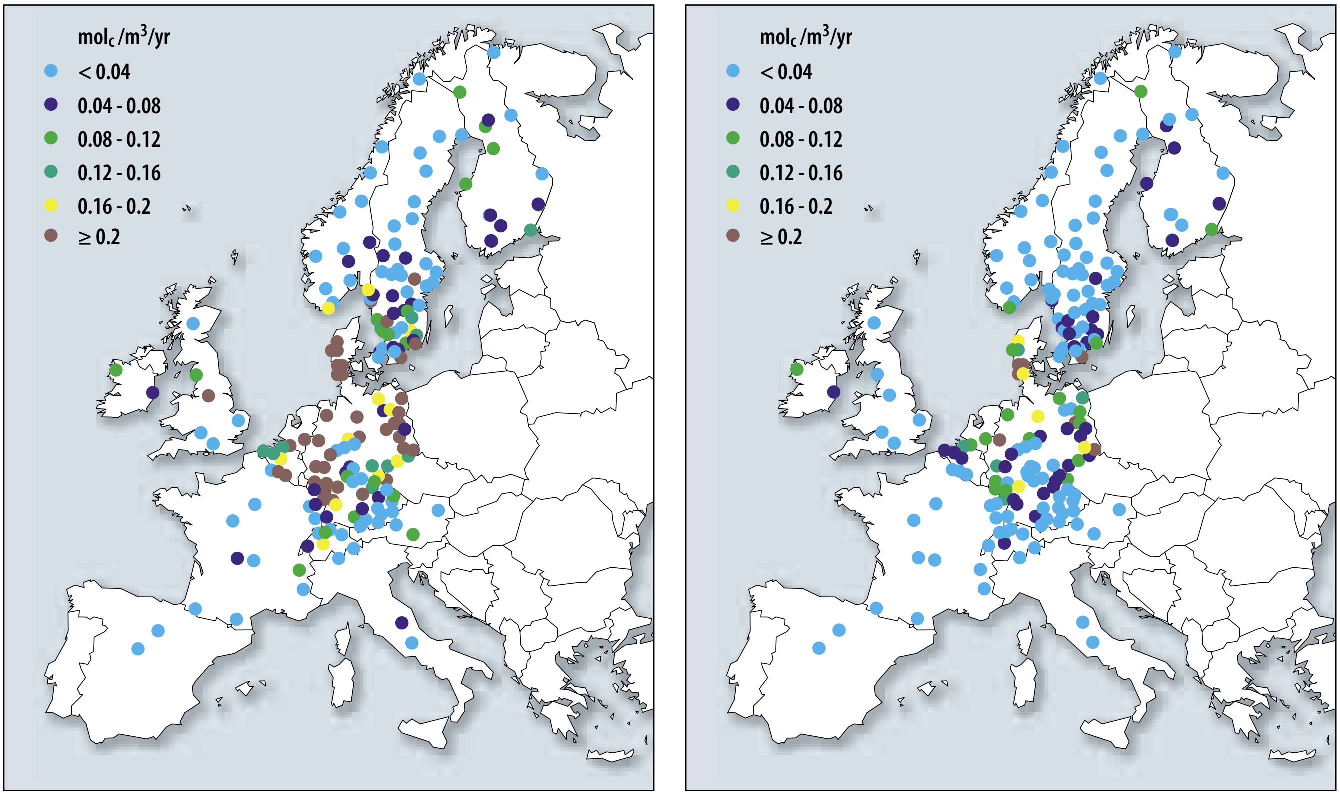


Figure 3-5: Simulated aluminium (Al) soil solution concentration on Level II plots in 1970 (left) and 2030 (right)

Passive samplers installed in Spain

4. Ozone concentrations in forests

Summary

- *Ozone is today regarded as one of the most pervasive air pollutants affecting forests.*
- *A test phase on selected plots shows that ozone concentration monitoring is feasible on remote sites and over large areas. Preliminary results are in line with present knowledge. Particularly high ozone concentrations frequently occur in southern Europe.*
- *The programme's currently developed visible ozone injury assessment is the first direct effect monitoring system at a European scale. Early results show that among the main tree species in Central Europe, also beech is affected by ozone. Many ground vegetation species that were not known to be ozone sensitive showed signs of ozone injury.*

Introduction

The large scale influence of atmospheric deposition on forest ecosystems was recognized many years ago and was a major reason for the implementation of the monitoring programme. Following its mandate, the programme has presented comprehensive monitoring results mainly related to sulphur and nitrogen inputs in many reports (see www.icp-forests.org). At the European and global level, the importance of green house gases like ozone and carbon dioxide was recognized subsequently. In 2001, the EU/ICP Forests programme launched a test phase to explore the monitoring of ozone at its mostly remote forest plots because most of the ozone data at a European level is currently derived from urban and sub-urban areas. The test phase focussed on air concentrations measurement by means of passive samplers and the assessment of visible ozone injury. Around 100 Intensive Monitoring Plots located in nine countries were included.

Passive sampling

The passive samplers tested proved to be a reliable and comparatively cheap method to gain information on ambient air quality, specifically in remote forest areas where no other technical facilities like continuous monitoring stations are available (Fig. 4-2).

Mean values from April to September 2001 showed higher concentrations in southern Europe (Fig. 4-1), with 58 % of the Spanish sites and 63 % of the Italian sites having a 6-month time-weighted average concentration in the range of 46-60 ppb. Also in Greece and Switzerland comparatively high concentrations occurred. In Germany, France, United Kingdom and Austria, the

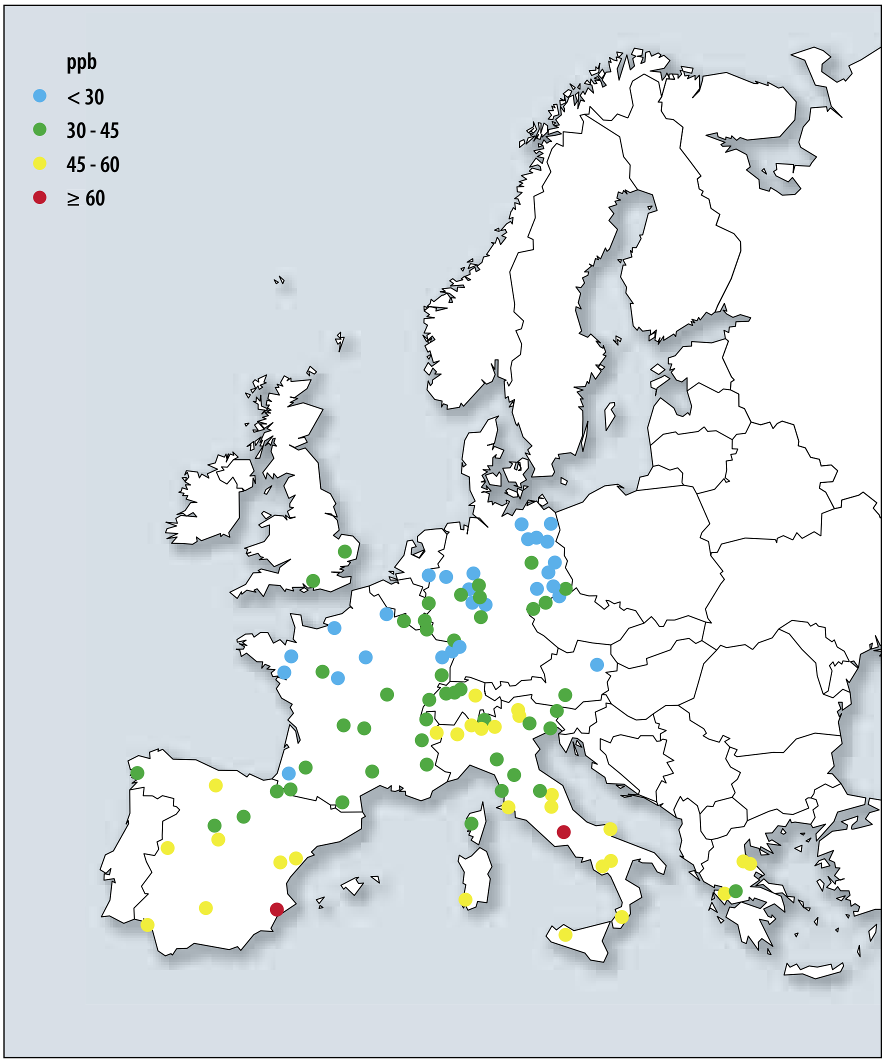


Figure 4-1: Average concentration of ozone from April 1 to September 30, 2001 measured by passive sampling on selected plots during the test phase

sites showed lower average concentrations. It should be kept in mind that in 2001 ozone concentrations were generally rather low compared to most previous years.

Visible ozone injury assessment

Ozone leaves no elemental residue that can be detected by analytical techniques. Therefore, visible injury assessments were carried out on needles and leaves from main tree species, as well as on ground vegetation, by nine countries on 72 plots in the year 2001. A website, including a photogallery with examples of ozone symptoms on leaves and needles, was made available to support the determination of ozone injury (http://www.gva.es/ceam/ICP-forests). Several training courses were conducted to build up necessary expertise in this field and to harmonize methods. Special microscopical methods were developed to validate symptoms in doubtful cases.

Visible injury on trees was reported from 17 of the plots. In Central Europe the investigations focussed on common beech. For this important tree species, injury was reported on 24% of the investigated plots. Many of the ground vegetation species that showed visible ozone injury in the field were not known to be ozone sensitive before.

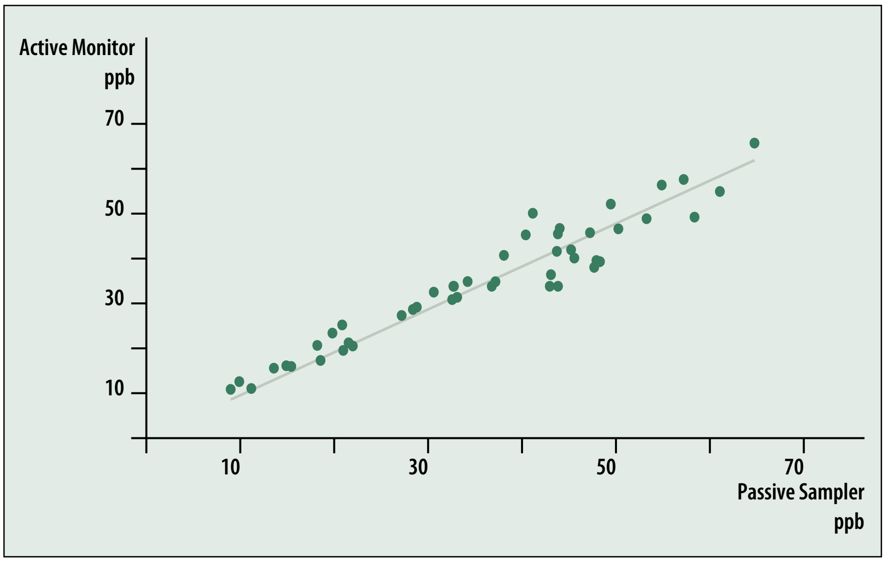


Figure 4-2: Comparison of two week average ozone concentrations by active and passive monitoring in Spain. The close relationship between the measured concentrations shows that passive sampling can give reliable measurements. Passive samplers contain chemical substances that react to the ozone in the air. After one to four weeks the samplers are collected and analyzed in the laboratory.

Visible ozone injury on leaves and needles of common beech, grey alder, and Aleppo pine. The differentiation from other damage symptoms requires considerable expertise.

Achievements and Outlook

During the test phase an ozone monitoring system for forests at European scale has been initiated and proven to be operational. Expertise on passive sampling was build up in many countries. The assessment of ozone injury on main tree species as well as on ground vegetation has to be considered as a first phase to implement a unique effects monitoring system on a European scale, based on validated field observations. It will also broaden knowledge on ozone-sensitive species. It is planned to refine the methods and to continue the passive sampling activities. Information from both surveys will be linked using a geographic information system (GIS). This will help to understand the effects of ozone on forest vegetation better and will also provide a good basis for calibrating models of the EU/ICP Forests and of other programmes under the Convention on Long-range Transboundary Air Pollution.

Further reading:

De Vries, W., G.J. Reinds, M. Posch, M. J. Sanz, G.H.M. Krause, V. Calatayud, J.P. Renaud, J.L. Dupouey, H. Sterba, M. Dobbertin, P. Gundersen, J.C.H. Voogd and E.M. Vel, 2003. Intensive Monitoring of Forest Ecosystems in Europe. Technical Report. EC, UNECE 2003, Brussels, Geneva, 170 pp.

Open air ozone fumigation experiment in Freising, Germany

OZONE

Global overview on the ozone situation

- Surface near (tropospheric) ozone (O_3) is estimated to have increased by about 35% since the pre-industrial era, with some regions experiencing larger and some with smaller increases. In 2001, the Intergovernmental Panel on Climate Change (IPCC) classified tropospheric ozone as the third most important greenhouse gas after carbon dioxide (CO_2, see also Chapter 5) and methane (CH_4).
- Whereas concentrations of surface near tropospheric ozone increase, losses have been observed in the stratosphere at altitudes between 15 and 50 km over the past two decades. This depletion is mainly caused by anthropogenic halocarbons and endangers the natural shield of the earth's atmosphere.

Ozone injury

Trees first respond to ozone when it enters the leaf through the stomata, small openings in the leaf surfaces through which gas exchange takes place. Within the leaf, ozone is transformed, producing a variety of cell damaging compounds called free radicals. There is scientific consensus that at levels in much of Europe and North America, ozone induces foliar injury, decreases foliar chlorophyll content and photosynthesis, accelerates leaf senescence, reduces growth, alters carbon allocation and predisposes trees to attack by pests. Tree species and individual trees within species vary greatly in their ozone tolerance.

Ozone research

Scientists responsible for the monitoring activities of the EU/ICP Forests programme closely collaborate with research institutions operating, among others, the two experiments depicted.

Starting in 2000, the effects of a chronic exposure of adult trees to twice ambient ozone concentrations are studied in a mixed beech and spruce forest near Freising, Germany. To date, beech leaves developed visible symptoms and accelerated autumnal senescence due to the free-air ozone fumigation whereas spruce appeared to be less susceptible. The results will help to interpret the multitude of available findings from containerized young plants that cannot be extrapolated to the reactions of mature trees unconditionally.

The Aspen FACE (Free-Air Carbon Dioxide Enrichment) Project in northern Wisconsin, USA comprises scientists from northern America and five European countries. In an open air research site effects of elevated CO_2, O_3, and $CO_2 + O_3$ concentrations are compared to ambient concentrations. Results from the first five years clearly show that elevated (>200 ppm) atmospheric CO_2 increased tree growth. Under elevated concentrations, O_3 damage cascaded all the way from gene regulation through to ecosystem levels. In combination, the beneficial effect of CO_2 was fully eliminated by the elevated O_3 treatment.

The international "Aspen FACE" experiment in Wisconsin, USA

Old growth oak stand with beech in Germany

5. CARBON SEQUESTRATION IN EUROPEAN FORESTS AND ITS IMPLICATION FOR CLIMATE CHANGE

Summary

- *Forests take up carbon from the atmosphere. The latest results of the monitoring programme suggest that the net increase in the forest carbon pool in Europe (both trees and soil) is around 0.1 Gigatons per year. This represents around 25 to 50% of the estimated total European carbon sink.*
- *Nitrogen deposition was calculated to account for 5% of the increase in carbon uptake by stimulating forest growth during the last 40 years over the whole of Europe.*
- *Carbon pools in trees are considerably lower than in soils. However the annual carbon sequestration in trees is presently around 5-7 times higher than in forest soils. With increasing age of the forest stands the sequestration will decrease and thus increase the relative importance of the soils.*

Introduction

The uptake of carbon in forests (sequestration) delays the rise of CO_2 concentrations in the atmosphere and thus slows down the rate of climate change. Important questions to be answered are:

- How much carbon is sequestered by the European forest ecosystems?
- What is the cause of the increase in net carbon sequestration in recent decades?

Available figures on carbon uptake vary considerably, largely due to different methodologies applied and partly because of the small number of experimental sites. Human influences like elevated nitrogen deposition on forests and forest management may play an important role in carbon sequestration. Possible other contributing factors are increases in atmospheric CO_2 concentrations and temperature. Data from 120 Intensive Monitoring Plots and 6 000 Level I plots provide an excellent basis to work on answering these questions.

Carbon sequestration on Intensive Monitoring Plots and Level I plots

The results at the Intensive Monitoring Plots show that annual uptake of carbon in the above ground tree biomass is generally 5-7 times higher than the estimated carbon sequestration in the soil (Fig. 5-2). As expected, the carbon uptake in the trees due to forest growth increases from northern to Central Europe. The evaluations for the Level I plots indicate the same geographical patterns across Europe (Fig. 5-3).

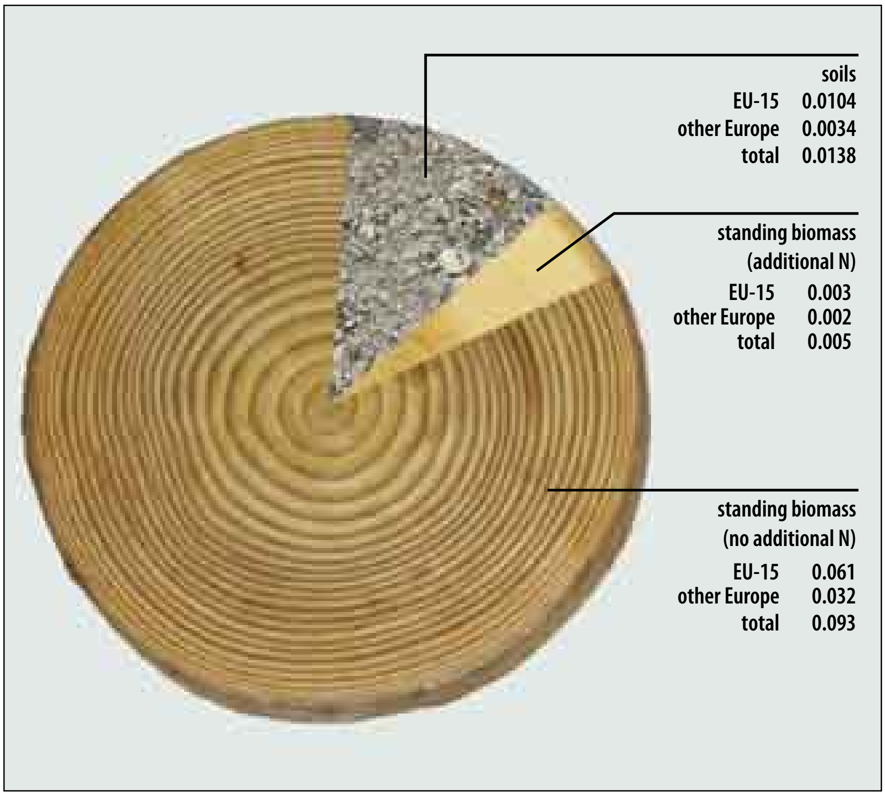


Figure 5-1: Annual net carbon sequestration of standing biomass and soils in European forests in Gton/ha/yr as derived from the Intensive Monitoring and Level I Plots. Carbon sequestration in standing biomass caused by additional nitrogen inputs is comparatively small. Total Europe refers to the forest area as defined in Annex I.

Carbon sequestration in European forests and the impact of nitrogen deposition

Modelled results based on 6 000 Level I plots estimate the total carbon uptake in tree wood due to growth as 0.3 Gton/yr for European forests during the period 1960-2000. This value is similar to the results of other research projects.

Estimating carbon losses due to, among others, wood harvesting, storms, and forest fires with an overall European average ratio of two thirds the net carbon sequestration was calculated as 0.1 Gton/yr for European forests. The contribution of nitrogen deposition to this annual increase of carbon in standing biomass was 0.005 Gton/yr (Fig. 5-1), accounting for around 5% additional carbon uptake due to enhanced nitrogen input since 1960. For Europe as a whole, nitrogen deposition thus had a comparatively small impact on carbon sequestration in trees, but in areas with high nitrogen deposition, the local impact can be substantial.

Carbon uptake in the soil is more difficult to calculate. A first estimate of carbon sequestration in the soils of eleven EU supported “CANIF” sites indicated a sink of 0.128 GtonC/yr. Very recently the CarboEurope cluster (see special focus) calculated even bigger sinks amounting to 0.194 Gton in the soils of around 2 mio km^2 of European forests. The calculation of net carbon sequestration based on the soils of 120 Intensive Monitoring Plots shows that in total, only 0.0138 Gton were sequestered in the year 2000 being more than 10 times lower. This large difference implies that further research is needed to substantiate the role of forest soils in carbon sequestration.

For 120 Intensive Monitoring Plots with a comprehensive database, carbon pools in stem wood and soil were calculated directly. It was also possible to establish statistical relations to transfer the carbon pools to 6 000 Level I plots assuming them to be representative for approximately 2.0 million km^2 of forests in Europe (see Annex I). 1960 was used as the reference for nitrogen deposition and the impact of additional nitrogen deposition until the year 2000 was calculated.

At the Intensive Monitoring Plots changes in tree carbon pools were directly derived from repeated growth inventories. Carbon changes in the soil were computed from nitrogen retention (deposition minus leaching), nitrogen uptake and a C/N (carbon to nitrogen) ratio assumed to be constant at different nitrogen input levels.

For the Level I plots nitrogen deposition was derived from model estimates. Nitrogen uptake by above-ground biomass was calculated from yield estimates as a function of site quality. For below-ground carbon pools and changes, nitrogen retention fractions in Level I plots were related to measured C/N ratios, using a relationship derived from Level II plots

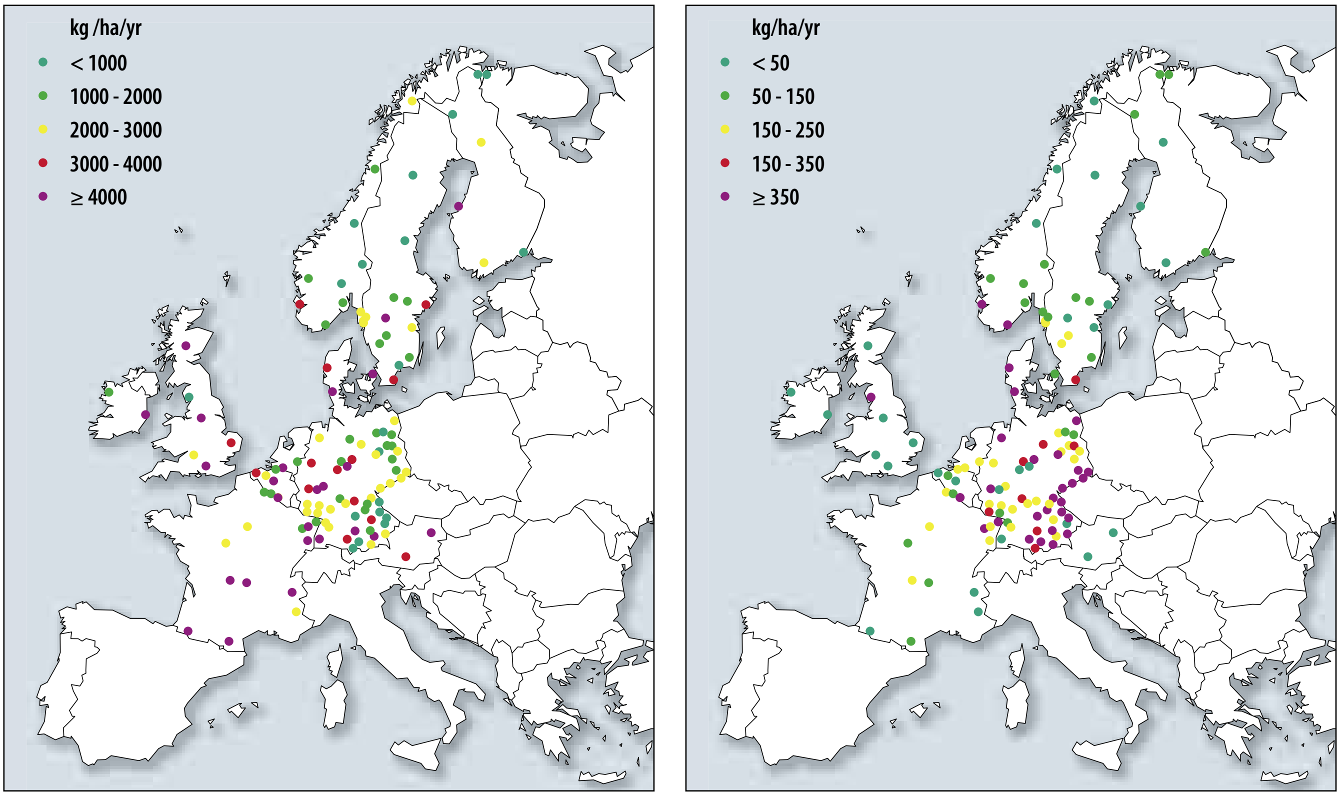


Figure 5-2: Calculated annual net carbon sequestration (kgC/ha/yr) in trees (left) and soil (right) at 121 Intensive Monitoring Plots for the year 2000. Observe the different scales in the legend!

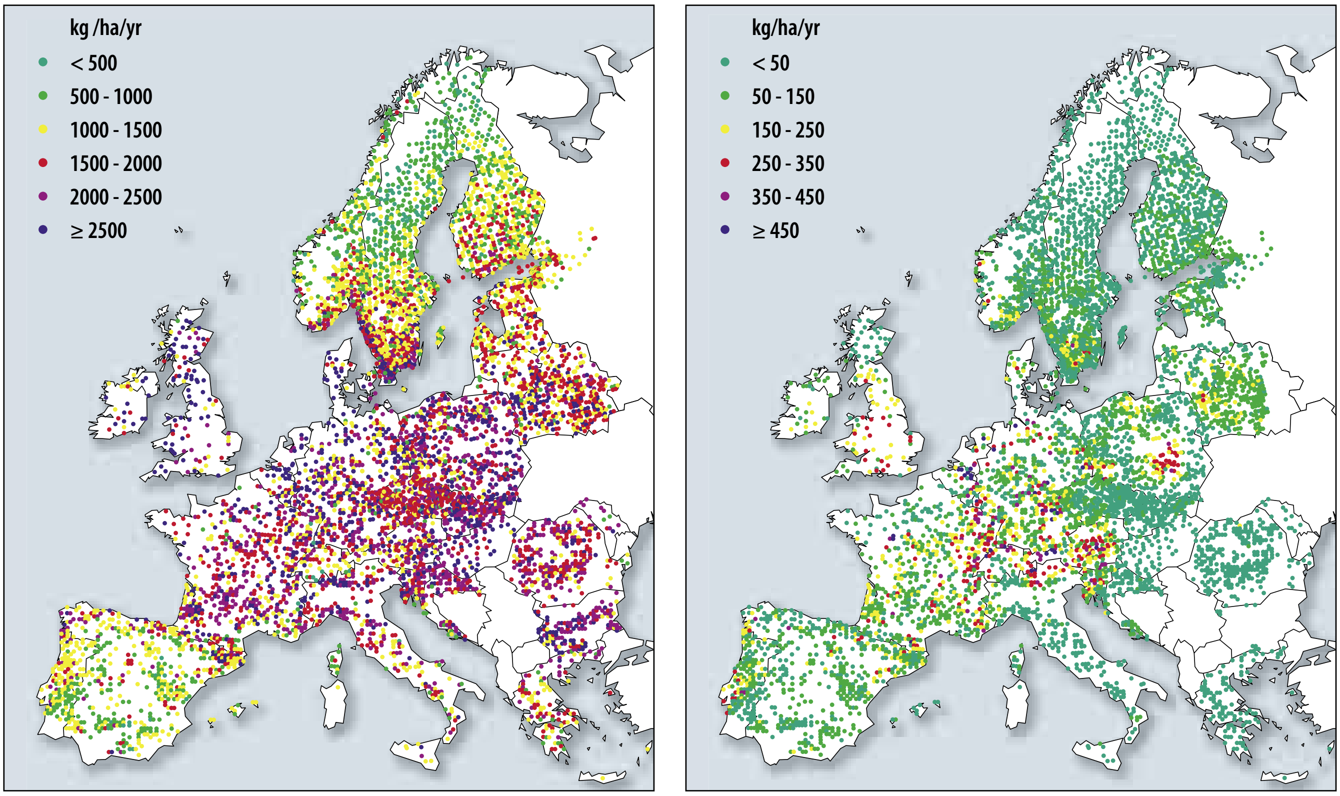


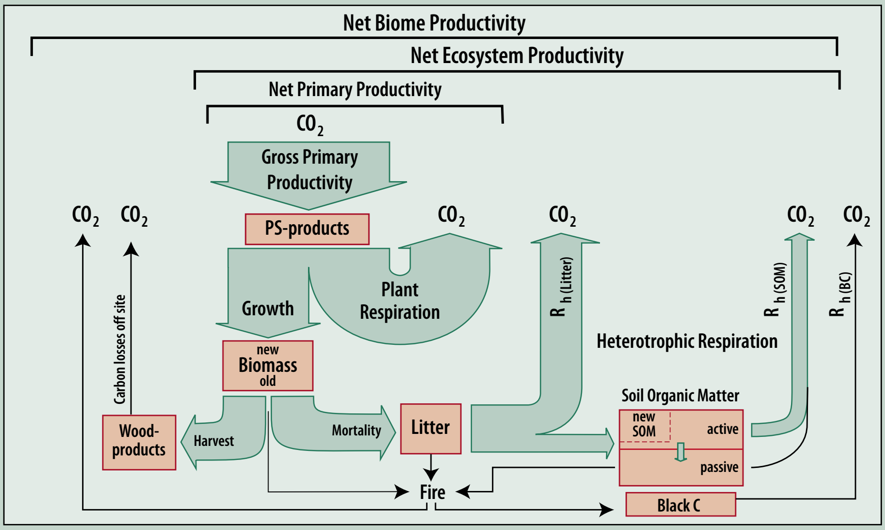
Figure 5-3: Calculated annual net carbon sequestration (kgC/ha/yr) in trees (left) and soil (right) at the 6 000 Level I plots for the year 2000. Observe the different scales in the legend!

Stands with high timber volumes at Level II plots store up to 250 tons of carbon per hectare (upper), whereas dark soils rich in organic matter accumulate up to 500 tons of carbon per hectare (lower). Carbon sequestration in above ground biomass is presently faster compared to soils. Carbon sequestration in soils is generally slow and can in many cases only be measured after decades.

Overall, the contribution of nitrogen deposition to carbon sequestration by tree wood and forest soil is likely to be low. Assuming an even smaller influence of elevated CO_2 concentrations and increasing temperature, this implies that the most likely cause for the increased carbon pools in standing biomass in Europe is the fact that overall timber removal is less than overall increment in existing and newly afforested stands. This hypothesis will require substantiation in the coming years.

Further reading:

De Vries, W., G.J. Reinds, M. Posch, M. J. Sanz, G.H.M. Krause, V. Calatayud, J.P. Renaud, J.L. Dupouey, H. Sterba, M. Dobbertin, P. Gundersen, J.C.H. Voogd and E.M. Vel, 2003. Intensive Monitoring of Forest Ecosystems in Europe. Technical Report. EC, UNECE 2003, Brussels, Geneva, 170 pp.



The carbon cycle. Terrestrial uptake of CO_2 is governed by the net biome production (NBP), which is the balance of net ecosystem productivity (NEP) and carbon losses due to fire, and harvested biomass.

CARBON SEQUESTRATION

Carbon Dioxide: Global situation, implications, research and policy reactions

Results of the Intergovernmental Panel on Climate Change (IPCC) indicate that:

- The earth's climate has demonstrably changed since the pre-industrial era. Since 1750, the atmospheric carbon dioxide (CO_2) concentration has increased by around 30% worldwide. The rate of increase over the past century is unprecedented, at least during the past 20 000 years.
- The present atmospheric CO_2 increase is caused by anthropogenic emissions. About three-quarters of these emissions are due to fossil fuel burning. Land use change, mainly deforestation, is responsible for the rest of the emissions.
- CO_2 concentrations as well as globally averaged surface temperature are projected to increase in the 21st century under all calculated scenarios.

Carbon interactions

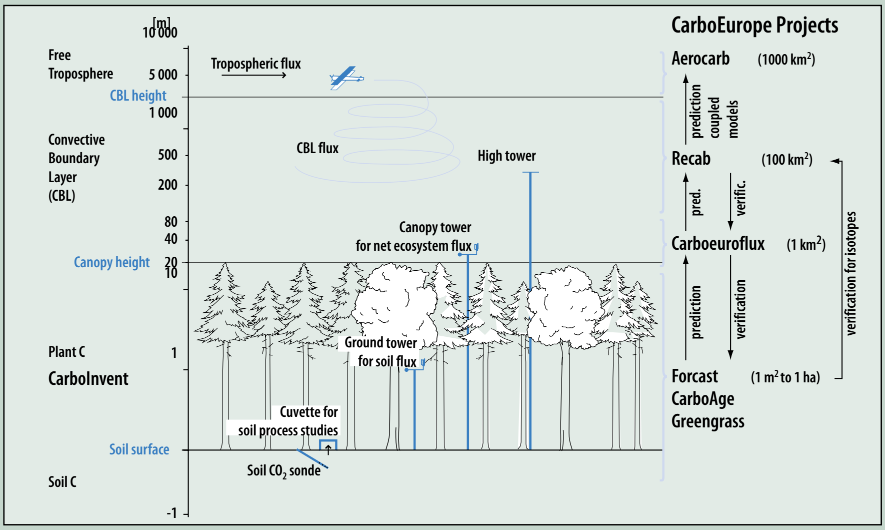
- Through photosynthesis, growing plants take up CO_2. They release oxygen to the ambient air and use the carbon as main component for building up biomass. Wood and the soil sequester carbon for long time periods; therefore they are regarded as effective carbon sinks. Forest management can enhance carbon uptake through the establishment of biomass rich stands and soil protection.
- Globally, oceans are the most important carbon sinks. However, the higher the CO_2 concentration, the lower the fraction that is taken up by the oceans.

Kyoto Protocol

In 2002 the European Community ratified the Kyoto Protocol within the UN Framework Convention on Climate Change and thus committed itself to an 8% reduction of CO_2 emissions by 2012 compared to the levels in 1990. The commitments for reductions vary among the signatory parties.

CarboEurope

CarboEurope is a research project cluster of the EU which develops methodologies to quantify the European carbon balance in view of the Kyoto Protocol. Carbon is measured and modeled at various scales ranging from tropospheric CO_2 concentrations to carbon flux measurements above the vegetation surface, and process measurements in soils. EU/ICP Forests data are contributing to the project. There is still a very large uncertainty in the estimates of the overall carbon balance. However, the most elaborate compilation of existing information suggests that, within Europe, forests represent the largest sink.



Set-up of CarboEurope

Cladonia chlorophaea is a commonly found lichen species in Scandinavian coniferous forests.

6. BIODIVERSITY ON INTENSIVE MONITORING PLOTS

Summary

- *The existing programme database contains valuable information on various aspects related to biological diversity in forests, including ground vegetation, tree species and size, stand age, and standing dead wood. When evaluating this together with other data assessed at the same plots – like deposition, weather conditions, biotic agents – the programme has potential to contribute to the international discussion on forest biological diversity.*
- *The ICP Forests test phase for further development of assessment methods and index calculation was launched in 2003. It also aims at exploring relations between key biodiversity factors such as stand structure and vegetation.*

Introduction

Since the UNCED Conference in Rio de Janeiro in 1992, biodiversity has gained attention in forests worldwide. It is now widely recognised as an important aspect in the evaluation and management of ecosystems. This is also in line with the processes of the Ministerial Conference on the Protection of Forests in Europe (MCPFE). Within the EU/ICP Forests monitoring programme, a study has investigated how far the existing intensive monitoring data could contribute to the understanding of biodiversity in forest ecosystems, keeping in mind the role of air pollution.

Ground vegetation in relation to environmental influences

In addition to tree species, ground vegetation is the strongest biodiversity indicator in Level II plots. Using multivariate statistics the relation between ground vegetation species and nitrogen deposition, as well as many other environmental factors, was evaluated. Statistically, 20 of those 63 species that were present on at least 50 plots showed a significant reaction to nitrogen deposition. Hemp-nettle (*Galeopsis tetrahit*) is one of the species that in particular occurs on plots with higher nitrogen deposition. Ground vegetation is a powerful bio-indicator for several environmental influences. It can give integrated information about soil fertility, acidity, nitrogen status, water availability, or climate conditions as well as of their changes.

Biodiversity parameters available in the current programme

From the existing data, parameters were tested which describe aspects of biodiversity at almost 800 Level II plots. They include species compo-

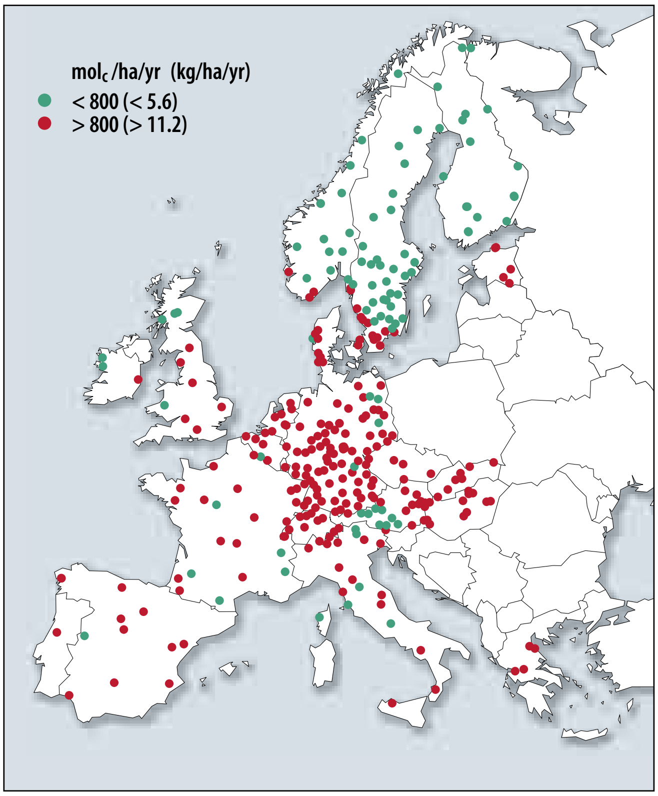


Figure 6-1: Total nitrogen deposition on Level II plots, 1998 - 2000. Modelled values in kg/ha/yr

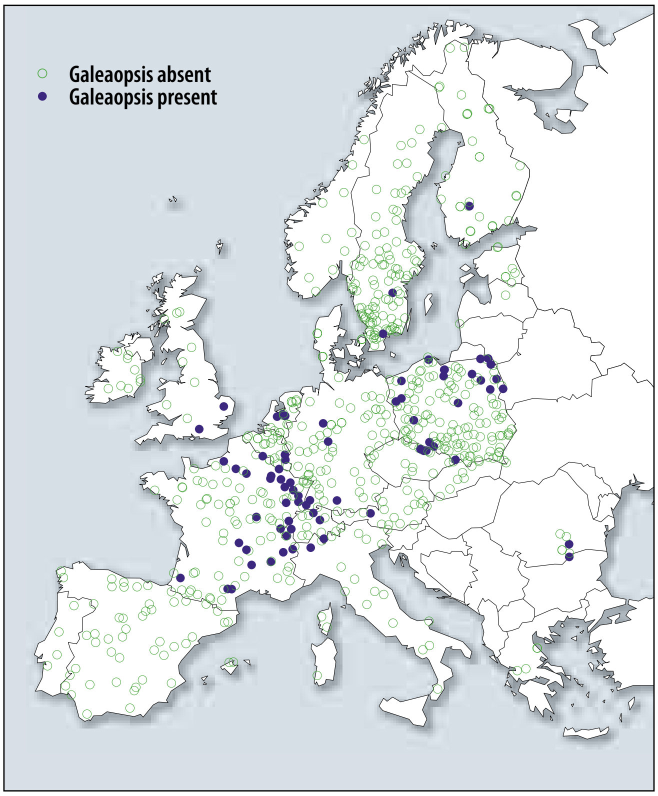


Figure 6-2: Occurrence of the herb Galeopsis tetrahit on Level II plots

Hemp-nettle (Galeopsis tetrahit) usually grows on nutrient rich soils and flowers from June to September.

Zannone Island situated off the Tyrrhenian coast in Italy is one of the few spots in southern Europe where forests hardly ever experienced direct human influence. Such remnants are today mostly strictly protected and serve as reference areas for sustainable management of other forests. Nevertheless, the flora of the island has demonstrably changed in past decades due to changing climate.

sition and stand structure, the latter being an important component and indicator of forest biodiversity. Stand age is important structural information because old stands generally offer richer habitats for many species groups. Also the variation of tree diameters within the stands can be calculated from the existing data and is of particular interest from a biodiversity point of view as such a variation is mostly linked to more ecological niches in a forest. Other stand structural parameters that can be calculated from the existing data are number of giant trees and number of dead trees per hectare. Compositional parameters are number of tree and ground vegetation species.

Outlook

The EU/ICP Forests Working Group on Biodiversity has made proposals for additional surveys that could contribute to the assessment of forest biodiversity in Europe. These methods include epiphytic lichen monitoring, improved stand structural assessments, the application of a forest type stratification, extended ground vegetation assessments and more detailed deadwood assessments. Data evaluation, including the elaboration of specific indices and their possible aggregation to more comprehensive indices, is another important task for the programme's experts. It is also planned to explore relations between biodiversity key factors such as stand structure and vegetation and thus contribute to the development of indictors applicable to a larger number of plots. Within ICP Forests, a test phase has been launched to carry out these activities. Cooperation between international organisations in the field of biodiversity is essential to reach highest possible synergy.

7. CONCLUSIONS

Main findings

1. Forests in Europe react to changing environmental conditions. Air pollution is one of the causes for changing forest condition. Different indicators reflect these changes:

- *Defoliation of main tree species remained high in 2002, with one fifth of the assessed trees classified as damaged. Defoliation was mainly related to unfavourable weather conditions, biotic factors and air pollution.*
- *Decreasing sulphur concentrations in pine and spruce needles reflect reduced sulphur deposition in recent decades.*
- *Earlier flushing and a longer growing season of spruce were correlated with changing climatic conditions.*

2. Scenario analyses assuming emission reductions according to international agreements predict a decrease of sulphur and nitrogen concentrations in the soil solution. The soil solid phase recovery can take much longer indicating that forest ecosystems will suffer for a long time from high deposition loads.

3. First evaluations of ozone measurements on the forest plots confirm high ozone concentrations in southern Europe. Ozone injury was visible on leaves of some main tree species such as beech as well as some ground vegetation species that have not been known to be ozone sensitive before.

4. At the European level, annual net carbon sequestration in trees was found to be 5-7 times as high as in forest soils. The extrapolation to the forest area of Europe corrected for harvesting and fire yield an average rate of 0.1 Gigatons per year. Increased forest growth due to nitrogen deposition resulted in a 5% increase in annual carbon sequestration.

Forest condition

The condition of European forests is changing under present environmental conditions. ICP Forests and EU are managing one of the world's largest biomonitoring networks in order to quantify these changes and to contribute to the understanding of cause-effect relationships.

Deposition

Air pollution is one of the causes of changing forest condition and a main field of the programme's monitoring activities. This report reflects the success of sulphur emission reductions of the last decades. Scenario analyses based on the Gothenburg Protocol of the Convention on Long-range Transboundary Air Pollution also predict a decrease of nitrate concentrations in the soil solution of most plots. However, atmospheric deposition is still increasing in many

Forest in Norway

regions with developing industries, requiring continued deposition monitoring expertise. In this context the achievements of ICP Forests and the EU have been acknowledged through the United Nations Forum on Forests at its third session and its monitoring methods have also been recommended for other regions of the world.

Ozone and carbon sequestration

Ozone concentrations above critical levels and rising carbon dioxide concentrations have become a threat to forest ecosystems. In 2002, the percentage of trees with damaged crowns remained high and visible ozone injuries were detected on many plots. It is still unclear how forest ecosystems on the large scale respond to rising concentrations of greenhouse gases and climate change, and the complex interactions between them. Already, open air research shows interactions between carbon dioxide and ozone. Results in this report show the effect of nitrogen deposition on carbon sequestration. With its unique system of monitoring plots and its database, the programme is in a strong position to provide a sound basis for future environmental policies in these fields.

Biodiversity

Various indicators assessed in the programme show that forest trees react to changing environmental conditions in different ways. During an ICP Forests biodiversity test phase, new monitoring methods will be developed. Additional indicators will help to improve and refine the documentation of the forests' diversity, with differing structure, composition and function.

Outlook

The programme will continue its regular overviews on forest condition in Europe. It will further produce policy relevant key information on stress factors such as air pollution and in this context will also contribute urgently needed information on climate change and forest biodiversity. Thus the monitoring activities will provide a sound basis for clean air and environmental policy as well as for sustainable forest management in the future.

ANNEX I: FORESTS, SURVEYS AND DEFOLIATION CLASSES IN EUROPEAN COUNTRIES (2002)

Results of national surveys as submitted by National Focal Centres

Participating countries	Forest area (x 1000 ha)	% of forest area	Grid size (kmxkm)	No. of sample plots	No. of sample trees	Defoliation of all species by class (aggregates), national surveys		
						0	1	2-4
Albania	1028	35.8	10x10	299	8970	42.4	44.5	13.1
Austria	3878	46.2	8.7x8.7	264	7029	60.2	29.6	10.2
Belarus	7845	37.8	16x16	407	9690	34.9	55.6	9.5
Belgium	691	22.8	4x4/8x8	132	3079	38.7	43.5	17.8
Bulgaria	3314	29.9	4x4/8x8/16x16	141	5303	24.1	38.8	37.1
Croatia	2061	36.5	16x16	80	1910	38.4	41.0	20.6
Cyprus	298	32.2	16x16	15	360	30.8	66.4	2.8
Czech Republic	2630	33.4	8x8/16x16	140	7013	11.6	35.0	53.4
Denmark	468	10.9	7x7/16x16	20	480	61.5	29.8	8.7
Estonia	2249	49.9	16x16	93	2169	45.9	46.5	7.6
Finland	20032	65.8	16x16/24x32	457	8593	54.6	33.9	11.5
France	14591	26.6	16x16	518	10355	40.1	38.0	21.9
Germany	10264	28.9	4x4/16x16	447	13534	35.1	43.5	21.4
Greece	2512	19.5	16x16	75	1768	42.1	37.0	20.9
Hungary	1804	19.4	4x4	1143	26921	38.1	40.7	21.2
Ireland	436	6.3	16x16	21	424	43.9	35.4	20.7
Italy	8675	28.8	16x16	258	7165	20.3	42.4	37.3
Latvia	2902	44.9	8x8	364	8682	19.8	66.4	13.8
Liechtenstein	8	50.0						
Lithuania	1858	28.5	8x8/16x16	220	5162	16.4	70.8	12.8
Luxembourg	89	34.4						
Rep. of Moldova	318	9.4	2x2	480	11489	25.2	32.3	42.5
The Netherlands	334	9.6	16x16	11	231	57.1	21.2	21.7
Norway	12000	37.1	3x3/9x9	1504	7421	35.0	39.5	25.5
Poland	8756	28.0	varying	1229	24580	8.8	58.5	32.7
Portugal	3234	36.4	16x16	145	4350	47.8	42.6	9.6
Romania	6244	26.3	4x4	4028	104366	62.7	23.8	13.5
Russian Federation	8125	73.2	varying	183	4144	37.9	51.2	10.9
Serbia Montenegro			16x16	46	1104	80.8	15.3	3.9
Slovak Republic	1961	40.0	16x16	111	4207	17.3	57.9	24.8
Slovenia	1099	54.2	16x16	39	936	32.3	39.6	28.1
Spain	11588	23.4	16x16	620	14880	24.2	59.4	16.4
Sweden	23400	57.1	varying	4180	16671	49.2	35.0	15.8
Switzerland	1186	28.7	16x16	49	1064	23.4	58.0	18.6
Turkey	20199	25.9						
Ukraine	9316	15.4	16x16	49	1204	8.9	63.4	27.7
United Kingdom	2156	8.9	random	356	8532	27.3	45.4	27.3
TOTAL	197549		varying	18124	333786			

Greece: Excluding maquis.
Sweden, Norway: Special study on birch.
Serbia and Montenegro: Montenegro only.
Russian Federation: Only regional surveys in northwestern and Central European parts of the Russian Federation.

Note that some differences in the level of damage across national borders may be at least partly due to differences in standards used. This restriction, however, does not affect the reliability of the trends over time.

ANNEX II: DEFOLIATION OF ALL SPECIES (1991-2002)

Results of national surveys as submitted by National Focal Centres

Participating countries	All species defoliation classes 2-4												change % points
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2001 / 2002
Albania								9.8	9.9	10.1	10.2	13.1	2.9
Austria	7.5	6.9	8.2	7.8	6.6	7.9	7.1	6.7	6.8	8.9	9.7	10.2	0.5
Belarus		29.2	29.3	37.4	38.3	39.7	36.3	30.5	26.0	24.0	20.7	9.5	-11.2
Belgium	17.9	16.9	14.8	16.9	24.5	21.2	17.4	17.0	17.7	19.0	17.9	17.8	-0.1
Bulgaria	21.8	23.1	23.2	28.9	38.0	39.2	49.6	60.2	44.2	46.3	33.8	37.1	3.3
Croatia		15.6	19.2	28.8	39.8	30.1	33.1	25.6	23.1	23.4	25.0	20.6	-4.4
Cyprus											8.9	2.8	-6.1
Czech Republic	45.3	56.1	51.8	57.7	58.5	71.9	68.6	48.8	50.4	51.7	52.1	53.4	1.3
Denmark	29.9	25.9	33.4	36.5	36.6	28.0	20.7	22.0	13.2	11.0	7.4	8.7	1.3
Estonia	*	*	*	*	*	*	*	8.7	8.7	7.4	8.5	7.6	-0.9
Finland	16.0	14.5	15.2	13.0	13.3	13.2	12.2	11.8	11.4	11.6	11.0	11.5	0.5
France	7.1	8.0	8.3	8.4	12.5	17.8	25.2	23.3	19.7	18.3	20.3	21.9	1.6
Germany	25.2	26.4	24.2	24.4	22.1	20.3	19.8	21.0	21.7	23.0	21.9	21.4	-0.5
Greece	16.9	18.1	21.2	23.2	25.1	23.9	23.7	21.7	16.6	18.2	21.7	20.9	-0.8
Hungary	19.6	21.5	21.0	21.7	20.0	19.2	19.4	19.0	18.2	20.8	21.2	21.2	0.0
Ireland	15.0	15.7	29.6	19.7	26.3	13.0	13.6	16.1	13.0	14.6	17.4	20.7	3.3
Italy	16.4	18.2	17.6	19.5	18.9	29.9	35.8	35.9	35.3	34.4	38.4	37.3	-1.1
Latvia		37.0	35.0	30.0	20.0	21.2	19.2	16.6	18.9	20.7	15.6	13.8	-1.8
Liechtenstein		16.0											
Lithuania	23.9	17.5	27.4	25.4	24.9	12.6	14.5	15.7	11.6	13.9	11.7	12.8	1.1
Luxembourg	20.8	20.4	23.8	34.8	38.3	37.5	29.9	25.3		23.4			
Rep. of Moldova			50.8		40.4	41.2				29.1	36.9	42.5	5.6
The Netherlands	17.2	33.4	25.0	19.4	32.0	34.1	34.6	31.0		21.8	19.9	21.7	1.8
Norway	19.7	26.2	24.9	27.5	28.8	29.4	30.7	30.6	28.6	24.3	27.2	25.5	-1.7
Poland	45.0	48.8	50.0	54.9	52.6	39.7	36.6	34.6	30.6	32.0	30.6	32.7	2.1
Portugal	29.6	22.5	7.3	5.7	9.1	7.3	8.3	10.2	11.1	10.3	10.1	9.6	-0.5
Romania	9.7	16.7	20.5	21.2	21.2	16.9	15.6	12.3	12.7	14.3	13.3	13.5	0.2
Russian Federation				10.7	12.5						9.8	10.9	1.1
Serbia Montenegro	9.8					3.6	7.7	8.4	11.2	8.4	14.0	3.9	-10.1
Slovak Republic	28.5	36.0	37.6	41.8	42.6	34.0	31.0	32.5	27.8	23.5	31.7	24.8	-6.9
Slovenia	15.9		19.0	16.0	24.7	19.0	25.7	27.6	29.1	24.8	28.9	28.1	-0.8
Spain	7.4	12.3	13.0	19.4	23.5	19.4	13.7	13.6	12.9	13.8	13.0	16.4	3.4
Sweden	*	*	*	*	14.2	17.4	14.9	14.2	13.2	13.7	17.5	15.8	-1.7
Switzerland	16.1	12.8	15.4	18.2	24.6	20.8	16.9	19.1	19.0	29.4	18.2	18.6	0.4
Turkey													
Ukraine	6.4	16.3	21.5	32.4	29.6	46.0	31.4	51.5	56.2	60.7	39.6	27.7	-11.9
United Kingdom	56.7	58.3	16.9	13.9	13.6	14.3	19.0	21.1	21.4	21.6	21.1	27.3	6.2

* = only conifers assesed

Czech Republic: Only trees older than 60 years assessed until 1997.

France: Due to methodological changes, only the time series 1990-94 and 1997-2002 are consistent, but not comparable to each other.

Germany: For 1990, only data for former Federal Republic of Germany.

Greece: Excluding maquis.

Italy: Due to methodological changes, only the time series 1989-96 and 1997-2002 are consistent, but not comparable to each other.

Serbia and Montenegro: In 2002, Montenegro only.

Russian Federation: Only regional surveys in northwestern and Central European parts of the Russian Federation.

United Kingdom: The difference between 1992 and subsequent years is mainly due to a change in assessment method in line with that used in other States.

ANNEX III

Tree species referred to in the text

Aleppo pine:	*Pinus halepensis*
Common beech:	*Fagus sylvatica*
European oak:	*Quercus robur*
Grey alder:	*Alnus incana*
Holm oak:	*Quercus ilex*
Maritime pine:	*Pinus pinaster*
Norway spruce:	*Picea abies*
Scots pine:	*Pinus sylvestris*
Sessile oak:	*Quercus petraea*
Silver fir:	*Abies alba*

Photo references

D. Aamlid: pp. 7, 10, 22, 23, 33 bottom, 35, 38/39; E. Beuker: p. 20; A. Fischer p. 31, R. Fischer: pp. 13, 18, 30, 33 top, 37; A. Fürst: p. 21 right; H.-D. Gregor: p. 6; K. Häberle: p. 29 top; D. Karnosky: p. 29 bottom; J. Kribbel: p. 36; M. Lorenz: p. 8/9; S. Meining: p. 19 right; M. Minaya: p. 26; E. Oksanen: pp. 11, 21 left; M.J. Sanz: p. 28 right; M. Schaub: p. 28 left, middle; H. Schröter: p. 19 left/middle; W. Seidling: p. 14

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