LRTAP
Long-range Transboundary Air Pollution

The Condition of Forests in Europe

2011 Executive Report






Institute for World Forestry

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ICP Forests

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forest monitoring for the future

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Preface

It is a pleasure for me to introduce the present Executive Report of ICP Forests and of the European Commission. Denmark's Ministry of the Environment supports and encourages the ongoing work of the programme and has hosted this year's Task Force meeting.

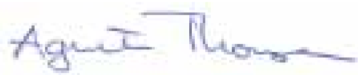
ICP Forests in cooperation with the European Commission utilizes harmonized methods and newest technology to gather data on the condition of forests in Europe. In recent years, the aims of ICP Forests have changed and broadened as new topics have become pressingly important, such as climate change, carbon sequestration, recreational values, biodiversity and other forest services. In close cooperation with the LIFE+ project FutMon, co-funded by the European Commission, ICP Forests has revised the European Monitoring System (i.e. methods, manuals, database), making the monitoring system more efficient, and ensuring a high degree of comparability between the datasets from different countries.

The data and findings from ICP Forests provide key information for managing the European forests in a future with changing climatic conditions and changing deposition of atmospheric air pollutants, while forest managers are also facing the challenge of halting the loss of biodiversity. Valuable knowledge concerning ongoing processes in the forest ecosystem has been obtained and utilized during the past 25 years. The future challenges of the programme lie in providing up to date information and in keeping the monitoring system sufficiently flexible that it is able to respond to ever more complex information needs.

Agnete Thomsen, Deputy Director General

I am convinced that based on the well-proven expertise and established infrastructure, ICP Forests and the European Commission will respond to these requirements and I would like to thank all involved participants for their qualified work.

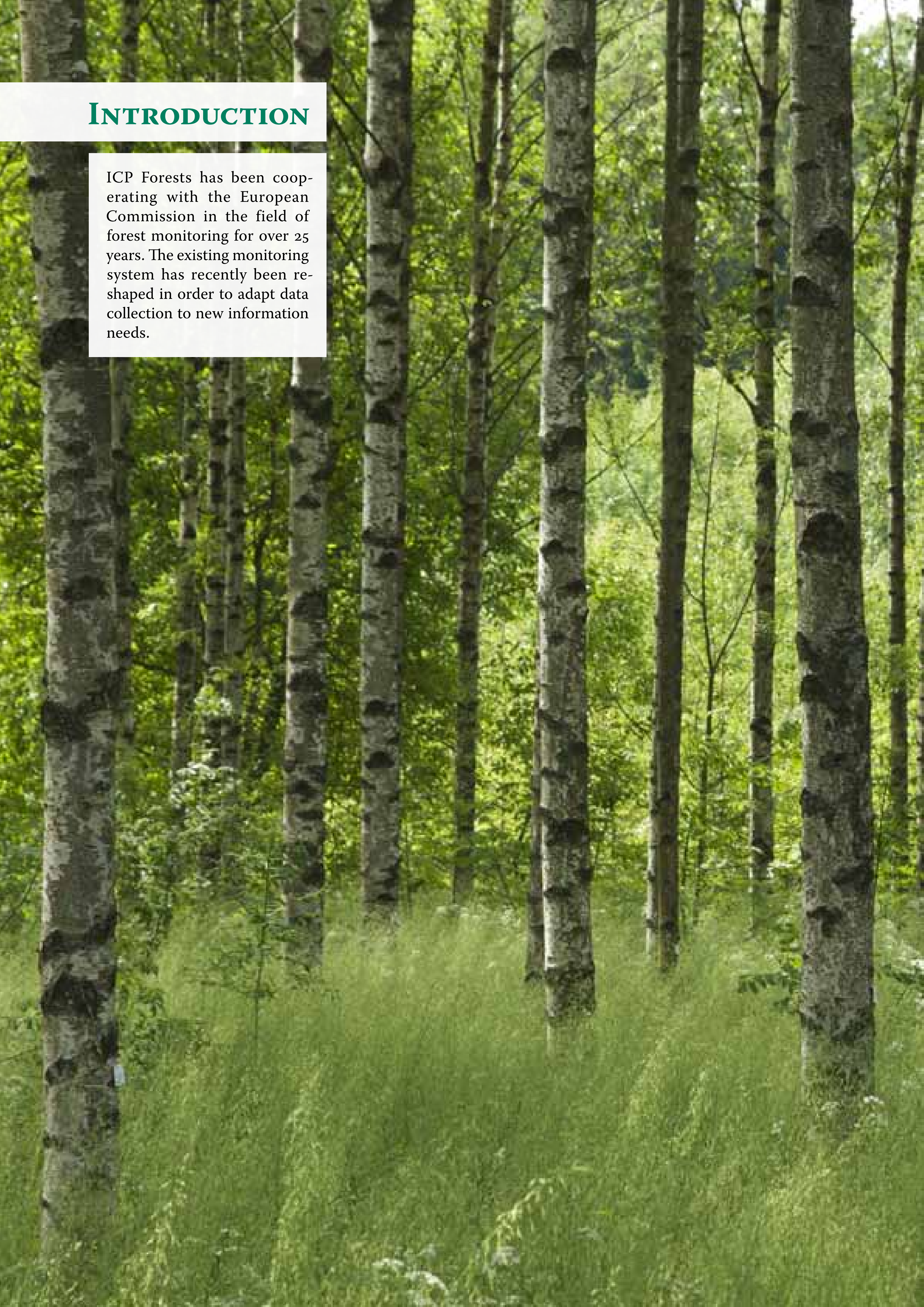
Danish Ministry of the Environment
Danish Nature Agency



Agnete Thomsen
Deputy Director General

Introduction

ICP Forests has been cooperating with the European Commission in the field of forest monitoring for over 25 years. The existing monitoring system has recently been reshaped in order to adapt data collection to new information needs.



1. Harmonized pan-European forest monitoring

Data for forest management and policy making

One third of Europe's land surface is covered by forests. Over large areas these forests constitute the natural ecosystems of the continent. They are a basis for economic activity and play a significant role in the development of rural areas, as well as being used for recreational purposes. The forests have major value in terms of nature conservation and environmental protection, and by acting as significant carbon sinks are very important in the context of climate change. Sustainable forest management and good environmental policy rely on the sound scientific resource provided by long-term, large-scale and intensive monitoring of forest condition.

Monitoring for the long term

The International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was established in 1985. The programme operates under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and provides regular updates on the condition of forests in Europe as a basis for the development of air pollution abatement strategies.

Since 1986, ICP Forests has been closely cooperating with the European Union. Up until 2006 this cooperation was based on a number of specific regulations. The 'Forest Focus' regulation (EC No 2152/2003) was the last of these regulations and constituted the legal basis for the co-financing of monitoring activities until 2006. Since its adoption in 2007, the 'LIFE+' Regulation (EC No. 614/2007) has formed the legal basis for co-financing of the future development of forest monitoring in the European Union.

The 'FutMon' project, providing co-financing under the LIFE+ regulation until mid-2011, has supported harmonised forest monitoring by linking existing and new monitoring mechanisms at the national, regional and EU level. Intensive monitoring activities have been reshaped over the past couple of years, with a drop in the number of plots monitored but an increase in the range of intensive measurements on those that remain. As a result, improved quantitative and qualitative forest data related to climate change, air pollution, biodiversity, and forest condition are now available.

The monitoring activities provide information for a number of criteria and indicators of sustainable forest management as defined by the Forest Europe Ministerial Conference on the Protection of Forests in Europe. Data are also contributed to the Framework Convention on Climate Change (FCCC) and the Convention on Biological Diversity (CBD). The programme also maintains close contacts with the Acid Deposition Monitoring Network in East Asia (EANET).

Challenging objectives and a unique monitoring system

One objective of the ICP Forests programme is to assess the status and development of European forest health and vitality at the large scale. Air pollution effects have been the original focus of the programme. Data are collected by participating countries on up to 7500 permanent and representative observation plots, known as 'Level I' plots. In many countries the Level I plots are a subset of national forest inventory systems. In addition to the annual crown condition surveys, a BioSoil demonstration project was undertaken in 2006 on Level I plots. Many of these plots were part of a soil survey undertaken in the early 1990s in many European countries.

To detect the influence of various stress factors on forest ecosystems, intensive monitoring is carried out on around 500 so-called 'Level II' plots (Table 1-1). These provide detailed data on trees, soil, water and meteorology and related stress factors and are located in forests that represent the most important forest ecosystems in Europe. Monitoring methodology has been documented from the start of the programme in a harmonized monitoring manual. This manual has been revised and updated as part of the FutMon project. Regular control analyses, laboratory intercomparisons and intercalibration courses ensure high data quality.

Survey	Plots	Frequency
Tree crown condition	559/938	Annually
Foliar chemistry	308/859	Two years
Tree growth	256/820	Five years
Phenology	188/240	Annually[1)]
Litterfall	162/276	Continuously
Leaf Area Index	107/107	Once
Extended Tree Vitality	115/115	Annually[2)]
Soil condition	68/753	Ten years
Soil solution chemistry	196/338	Continuously
Soil water	46/46	Once
Deposition	287/654	Continuously
Ambient air quality (active)	28/46	Continuously
Ambient air quality (passive)	167/377	Continuously
Ozone induced injury	123/188	Annually
Meteorology	210/327	Continuously
Ground vegetation	169/815	Five years
Nutrient budget of ground veg.	83/83	Once

Table 1-1: Level II data surveys, monitoring plots (data submitted 2009/plots installed) and assessment frequencies. 1) Several times per year 2) Some plots continuously

Forest health and vitality

Crown condition is a fast-reacting indicator for many environmental factors affecting tree vitality. The annual large-scale assessments of the programme constitute a valuable early warning system that also provides information on the major directly visible damaging agents such as insects and fungi.

Photos: Maritime pine *(Pinus pinaster)* with slight and moderate defoliation (top) and different stages of severe defoliation (bottom). Mediterranean lowland pines have shown comparatively low, but increasing defoliation over the past ten years.

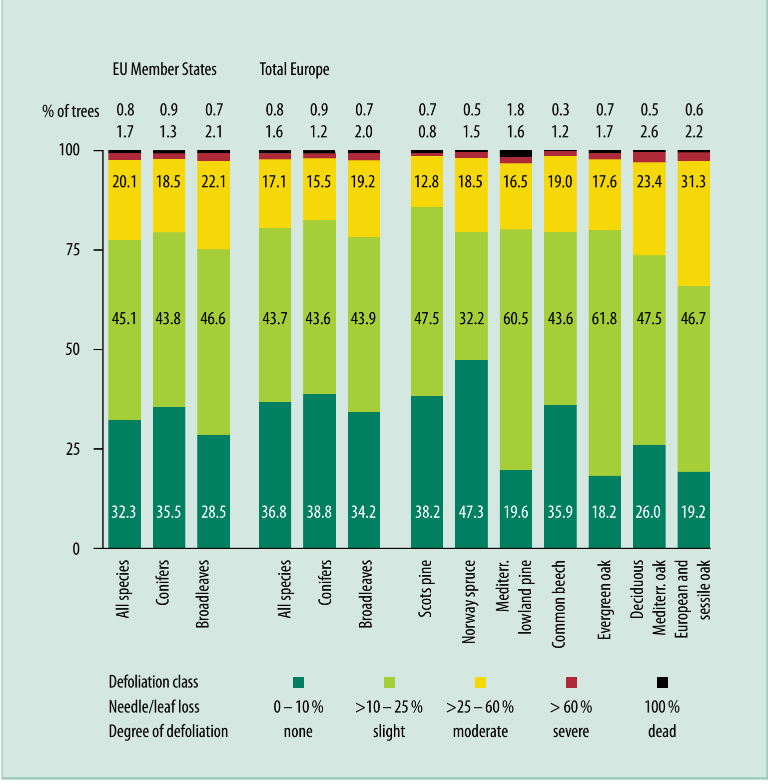


Figure 2-1: Extent of defoliation for the main European tree species (-groups) in 2010.

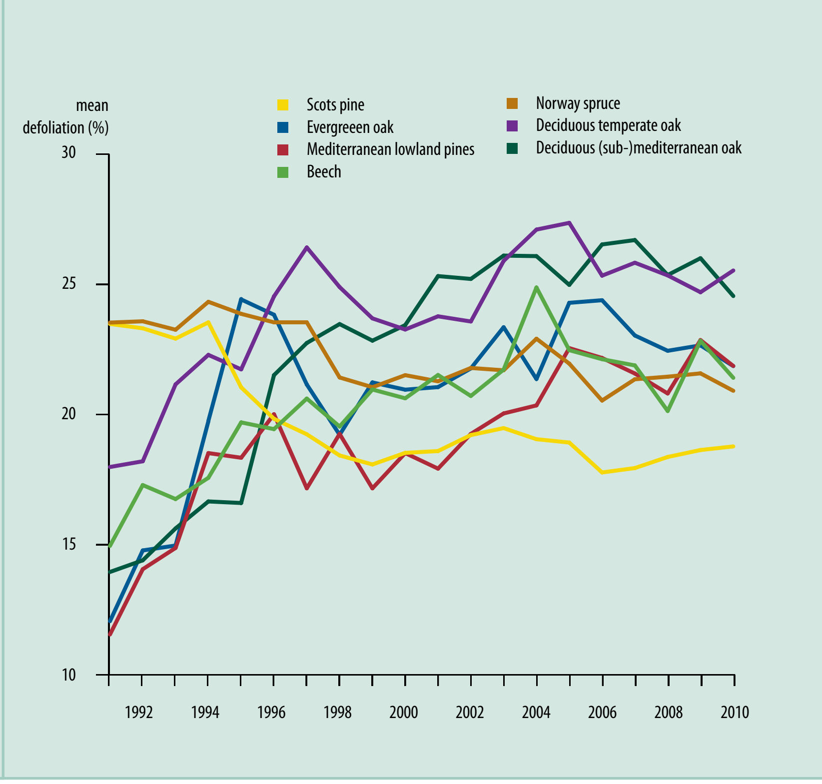


Figure 2-2: Mean percentage defoliation for the most frequent tree species (-groups) in European forests. Samples only include countries with continuous data submission.

2. Little change in forest condition at the European scale

Summary

- *Forest health status has remained unchanged on around three-quarters of all plots continuously assessed since 2002. 19.5 % of all trees assessed were classified as either damaged or dead in 2010.*
- *Mediterranean and central European oak species have been the most severely damaged tree species over the past ten years. Scots pine and Norway spruce, the most frequently occurring species, show a comparably good and stable health status. Mediterranean lowland pines have shown an almost continuous decline over the past ten years.*
- *Insects and fungi are the most frequently occurring directly visible causes of tree damage. Even though many insect species naturally live and depend on forest trees, clusters of plots with high proportions of affected trees need to be observed more carefully. Such clusters occur at the eastern edge of the Pyreneans, the Apennine Mountains and in Cyprus.*

A fifth of all trees rated as damaged

In 2010, 19.5 % of all trees assessed had a needle or leaf loss of more than 25 % and were thus classified as either damaged or dead (Fig. 2-1). Of the main tree species, European and sessile oak had the highest levels of damaged and dead trees, at 34.2 %. The percentage was lower for conifers (17.6 %) than broadleaves (21.9 %). Defoliation represents a valuable early warning system for the response of the forest ecosystems to change – this is particularly relevant as climatic extremes are predicted to occur more frequently in the relatively near future.

Highest damage in oaks, damage in Mediterranean pines increasing

There was no change in tree crown condition on 73.2 % of the plots continuously assessed since 2002. Defoliation increased on 16.9 % of plots monitored and decreased, indicating an improvement in crown condition, on only 10.0 % (Fig. 2-3).

Deciduous oaks have been the most severely defoliated tree species over the past five years (Fig. 2-2). Defoliation of deciduous Mediterranean oak peaked in 2006. Temperate oaks as well as beech trees showed highest defoliation after the dry and hot summer of 2003 but have since recovered. Scots pine is by far the most common tree species in the sample, occurring from northern Scandinavia to the Mediterranean region. Norway spruce is the second most frequently occurring tree species in the large-scale tree sample. For both species, the large sample sizes integrate regional differences at the European level and in general the low defoliation values indicate a stable health status. Mediterranean lowland pines show an almost constant decline in health over the past ten years. Mean defoliation of Mediterranean lowland pines in the sample increased from 17.1 % in 1999 to 22.6 % in 2005 and has since fluctuated. Plots with increasing defoliation are mainly located along the French Mediterranean coast and in northern Spain.

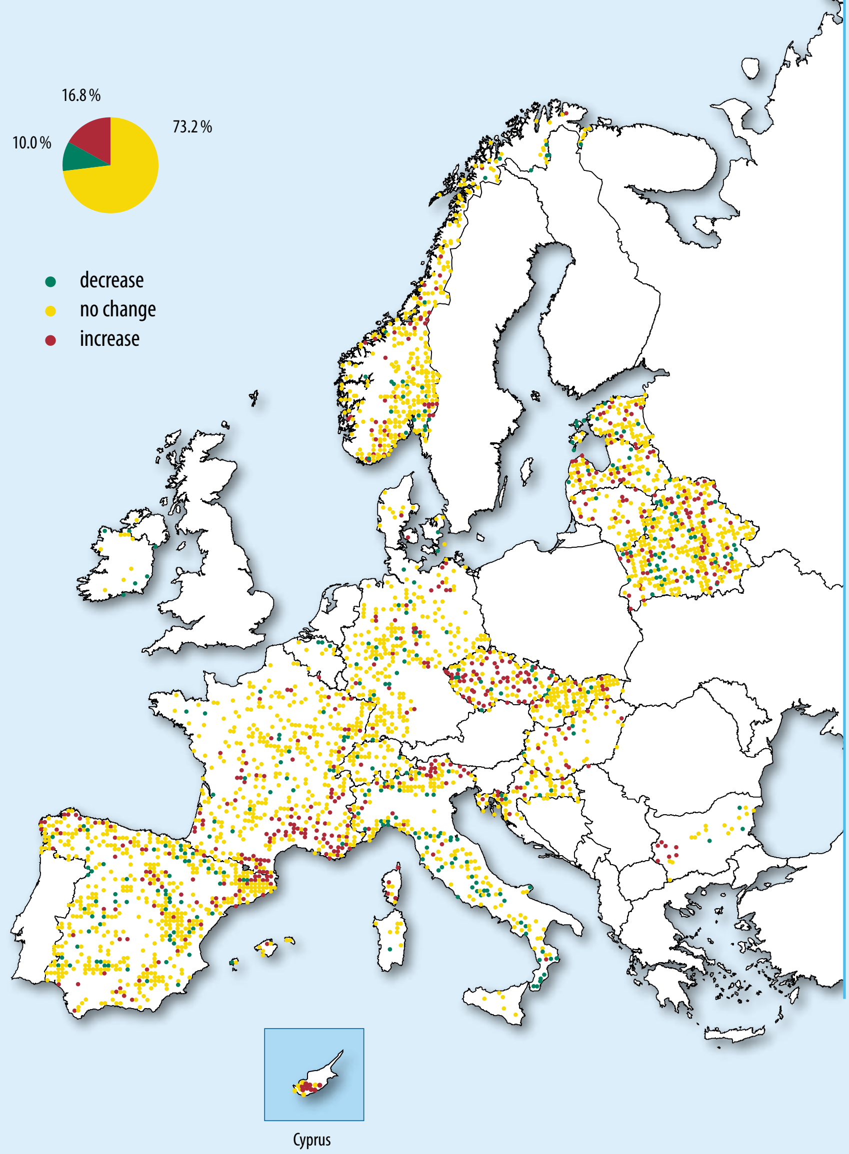


Figure 2-3: Development of mean plot defoliation for all species between 2002 and 2010.

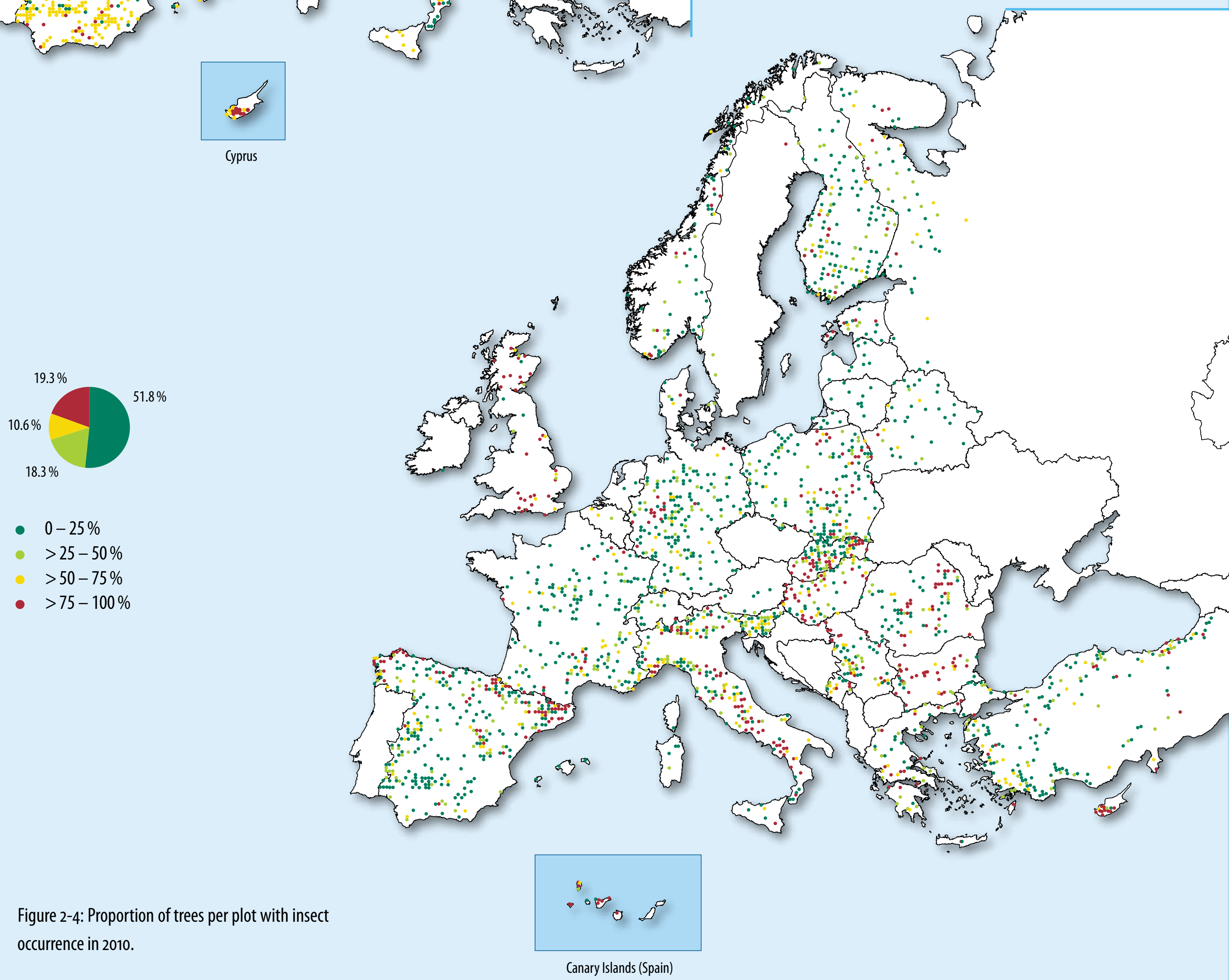


Figure 2-4: Proportion of trees per plot with insect occurrence in 2010.

Methods and data

The health status of European forest trees is monitored over large areas by surveys of tree crown condition. Trees that are fully foliated are considered healthy. The Forest Europe Ministerial Conference on the Protection of Forests in Europe uses defoliation as one of four indicators of forest health and vitality.

In 2010, crown condition data were submitted for 7503 plots in 33 countries. In total, 145 323 trees were assessed. This particularly large number of plots is mainly due to the re-approved co-financing of monitoring activities within the EU from 2009 to mid 2011 under the FutMon project which led to assessments on more plots than in earlier years. Montenegro submitted data for the first time. Finland (932 plots) and Sweden (830 plots) had the highest number of plots. Only countries with continuous assessments and data submission are used for temporal trend analyses. Within FutMon, the large-scale plots of ICP Forests were integrated with national forest inventories in many countries to increase synergies between the systems.

In 2010, causes of damage were assessed on 6413 plots in 32 countries. This is the highest number of assessed plots since the start of extended damage cause assessment in 2005. This is partly due to the first damage assessments having taken place on plots in Turkey (415 plots).

Tree species groups

For analysis, several oak species were aggregated into the following groups: Deciduous temperate oak (*Quercus robur, Q. petraea*), Mediterranean lowland pines (*Pinus brutia, P. pinaster, P. halepensis, P. pinea*), Deciduous (sub-) temperate oak (*Q. frainetto, Q. pubescens, Q. pyrenaica, Q. cerris*) and Evergreen oak (*Q. coccifera, Q. ilex, Q. rotundifolia, Q. suber*).

Insects currently the greatest cause of tree damage

Tree crown condition and thus the health status of forest trees depends on multiple influences. Damaging factors that are directly visible are regularly assessed together with defoliation. In 2010, over 20 000 trees corresponding to 27 % of the trees with damages recorded displayed symptoms caused by 'insects' (Fig. 2-5). Roughly half the insect-caused symptoms were attributed to leaf-eating insects (defoliators) with the remainder due to wood borers and other insects. Around 15 % of trees (just over 11 000) had damage caused by 'fungi'. 'Abiotic agents' such as drought or frost were responsible for damage in about 10 000 trees. 'Direct action of man' includes damage induced by harvesting operations or road construction. On roughly 20 000 trees, damage was registered but the cause could not be identified. Identification of specific types of tree damage requires highly specialized expert knowledge. Damage due to 'air pollution' only refers to the direct impacts of smoke or gaseous pollutants, indirect effects were not assessed. 'Game and grazing' only reflects damage to adult trees.

Many insect species naturally live and depend on forest trees. Thus, the information on insects influencing tree condition also reflects aspects of biodiversity and the observed symptoms are not exclusively interpreted as damage. However, when forests are already damaged by storms, drought or other stress factors, insect populations can increase and cause severe economic damage. Hot spots with high insect occurrence in 2010 were at the eastern edge of the Pyreneans, the Apennine Mountains, in Cyprus and in the east of the Slovak Republic (Fig. 2-4). Insect and fungi occurrence react dynamically to changing environmental conditions and their continued annual assessment is of high importance. The ICP Forests monitoring programme is the only system providing transnational and harmonized data on damaging agents on an annual basis.

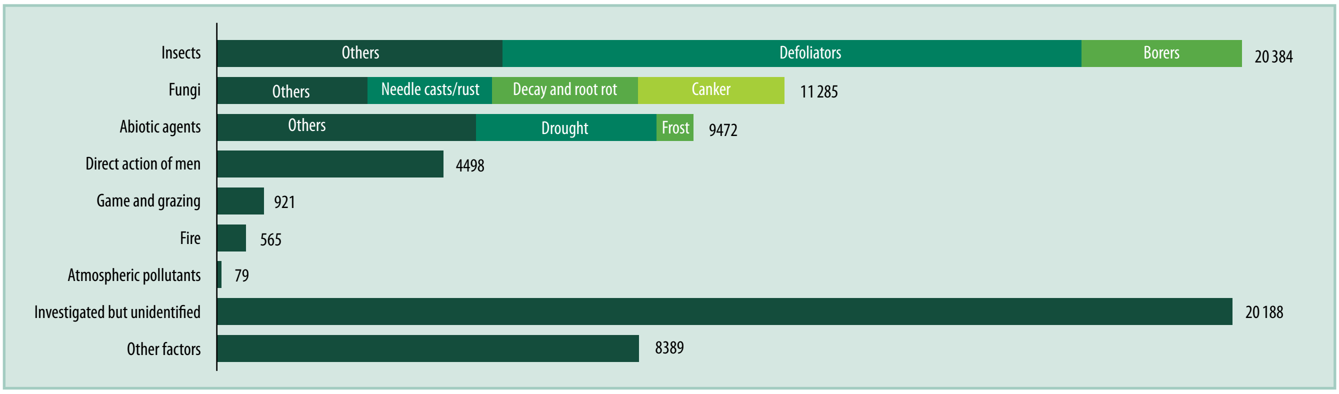


Figure 2-5: Frequency on different agents of trees in 2010. Figures indicate numbers of trees. Damage causes occurred on 64% of all trees assessed.

Soils and atmospheric deposition

Nutrient, carbon and water cycles depend on intact soils. Pollution and inadequate forest management practices are major threats. Forests are exposed to particularly high air pollution inputs as their large crown surfaces are very effective at capturing deposition.

Photo: Intensive Forest Monitoring plot in Finland with snow samplers (plasic bags), litterfall traps (green), wet deposition samplers (black/orange) and suction cup lysimeter for sampling of soil water (glass bottle).

3. Slight recovery only for extremely acid soils

Summary

- *A systematic forest soil survey based on over 5000 plots indicates that 14 % of plots suffer from soil nutrient imbalances induced by excess nitrogen input. Organic matter and nutrient cycling are likely to be disturbed at these sites and forest health and vitality may also be at risk. Over the past 15 years there has been little change in the C/N index.*
- *A slight recovery in soil acidification at the European level was only observed in extremely acidic forest soils, less acidic soils still showed increasing acidification.*
- *The soil data offer information about carbon storage in forest soils and show the importance of soils in the context of climate change mitigation. The highest organic carbon contents in the organic layer were reported for sites in the northwestern European region. An increase in organic carbon content was detected in most of the sites revisited, but uncertainties about changes in carbon stocks over the past 10 to 20 years remain high.*

Little change in soil nutrient imbalances

Disturbances in nutrient cycling as indicated by the C/N index mainly occur in central-western Europe and parts of central-eastern Europe and the Baltic States (Fig. 3-1). Forest growth is strongly stimulated by nitrogen deposition and by lower C/N ratios in the forest floor. However, if the forest soil cannot supply other nutrients in a balanced manner, impaired tree health is likely to occur. Nitrates may also leach from the soil into groundwater and surface waters.

Only a very minor decrease in the percentage of affected plots was observed between the two soil surveys, from 17 % (1986–1996) to 14 % (2004–2008). In the first soil survey, nine countries had more than 20 % plots with a C/N index below 1 compared to five countries in the second survey. However some countries were not reassessed. This shows the importance of a systematic reassessment on the same plots in all countries in order to draw stronger conclusions.

Methods and data

More than 5000 ICP Forests Level I plots were monitored in two forest soil surveys across Europe. The first took place between 1986 and 1996 and the second between 2004 and 2008 under the Forest Focus Regulation (EC No. 2152/2003). For estimating changes in forest soil properties at regional and European scales, the sample sites of both surveys were arranged systematically on the same 16 × 16 km ICP Forests Level I grid in most countries.

The ratio of carbon to nitrogen (C/N ratio) in organic layers and soils is a good indicator for the rate of organic matter decomposition, the availability of nitrogen and the turnover of nutrients. In healthy forests the C/N ratio of the forest floor is higher than for mineral soils. However, in areas with a high nitrogen deposition this relation is reversed and the C/N index drops below 1. The proportion of C/N in the forest floor over C/N in mineral soils, referred to as the C/N index, is a useful indicator for imbalance induced by excess nitrogen input.

Soil pH indicates the degree of acidity or alkalinity of a soil. The base saturation, calculated as the proportion of basic exchangeable cations (Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}) to the cation exchange capacity of the soil, is considered a measure of the buffering capacity of the soil against acidification.

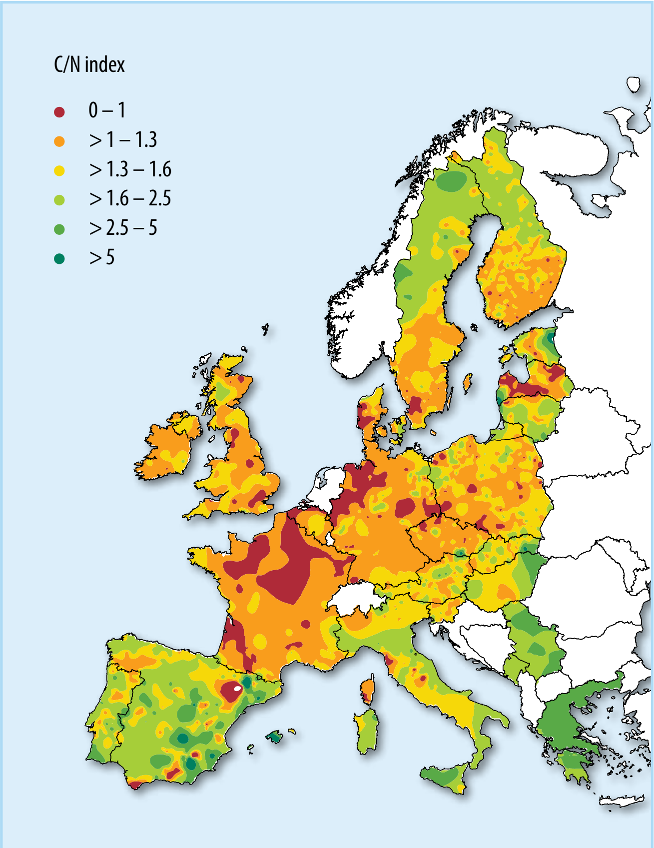
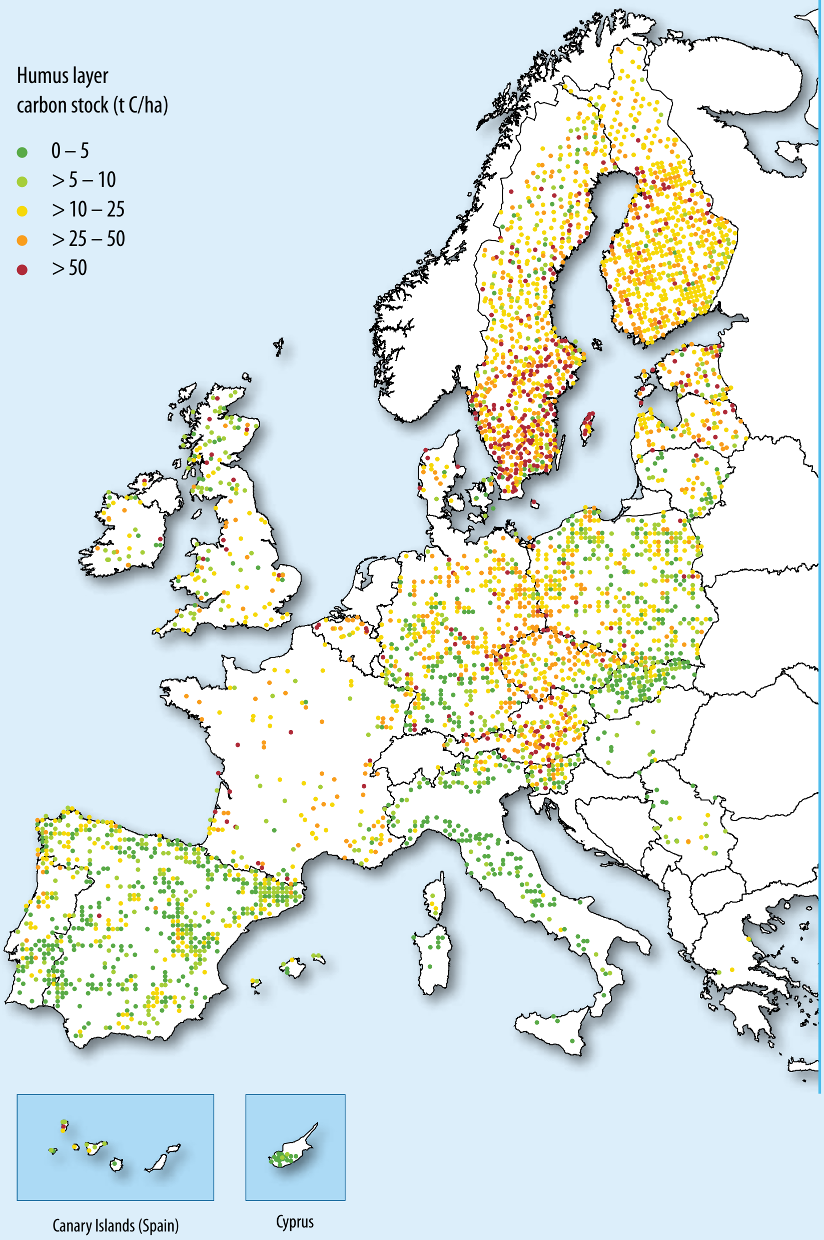


Figure 3-1: European areas where forest soil nutrient imbalances due to excess nitrogen deposition are suspected based on the C/N index. Affected areas (C/N index < 1) are indicated in red. Countries marked in white did not participate in the survey.



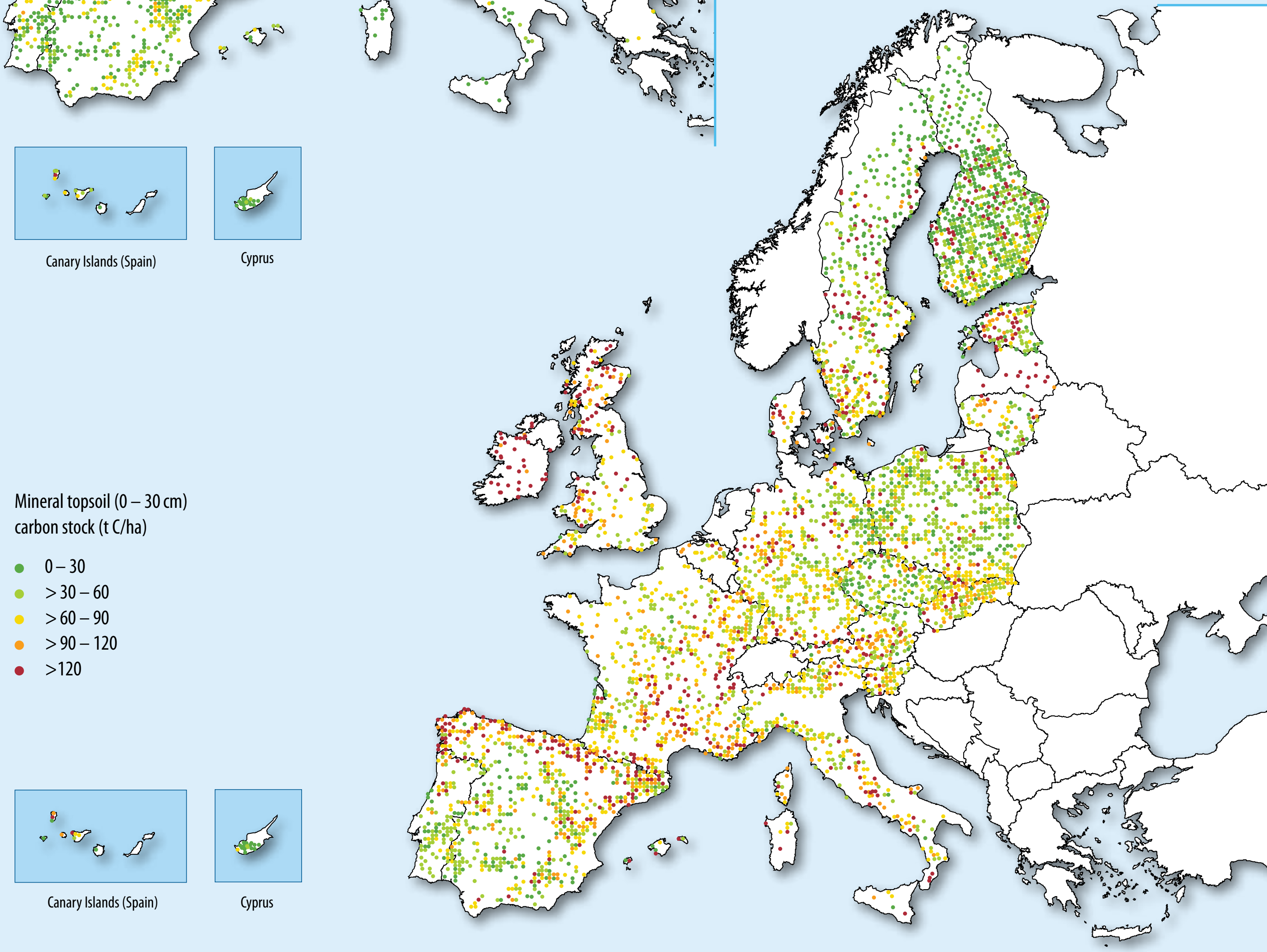


Figure 3-2: Carbon stocks in humus layers and in mineral topsoil (0 - 30 cm) as observed during the BioSoil survey (2004-2008).

Recovery of very acid soils

The pH value remained stable on 57 % of over 2000 plots re-visited in the second soil survey. However, pH increased in the extremely acidic forest soils (with pH below 4.0), but decreased in forest soils with pH above 4.0. Following the change in pH, the base saturation increased significantly in the acidified forest soils (with base saturation values below 20 %) and decreased in forest soils with base saturation values above 20 % in the first survey. The percentage of plots with low buffering capacity decreased from 48 % in the first survey to 28 % in the second survey. This could indicate a slight recovery from soil acidification at the European level. Large forest areas have been limed during the past 20 years; the recovery effect may be partly related to this measure.

Carbon storage in forest soils helps mitigate climate change

Forest soils tend to store more carbon than arable soils. Organic carbon in forest soils was separately determined for mineral soils to a depth of 1 m and for the relatively thin humus layers that cover the forest floor and add an extra 20 % to the total soil organic carbon.
Europe-wide forest floor carbon stocks could be reliably quantified for the first time following the second soil survey. Average carbon stocks in the humus layers are 23.8 t/ha. Carbon stocks are typically higher in Nordic forests (25 to 50 t/ha) than in the Mediterranean region (5 to 25 t/ha).

Peat soils store high amounts of carbon

Organic carbon stocks in the upper 30 cm of mineral soil are 64.3 t/ha on average (Fig. 3-2), but are much higher in peat soils amounting to 208 t/ha. The importance of peat soils is even more evident when considering the average carbon stocks to 1 m depth: 633 t/ha compared to 108 t/ha for a forest soil without peat layers. For climate change mitigation, conservation of peat-land forests is of the utmost importance and where climatic and environmental conditions allow, these areas should be extended. Most Level I plots on peat land are situated in Sweden, Finland, Poland, UK, Ireland and the Baltic states.
In mineral forest soils analysed to a depth of 1 m, about 60 % of the carbon stock is stored in the upper 30 cm. In cultivated soils, this stock is prone to oxidation and is partly re-emitted to the atmosphere, accelerating climate change. Conversely, due to limited perturbation and the continuous input of litter, forest soils have the unique ability to conserve their carbon stores. The second European forest soil survey found an increase in organic carbon in the organic and upper 20 cm soil layer for most of the sites revisited. However, some of this increase might be due to different methodology in the assessments and analysis and a clear European-wide picture will only become available following a third survey of the same sites.

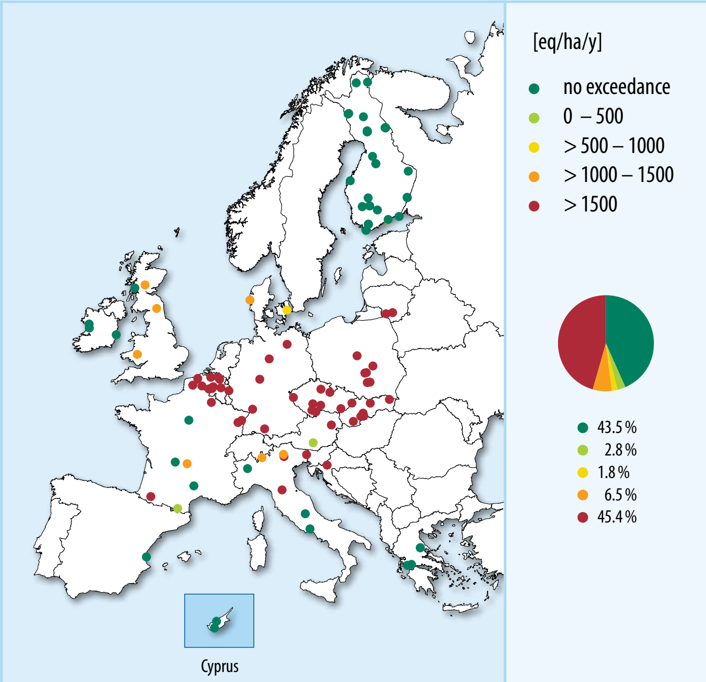
4. Critical load exceedance for nitrogen continues

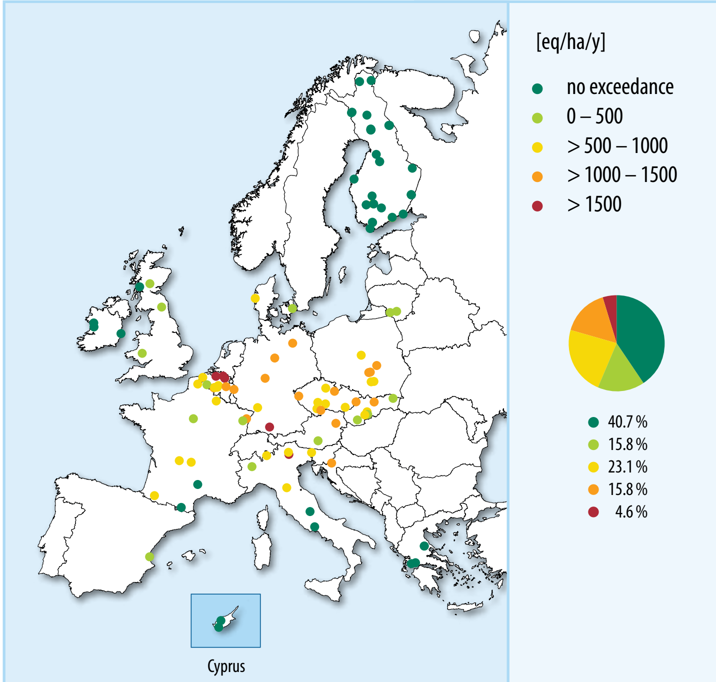
Summary

- *Critical load exceedances for acidic deposition are declining. This shows the clear success of clean air policies. However, previous soil acidification is still a burden to forest soils as recovery takes decades.*
- *Continued exceedance of critical loads for nitrogen deposition indicates the need for further emissions reduction. Critical loads for nitrogen deposition are likely to be exceeded on 30 % of plots by 2020 (compared to 50 % of plots in 1980). Maximum feasible technological reduction could reduce this to 10 % of plots.*
- *Depletion of base cations by acidic deposition and continued input of nitrogen even beyond nitrogen saturation levels leads to nutrient imbalances in soils at many forest sites and implies a risk for forest health and stability.*

Reduced acidic deposition reflects success of clean air policies

In 1980, critical loads for acidity were exceeded on 56.5 % of plots (Fig. 4-1). Lack of exceedance on a number of plots was because sulphur deposition on calcareous soils (e.g. many Mediterranean sites) did not exceed critical loads for acidity, while other plots were in low deposition areas (e.g. in the Nordic countries). In general, exceedances declined between 1980 and 2000 when critical loads were exceeded on only 17.6 % of plots. Deposition scenarios for 2020 based on current national legislation project that sulphur deposition will only just exceed critical loads for acidity. Critical loads for nitrogen were exceeded on 59.7 % of the plots in 1980 (Fig. 4-2). Models suggest that emissions reduction based on current legislation will reduce the share of plots with critical load exceedances for nitrogen to 30.6 % by 2020. Maximum feasible technological


[eq/ha/y]
no exceedance
0 – 500
> 500 – 1000
> 1000 – 1500
> 1500
43.5 %
2.8 %
1.8 %
6.5 %
45.4 %
Cyprus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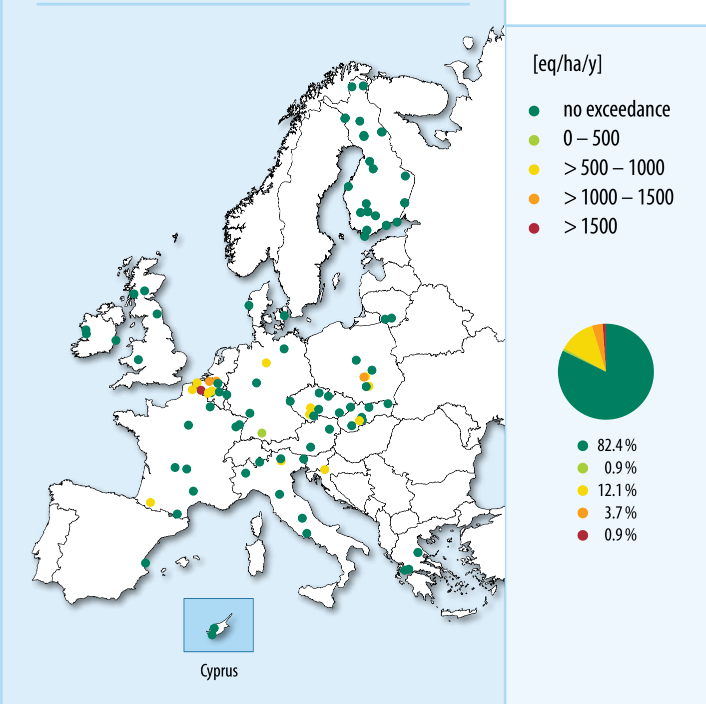
40.7 %
15.8 %
23.1 %
15.8 %
4.6 %
Cyprus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no exceedance
0 – 500
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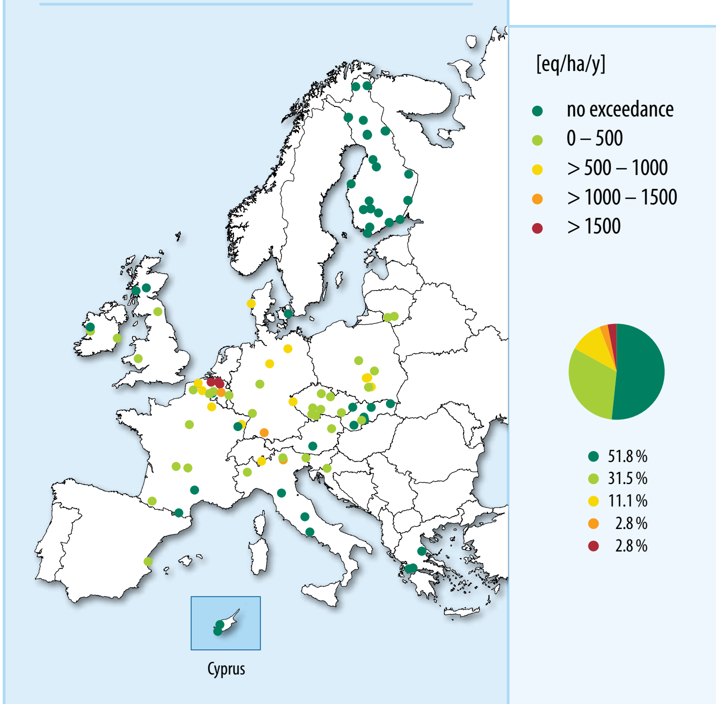
> 1500
82.4 %
0.9 %
12.1 %
3.7 %
0.9 %
Cyprus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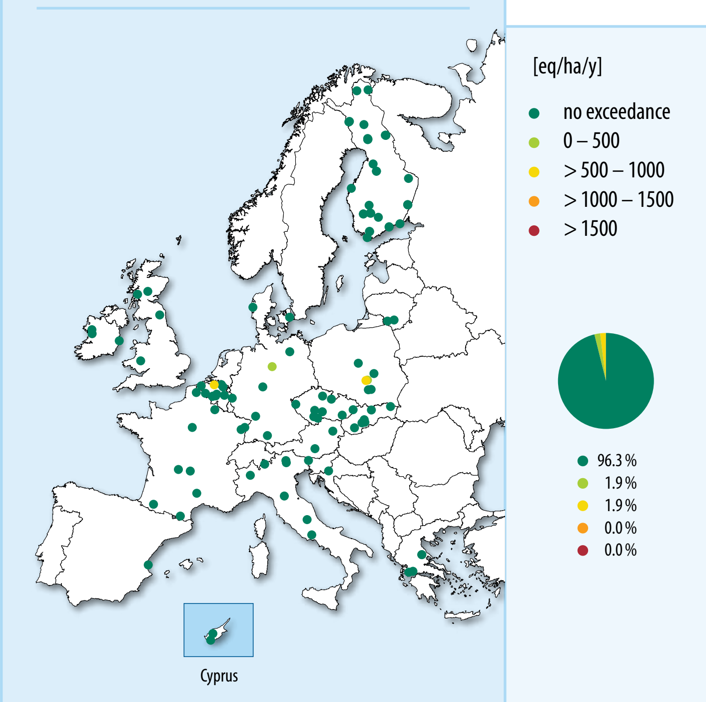
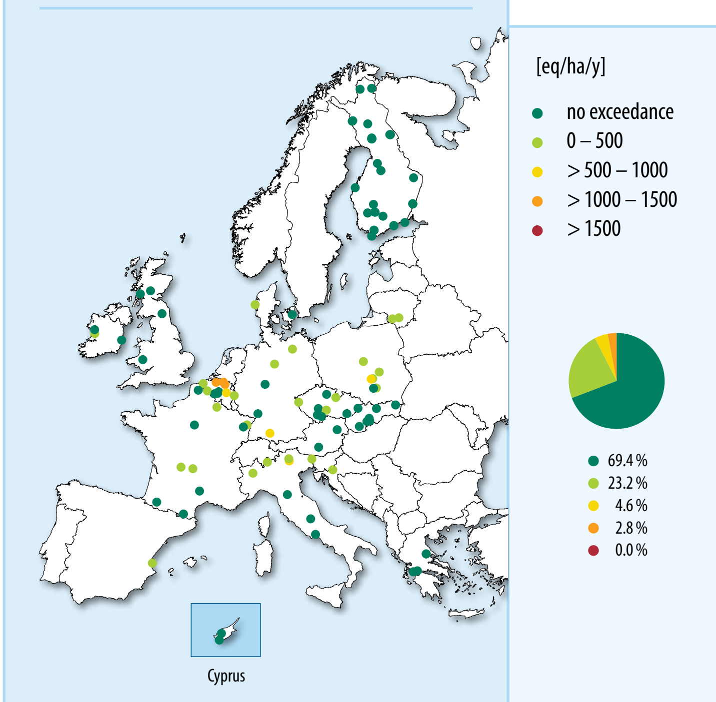
no exceedance
0 – 500
> 500 – 1000
> 1000 – 1500
> 1500
51.8 %
31.5 %
11.1 %
2.8 %
2.8 %
Cyprus


[eq/ha/y]
no exceedance
0 – 500
> 500 – 1000
> 1000 – 1500
> 1500
96.3 %
1.9 %
1.9 %
0.0 %
0.0 %
Cyprus


[eq/ha/y]
no exceedance
0 – 500
> 500 – 1000
> 1000 – 1500
> 1500
69.4 %
23.2 %
4.6 %
2.8 %
0.0 %
Cyprus

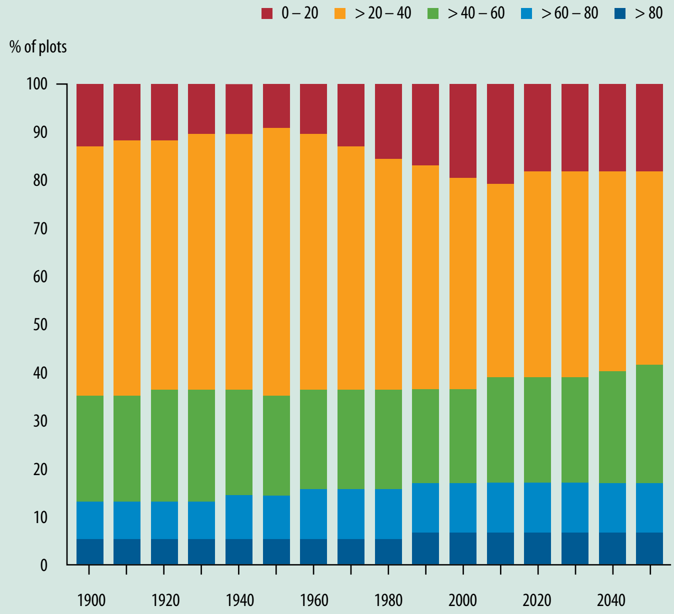


Figure 4-3: Development of modelled base saturation in soil water for 77 plots. Decreasing base saturation indicates reduced buffering capacity of soils to acidification.

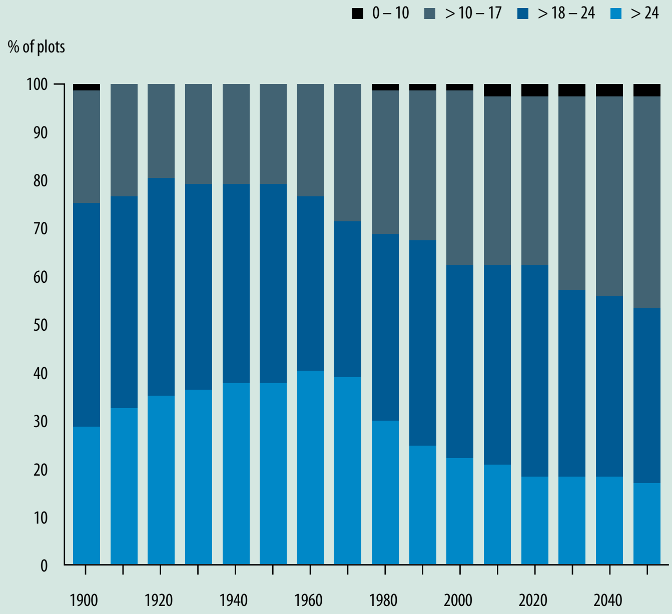


Figure 4-4: Development of modelled carbon to nitrogen (C/N) ratio in soil water for 77 plots. A decreasing C/N ratio indicates that more nitrogen is available.

nitrogen emission reductions (not depicted) could, however, reduce exceedances to below 10 % of plots.

Loss of nutrients due to previous acidic inputs

The acidic inputs of past decades have changed soil chemistry. Base cations, which are important nutrients and which buffer soils against acidic inputs have been leached from mineral topsoil layers. This is reflected in model results from plots in most regions of Europe and also in the generally decreasing base saturation of the soils (Fig. 4-3). It is likely to take many decades for base saturation to recover to pre-industrial levels. Nutrient imbalances result from lower availability of base cations and increasing availability of nutrient nitrogen in the soil solution. Such imbalances can have direct effects on forest ecosystems including increased susceptibility to pathogens and pests.

Eutrophication due to nitrogen pollution continues

Models indicate a significant decrease in the carbon to nitrogen (C/N) ratio since the mid-1980s, which suggests increased nitrogen saturation owing to continued high (but on some plots decreasing) inorganic nitrogen deposition. The ongoing decrease in the C/N ratio indicates continuous eutrophication of the forest stands. This is closely linked to the modelled exceedance of critical loads for nutrient nitrogen. The baseline scenario calculated by the ICP Modelling and Mapping programme estimates that for sensitive ecosystems in the EU, 61 % of the area is expected to be at risk of nutrient nitrogen (eutrophication) by 2020 but only 7 % of the area is at risk of acidification.

Figure 4-1 (left column): Exceedance of critical loads for acidity in 1980 (top), 2000 (middle), and 2020 (bottom) assuming deposition scenarios based on current national legislation.

Figure 4-2 (right column): Exceedance of critical loads for nutrient nitrogen in 1980 (top), 2000 (middle), and 2020 (bottom) assuming deposition scenarios based on current national legislation.

Methods and data

Critical loads – thresholds derived from ecosystem models below which environmental damage is not expected to occur – are calculated to identify sites where deposition levels have reached a critical state and ecosystems could be at risk. Calculation of critical loads is based on a mass balance approach that takes into account atmospheric deposition, stand structure, bedrock and soil chemistry. The present assessment is based on Level II sites in 17 countries with recently updated soil, soil solution and deposition data. Deposition scenarios compiled by the Centre for Integrated Assessment Modelling (CIAM) of the European Monitoring and Evaluation Programme (EMEP) were provided by the ICP Modelling and Mapping programme. This dataset was used to model effects of future nitrogen and sulphur deposition. Effects of past and future nitrogen and sulphur deposition were projected using the dynamic soil chemistry model VSD+. This model needs data on deposition fluxes, nutrient uptake, mineralization and weathering.

Air pollution effects on biodiversity

Forest biodiversity refers to multiple services and functions that forests provide. Among these, species composition is of major importance. Epiphytic lichens are among the most sensitive bioindicators for environmental change.

Photo: *Parmotrema stuppeum* is an epiphytic lichen species adapted to nutrient-poor conditions. Epiphytic lichens are bioindicators for environmental factors such as air quality or deposition.

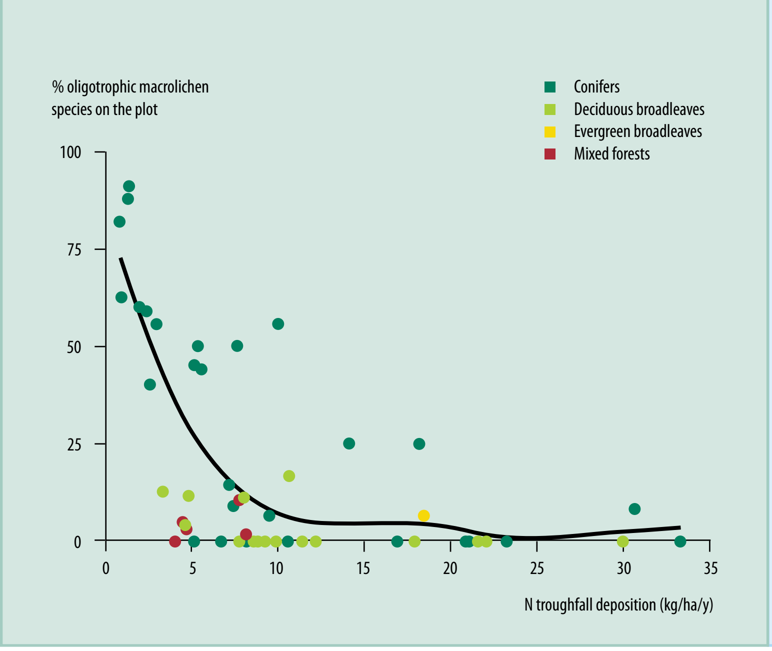


Figure 5-1: Percentage of macrolichens species adapted to nutrient-poor conditions as a function of the nitrogen throughfall deposition at plot level.

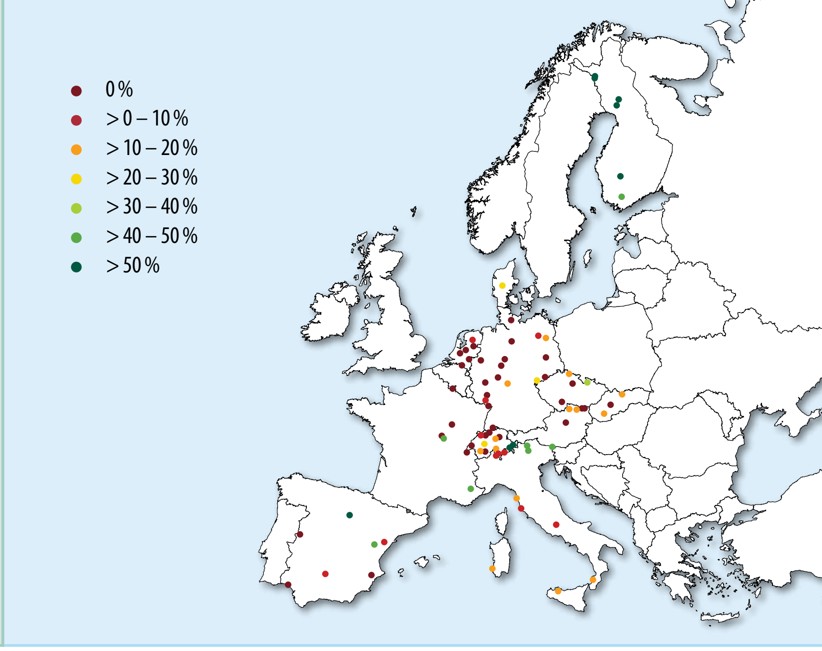


Figure 5-2: Percentage of lichen species adapted to nutrient-poor conditions. Low percentages of such species clearly indicate high nitrogen deposition loads.

5. Nitrogen deposition affects lichen species diversity

Summary

- *Epiphytic lichens are among the most sensitive bioindicators for different environmental stress factors including nitrogen deposition. On 80 % of the plots assessed, lichen species composition indicates unsustainably high nitrogen deposition.*
- *Lichen species are just one specifically sensitive example. Earlier studies of the programme reveal clear effects of nitrogen deposition on forest ground floor vegetation. The European Nitrogen Assessment estimates that ammonia (NH_3) and nitrogen oxide (NO_X) emissions have reduced forest biodiversity by more than 10 % over two-thirds of Europe.*

The share of oligotrophic lichens on the plots on average decreased below the 40 % threshold as soon as nitrogen deposition measured below the forest canopy exceeded 3.8 kg/ha/y (Fig 5-1). This shows that even a relatively low nitrogen deposition has a clear influence on the species composition of epiphytic lichens. The critical load for nitrogen of 3.8 kg/ha/y was exceeded on 80 % of plots. Effects on other species groups only occur at higher nitrogen inputs. The effects of nitrogen deposition on epiphytic lichens are much less evident in coniferous than broadleaved forest types. The greater effect of nitrogen deposition in broadleaved forests needs to be explored in more detail.

The highest percentages of oligotrophic lichen species and thus the smallest effects of nitrogen deposition were observed in Finland and some Mediterranean plots in Italy and Spain. In contrast, most of the plots in central Europe especially in Germany were characterized by very low percentages of oligotrophic lichen species, indicating high nitrogen inputs (Fig 5-2).

Methods and data

Lichens can be used as early-warning indicators as they are likely to be the first species group to react to atmospheric pollutants. Oligotrophic lichens are those that are adapted to growth in nutrient-poor conditions. Increasing nitrogen deposition adds nutrients to the forest ecosystems and causes a change in species composition. To assess the effects of nitrogen deposition the lichen species were first classified into oligotrophic and non-oligotrophic species on the basis of recent information from the literature. In this assessment, a value of 40 % of all lichens species on a plot being oligotrophs is considered a critical threshold for nitrogen deposition. The evaluations here are based on a dataset of 292 epiphytic lichen species determined on 1155 trees at 83 Level II plots. 142 species corresponding to 49 % of all species determined were classified as oligotrophic. The data were collected between 2004 and 2006 in ten countries within the ForestBIOTA project (www.forestbiota.org).

Forest growth and climate change

Tree growth and stocking volume of wood are of immediate economic relevance but are also of high importance as an ecological indicator of forest condition. Forests are huge carbon pools that sequester carbon dioxide from the air. Net increment of wood provided they can thus help mitigate climate change.

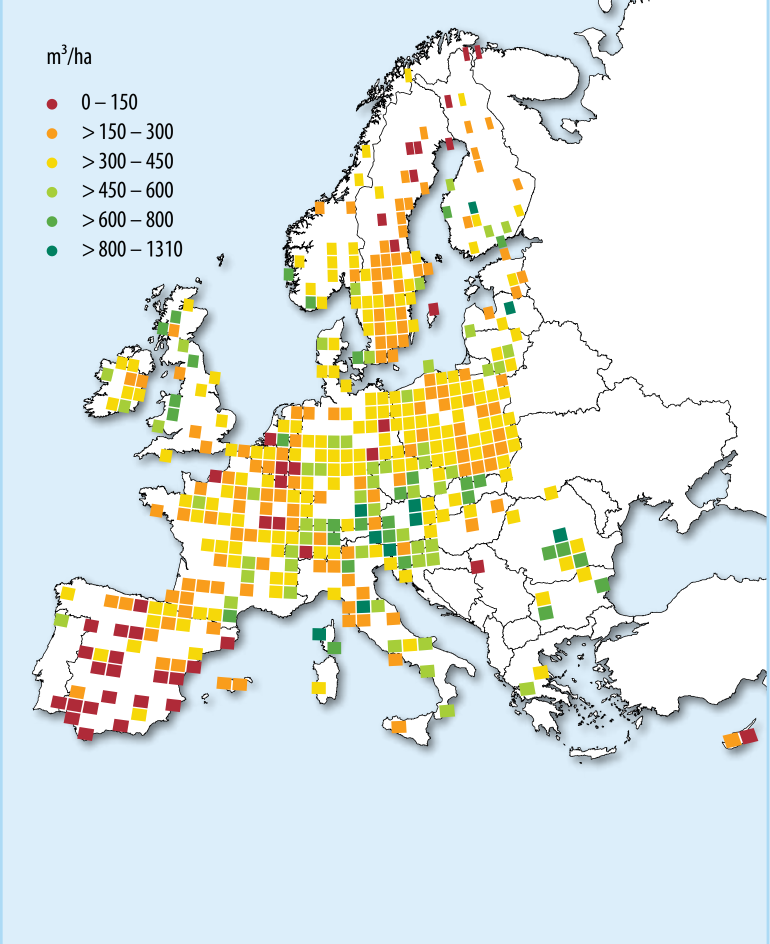


Figure 6-1: Stocking stem volume (m³/ha). Plot data averaged to means per grid cell.

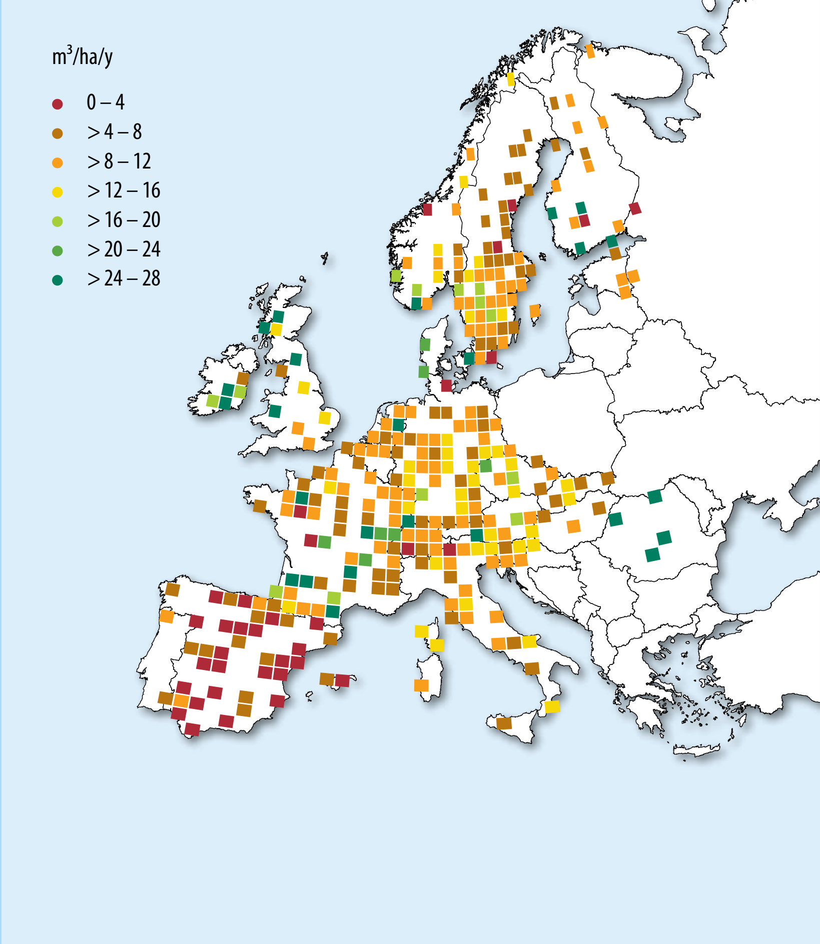


Figure 6-2: Median of stem volume increment (in m³/ha/y).

6. Harmonized tree growth data from plots across Europe

Summary

- *Results from Level II plots reflect natural growth conditions, with higher wood volumes and growth rates on plots in central Europe and the Alps and lower values in northern and southern Europe. Such data are useful for studying links between forest growth and vitality and change in environmental conditions.*

Natural growing conditions reflected well in European dataset

Higher wood volumes per hectare were found for plots in central Europe and the Alps and lower volumes per hectare in the northern and southern regions (Fig. 6-1). Many plots have between 300 and 600 m³/ha. This mainly reflects natural growing conditions. Whereas the climate is often too hot and dry in the South, low temperatures prevent more growth in the North. High volumes in the Alps occurred at lower, montane altitudes where good water supply coincides with moderate temperatures, lower harvest intensities and higher stand age, rather than under alpine conditions. Stem volume increments show similar spatial patterns (Fig 6-2). Increment and wood volumes also depend on tree species. Differences for single tree species are not depicted in the summary graphics.

The results provide a unique overview of forest growth based on standardized measurements. They are a valuable basis for future validation, refinement or creation of forest growth models, for determining growth responses to site and environmental conditions and their changes, and for estimating harvestable wood and potential stocking biomass in European forests under different management scenarios. To date, such studies have mostly been undertaken at the plot or regional level and have only just begun at the European scale.

Methods and data

Growing stock was evaluated for 822 plots in 30 European countries based on breast height diameter measurements and heights of selected trees. For nearly 600 plots repeat measurements were available for different measurement intervals allowing the determination of forest growth between two or more assessments. Data were averaged per grid cell.

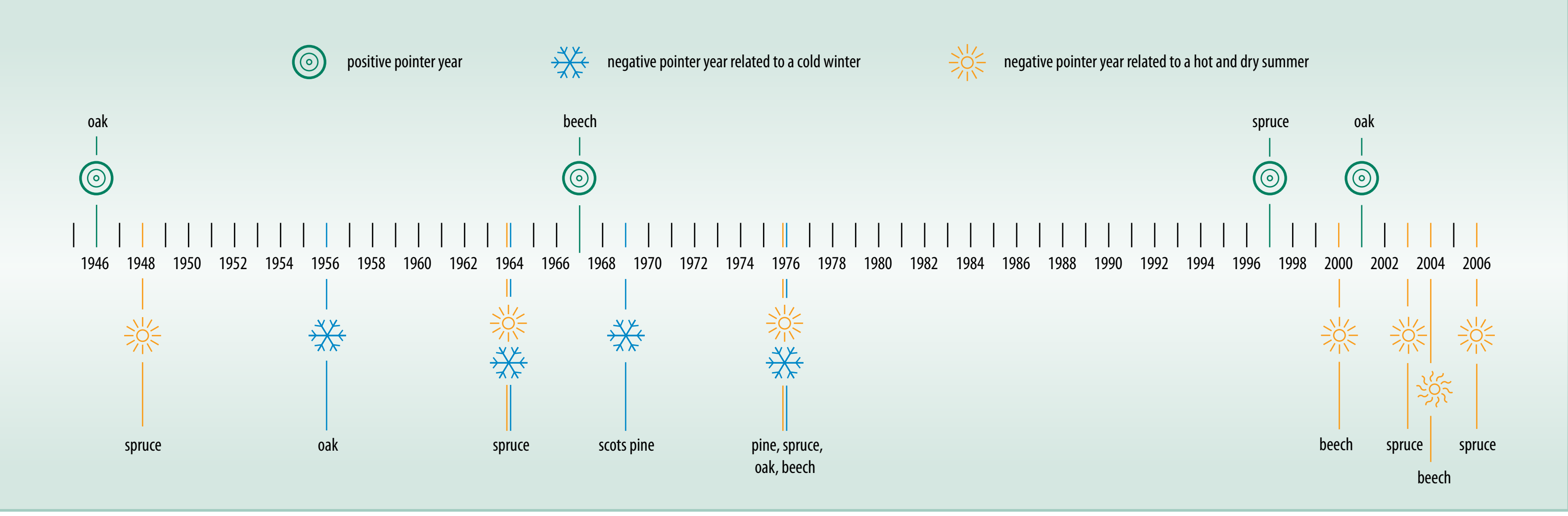


Figure 7-1: Occurrence of positive and negative pointer years for the main tree species in Germany between 1945 and 2006. Tree growth reactions over the past decade indicate an increasing frequency of extreme weather conditions.

7. Extreme weather conditions becoming more frequent

Summary

- *Forest trees indicate an increased frequency of summer heat and drought over the past decade for central Europe. Tree cores covering the past 60 years were analysed on 88 German Level II plots.*
- *Of the four main tree species analysed, Norway spruce reacted most strongly to extreme heat and drought and showed little recovery in subsequent years. The data support forest management decisions on future selection of tree species aiming at adaptation of forests to climate change.*

Increasing frequency of extreme weather conditions

From 1945 to 2006 there were more negative than positive pointer years indicating extreme weather conditions. 1976 was the most extreme as it is the only year where all

Methods and data

Tree rings provide a retrospective method for analysing tree growth. They contain information on growth and vitality over the lifetime of the trees. Tree cores were sampled from over 2000 standing trees representing 88 German Level II plots between 2005 and 2007. Growth was analysed for: 33 Norway spruce plots; 19 Scots pine plots; 25 common beech plots; 11 European and sessile oak plots.

The effect of weather conditions in single years was evaluated by determining so-called 'pointer years'. In such years, most of all trees sampled in a stand show similar positive or negative growth reactions, reflecting extreme weather conditions. Pointer years are mostly species-specific as tree species react differently to such extremes. Pointer years were related to daily-resolution climate data.

tree species were affected (Fig. 7-1). Extreme growth reductions were due to a cold and late winter and spring, followed by a hot and dry summer. The combination of two climatic extremes within one year resulted in an outstandingly negative pointer year across most parts of central Europe. From 2000, negative pointer years occurred frequently for beech and spruce and were mainly caused by hot and dry summers.

Most severe effects shown by Norway spruce

Reactions of different tree species to the extreme summer heat and drought in 2003 in central Europe were analysed in more detail (Fig. 7-2). Norway spruce showed the strongest growth reductions and the longest lasting effects. The spruce stands investigated show hardly any recovery. Most of these stands grow in the central European lowlands and lower mountain regions where Norway spruce does not naturally occur. The species is less adapted to the site conditions and is most sensitive to the observed heat and drought.

Beech trees with faster recreation

Common beech occurring naturally on most sites shows a clear but delayed growth reduction in 2004. However, the recovery progress is relatively fast. The pine trees show prompt growth reductions but also fast recovery. European and sessile oaks show small growth reductions and higher drought stress tolerance.

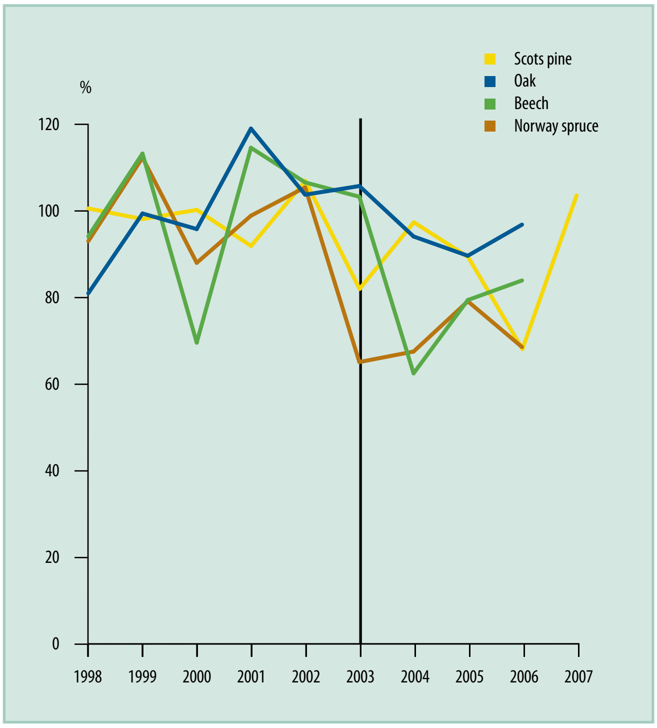


Figure 7-2: Relative mean tree ring width after 1998 for Norway spruce, Scots pine, common beech, and European and sessile oaks over all Level II plots in Germany. Norway spruce showed the most severe reactions to extreme drought in 2003, whereas the oak species were better adapted. (Mean growth for all plots between 2003 and 2007 is related to the mean of a reference period from 1998 to 2002. Pine cores were sampled later and thus represent one more year.)

8. Tree growth and vitality severely affected by drought

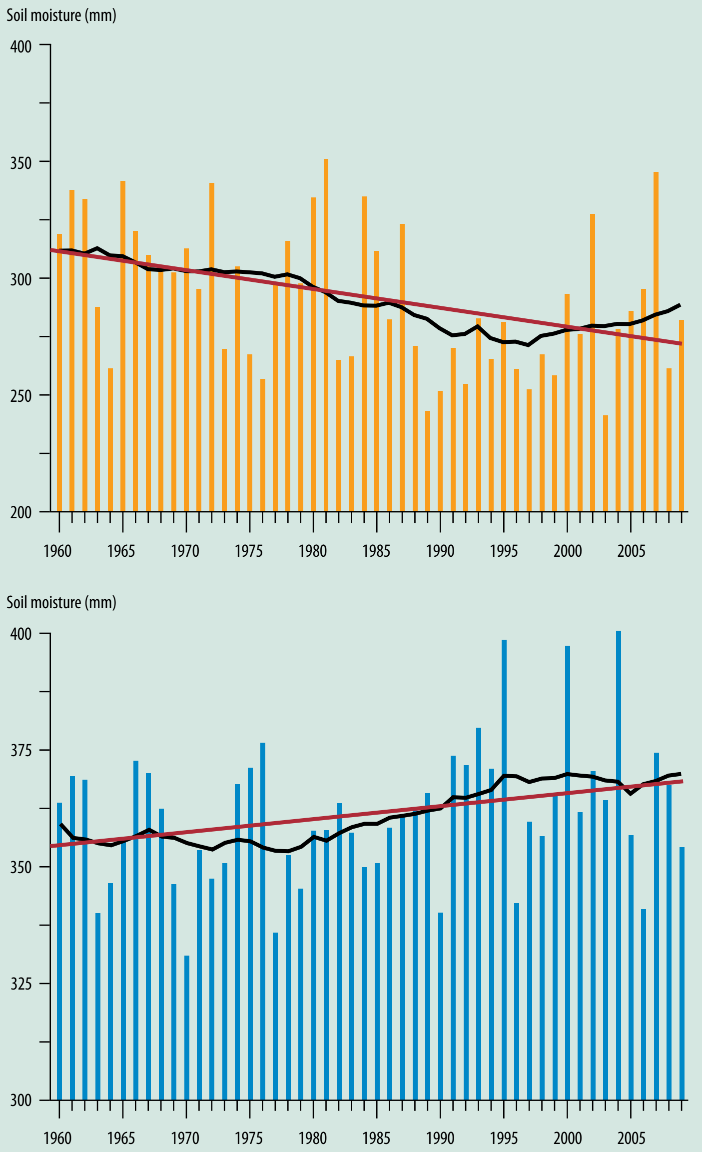
Summary

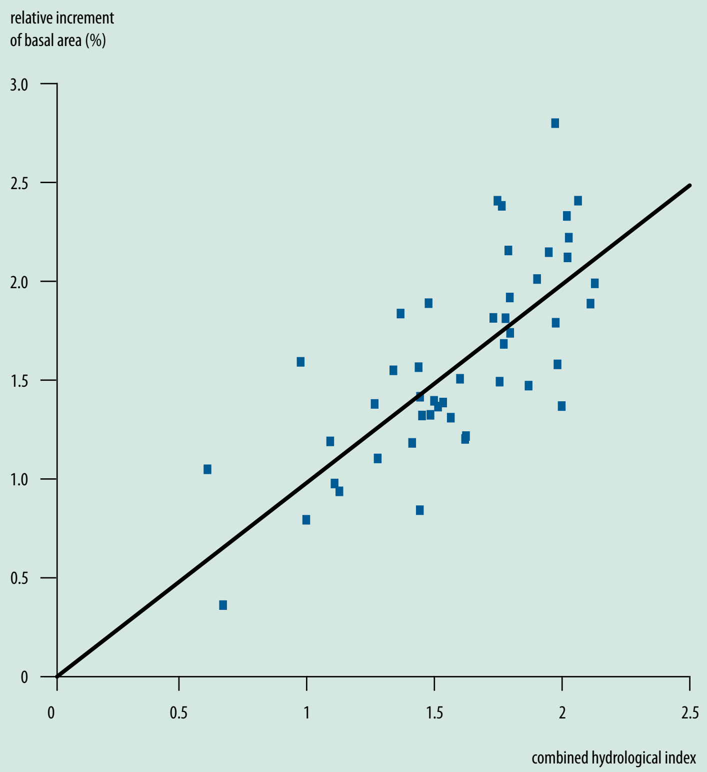
- *Model results show decreasing water availability in summer and increasingly wet site conditions in winter. They also confirm that such conditions are strongly linked to reductions in tree growth.*
- *Climate change scenarios project a further increase in summer drought and winter precipitation and rising air temperature, and thus increasing risks for forest tree vitality.*

Long-term simulations for 1960 to 2009 on one of the most intensively monitored Level II plots in central Europe show that soil water availability in the summer months decreased by 13 % (beech stand) and 7 % (spruce stand). The five driest summers occurred during the last 20 years of the study period. Soil water availability was highest in summer 1981 and lowest in summer 2003. In contrast to the decrease in soil water availability, soil water content increased in the winter months, with the three wettest winters occurring during the last 20 years (Fig. 8-1).

Methods and data

Water availability is a key variable in understanding nutrient uptake, CO_2-uptake, tree growth and the response of trees to biotic stress factors. The Level II plots provide data on climate, soil moisture, and nutrients, as well as on tree growth and vitality. Water budgets, representing the water flux through forests and soil, cannot be measured completely, but may be calculated using models that are calibrated using measurement data. Water budget models help to assess water-related effects on tree vitality and forest condition and can extend time series on soil moisture. Within the FutMon project, water budget models were compared against measured data from plots across Europe in order to improve the model application. The 'Solling' site in central Germany provides comprehensive measurements since 1966 and is an important reference site for model development and testing.





Growth reductions following years with strong soil water changes

Models and tree growth measurements confirm the strong influence of soil water availability on tree growth. A hydrological index could explain more than 50 % of the measured variability in growth rates of beech trees at Solling (Fig. 8-2). The strongest growth reductions were apparent following years with marked changes in soil water (1975/76, 1999/2000, 2003/04), when extremely dry summers in the preceding year were followed by extremely wet winters and quickly drying soil conditions in spring. In contrast, the strongest growth increments were recorded in years with moderate soil water changes (1966/67, 1996/97, 2000/01, 2005/06). The index applied aggregates water availability in the preceding summer, soil water content in the preceding winter and the speed of soil drying in spring.

Severe risks through climate change

For almost all parts of Europe, climate scenarios from the Intergovernmental Panel on Climate Change (IPCC) project rising precipitation rates in winter and/or lowered precipitation rates in summer as well as rising air temperatures. The Solling case study demonstrates that the combination of these factors has substantial effects on soil water availability and subsequently on tree growth as they result in very wet winters, extended drought periods in summer, and marked changes in soil moisture over the year as a whole. Rising air temperatures would aggravate the hydrological effects. Together, these effects represent severe risks for beech tree growth. Effects on other tree species and possibly counteracting effects of rising temperatures such as the acceleration of growth processes or extension of the growing season are currently being studied within the monitoring programme.

Figure 8-1: Modelled soil moisture in summer (top) and winter (middle) within the rooting zone [in mm] for the 'Solling' site in central Germany. The frequency of dry summers and wet winters have increased over the past 50 years. (Deviation from the mean and moving average with linear trend.)

Figure 8-2: Relation between hydrological index and tree growth based on basal area increment. Soil water content and the speed of changes in soil water content are closely related for tree growth.
(The hydrological index is based on water availability in summer and winter and on the speed of soil drying in spring.)

Intensive Monitoring site in mountain beech forest.

8. Conclusions

The topics that have been under debate over the past decades reflect the multiple functions and services that forests provide. In the 1980s, fears of widespread forest decline due to acid deposition lead to the birth of ICP Forests. However, in the 1990s it became clear that despite previous and ongoing atmospheric inputs wood increment was increasing across Europe. At the turn of the century effects of climate change became increasingly obvious and questions of forest ecosystem adaptation and mitigation now need scientific clarification. The aim of halting biodiversity loss by 2010 implied a general decline in biological diversity. In recent years, the green economy and resource efficiency approaches have led to increasing demands for bio-energy and thus increased fellings.

Results of the programme show that at the large scale forest condition has deteriorated far less severely than was feared back in the 1980s. For single species, however, tree crown defoliation shows peaks and declining trends, although these are mostly triggered by regional climatic conditions. Over the past ten years, Mediterranean lowland pines have shown a consistent decline. Temperate and Mediterranean deciduous oak species showed the highest levels of defoliation.

Acid deposition has been successfully reduced in most European areas over the past decades. Based on UNECE deposition scenarios it is assumed that by 2020 critical loads for acid deposition will no longer be exceeded on over 90 % of the intensive (Level II) monitoring plots. Nutrients have been leached from mineral soil layers for many years, however, and recovery is expected to take decades. A repeat large-scale European forest soil survey shows hardly any change in soil acidity status between the mid-1990s and 2008. At the same time, nitrogen inputs have continued to exceed critical loads and this is projected to continue to be the case for 30 % of plots in 2020. Results of the ICP Modelling and Mapping programme even assume exceedances on 60 % of the forest area. On plots that are not yet nitrogen-saturated the inputs can increase forest growth; but at saturated sites nitrate is leached into groundwaters and drinking waters and nutrient imbalances are likely. Such imbalances make forest ecosystems more susceptible to additional stress factors such as drought, storm damage or insect damage. Recent results show shifts in vegetation and lichen species composition related to nitrogen deposition.

Tree growth reacts to weather extremes and climatic changes. Retrospective tree ring analyses indicate an increased frequency of summer heat and drought over the past decade for central Europe. Model results show that it is not only summer heat but also increasing soil moisture in winter and the increasingly sharp transition between both extremes that provokes a decline in tree growth. For the near future, a continuous increase in such conditions is predicted by current climate change scenarios. Growth reactions to extreme drought differ for the main tree species and in central Europe were most severe for Norway spruce, while beech trees showed a quicker recovery. Oak and Scots pine are better adapted to such climate. Modelling work is ongoing to study whether growth acceleration due to rising temperature, rising CO_2 concentrations and ongoing nitrogen inputs will outweigh drought effects in the future. Different forest management scenarios are important to be considered for future risk assessment.

Over the past 25 years, the cooperation between ICP Forests and the European Commission has been the basis for provision of European-wide harmonized data on major forest ecosystem services. In recent years cooperation with National Forest Inventories in many European countries has gained importance. At the international level, ICP Forests is intensifying collaboration with the USDA Forest Service and the Acid Deposition Monitoring Network in East Asia (EANET). Such networks will form the basis for making available data and information to policy- and decision-making processes, science partners, forest managers and the wider public.

Annex

Photo references

Page	Name
3 (portrait)	Danish Nature Agency
3 (landscape), 4, 17	Dan Aamlid
6	Institute for Worldforestry
10	Gabriele Tartari
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