FutMon Scientific Report

Further Development and Implementation of an EU-level Forest Monitoring System (FutMon)

Prepared by the partners of the EU-LIFE+ project FutMon

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Preface

Forests cover around one third of the land surface of the European Union. Besides their utmost importance for the earth's climate, carbon cycle, and biodiversity, forests are a major component of rural development, providing protective functions for soil, water and infrastructure, and contributing goods and services to the economic sector. These benefits, however, are jeopardised by anthropogenic stressors like climate change, air pollution, and changes in land use. For effective forest and environmental politics, scientific information on the large-scale development of forests as well as on cause-effect relationships involved is needed.

Forest monitoring has already proven useful for environmental politics in Europe for more than a quarter of a century. Supported by the European Commission for many years, the largest harmonised forest monitoring system in the world (ICP Forests) has been running under UNECE as a scientific basis for clean air politics in Europe. But the problems facing the European forests have changed in the last decades and so have the information needs. They go beyond those on air pollution effects and require a further development of forest monitoring to include also the effects of a changing climate or the impact of land use on the forests. Against this background it is my pleasure to introduce the Scientific Report of the LIFE project "Further Development and Implementation of an EU-level Forest Monitoring System" (FutMon). I am pleased to see that 22 EU-Member States under FutMon revised their forest ecosystem monitoring so that it is now better suitable for modelling relationships between forest health, forest growth, carbon fluxes, climate change, air pollution, and biodiversity. The present report shows how this information can be used for scenario analyses describing the response of forests to future stress on one hand and evaluating the effectiveness of environmental politics on the other hand.

The FutMon Scientific Report is presented at the right time as the European Commission is striving for an EU-level forest monitoring which is based on existing systems. With its complementary large-scale and ecosystem-scale approaches it is a crucial source of information for the understanding of the impact of climate change, eutrophication, and other stressors on forest health and forest biodiversity across Europe. With this information it can not only continue to enable EU-Member States to meet their reporting obligations under Forest Europe, the Convention on Biodiversity, the United Nations Framework Convention on Climate Change, and several other international processes of forest and environmental politics but it also provides risk assessments and predictions of future developments concerning forests.

Rebecca Harms, President of The Greens / EFA group in the European Parliament

Summary

The EU-LIFE project "Further Development and Implementation of an EU-level Forest Monitoring System" (FutMon) established a pan-European forest monitoring system which can serve as a basis for the provision of policy relevant information on forests in the European Union. The project was implemented by a consortium of 38 ministries and research institutes in 22 EU-Member States. The new forest monitoring system constitutes a further development of a system (ICP Forests) established under UNECE in 1986. It comprises a large-scale forest monitoring grid with links to national forest inventories (NFIs) as well as a forest ecosystem monitoring grid. The large-scale grid comprises 5455 plots in 26 EU-Member States and 7503 plots together with the non-EU-countries. The forest ecosystem monitoring grid comprises 252 plots furnished with a particularly high monitoring intensity under FutMon in EU-Member States. Together with the remaining forest ecosystem monitoring plots (with lower monitoring intensity) there are more than 800 plots with about 30 of them situated in non-EU-countries.

Harmonised methods and standards further developed under FutMon, taken over by ICP Forests in its Manual, and respected across all EU-Member States guarantee long-term comparability of data. An innovative database permits on-line data submission, automated data validation and an inter-active Web-GIS. The scientific analysis of forest ecosystem monitoring data in combination with large-scale forest monitoring data permits the holistic view of the interactions between climate change and other impacts on forests postulated in the Green Paper (KOM(2010)66). Such scientific analyses were started under FutMon, involving all available data including the small additional portion from non-EU-countries. The results refer to relationships between climate change, carbon fluxes, air pollution, forest health, forest growth, and biodiversity.

Results of FutMon reflect the successful reduction of sulphate emission under CLRTAP and EC policies, but show that nitrogen deposition decreased only little. Nitrogen and sulphur deposition was highest in Central Europe, with sulphur deposition showing an obvious decrease. On about 160 plots mean sulphur throughfall decreased from 8.9 kg ha^{-1} yr^{-1} in 1998 to 5.1 kg ha^{-1} yr^{-1} in 2007. In contrast, throughfall of ammonium decreased only from 6.7 kg ha^{-1} yr^{-1} to 5.9 kg ha^{-1} yr^{-1} and throughfall of nitrate hardly showed a decrease at all in the same period.

Atmospheric deposition, in particular that of nitrogen, still affects forest soils, forest trees as well as forest ground vegetation, and therefore biodiversity. In forest soils, N deposition was found to cause disturbed organic matter and nutrient cycling evidenced by a C/N index lower than 1 on 14% of the plots. These plots were particularly frequent in central-western Europe. In comparison to the soil surveys carried out between 1986 and 1996, pH and base saturation increased in the very acid forest soils but decreased in the other soils.

A measure for the risks posed by deposition to a forest ecosystem is the exceedance of critical limits. Exceedances of critical limits for total nitrogen concentrations in soil solution were calculated based on samples from 171 Level II plots from the early 1990s to 2006. Mean concentrations were compared to critical limits that were available from literature. Results show that N concentrations in soil solution regularly exceed two widely used critical limits on the

majority of Level II plots in Europe. On 93% of the plots critical limits for nutrient imbalances in the organic layer were exceeded in more than 50% of the measurements. On 67% of the plots critical limits for elevated N leaching in the organic layer were exceeded in more than 50% of the measurements. For the mineral topsoil and subsoil, the critical limits for elevated N leaching were exceeded on 38% and 37% of the plots, respectively, in more than 50% of the measurements. The respective share of plots where limits for reduced fine root biomass or enhanced sensitivity to frost and fungi were exceeded in organic layers were 32% and 16%. Exceedances in the mineral soil layers were lower. Data from 140 plots were available for the calculation of time trends of at least five years per plot. In most of the plots there was no temporal trend in the critical limit exceedance for nitrogen. In cases where trends could be documented they were usually decreasing. Nutrient imbalances and N saturation and leaching to deeper soil layers are expected consequences of these findings in large parts of Europe. Nitrate concentrations in the ground water violating the permissible values of Council Directive 91/676/EEC had been found already on a quarter of the Level II plots by an earlier study.

A key question of clean air politics is if the prevailing deposition will sooner or later lead to the exceedance of critical limits. The answer to this question is the critical loads concept. The critical load is the deposition per unit of time which an ecosystem can tolerate without negative consequences for its functioning. Exceedances of critical loads for acidity and nutrient nitrogen therefore indicate a risk of acidification and eutrophication. Modeling results for the large-scale plots indicate high risks for acidification of forest soils especially in central Europe in 1980. The dynamic model VSD+ was used to estimate future critical loads exceedances assuming continued implementation of legally binding protocols of clean air politics. Results show that in 2020 forests will be protected against acidification on nearly all the plots. For nitrogen inputs, however, the share of plots with exceedances decreased by 10% only between 1980 and 2000. The scenarios for the future indicate a further increase in the number of sites protected against eutrophication, but no protection of all sites. The Level II plots provide the basis for the risk assessment and for evaluating potential recovery of forest ecosystems under reduced atmospheric deposition and climate change. These future tasks require adaptation of forest management and nature conservation practices as well as continued monitoring and modeling.

The results of the dynamic modelling of soil chemistry obtained with VSD+ were coupled with the BERN model permitting an estimation of future regeneration abilities of plant communities. Tree species may not be adapted to changes in soil properties induced by deposition. Low adaptation poses a risk to the sustainable development of the affected stands. In such cases changes in tree species may be a suitable management target. Though the number of plots available for this pilot study was low and not representative for Europe, the methodology offers a wide range of estimating future effects as well as suitable management adaptations.

The carbon budget of 28 selected Level II plots was simulated using the simulation model Biome-BGC (version ZALF). Level II data on meteorology, stem growth, litterfall, phenology, leaf area index, soil respiration, stand precipitation, soil water content, and soil temperature were used for the initialisation and calibration of the model. As result of the model calibration 22 plots could be identified as carbon sinks and 6 plots as carbon sources between 1996 and 2009. For the period 2040 to 2059 and 2080 to 2099 the development of carbon budgets on the Level II plots was simulated based climate projections assuming IPCC scenarios. In general, the carbon sink function was found to increase under expected future climate conditions.

Air pollution and climate change may influence forest health and forest growth. Forest growth has been evaluated under FutMon on Level II plots. Data include information on breast height diameter of all trees, heights of selected trees and plot area. The results provide a unique overview on forest growth based on standardized measurements. They are a valuable basis for future validation, refinement or creation of forest growth models, for the determination of growth responses to site and environmental conditions and their changes as well as for the estimation of harvestable wood and potential stocking biomass in European forests under different management scenarios. The calculated forest increment for the first five year period (1994-1999) was used to test if current growth deviates from the expected growth based on stand site condition, stand density and stand age and if environmental factors, such as nitrogen deposition or temperature increase, can explain these growth deviations. Nitrogen deposition and above-average temperature had a positive effect on tree growth. However, on soils with already higher nitrogen content nitrogen deposition had almost no effect.

After the increase observed since the mid 1980s, defoliation has changed little during the last ten years on around three quarters of the plots, but varies greatly among tree species and regions. Crown condition of Scots pine - the most frequent species -, after its recuperation in central and eastern Europe attributed partly to improved air quality remained stable in recent years. Little changes in crown condition were also observed for Norway spruce. In contrast to Scots pine, however, Norway spruce and in particular common beech had higher defoliation after the drought year of 2003. The most severely damaged species over the past ten years were Mediterranean and central European oak species. In the same period, Mediterranean lowland pines have shown an almost continuous decline. First evaluations of the new harmonised damage cause assessments showed that insects and fungi were the most widespread agents occurring on 27% and 15% of the trees, respectively. The occurrence of these factors shows clear regional trends like plots with high insect damage in north-eastern Spain, Italy or Hungary or high occurrence of trees with fungal infestations in Estonia.

The results obtained by FutMon reveal that the improved monitoring system provides politically and scientifically relevant information. A large portion of the monitoring data is relevant to the MCPFE/FE indicators defoliation, forest damage, forest growth, soil condition, and deposition and was already used for MCPFE/FE reports. Large-scale forest monitoring reflects the spatial and temporal variation of forest health (including various damage types), forest soil condition, needle-leaf chemistry, and ground vegetation. Forest ecosystem monitoring contributes to the understanding of cause-effect relationships and permits modelling and up-scaling approached permitting the interpretation of the large-scale observations. In this way, the further developed forest monitoring system can be used as a long-term tool for providing harmonised scientific information on relationships between forest health, forest growth, carbon fluxes, climate change, and biodiversity to international processes of environmental politics.

1. Introduction

Martin Lorenz[1]

The LIFE project “Further Development and Implementation of an EU-level Forest Monitoring System” (FutMon) aimed at the establishment of a pan-European forest monitoring system in the years 2009 to 2011, which can serve as a basis for the provision of policy relevant information on forests in the European Union (EU). Such information is required under Key Action 8 of the EU Forest Action Plan and several international processes of environment and forest politics. FutMon was a LIFE project of its own which supports forest monitoring in Europe as conducted for instance by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). This objective was reached by a consortium of 38 Beneficiaries in 22 EU-Member States. The main innovations and accomplishments of FutMon were:

- The establishment of an improved European-wide forest monitoring system featuring an administrative structure, expert knowledge, and harmonized methods for assessments at the large-scale (“Level I”) and at the forest ecosystem scale (“Level II”) in combination;
- A revised Level I forest monitoring grid featuring synergies with National Forest Inventories (NFIs), including contributions to the harmonization of NFI methods;
- A revised Level II forest monitoring grid with newly developed surveys and higher moni-toring intensity than ever before on about 250 plots, permitting assessments of relationships between forest condition, forest growth, climate change, carbon fluxes, air pollution, and biodiversity;
- Harmonized methods and standards laid down in the ICP Forests Manual and respected across all EU-Member States guaranteeing long-term comparability of data assessed on thousands of plots;
- Synergies between Level I and Level II monitoring permitting cause-effect studies, mod-elling approaches, and up-scaling approaches which were out of reach before the imple-mentation of FutMon;
- A system of training and intercalibration permitting that quality assurance will be guaranteed over the long term;
- The implementation of an innovative database permitting on-line data submission, automated data validation with immediate automated validation reports, data storage, an interactive Web-GIS, and data dissemination.

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The further developed forest monitoring system can be used as a long-term tool for providing harmonised scientific information on relationships between forest health, forest growth, carbon fluxes, climate change, and biodiversity to international processes of environmental politics. The system is made available in due time as the Standing Forestry Committee (SFC) of the European Commission (EC) has started debating future forest monitoring. This corresponds fully with the postulates of the Green Paper (SEC (2010)163 final), the LIFE-Regulation (EC) No. 614/2007, the 6th Environmental Action Plan of the EU (6th EAP, Decision No.1600/2002/EC) with its main focus on reduction of greenhouse gas emissions, as well as with the Thematic Strategy on Air Pollution (Com (2005, 446 final) aimed at avoiding exceedances of critical loads and levels of air pollutants.

The scientific analysis of the monitoring data led to the following new and policy relevant results:

- Forest soil condition and its changes at the European-wide scale and at the forest ecosystem scale;
- Spatial and temporal trends in deposition of acidity and nitrogen with longer time-series;
- Comparisons of measured deposition data with respective data calculated by models;
- Cause-effect relationships between deposition and vegetation response;
- Forest growth under the influence of deposition and climate change;
- Critical loads for acidity and nitrogen;
- Exceedances of critical loads as a basis for risk assessment;
- Prediction of the response of forest ecosystem to clean air politics.

Due to improved availability of weather and ground vegetation data the last one of the above items includes the response of plant species diversity under the combined influence of clean air politics and climate change.

The basics of the revision of the monitoring system and the results of the scientific analysis of the monitoring data are described in the present report. Chapter 2 focuses on the improvement of the monitoring system including data quality assurance and data base management. The development of tree crown condition as an indicator of forests health - including the main biotic and abiotic damage factors – is described in Chapter 3. Chapter 4 highlights the temporal and spatial variation of acidity and nitrogen deposition. Chapter 5 describes the status and development of forest soils under the impact of atmospheric deposition. Moreover, exceedances of critical loads and limits are calculated and the response of forest soils under different air pollution and climate change scenarios is predicted. The impact of combined effects of air pollution and climate change on biodiversity is analyzed in Chapter 6, with emphasis on forest trees, forest ground vegetation, and epiphytic lichens. Chapter 7 describes relationships between climate change, carbon budgets, water budgets and forest growth. Conclusions from the results of FutMon are drawn in Chapter 8.

2. Improvement of the monitoring system

2.1. Revision of the monitoring grids

Martin Lorenz[1] and Oliver Granke[2]

Abstract

The monitoring grids installed under ICP Forests were revised aimed at meeting the information needs regarding the relationships between forests, carbon fluxes, climate change, air pollution, and biodiversity. The large-scale forest monitoring grid is largely linked with NFI grids and comprises about 7500 plots. Forest ecosystem monitoring rests on about 250 plots on which up to 17 surveys can be conducted. Large-scale forest monitoring reflects the spatial and temporal variation of forest health (including various damage types), forest soil condition, needle-leaf chemistry, and ground vegetation. Forest ecosystem monitoring contributes to the understanding of cause-effect relationships and permits modelling and up-scaling approached permitting the interpretation of the large-scale observations.

2.1.1. Introduction

Forest monitoring in Europe has been conducted for 26 years according to harmonised methods and standards by the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The complete methods of forest monitoring by ICP Forests are described in detail in the “Manual on methods and criteria for harmonised sampling, assessment, monitoring and analysis of the effects of air pollution on forests” (ICP Forests 2010). For many years forest monitoring according to the ICP Forests Manual was conducted jointly by ICP Forests and the European Commission (EC) based of EU co-financing under relevant Council and Commission Regulations. In order to better meet the new information needs with respect to carbon budgets, climate change, and biodiversity, the forest monitoring system was further developed under FutMon. This was accomplished by FutMon using synergies with ICP Forests and the National Forest Inventories (NFIs) in the following way:

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- The large-scale systematic grid (Level I) was largely merged with the NFI grids permitting assessments of more information on the same plots to the extent to which the EU-Member States agreed;
- Of the forest ecosystem monitoring plots (Level II), 252 were selected representing the main forest types in Europe and were furnished with equipment permitting assessments of more information on the same plots;
- New monitoring methods were developed aiming at the relationships between biodiversity, climate change, carbon fluxes, and air pollution.

The following subchapters explain the new set-up of the large-scale and forest ecosystem monitoring. Finally, conclusions are drawn regarding the success of the revision and its relevance for current international processes of environmental politics.

2.1.2. Large-scale forest monitoring (Level I)

The large-scale forest monitoring grid resulting from FutMon consists of more than 7500 plots. The selection of Level I plots was within the responsibility of the participating countries, but the selected plots were supposed to preferably constitute a subsample of the NFI. The density of the plots was supposed to resemble that of the previous 16 x 16 km grid. For this reason, the number of plots in each country should be equal to the forest area of the country (in km^2) divided by 256. The spatial distribution of these plots is shown in Figure 2.1.2-1. In the 23 EU-Member States having participated in FutMon, 58% of the Level I plots are now linked with NFI plots. No link with NFI plots was given for 29% of the plots. It is expected, however, that a number of countries will merge these plots with NFI plots at a later date. For the remaining plots no information was made available.

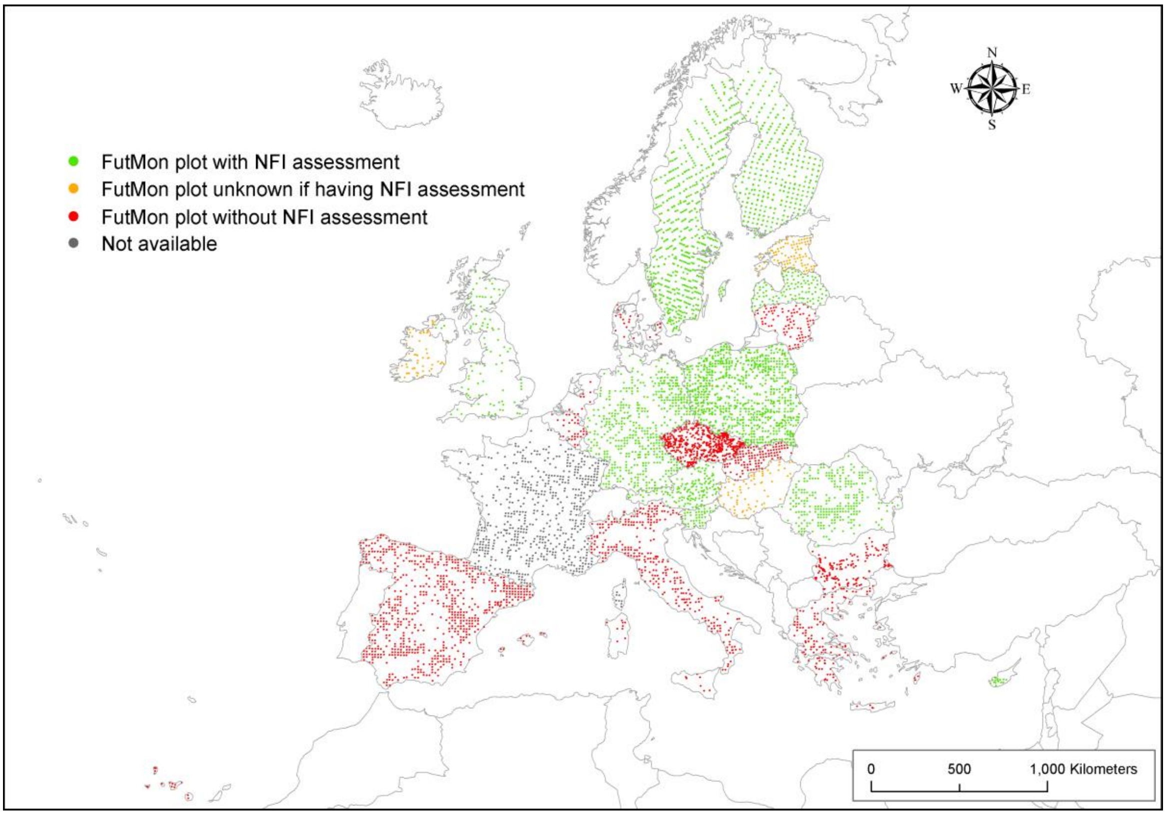

Figure 2.1.2-1: Spatial distribution of the large-scale plots under FutMon. Green colour implies a coincidence with NFI plots.

On most of the Level I plots tree crown condition is assessed every year. In 1995, element contents in needles and leaves were assessed on about 1500 plots and a forest soil condition survey was carried out on about 3500 plots. The Level I soil condition survey was repeated on about 5300 plots in 2005 and 2006 and the species diversity of forest ground vegetation was assessed on about 3400 plots in 2006 under the Forest Focus Regulation of EC within the BioSoil project (Figure 2.1.2-2).

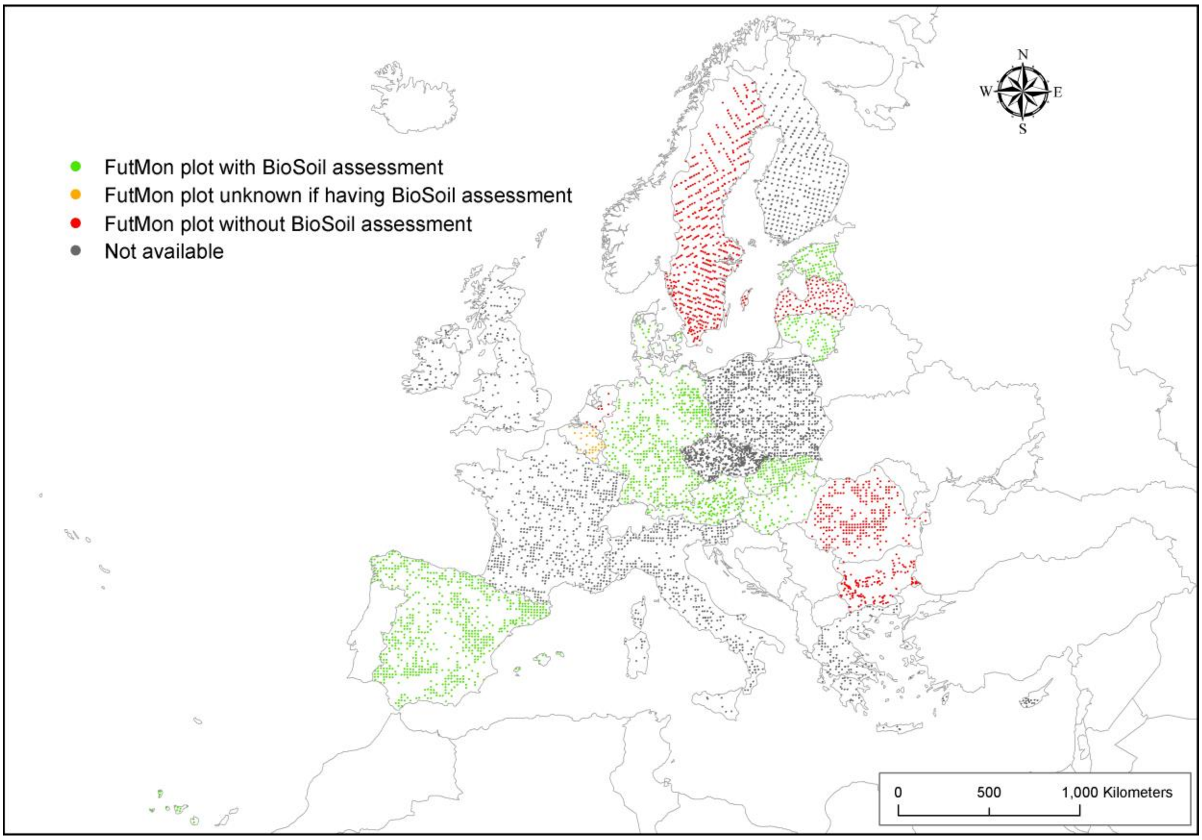

Figure 2.1.2-2: Spatial distribution of the large-scale plots under FutMon. Green colour implies inclusion in the BioSoil project under the Forest Focus Regulation of EC.

2.1.3. Forest ecosystem monitoring (Level II)

Forest ecosystem monitoring in 2009 comprised up to 17 surveys on different numbers of Level II plots depending on the survey (Table 2.1.3-1). Of these surveys many are not conducted continuously or annually, but are due only every few years. Moreover, on most plots only part of the surveys can be conducted. The fragmentary coverage of the plots by important surveys constituted a major problem for data analyses.

One of the aims of FutMon was to bundle resources and to reduce the number of Level II plots for the benefit of higher numbers of surveys per plot. For each survey Table 2.1.3-1 shows the number of plots from which data were submitted in 2009. The number of installed plots reflects those plots from which data are available in the data base. The map in Figure 2.1.3-1 shows those plots on which crown condition was assessed in 2009, coming close to the total of all Level II plots assessed in 2009. Moreover, the map indicates the locations of Level II plots of previous years. More details regarding the selection of Level II plots are provided in Chapter 2.3.

Table 2.1.3-1: Surveys, numbers of Level II plots and assessment frequencies in 2009

Survey	Data submitted for 2009	Plots installed	Assessment frequency
Crown condition	559	938	Annually
Foliar chemistry	308	859	Every two years
Soil condition	68	753	Every ten years
Soil solution chemistry	196	338	Continuously
Tree growth	256	820	Every five years
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
Phenology	188	240	Several times per year
Ground vegetation	169	815	Every five years
Litterfall	162	276	Continuously
Nutrient budget of ground vegetation	83	83	Once
Leaf Area Index	107	107	Once
Soil Water	46	46	Once
Extended Tree Vitality	115	115	Annually/ Continuously

Figure 2.1.3-1: Level II plots with crown condition assessments in 2009. Also shown are plots with other surveys and of previous years.

2.1.4. Conclusions

The further developed forest monitoring system can be used as a long-term tool for providing harmonized scientific information on relationships between forest health, forest growth, carbon fluxes, climate change, and biodiversity to international processes of environmental politics.

The revision of the large-scale monitoring led to links between nearly two thirds of the Level I plots with NFI plots. For the remaining plots, part of the concerned EU-Member States are still considering the linkage whereas another part has decided to keep the two systems separate. Linkages between the two systems have been postulated by DG Env at several occasions and are discussed by Standing Forestry Committee (SFC) of EC because of the following synergies: Qualitative information from Level I assessments (crown condition, soil condition, foliage chemistry, pests and diseases) can be linked to quantitative information (growth and volume). More parameters on the large-scale plots in turn mean better possibilities of linking large- scale to forest ecosystem-scale (Level II) data. NFIs provide data with high spatial but low temporal resolution for parameters which are less costly to obtain. Level II provides information based intensive measurements for a smaller number of plots which are the basis for explaining cause-effect relationships. Regional applications have already shown the benefit of combined applications which can upscale information on ecosystem processes (tree growth, carbon storage, nutrient cycling, development of species composition, critical loads exceedances) to NFI plots. For the European level, joint efforts are needed in order to parametrize cause effect models on intensive monitoring plots and to use key parameters for such up-scaling approaches.

The revision of forest ecosystem monitoring (Level II) has led to about 250 Level II “basic” plots on which more information than previously is assessed in a harmonized way: Crown condition, forest growth, foliar chemistry, ground vegetation, deposition, ambient air quality, visible ozone injury, soil condition, and meteorology. This lets scientific data analyses reach beyond air pollution effects towards the relationships between forest health, carbon sequestration, climate change and biodiversity including up-scaling to the large scale. First results of such data analyses are presented in this report.

2.1.5. References

ICP Forests (2010): Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE ICP Forests Programme Co-ordinating Centre, Hamburg [http://www.icp-forests.org/Manual.htm].

2.2. Large scale representative monitoring: test of methods for harmonising information from national forest inventories (NFIs)

Annemarie Bastrup-Birk[1] *and Göran Ståhl* [2]

Abstract

Harmonisation of information from National Forest Inventories is important for the comparability of forest information at European level. Still harmonisation allows for maintaining the time series for local and national forest management. Reference definitions and corresponding bridging procedures have been developed recently under a COST Action E43 on Harmonisation of National Inventories in Europe. The present work under the LIFE$^+$ FutMon project aimed at developing country-level bridges for the following variables: forest and other wooded land, growing stock volume at the tree level, and volume of dead wood at the tree level, including downed tree parts. The variables were assessed according to the reference definitions and the national definitions of the respective countries. The Actions on Harmonisation of NFI core variables supported the results achieved with further developments of guidelines and recommendations to NFI-based analyses through elaboration of methods. Results are promising and are summarised in the present chapter. The study underlines the importance of harmonising NFI variables, gives an insight in the resource needed for such a process, and highlights the importance of identifying and testing suitable harmonisation approaches also in the future.

2.2.1. Introduction

Harmonisation of information from National Forest Inventories *(NFIs)* is important as it is neither meaningful nor possible to adopt standardised definitions and measurement protocols due to the importance of maintaining well-known national time series for the decision making related to national forest policies. However, the development of ’bridging procedures’ facilitates reporting according to agreed-upon reference definitions and thus makes information comparable across countries. Bridge building procedures build on the concept of reference definitions. This concept was developed within COST Action E43 and is a prerequisite for harmonised reporting. Reference definitions have to fulfil several criteria to meet international requirements and ensure applicability at the national level. These criteria have to be taken into account when reference definitions are established (Vidal et al. 2008). Target variables are needed for the estimation of population parameters of primary interest for common reporting. Target variables are, e.g., forest and other wooded land, growing stock volume at the tree level, and volume of dead wood at the tree level, including downed tree parts. When comparing the national definitions of the target variables, the variables and their associated thresholds vary between countries. For harmonisation, a common definition of the target variables is needed. An agreed definition for a target variable is called a *reference definition*. The variables needed in the description of the reference definition are called *core variables*, with

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commonly agreed thresholds for quantitative variables and modalities for qualitative variables (Vidal et al. in review).

The Actions C1-NFI (DK) and C1-NFI (SE) activities of the Life+-FutMon project activities built upon the experiences reached in the COST Action E43 and other projects on harmonisation of National Forest Inventories in Europe (http://www.metla.fi/eu/cost/e43/). The Actions C1-NFI (DK and SE) - Harmonisation of NFI core variables - supported the activities and results achieved under the Action L2b with further developments of guidelines and recommendations to NFI-based analyses through elaboration of methods and compilation of summary results. The overall idea was to develop country-level bridges for selected variables, to enhance the usage of NFI data in connection with international reporting according to common reference definitions (those of COST E43). The process of harmonisation of core variables is illustrated in Figure 2.2.1-1.

The project resulted in the development and improvement of bridging procedures for the selected set of core variables. Analyses were performed to study the deviation between national standards and references. The improved national bridging procedures between NFI data and the references to be applied at country level are described in detail in the final report of the project accompanying the countries' reports on the L2b activities.

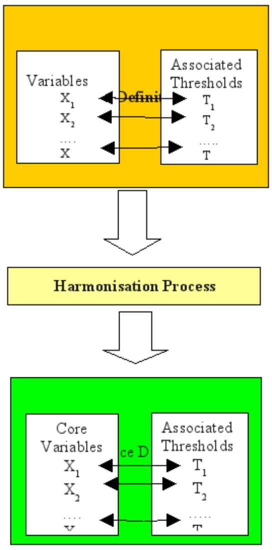

Figure 2.2.1-1: National and reference definitions. Core variables with associated thresholds are defined in the harmonisation process (Vidal et al. in review).

2.2.2. Material and methods

13 countries participated fully in the L2b, C1-NFI Actions: Austria, Germany (Baden Württemberg), Belgium-Flanders, Denmark, Hungary, Italy, Latvia, Lithuania, Romania, Slovakia, Slovenia, Sweden, and Great Britain. Several workshops were held to discuss and select a set of core variables of relevance for the respective participating countries. Table 2.2.2-1 summarises the selected target variables selected by the respective countries.

Table 2.2.2-1: Each participating country selected a set of variables for the field studies.

Variable	Countries
Forest area	Austria, Great Britain, Hungary, Latvia, Lithuania, - Slovakia, Slovenia
Area of other wooded land	Austria, Hungary, Latvia, Lithuania, Slovenia
Growing stock	Austria, Italy, Great Britain, Hungary, Romania, Slovakia, Slovenia
Small trees	Austria, Denmark, France, Hungary, Italy, Latvia, Romania, Slovakia, Slovenia
Above and below ground biomass	Denmark, Sweden
Deadwood	Belgium/Flanders, Denmark, Germany Baden-Württemberg, Slovenia, Slovakia, Sweden

Field studies were conducted on subsets of the NFI samples during the years 2009 and 2010 to collect data and test reference assessment methods. All field assessments were done on a subsample of plots according to the reference definition. Photo interpretation and use of forest maps could also have been used. The used methods depend on whether field visits to the NFI plots were necessary or not. A possible exchange of knowledge for photo interpretation within the project was discussed. The field studies were designed to meet the needs for harmonisation of each participating country; typically the field assessments included collection of NFI data following national standards, following reference procedures, as well as other specific data needed for the development of bridging functions. A minimum of 150 NFI plots per country was required.

Based on these data bridging procedures were developed and evaluated. Bridges can be of many different kinds. From the point of view of data availability, bridges can be reductive, neutral, expansive, or mixtures. For **reductive bridging,** data on core variables are available in surplus. For **neutral bridging**, the same data material on core variables is available or needed for the national and the reference definition. This bridging typically implies recoding, using other subdivisions between classes, etc. For **expansive bridging**, data on core variables are lacking for converting from national to reference definition. The expansive bridges are the most problematic type of bridges as well as **mixed bridging** as it might be necessary to include several components and thus cannot be easily classified as ’reductive’ or ’expansive’.

2.2.3. Results

Forest area and OWL were selected by 5 countries (Latvia, Hungary, Slovakia, Austria, and Slovenia). The variables used in the reference definition of forest area and other wooded land area were also used in the countries, in some cases proxies could be used. The thresholds in the key definitions showed to be different as, e.g., Italy applies the FAO forest definition, while most countries are in the same situation as Austria, not using the FAO definition. The discussion on OWL was parallel to the forest area discussion. It was recommended to focus on the main differences in terms of possible results and in terms of time and fund restrictions in FutMon. The recommendations were that the country should decide whether to use photo interpretation or field work, consider the intensity of the subsampling and finally try to combine as many variables as feasible. A final recommendation was to aim for the FAO definitions in a longer time perspective.

Data on growing stock and small trees assembled 6 countries (Italy, Austria, Slovakia, Slovenia, Romania, and Latvia). Regarding the growing stock, the problem of exclusion/inclusion of tree elements was discussed. Most countries excluded branches (RO), included large branches but excludes small branches (IT), included stumps (LT) or included tree top (ML) or excluded tree top (IT). As proposed solutions, it was recommended to look for available models/coefficients (sorting tables, others, exchange among countries) and/or derive values from existing models. For small trees the problem was often the lacking basic data (number, species, diameter, height), the lack of volume data (all countries), the lack of models for small DBH ranges (all countries), and finally the lack of a harmonised list of tree/shrub species (shrubs are very common in the smallest DBH classes) (all countries). The possible solutions were to take measurements on a sub-sample, to make height measurements (almost all countries), to use density and height information from other sampling units to predict the small trees (LV), to extrapolate from existing functions/models (all countries) and/or to provide new models/average values from sample trees (IT, RO). The plans were thus to look for existing models/coefficients/literature and to plan additional measurements on the plots.

Dead wood assembled 7 countries (Belgium/Flanders, Denmark, Germany/Baden-Württemberg, Great Britain, Slovakia, Slovenia, and Sweden). The components of deadwood are assessed in different ways in different countries. For example, standing dead wood is assessed including or excluding stumps, tops of stems, and within different diameter thresholds. Lengths of lying dead wood also have different thresholds. Some countries measure only deadwood within the plot while some include also the parts outside the plot when the reference point of a piece is inside the plot. Further, for downed trees line intersect sampling is an important alternative to plot sampling as it is applied in many countries.

For deadwood, expansive and reductive as well as mixed bridges will be required. For the bridging, the project agreed to use the reference definition proposed under the COST Action E43, although that definition was never firmly adopted during the COST Action E43. As the reference definition may be modified in the future many countries chose to perform dead wood assessments in such a way that the data would be useful also with new reference definitions. For example, for lying deadwood all pieces down very small diameter thresholds were measured by some countries.

Aboveground and belowground biomass should be reported separately according to the Kyoto Protocol. Two countries, Sweden and Denmark, chose to work with biomass in order to develop bridges that would meet the requirements of the Kyoto Protocol and the Climate Convention. In this case total biomass of trees is obtained from functions but these functions provide aboveground biomass as the biomass component above stump height rather than strictly above ground level, as is required. Thus, there is a need to develop neutral bridges that reallocate some parts from the belowground component to the aboveground component. To achieve this stump volume and biomass was quantified within the project.

Each country developed a bridging procedure to be applied on the country NFI definition to close the gap between the national definition and the reference definition. All the 3 types of bridging procedures were applied to harmonise forest area and other wooded land definitions to the reference definition. Table 2.2.3-1 summarises the needed bridging procedures.

Table 2.2.3-1: Overview of bridging procedures used to harmonise the forest attributes.

Variables	Attribute	Neutral bridges	Reductive bridges	Expansive bridges
Forest area	*Area*	HU, SK	AT, SI, LT	
	Height	AT, SI, SK	HU	LT
	Crown cover	SK		HU, AT, SI, LT
	Width		AT	
	Land use	HU	AT	
	Temp unstocked	HU		
	Linear formations	HU		
Other wooded land	*Area*	SK	AT, SI, LT	HU
	Height	SI		HU, LT
	Crown cover			HU, AT, SI
	Width		AT,	HU
	Land use			HU
Growing stock	*Living stems only*	HU		SI
	Minimum diameter			HU, AT, GB
	Top of stem	HU		GB
	Branches		HU, SI	
	Bark	HU	SK	SK
	Stump	HU	SI,	
	Volume of small trees		SK, LT	AT, RO, SI, SK, LT, IT, GB
Dead wood	*Standing trees*			DK, SE, SI,
	Lying trees		SI	DK, SE
	Stumps		SI	
Biomass		DK, SE		

The approach varies depending on the type of bridge and the variables. Most neutral and reductive bridging procedures have been performed using the existing field data, databases, or using maps and orthophotos to complement the field information. Some countries did not have the needed data to build an expansive bridge; some had the data but experimented with the ways such a bridge could be built.

2.2.4. Conclusions and recommendations for the future

Reporting in accordance with the common reference definitions (Tomppo et al. 2010) is an important aim of the European NFIs. The results of this study are promising and facilitate that estimates can be provided according to the reference definition for the selected variables. Selected attributes were tested in the field using databases and complementary information for building bridging procedures to harmonise the national definitions to internationally agreed reference definitions. The experience of this study reinforces the importance of harmonisation. The study reveals the many steps and components of the bridging that affect the results of the harmonisation process. Many of the countries participating in this study point out the importance of a correct and detailed identification of all components and a thorough analysis of each component to ensure the best possible results.

Several problems were raised during the process of harmonisation. Some of the critical issues lie in the definitions like e.g. forest area, crown cover, delineation of the area, land use, and even tree height. This study underlines the importance of sharing national experiences on impacts of bridging procedures on the results of each variable, also in order to reach an optimal outcome of the work. Further, all countries were allowed to use different sampling methods for the bridging adapted to national conditions. However for the expansive functions where new data had to be collected like e.g. small trees, it would be relevant to use the methodology and threshold for classification of the small trees. In such cases where the methodology may have considerable effect on the harmonisation process, workshops or common projects are needed to assist this process. Agreement on definitions and methodology may not be sufficient to reach an optimal harmonisation; common approaches, manuals and training of field crew are needed in cases when the decision depends on observations and correct usage of definitions.

The study highlights the resources needed for the harmonisation process as the data acquisition for the development of bridging procedures requires time and money. Sharing experiences would improve efficiency of the harmonisation. In the case of expansive bridging procedures, new data collection needs to be introduced in the NFIs, like for the small trees, where there is a lack of information. This is feasible as long as the additional work only uses small resources. However, in cases it requires larger resources, each country must decide on how long the complementary assessment of the given attributes has to take place. Getting more information on the given area will be decisive for the continuation of further work.

The testing of various methods for adapting data from NFIs within the Life+ - FutMon project provided knowledge from many countries. From these experiences additional input can be expected towards the development of optimised bridge building. The different sampling techniques applied by the participating countries are of particular interest. Also additional equations and models are now available and will enhance the possibilities for calculation of harmonised estimates. This study developed mainly straightforward bridging procedures in the form of conversion factors for reductive and expansive bridging. In the future we would need more advanced bridging based on plot level data and regression functions. From the various bridging techniques developed and employed in the Life$^+$ - FutMon project several will be applicable to several countries, but for others the results may be less satisfactory as it is stated in Tomter et al. (in review). Therefore, the testing of the available and the identification of the most suitable approaches will be of central importance also in the future.

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2.3. Representativeness analysis for intensive forest monitoring plots – Evaluation and optimization based on representative information from small scaled maps

Bernd Ahrends[1]

Abstract

The study evaluates the distribution of European intensive forest monitoring plots of the joint ICP Forests / FutMon programme. The transnational set of existing intensive monitoring plots was originally based on national initiatives and the study presents the first overall representativeness analysis with respect to different environmental factors. External information for these factors was available from different independent data sources like small scaled maps and the values and properties from these maps at coordinates of the intensive monitoring plots was compared to the distribution of these factors in the forested area in Europe. The evaluation procedure shows that in general the spatial distribution structure from existing intensive monitoring plots is very similar to that of the forested area in Europe with respect to the selected environmental factors. A simple decision tree for optimization of "core plots" selection on the European scale was developed which could still improve the representativeness of the plots with respect to important key factors.

2.3.1. Introduction

Intensive forest monitoring provides key information for forest management and environmental policy and helps to assess the impact of different causes and stress factors on European forest ecosystems. Under FutMon, assessments on around 300 intensive forest monitoring plots in EU-Member States were co-financed. A follow-up proposal called EnForMon (Environmental Forest Monitoring) has been submitted under the 2011 LIFE+ call. In this context the representativeness of the existing monitoring system has been questioned (e.g. EC, 2010).

Since the inception of the intensive monitoring programme, plot selection has been under the responsibility of the participating countries. The guidelines of ICP Forests and the first EU regulations state that intensive monitoring plots should be selected "in forests that represent the most important forest ecosystems in Europe" (Fischer et al 2011). However, additional factors influenced the selection of the today existing plots, including national interests, already existing monitoring infrastructure, availability of national funds, and co-financing by the European Commission over many years.

Given the importance of forest ecosystem information based on this European-wide set of plots, it is necessary to conduct such monitoring on a network representative for the most important environmental factors. As intensive monitoring is costly, the density of this network is limited. Consequently, the aim of this study is to compare the distribution of different envi

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ronmental factors in European coniferous, mixed, and broad-leaved forests with the distribution of the same factors on intensive monitoring plots. Finally, a simple optimization procedure was used to select "core plots" from the given distribution of intensive monitoring plots. The approach only considers easily and freely available geodata (CORINE, WORLDCLIM, EUROPEAN SOIL DATABASE etc.). To avoid an overcategorization (Spangl et al. 2007) the analysis was restricted to a limited number of environmental factors, which are frequently used in assessments of forest condition.

2.3.2. Material and Methods

2.3.2.1. Terms and Definitions

Types of intensive monitoring plots (ICP Forests 2010)
Intensive monitoring standard plots with mandatory surveys of: crown condition, tree growth, foliar chemistry, ground vegetation, deposition, soil conditions, meteorology and intensive monitoring core plots with additional mandatory surveys of: litterfall, tree phenology, growth (intensified survey), soil solution, soil water, air quality, ozone injury, meteorology (intensified survey).

Representativeness: The term representativeness is used in the sense of the definition given by Nappo et al. (1982) which states that the plot-to-area representativeness is the probability that a plot measurement lies within a defined range of the small scale areas. In this context the representativeness definition is not used in the sense of a grid or random sampling strategy, but in the sense of an area-related transfer of environmental factors, such as soil type, deposition, temperature etc. Therefore we used the mapped polygons and grids of the environmental variables in a kind of a priori stratification. This has the advantage of incorporating the main variables, which are involved in many processes in forestry.

Area of representativeness: Describes the area in which the parameter of interest does not differ by a defined uncertainty from the value observed or regionalized at the plot site (Larssen et al. 1999). The uncertainty has to be assessed for each individual parameter. In this study the analyzed area is a forested area with a size of 250 x 250 m.

2.3.2.2. Indicators used for representativeness analysis

Indicators are environmental factors that can be measured to monitor changes in forest ecosystems and that can be used for modelling the impact of climate and environmental changes to forest sites. The annual mean air temperature (AMT) or the temperature sum in the vegetation period is a good indicator for the site productivity of forest ecosystems (Albert & Schmidt 2010, Laubhann et al. 2009, Pretzsch 2002) and the amount of foliar and total litterfall (Albrektson 1988, Berg et al. 1993, 1999, Liu et al. 2004, Starr et al. 2005, Saarsalmi et al. 2007). The temperature conditions in forests are also important for the incidence of biotic stressors (Baier et al. 2007).The annual precipitation (PREC) or the precipitation in vegetation period is often correlated with forest growth (Albert & Schmidt 2010, Laubhann et al. 2009, Pretzsch 2002) and litterfall (Albrektson 1988, Berg et al. 1993, 1999, Liu et al. 2004, Starr et al. 2005, Saarsalmi et al. 2007). Additionally, precipitation could be a good indicator for the estimation of rooting depth (Czajkowski et al. 2009) or seepage fluxes from forest ecosystems (Borken & Matzner 2004). Generally altitude (ASL) is closely related to climatic variables such as temperature, precipitation or wind speed. But elevation is as well regarded as predictor for organic matter concentrations (Hengl. et al. 2003) or organic carbon stocks in soils

(Olsson et al. 2009, Stendahl et al. 2010), for the amount of litterfall (Lonsdale 1988) and for the estimation of biomass components with allometric functions (Wirth et al. 2004, Wutzler et al. 2008). The Sulphur deposition (SDEP) is a suitable indicator for the risk of acidification of forest ecosystems (Alewell 2001). In this context soil acidification due to excess input of S over base cations may have a negative impact on forests growth (Sverdrup & Warfvinge 1993, Sverdrup et al. 1994). In general, deposition of nitrogen (NDEP) can lead to fertilization, eutrophication, or acidification of forest ecosystems. Therefore nitrogen deposition to forest ecosystems is often used as predictor for forest growth conditions (Albert & Schmidt 2010, Laubhann et al. 2009). Additionally N deposition is frequently used to asses the risk of N leaching from forest soils (Ahrends et al. 2010, Gundersen 1995, Borken and Matzner 2004). De Vries et al. (2006) used N deposition for modeling the carbon sequestration on a European scale. Bonten et al. (2011) took into account the effect of N deposition on the N content in needles and litterfall. But there are not only risks from high deposition levels. In many European regions N deposition level is on comparatively low levels. This implies that forestry with high harvest intensities will not be sustainable unless nitrogen is added through compensation fertilization (Akselsson & Westling 2005, Akselsson et al. 2007). Generally, ozone (O_3) is considered the most important gaseous air pollutant in areas that are not urbanized (Pleijel 1985). At high ozone concentrations, sensitive trees show injury (Ollinger et al. 1997). At lower ozone levels photosynthesis of trees is reduced (Ollinger et al. 2002) and consequently forest growth is reduced. Nitrogen dioxide (NO_2) is one in a group of highly reactive gases generically referred to as “nitrogen oxides” (NOX). The NOX concentration plays a major role in forest growth (Pretzsch 2002) and in the formation of ozone in the atmosphere (Blanchard et al. 1999). NO_2 is the most widespread and commonly found nitrogen oxide. Soil types (ST) are a good indicator for the soil nutrient status, for weathering rates (Spranger et al. 2004) and the water budgets of soils (e.g. gleyic soils). The available soil water capacity (AWC) (Müller 2006, Spellmann et al. 2007) or the actual fraction of the available soil water capacity (REW) (García-Santos et al. 2009, Granier et al. 2003, Maseyk et al. 2008) is frequently used for the assessment of drought stress risks of forest ecosystems. Additionally the AWC is an important parameter for soil water budget models (e.g. Watbal: Knudsen et al. (1986) or water balance programs like the Thornthwaite monthly water balance program (McCabe & Markstrom 2007).

2.3.2.3. Kernel estimate of density (KDE)

A kernel density estimate (KDE) is a nonparametric method for the estimation of probability distributions functions from data that are related to classical histograms (Horova et al. 2003, Lall et al. 1996). Here, the KDE is used to analyze the distribution of different environmental parameters for the forested area in Europe and the distribution of the same parameters at intensive monitoring plots. If $x_1,\ldots,x_n$ are a given set of observations, the KDE is defined as follows:

$$\hat{f}(x) = \frac{1}{hn}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \qquad (1)$$

where K() is a weight or kernel function and h is a bandwidth.

2.3.2.4. Data sources

From the database of TI in Hamburg we take only those plots into account, which have been reported for the EnForMon proposal. For this “First Step Analysis” the coordinates from the monitoring plots are used and not the measured values. Such an analysis would be very time intensive and have a lot of methodical problems. For example the nitrogen deposition is strongly affected by canopy exchange. For that reason modeled total deposition from throughfall data with canopy exchange models is difficult to compare with calculated deposition data by EMEP (Westling et al. 2005). A large proportion of the uncertainties are inherent in the deposition monitoring methods and models themselves (Erisman et al. 2003, 2005). Another example are the climate parameter, which are given as mean values for the period from 1950-2000 (Hijmans et al. 2005). Westling et al. (2005) found that precipitation values reported by some ICP Forests sites could show very large variation between 1997 and 2000. Therefore, a direct comparison is not straightforward.

In order to analyse the representativeness of the intensive forest monitoring plots of the ICP Forests / FutMon programme in Europe different spatial datasets from various European databases were used. For a pan-European analysis of station representativeness, high spatial and temporal resolution climate and air quality data are currently not available. However, for the climate parameter (temperature and precipitation) we could use a 1 km gridded world wide dataset. Unfortunately, no kilometre - scale deposition and air concentration data set was available for this study on a European scale.

The forest area analysis is based on the European land cover data set CLC2000 (The European Topic Centre on Land Use and Spatial Information 2009). Forested areas are differentiated into coniferous, broadleaf and mixed forests. The horizontal resolution of the gridded data is 250 x 250 m. Each forested grid cell was intersected with the different indicators (temperature, precipitation, soil type etc.). Climate variables for this study were taken from Hijmans et al. (2005), offering a 1 km gridded freely available precipitation and temperature world wide dataset. Data consist of 1950-2000 mean monthly precipitation and minimum, maximum and mean monthly air temperature. In addition, the data set contains elevation above see level. The EMEP (www.emep.int/) (European Monitoring and Evaluation Programme) deposition and air concentration maps (50 km by 50 km spatial resolution) were intersected with all forested areas from the CORINE dataset using ArcGis 9.3. The analysis took into account the most recent year (2008) available from the EMEP database. Soil type (ESDB 2004) Information on soil types and available soil water capacity was taken from the European Soil Database (ESDB 2004).

2.3.3. Results

Kernel density estimates of the selected indicators were calculated for the forested area in Europe separately for the forest types broad-leaved forests, coniferous forests and mixed forests as well as for all intensive monitoring plots, intensive monitoring standard plots and intensive monitoring core plots available in the FutMon/ICP Forests database at TI. The results for the intensive monitoring plots were compared to the kernel density estimates for the forested area of Europe in order to identify ranges of the respective environmental factors which are overrepresented or underrepresented. Results are presented as kernel density plots.

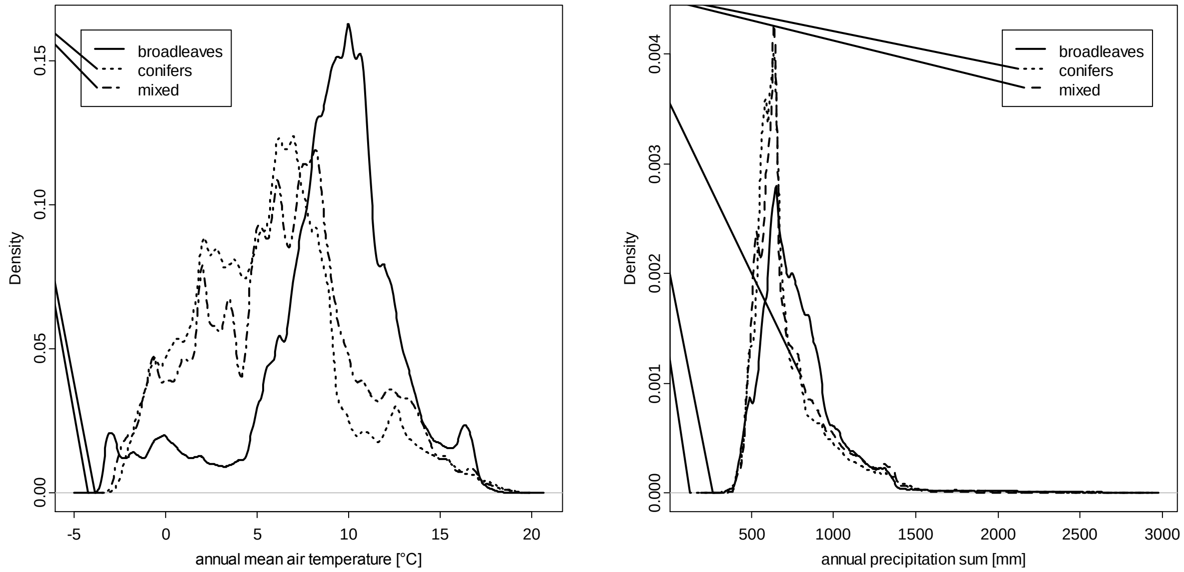
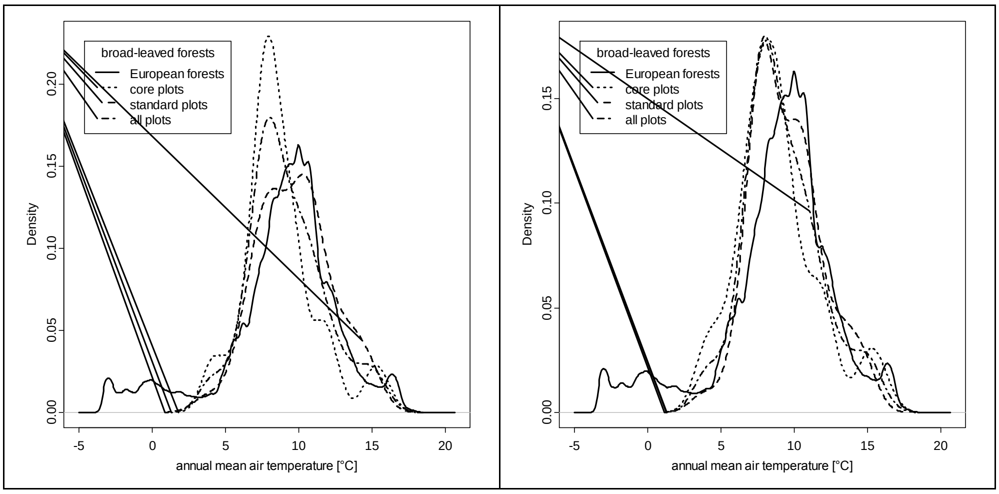


Figure 2.3.3-1: Kernel estimated probability density functions (pdf) of annual mean air temperature (left) and annual mean precipitation sum (right) for European forests based on Hijmans et al. (2005).

As an example the distribution of annual mean air temperature and annual precipitation sum for forest areas in Europe is given in Figure 2.3.3-1. Broad-leaved tree species show higher frequencies in warmer areas with higher precipitation rates as compared to mixed and coniferous forests. The suggested intensive monitoring core plots overrepresent colder sites and underrepresent warmer sites especially for broad-leaved forests (Figure 2.3.3-2). The bias is reduced after optimization (Figure 2.3.3-2). Coniferous forests are also well represented by intensive monitoring core plots after optimization, especially for the temperature range between 0 and 5°C (Figure 2.3.3-2).



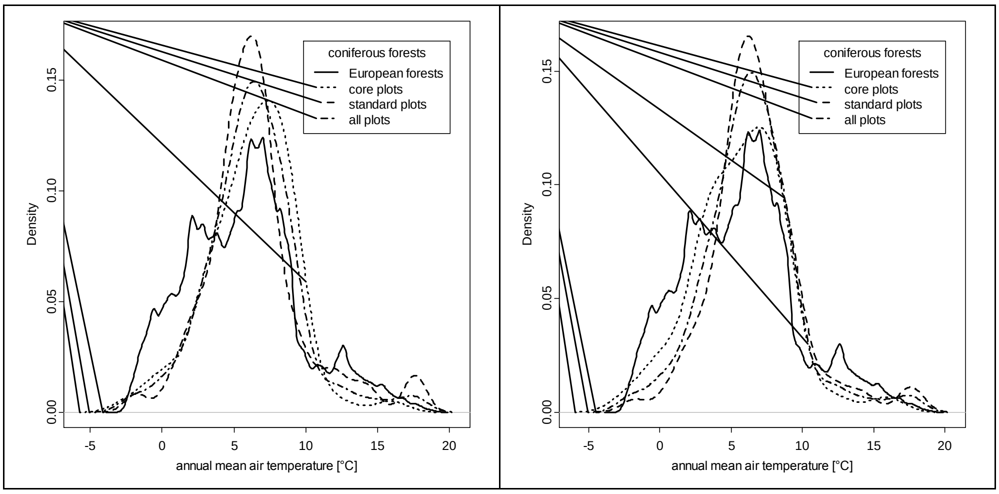


Figure 2.3.3-2: Kernel estimated probability density functions (pdf) of annual mean air temperature for forested areas in Europe, intensive monitoring core plots and intensive monitoring standard plots before (left) and after (right) optimization procedure.

Another example is the distribution of mean annual precipitation for the period from 1950 to 2000 for European forest sites and intensive monitoring sites. The suggested intensive monitoring core plots, especially for broad-leaved forests, overrepresent areas with annual precipitation between 700 and 900 mm. Coniferous intensive monitoring core plots overrepresent precipitation regimes above 800 mm. After optimization the bias is reduced for both forest types (Figure 2.3.3-3).

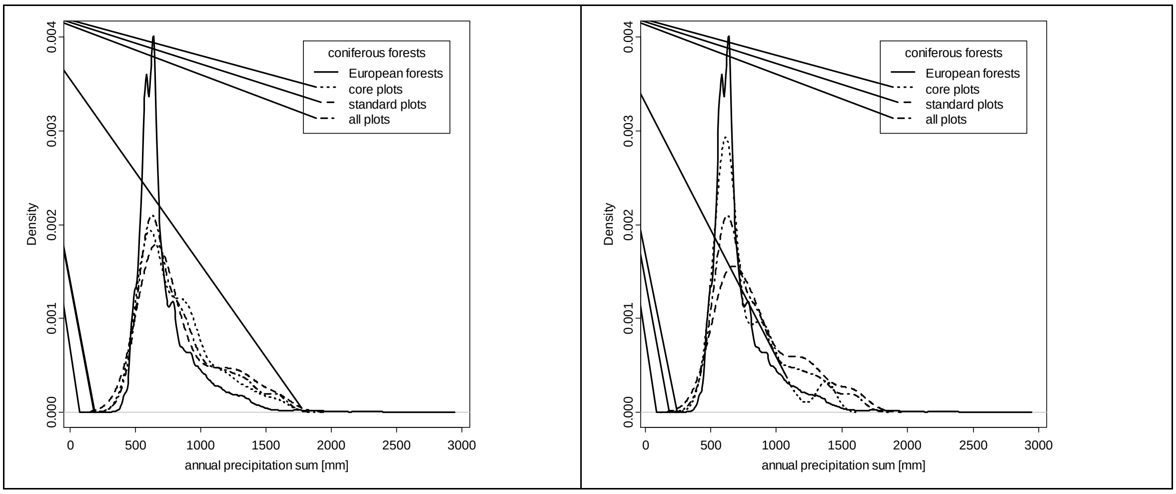


Figure 2.3.3-3: Kernel estimated probability density functions (pdf) of mean annual precipitation for forested areas in Europe, intensive monitoring core plots and intensive monitoring standard plots before (left) and after (right) optimization procedure.

2.3.3.1. Decision criteria for core plot selection

Figure 2.3.3.1-1 shows the decision tree used for the core plot selection procedure that was applied for plot selection in the EnForMon project proposal. This selection was firstly based on the intensive monitoring plots, which were suggested as core plots for the EnForMon proposal by the associated beneficiaries. If the number of suggested core plots per beneficiary was equal or below 3.3% of the large scale (Level I) plots of the respective beneficiary all suggested core plots were accepted. If this number was above the 3.3% criterion, plots with the highest representativeness were selected as core plots. The criteria which were applied to the different forest types to calculate the decision matrixes are derived from the deviation of the kernel estimated probability density functions (pdf) for the selected plots. The total score was calculated as the sum of the scores of the different criteria. In case of the same score for two or more intensive monitoring plots, the length of existing data series was used as a further criterion.

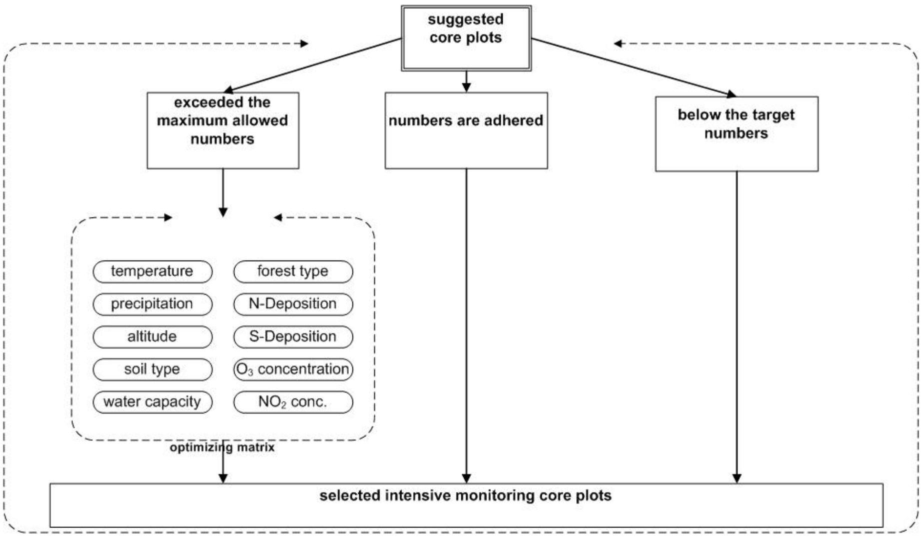


Figure 2.3.3.1-1: Decision tree for the core plot selection procedure.

2.3.4. Conclusions

This study presents an analysis of indicators characterizing the spatial representativeness of intensive monitoring plots of the ICP Forests / FutMon programme in relation to the European forest area as represented by large scale data sets. Furthermore, a simple optimization procedure was developed and used for core plot selection at the European scale.

Results indicate that intensive monitoring plots suggested for the EnForMon proposal represent European forests sites satisfactorily with respect to various environmental parameters. After performance of a simple optimization procedure the representativeness of intensive monitoring core plots could be improved. However, in this First Step Analysis the reader should keep in mind that spatial representativeness of the different environmental factors was only graphically evaluated and there are several ways to evaluate the representativeness of a specific parameter. Furthermore the analysed datasets originate from large scale maps. It should be noted that e.g. the EMEP data, with Na grid size of approx. 50x50 km² cannot be expected to reproduce site specific variations in deposition regimes, caused by tree height, topography, local emissions or fog. In such cases the representativeness analysis is limited by the quality of “ground truth” information. Finally we need to take in account that the spatial distribution of most of the examined parameters is different and therefore a set of monitoring plots cannot – to the same extent - be representative for different environmental factors. Therefore and given the broad range of topics of interest it is necessary to maintain a higher number of insensitive monitoring plots with long time series, in order to be able to still select sub sets of the appropriate plots, depending on analysis and political question.

In general it needs to be taken into account that for cause-effect studies and model development it is even more efficient to select intensive monitoring plots that cover wider parameter distributions instead of strictly following representativeness considerations leading to higher repetitions of plots with similar ecological conditions.

At this stage the study provides a general framework for a representativeness analysis of monitoring networks. Results are only valid for the environmental factors analysed. If other selection criteria are in focus or if the spatial distribution of the indicators changes, e.g. due to climate change or clean air policies, the representativeness of the monitoring network needs to be re-analysed.

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2.4. Implementation of a quality control system

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Abstract

Monitoring methods were entirely revised and different method' sources were integrated into a consistent new Manual. Data Quality Requirements were set for ca. 2/3 of the measured variables, and data quality tested and reported for ca. 1/3. This is quite an improvement with respect to the situation before the FutMon project.

2.4.1. Implementation of a quality control system

Quality of forest monitoring data is a scientific and policy goal. This is because the decision- making process needs sound science and good data as a basis: "what we measure affects what we do: and if our measurements are flawed, decision may be distorted" (Stiegliz et al., 2009). In this respect, data quality has an impact on the scientific value of the monitoring, on its potential in the decision-making process, and on the defensibility of resulting decision. The question is therefore „how to guarantee defensibility of ecological information, i.e., how to define quality needs for ecological data and how to achieve, keep and document such a quality"(Ferretti, 2011). This has been addressed within the FutMon project where different actions were concerned with Quality Assurance (QA), i.e. the set of activity adopted to ensure that "data are fit for use" (Durrant Houston and Hiederer, 2009). The activities carried out within FutMon targeted three main fields: (i) the revision and harmonization of the Standard Operative Procedures (SOPs, i. e. the monitoring Manual) with an explicit, new set of Data Quality Requirements (DQRs), formally incorporated in the SOPs; (ii) an extended series of training sessions; and (iii) inter-comparison rounds. Results are summarized below.

2.4.2. Revision and harmonization of the forest monitoring methods

A set of methods (hereafter referred to as Standard Operative Procedures, SOPs) with explicit data quality requirements (DQRs) and explicit demand for data quality assessment are the foundation of the overall quality of monitoring data. The SOPs have been revised and integrated in terms of structure and content by a process carried out in 2009 and 2010. Now the monitoring Manual integrates into a consistent document four sources of methods, namely the ICP Forests Manual, the Forest Biota Methods, the BioSoil Manual, and the FutMon Field Protocols. The identification of Data Quality Requirements (DQRs) for a series of key monitoring variables covering all the monitoring area was one of the main aims of the revision process. DQRs were identified in terms of Measurement Quality Objectives (MQOs) and Data Quality Limits (DQLs). MQO is the expected level of precision/accuracy for individual observations; DQL is the minimum acceptable frequency of observation that should be within the MQOs. The revision process resulted in a steady increase of variables for which data quality requirements are now specified, from 33 to 63% (Table 2.4.2-1). It means that it is now

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possible to document and report on data quality for ca. 2/3 of the variables measured. It is worth noting that the coverage of DQRs is now extended to field measurements like tree condition, ground vegetation, litterfall, ozone injury, tree growth and phenology.

A further step of the process was to evaluate the overall quality of the FutMon monitoring data. This has been done on the basis of a number of inter-comparison exercises and ring-tests carried out in 2009 and 2010. All in all, ca. 90 different variables were tested with ca. 230 different participating field crews and/or labs. Results in terms achievements of MQOs and DQLs are reported in Figure 2.4.2-1.

Table 2.4.2-1: Investigation category, FutMon related actions, number of variables and percent with/without DQRs before and after the C1-QAC-15(IT).

Investigation	**FutMon related actions**	**Variables, n**	**Before, %**		**After, %**	
			With DQR	**Without DQR**	**With DQR**	**Without DQR**
Tree condition	L2, IM1, D1	20	0.0	100.0	10.0	90.0
Ground vegetation	IM1, D2	16	0.0	100.0	18.8	81.3
Litterfall	D1, D2	33	73.7	26.3	84.8	15.2
Ozone injury	IM1	6	0.0	100.0	83.3	16.7
Meteorology	IM1, D3	13	60.0	40.0	92.3	7.7
Tree growth	IM1, D1	16	31.3	68.8	93.8	6.3
Tree phenology	IM1, D1	13	0.0	100.0	100.0	0.0
Soil	IM1, D2, D3	83	50.6	49.4	50.6	49.4
Foliar	IM1, D2	29	96.6	3.4	96.6	3.4
Deposition	IM1	26	50.0	50.0	50.0	50.0
Ambient air	IM1	8	0.0	100.0	50.0	50.0
Total		263	32.9	67.1	62.7	37.3

DQLs were achieved for ozone injury and concentrations, foliar, soil and water analysis. Tree growth, ground vegetation and phenology were below the required limit. It was not possible to evaluate the performance in the assessment of biotic/abiotic damage because there is no formal DQL set.

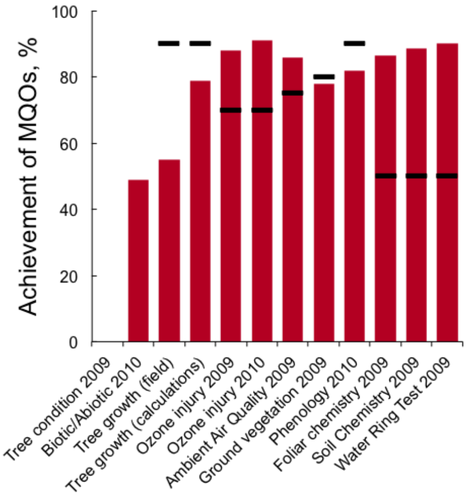

Figure 2.4.2-1: Frequency of achievement of MQOs (red bars) for different investigations (x axis). DQLs set to identify the desired quality levels are the black lines.

The main objectives of the revision/harmonization process carried out under Action C1-QAC-15(IT) (continuous harmonization of methods; setting data quality requirements; monitoring, summarizing and reporting data quality status) were achieved. The main conclusions can be summarized as follows:

(i) There is now a harmonized set of methods that integrate and harmonize the ones previously used on the monitoring plots.

(ii) There is now a solid basis to document the overall value of the monitoring data. This is a unique feature of the monitoring system created under FutMon.

(iii)The quality of monitoring data has been tested and documented for ca. 90 of the variables.

These results are important in scientific and political terms because they increase the defensibility of the data and – therefore – the defensibility of political decisions made on the basis of such data. Future activity in the QA needs to consider that,

(i) Efforts on QA must be kept as well as field exercises and ring tests. Field exercise should consider some sort of “inter-comparison transect” across Europe.

(ii) For some variables, MQOs and DQLs need to be revised or identified at all. It would be important that each investigation identifies key variables to be used as “flags-for-quality”, and to concentrate on these ones: this is particularly true for field based investigation for which an ample coverage of the whole set of variables seems problematic;

(iii) Field sampling must be considered as the priority for the improvement of data quality: it will be a non-sense to further strengthen the precision and accuracy of measurements without improving field sampling.

2.4.3. Quality management in laboratories

For quality assurance in laboratories 5 actions have been installed in the programme. The aim of these actions was the improvement of the quality of the analyses for the FutMon project and the ICP Forest programme.

Within the ICP Forests programme a Working Group QA/QC in labs already had been installed. Under FutMon the work of this group has been continued and extended. The aim of this group was and is:

- the evaluation of analytical methods used in terms of their comparability and acceptability and the elimination of unqualified methods
- the amendment of the ICP Forests manuals with information about usable methods for sample pre-treatment and analysis

- the development and introduction of new methods for quality control in the laboratory
- the organization of practical help for laboratories with analytical problems and
- the organization of ring tests to control the development of quality in the labs

Within the FutMon project this group had 4 meetings and – in addition – organized 2 meetings of the heads of the labs. Beside the discussion about analytical methods and problems and their solutions in these meetings the results of all ring tests have been discussed and as a consequence unqualified methods have been eliminated from the lists of usable methods.

For labs with analytical problems or bad ring test results a helping programme with bilateral visits of the labs and active help has been organized. Within the FutMon project 3 labs from Romania got help from colleagues from Austria, Bavaria, Belgium and Italy. For smaller analytical problems and quick help an internet platform has been installed for help to each other. This platform has been used very effective; more than 50 inputs have been done by the participants.

The review of possible quality checks and other forms of assistance for labs written by the Working Group QA/QC in Labs in 2008 was used as the basis for the for the revision of the ICP Forests manual. The final manual has information about the use of reference materials, the use of control charts, many different quality checks for different sample typs, interlaboratory quality assurance and quality indicators (ICP Forests 2010). Quality indicators have been developed and integrated into the revised manual. In its annex a list of commercially available reference materials and information about the use of 2 different excel files for laboratory quality control can be found. The excel files can be downloaded from the ICP Forests website.

The data submission forms for the FutMon database have been revised and new submission forms for quality and method information have been developed and adopted.
For the first time all important method information, quantification limits and the qualifying of the labs via ring tests are now stored in the FutMon database and can be used for the validation of the monitoring data.

The most important step to force quality assurance and control in labs was the introduction of regularly ring tests for water, soil and plant samples. Within the FutMon project 6 mandatory ring tests have been prepared, organized, arranged and evaluated: 3 for water samples, 3 for foliar samples, 1 for soil samples and 1 soil physics (Cools, N. ,De Vos, B. 2010; Fürst A., 2009; Fürst A., 2010; Fürst A., 2011; Marchetto et. al. 2009; Marchetto et. al. 2010; Marchetto et. al. 2011). Additionally a qualification system by the ring tests was introduced. Tolerable limits for ring test results and criteria for the qualification of the labs have been developed and a qualification report for ring tests has been introduced. A procedure for the requalification of labs with unacceptable ring test results has been decided and introduced.

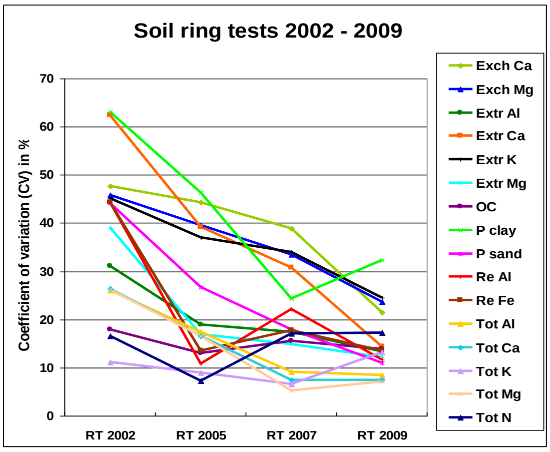

Figure 2.4.3-1: Results of the soil ring tests: development of the mean coefficient of variation between labs for the most important soil parameters over time (FutMon ring test: 2009).

The evaluation of the ring test shows a continuous improvement of the quality of the FutMon laboratories. Together with the previous ICP Forests ring tests 6 soil, 5 water and 13 foliar ring tests have been organized within the ICP Forests program and FutMon project. From the results of these ring tests the development of quality in the labs can be seen.

In Figure (2.4.3-3) the results of the water ring test are mapped. The percentage of results out of the tolerable limits has been reduced over 9 years from 20-60 % to 5-30 %. The same trend can be seen for the results of the last 4 soil ring tests in (Figure 2.4.3-1): the coefficient of variation (CV in %) for the results of all participants for the shown parameters lowered over 7 years from 15-65 % to 10-35 %. For the foliar ring tests (Figure 2.3.3-2) the trend towards better results reached already in 2005 a level of 3-8 % results out of the tolerable limits. It is difficult to improve further beyond this level.

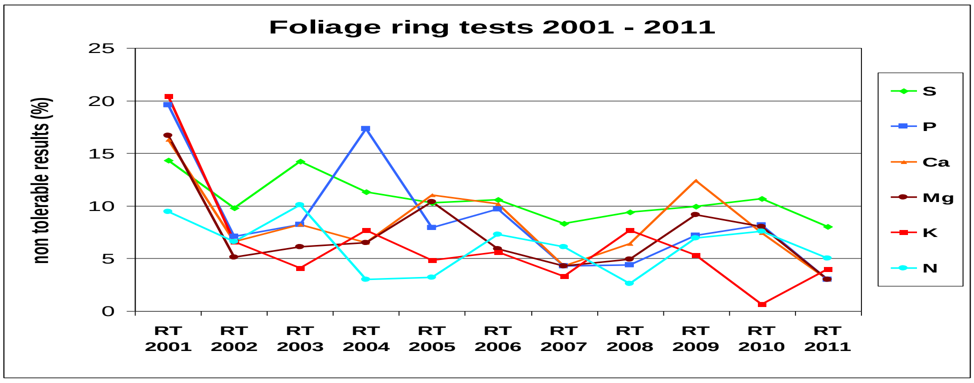

Figure 2.4.3-2: Results of the foliar ring tests: development of the percentage of non - tolerable results for all mandatory deposition and soil solution parameters over time (FutMon ring tests: 2009 – 2011).

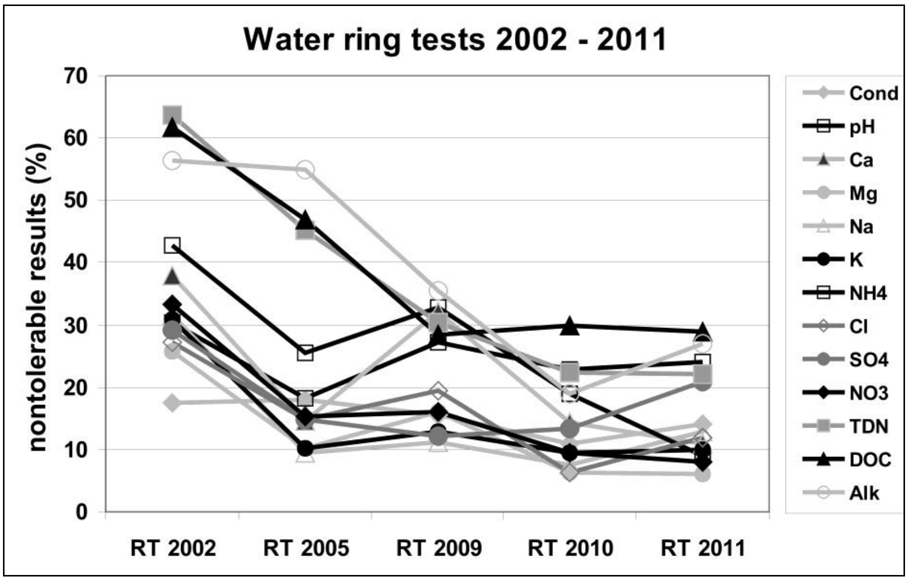

Figure 2.4.3-3: Results of the water ring tests: development of the percentage of non-tolerable results for all mandatory deposition and soil solution parameters over time (FutMon ring tests: 2009 – 2011).

The comparability and quality of the soil analyses are inferior to those of water and plant analyses as supported by the soil ring tests. One reason might be the more complicate analytical 2-step methods for soil analysis (digestion/extraction and measurement). But also the quality of water analyses can still be improved. Therefore regularly ring tests are still important for the improvement of the quality of analyses in an environmental forest monitoring programme (König et. al. 2010).

As a conclusion it can be ascertained that by the different working steps of the quality actions within the FutMon project the quality of the laboratories has been achieved. This can be seen in better ring test results in the last years. This leads to a higher quality of the analytical data and better comparability within the European FutMon and also the ICP Forests programme.

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3. Tree condition

3.1. Tree crown condition as an indicator for forest health

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Abstract

The study presents results of the 2010 crown condition survey carried out on the large-scale grid. With 145.323 sample trees assessed on 5.455 plots in 24 EU-Member States the 2010 survey was the most comprehensive ever. Results show that crown condition has remained unchanged on around three-quarters of all plots continuously assessed since 2002. In the EU-Member States, 17.1 % of all trees assessed were classified as damaged and 1.6% of all trees were classified as severely damaged. A share of 0.8% of the sample trees was dead. 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.

3.1.1. Introduction

The vitality of a tree is largely reflected in the condition of its crown. Increased defoliation attributed to air pollution in the early 1980s gave rise to the European-wide annual crown condition assessments implemented by ICP Forests since 1986. In a time of widespread fear of forest dieback due to air pollution the monitoring of crown condition contributed to a better understanding of the situation. Results indicated that, at the large scale, forest condition deteriorated less severely than feared. Also, most of the defoliation which had triggered the intial concern was shown to be actually due to natural factors such as tree age, extreme weather conditions and pests. At the regional and local level, however, studies confirm the hypothesis of classic forest damage. Monitoring data indicate correlations between defoliation and the deposition of pollutants from the air. This implies an ongoing threat to the functioning of forest ecosystems. Also in the context of climate change, crown condition is considered an important indicator for the response of trees to drought and pests. Under FutMon the analysis of crown condition data was for the first time amended by an analysis of a comprehensive set of data on damage types like e. g. weather extremes and pathogens. Defoliation and forest damage are indicators for sustainable forest management adopted by the Ministerial Conference for the Protection of Forests in Europe (MCPFE).

Broadly speaking, defoliation of the main tree species in Europe increased until the mid1990s. Then Scots pine showed a remarkable recuperation with mean defoliation dropping from about 24% in 1994 to 18% in 1999. Having occurred primarily in Poland as well as in parts of the Czech Republic, the Slovak Republic, Germany, and the Baltic States, this recuperation was attributed partly to the improvement of air quality and partly to favourable weather conditions. In contrast, defoliation of central European and Mediterranean oak spe-

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cies continued to increase. The results gained under FutMon show that these oak species - among the seven most frequent tree species in Europe - constitute the most severely damaged ones. After a brief explanation of the monitoring method, Sub-chapter 3.1.3 describes the status and development of defoliation as assessed under FutMon. In order to connect the results to time series established previously by ICP Forests, defoliation data of some non-EU countries were included in the study. The same applies to the damage factors analysed in Chapter 3.2

3.1.2. Methods

Crown condition assessments were carried out according to the harmonized methods laid down in the Manual (ICP Forests 2010) on Level I plots in 2009 and 2010. The following stand and site characteristics are reported from transnational plots: country, plot number, plot coordinates, altitude, aspect, water availability, humus type, and mean age of dominant storey. Besides defoliation and discolouration, the tree related data reported are tree numbers, tree species and identified damage types. Also recorded is the date of observation. Mostly between 20 and 24 sample trees were selected on each plot according to national procedures. The 2010 sample was the largest ever with 145.323 trees assessed on 5.455 plots in 24 EU-Member States.

The results of the evaluations of the crown condition data are presented in terms of mean plot defoliation or the percentages of the trees falling into 5%-defoliation steps. In previous presentations of survey results, partly the traditional classification of both defoliation and discolouration had been applied, although it is considered arbitrary by some countries. This classification (Table 3.1.2-1) is a practical convention, as real physiological thresholds cannot be defined.

Table 3.1.2-1: Defoliation and discolouration classes according to UNECE and EU classification

Defoliation class	needle/leaf loss	degree of defoliation
0	up to 10 %	none
1	> 10 - 25 %	slight (warning stage)
2	> 25 - 60 %	moderate
3	> 60 - < 100 %	severe
4	100 %	dead
Discolouration class	foliage discoloured	degree of discolouration
0	up to 10 %	none
1	> 10 - 25 %	slight
2	> 25 - 60 %	moderate
3	> 60 %	severe
4		dead

Classically, trees in classes 2, 3 and 4 are referred to as "damaged", as they represent trees with considerable defoliation. In the same way, the sample points are referred to as "damaged" if the mean defoliation of their trees (expressed as percentages) falls into class 2 or higher. Otherwise the sample point is considered as "undamaged".

3.1.3. Results

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 (Figure 3.1.3-1). 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%).

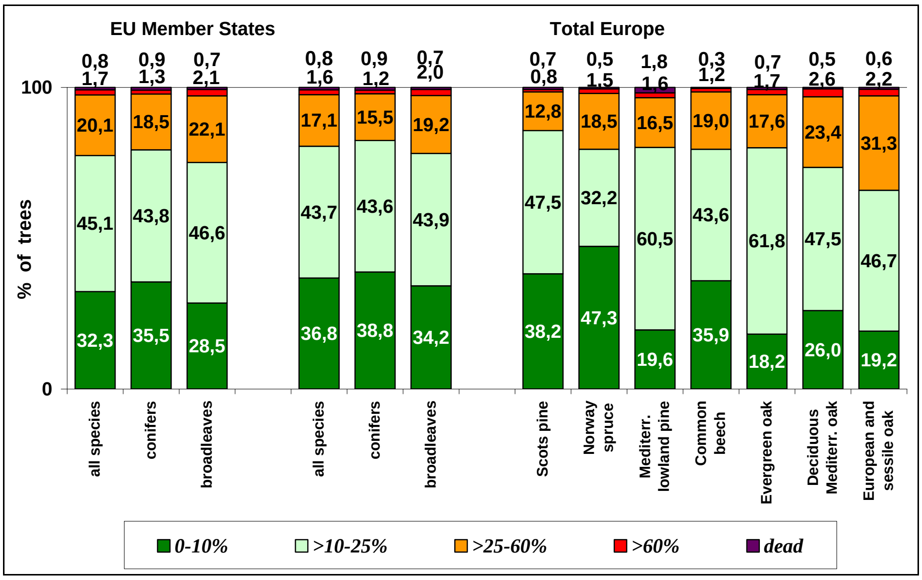

Figure 3.1.3-1: Extent of defoliation for the main European tree species in 2010

There was no change in tree crown condition on 73.2% of the plots continuously assessed since 2002. Defoliation increased on 16.9% of the plots monitored and decreased, indicating an improvement in crown condition, on only 10.0% (Figure 3.1.3-2). Deciduous oaks have been the most severely defoliated tree species over the past five years (Figure 3.1.3-3). 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.

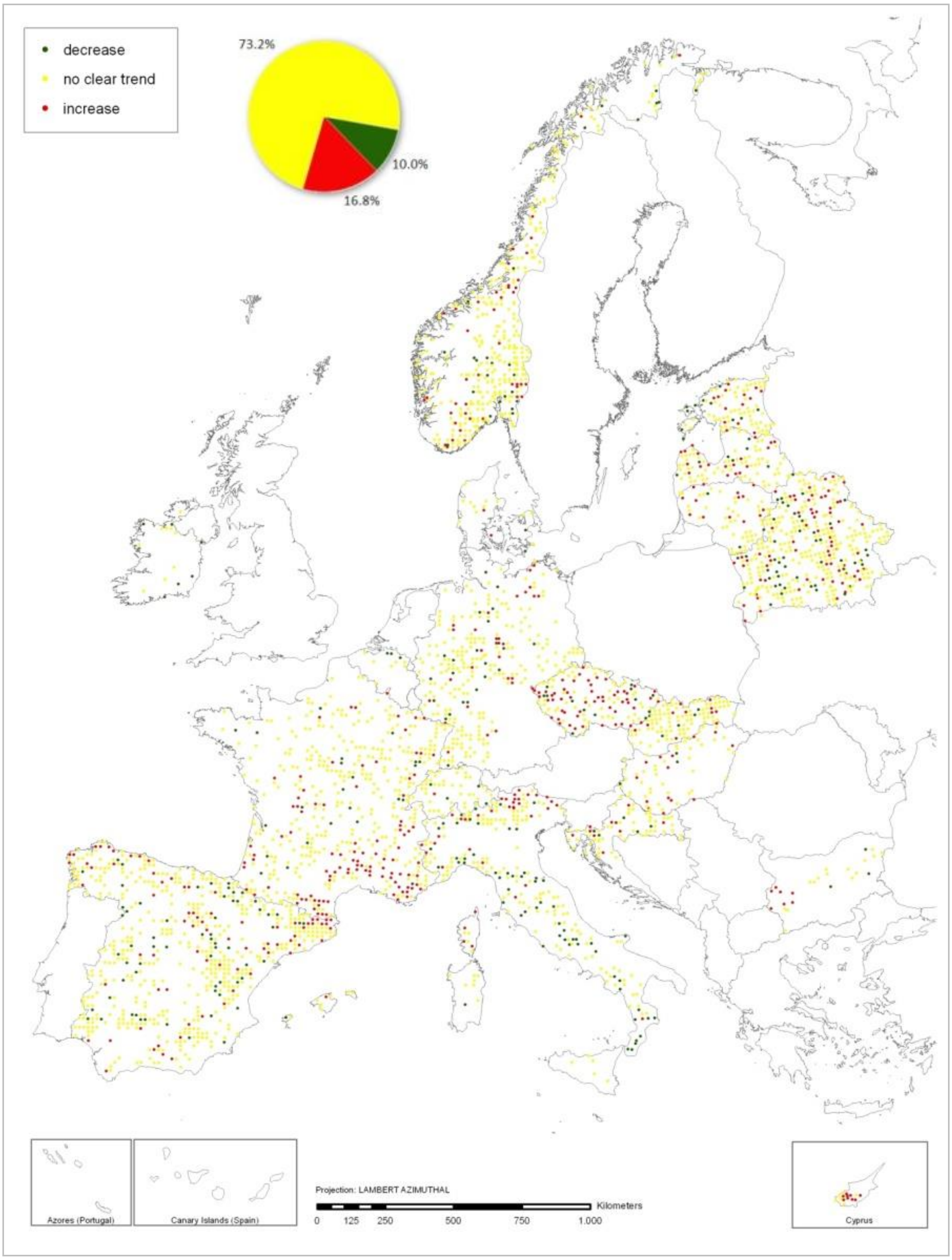

Figure 3.1.3-2: Development of mean plot defoliation (slope of linear regression) for all species between 2002 and 2010.

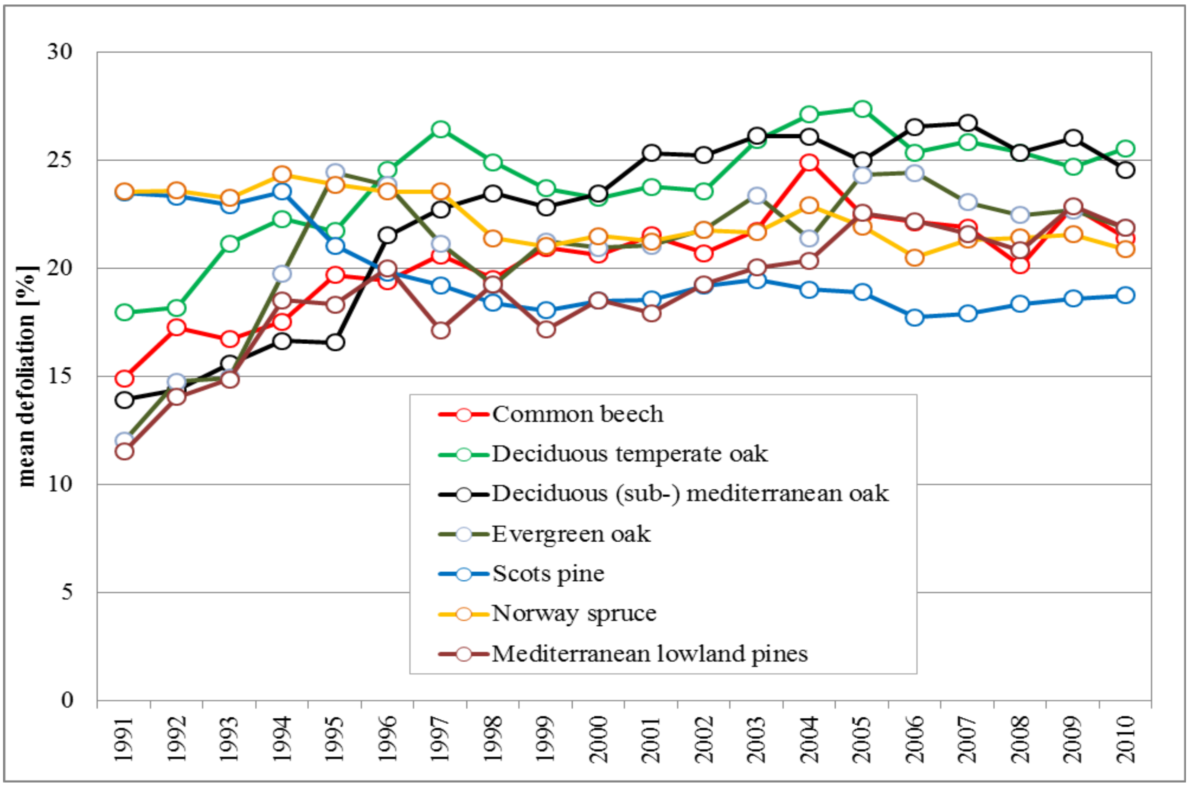

Figure 3.1.3-3: Mean percentage defoliation for the most frequent tree species in European forests. Samples only include countries with continuous data submission.

3.1.4. Conclusions

The 2010 large crown condition survey was the most comprehensive that has ever been carried out on the Level I network. It also included the first comprehensive, even though descriptive, presentation of results from damage cause assessments. Crown condition reflects the impact of numerous natural and anthropogenic factors. Its assessments have therefore been questioned because – taken alone – they hardly lead to conclusions on effects of specific stressors like air pollution or climate change. Yet the participation in crown condition assessments by the EU-Member States is high. The reasons for this involvement of the countries are the following:

Crown condition is used as a quickly reacting indicator for numerous stressors. Its assessments serve as an early warning system for many environmental threats to forests. Defoliation has drawn the attention of foresters to the problem of long-range trans-boundary air pollution. And systematic defoliation assessments have improved the knowledge of the actual extent and development of resulting forest damage in Europe. Though effects of air pollution persist, the political debate of today focuses on effects of climate change. In this regard effects of heat and drought are quickly recognised by means of increasing defoliation and the occurrence of insects and fungi. These are the reasons why defoliation and forest damage are among the MCPFE/FE indicators. The ICP Forests and FutMon data base offers the only transnational, harmonized, and plot based information system for such information in Europe. Moreover, defoliation is used as a response variable in analyses of the impact of environmental factors on forests. All this information can be gained at relatively low costs.

The extreme heat and drought in summer 2003 is reflected in defoliation of the tree species occurring in temperate Europe, with the exception of Scots pine. The sharp increase of defoliation for four species at the beginning of the study and the continued fluctuation at comparatively high defoliation levels since then show that the development of tree health and vitality in terms of tree crown defoliation still requires further attention. Through the increasing number of trees in the survey regional developments are more and more levelled off in European mean values. This calls for additional national and regional studies.

The persisting threats to forests and the extent and development of damage to tree crowns indicate the need for continued assessments leading to longer time series. Recommendations for the future monitoring of crown condition are provided in Chapter 3.3.

3.1.5. References

ICP Forests (2010). Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE, ICP Forests, Hamburg. ISBN: 978-3-926301-03-1. [http://www.icp-forests.org/Manual.htm]

3.2. Damage Cause Assessment

Peter Roskams[1]

Abstract

The assessment of damage causes is part of the visual assessment of crown condition, which is the most widely applied indicator for forest-health and vitality in Europe. In order to interpret the crown condition accurately, it is necessary to assess all parameters that have an influence on tree vitality. In addition to defoliation, other parameters assessed include discolouration and damages caused by biotic and abiotic factors. Through the assessment of damage and its influence on the crown condition, it is possible to draw conclusions about cause-effect mechanisms.

Since 2005, all of the trees in the crown condition survey (Level I) have been examined on ICP Forest plots according to an amended method for damage assessment. This method allows access to more information on injury symptoms, possible causes of damage, and the extent of the injury. The aim of the damage cause assessment is to collect as much information as possible on the causal background of tree damages in order to enable a differential diagnosis and to better interpret tree vitality.

3.2.1. Methods

In 2010, damage causes were assessed on 6 413 plots in 32 different countries, including 24 EU member states (Figure 3.2.1-1). This is the highest number of assessed plots since the start of the extended damage cause assessment in 2005. This is partly because the first damage assessments were carried out in Turkey, where 415 plots complete the survey in 2010. In total, over 96 000 trees in Europe were included in the assessment of damage cause.

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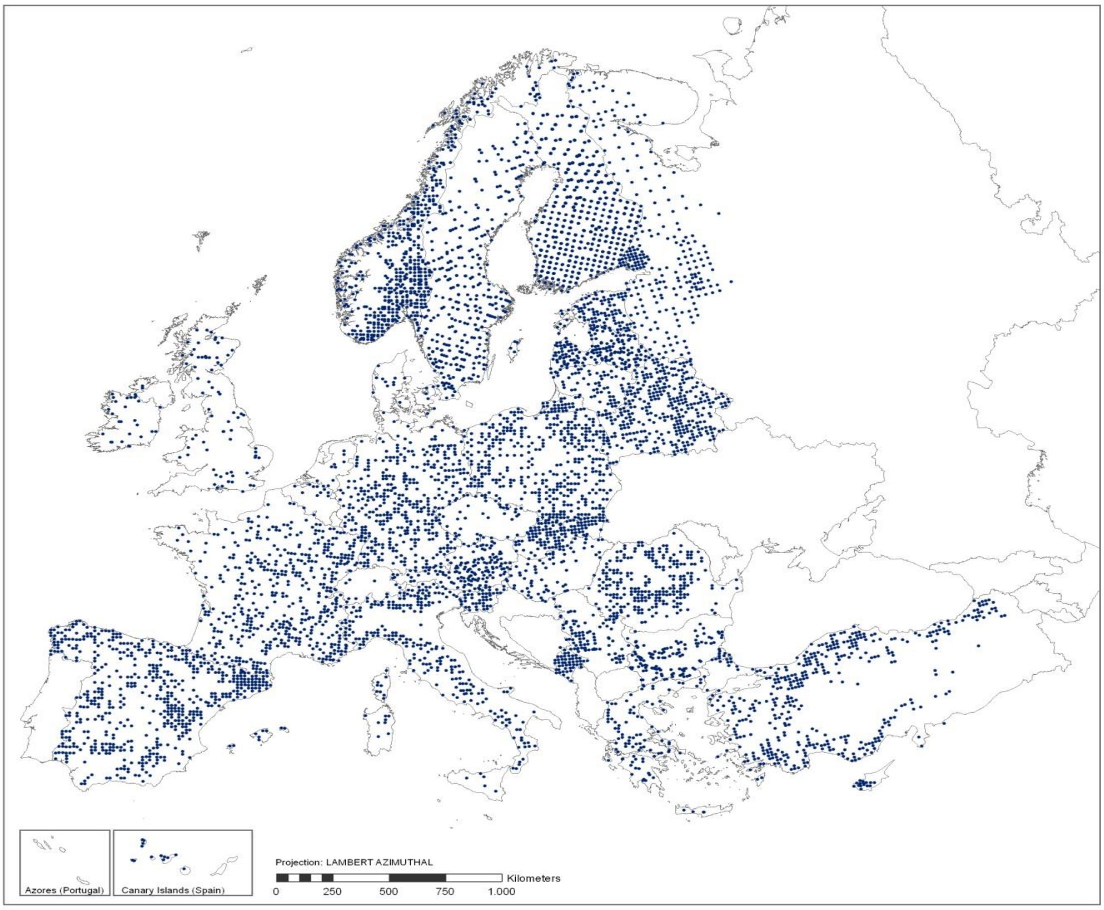

Figure 3.2.1-1: Plots with damage cause assessment 2010

The assessment of damaged trees based on the ICP Forests methodology includes three steps: symptom description, determination of the cause, and quantification of the symptoms. Several damage symptoms can be described for each tree. The symptom description should focus on important factors which may influence crown condition.

1. Symptom description: Symptom description aims to describe visible damage occurring on individual trees. First, all damages should be recorded and described in detail. Three main categories are distinguished for indicating the affected part of each tree: (a) leaves/needles, (b) branches, shoots, & buds, and (c) stem & collar. For each affected part further specifications are required. Symptoms are grouped into several categories, i.e., devoured, bronzing, broken, etc.

2. Quantification of the symptoms: The extent of the damage indicates the quantity of the affected part of the tree. The damage extent is classified in eight classes.

3. Determination of the cause: For each symptom description a causal agent must be determined. Causal agents are grouped into nine categories (insects, fungi, abiotic agents, fire etc.). In each category a more detailed description is possible.

3.2.2. Results

In 2010, almost two thirds of all investigated trees showed symptoms which were due to biotic or abiotic damage. Most of the trees exhibited damage on needles and leaves (37%). In particular, damage to deciduous trees (broadleaves) makes up large share of these. Damage to the stem and branch areas were slightly less, with 21 and 23%, respectively. Just over one third of all trees showed no symptoms at all (Figure 3.2.2-1)

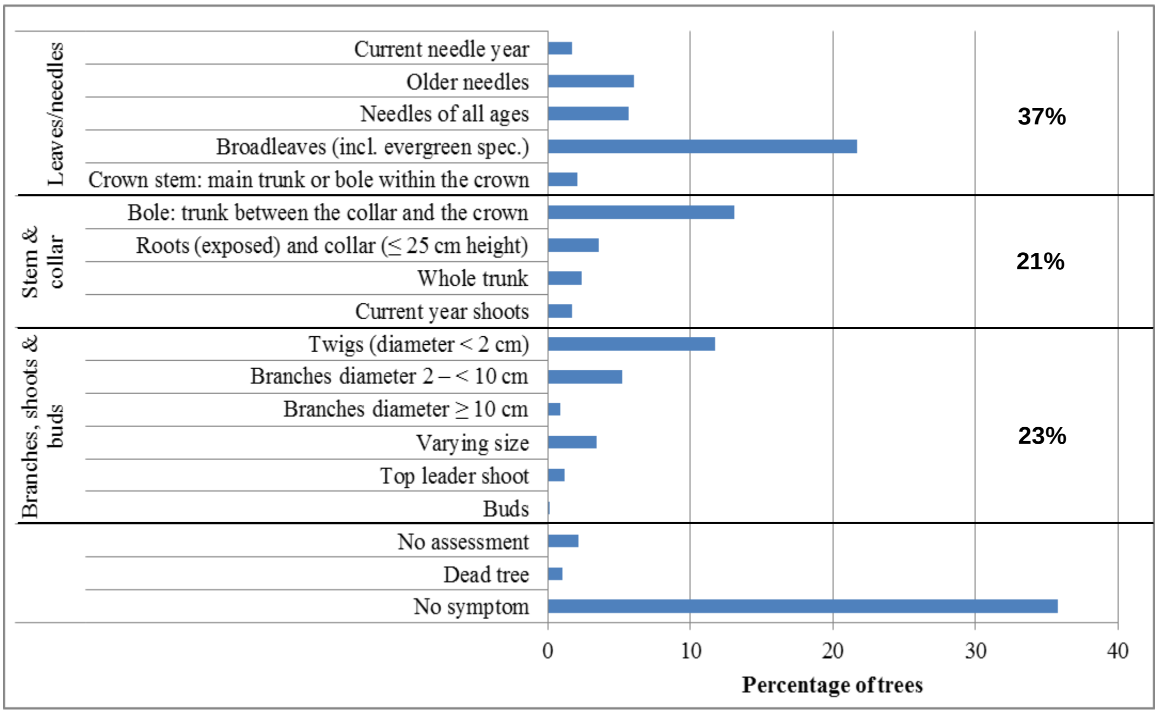

Figure 3.2.2-1: Frequency of affected part 2010

In most cases, the severity of the symptoms occurred within the smallest damage class. Almost the half of all the trees had a damage extent class of 1, which means the damage affected between 1-10% of the part. About one quarter of the trees showed a damage extent of up to 20 and 16% of all trees up to 40%. Higher classes rarely occurred in the survey of 2010.

Table 3.2.2-1 depicts the share of damage done to trees by the various agent groups for each country in 2010. In 2010, damages from insects were most common in Europe, which influenced the general crown condition significantly and led to a reduction in tree vitality.

Over 20 000 trees (27%) displayed symptoms caused by insects. Roughly half of the damage was caused by caterpillars, which harm the tree by feeding on leaves or needles (defoliation). The other half was due to borers and other insects. Significantly fewer trees, just over 11 000 (15%) displayed damage caused by fungi. Abiotic agents such as drought or frost were responsible for damage in about 10 000 trees. Less than 5 000 trees were damaged by human activity, i.e. mainly influenced by timber harvesting or road construction. Only minor damage from game and grazing was observed on the assessed trees. Damage due to fire occurred relatively infrequently throughout Europe, but often involved several trees on one plot and could have had a big impact locally. Damage due to “air pollution” only refers to the direct impacts of smoke or gaseous pollutants, indirect effects were not assessed. Altogether, a causal agent could not be identified for ca. 20 000 trees (Figure 3.2.2-2).

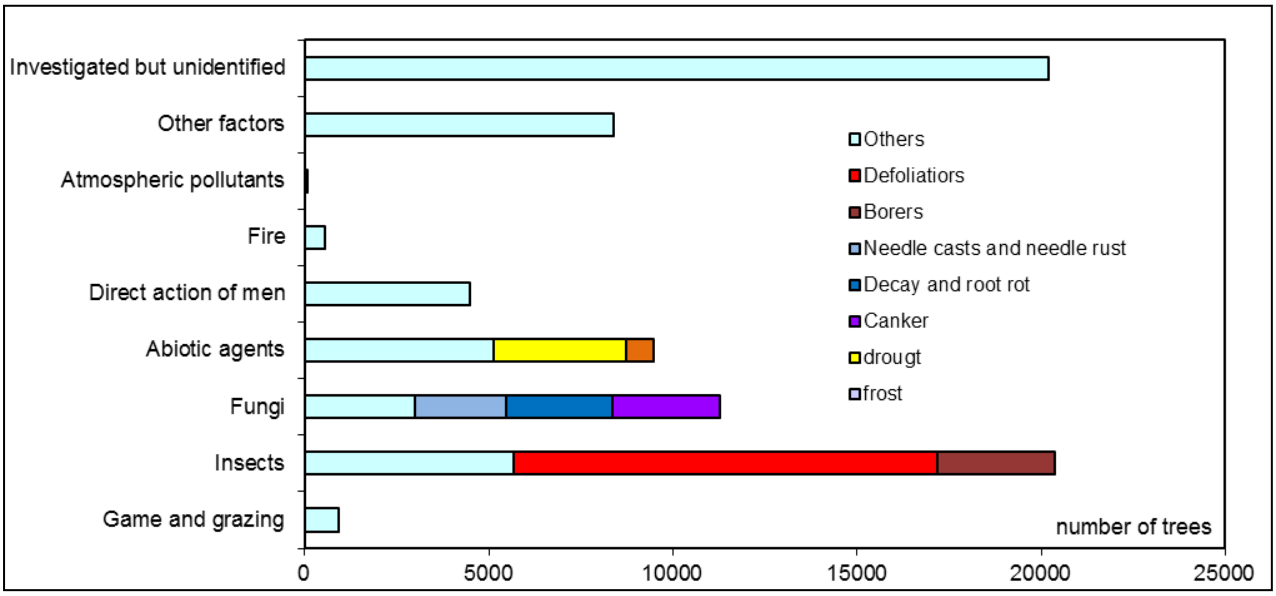

Figure 3.2.2-2: Frequency of agent groups

The individual agent groups are interrelated to other agent groups, which means that they can increase or decrease in its effect on the tree. When forests are already damaged by storms, drought or other stress factors, insect populations can increase and cause even more severe economic damage. Trees damaged by insects were the most frequently detected agent group in 2010. They were observed in different intensities throughout Europe. On around half of all affected plots, more than 25% of the trees were damaged by insects. Plots with over 75% of affected trees accounted for 19% of the total plots. They are clustered mainly at the eastern edge of the Pyrenean Mountains, Italy, Cyprus, and in the east of Slovak Republic (Figure 3.2.2-3).

Table 3.2.2-1: Share of damages by agent group and country for the year 2010

share of damages by agent group and country for the year 2010	Game and grazing	Insects	Fungi	Abiotic agents	Direct action of men	Fire	Atmospheric pollutants	Other factors	Investigated but unidentified
Austria	9	4	10	29	21	0	0	19	8
Belgium	1	15	19	5	10	0	0	0	50
Bulgaria	0	46	29	3	5	0	0	0	16
Cyprus	0	81	0	12	0	0	0	7	0
Czech Rep.	31	0	1	36	6	0	0	10	15
Denmark	5	72	2	9	3	0	0	1	7
Estonia	1	6	37	5	6	0	0	1	43
Finland	1	21	20	14	8	0	0	18	18
France	0	12	6	7	0	0	0	2	73
Germany	4	47	10	4	5	0	0	5	25
Greece	2	26	6	26	4	0	0	31	6
Hungary	1	36	26	13	14	2	0	8	1
Ireland	0	1	27	43	27	0	0	2	0
Italy	1	33	7	5	0	0	0	6	48
Latvia	22	3	16	12	34	0	4	4	4
Lithuania	6	6	19	26	15	0	0	4	25
Netherlands	0	7	9	75	0	0	0	1	8
Poland	1	20	11	8	12	0	1	24	24
Romania	3	46	9	26	7	0	0	8	2
Slovak Rep.	1	29	23	11	11	0	0	17	8
Slovenia	0	30	14	8	8	0	0	5	34
Spain	0	30	14	28	5	3	0	12	7
Sweden	5	1	8	14	19	1	0	1	52
United Kingdom	0	40	10	12	2	0	0	15	21
EU	**1**	**27**	**14**	**13**	**6**	**1**	**0**	**10**	**28**
Andorra	0	13	63	13	0	0	0	0	13
Belarus	1	13	36	7	22	1	1	13	7
Montenegro	0	28	8	5	9	3	0	0	48
Norway	2	30	29	14	1	0	0	3	22
Russian Fed.	0	13	28	13	5	3	0	15	23
Serbia	0	67	24	3	2	1	0	4	1
Switzerland	0	45	0	18	8	0	0	30	0
Turkey	0	34	4	11	1	0	0	22	27
Total Europe	**1**	**27**	**15**	**12**	**6**	**1**	**0**	**11**	**27**

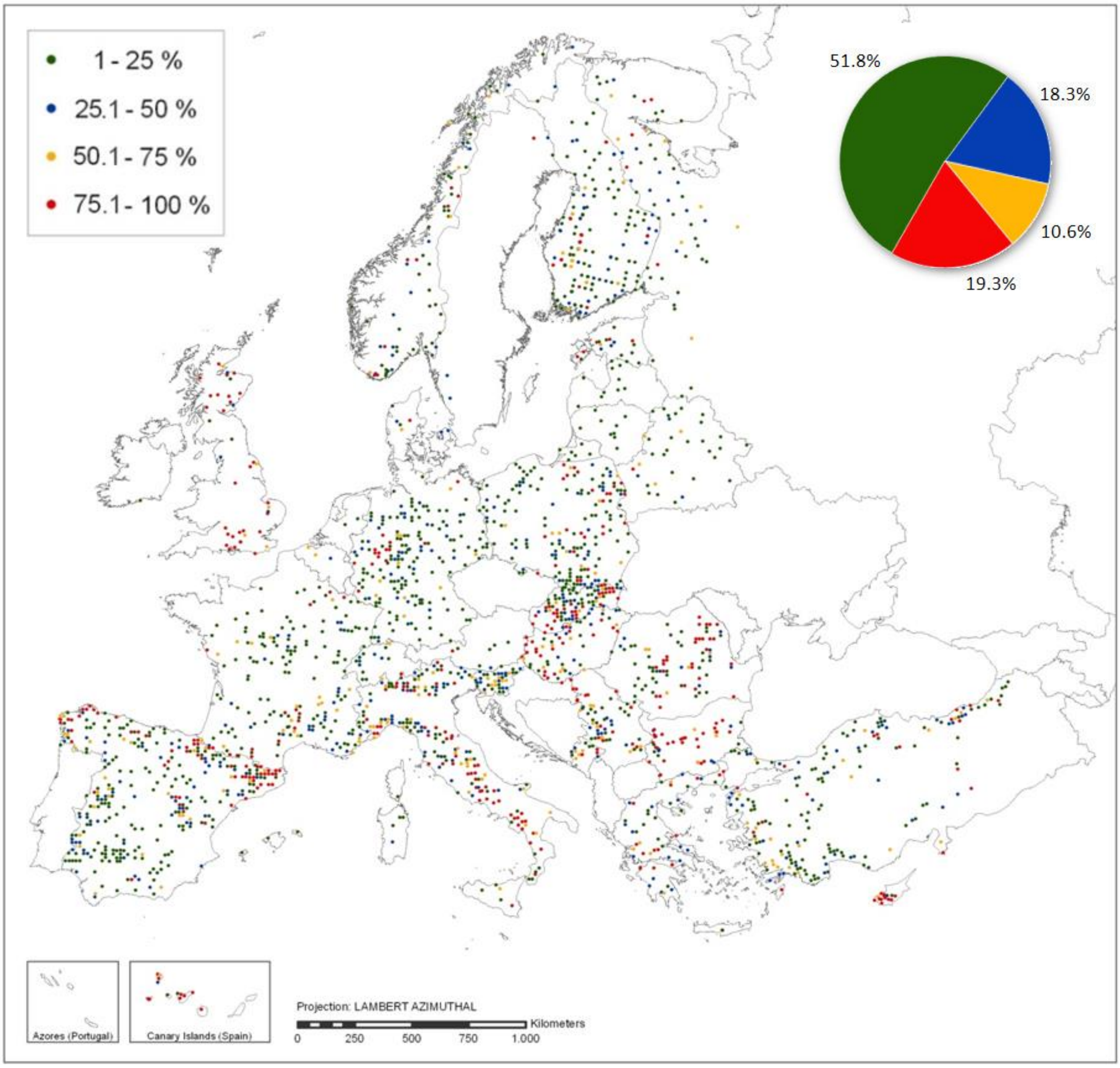

Figure 3.2.2-3: Shares of trees per plot with recorded agent group “insects”, 2010.

The crown condition of trees depends on a variety of natural and human induced influences. Weather and site conditions as well as pollutants or biotic damage influence the health of forest ecosystems. The newly introduced damage cause assessment is important because it shows the extent of such factors. Insects and fungi are the most widespread agents that were assessed on the trees within the survey. The occurrence of these factors shows clear regional trends like plots with high insect occurrence in north-eastern Spain, Italy and Hungary. The occurrence of insects and fungi is a significant indicator for forest health and vitality as well as for forest management. Forest damage is one of the four indicators under the criteria of the Forest Europe Ministerial Conference on the Protection of Forests in Europe. The ICP Forests and FutMon database offer the only transnational, harmonized and plot-based information system for such information in Europe. The assessment of damage cause is an essential component for the study of cause-effect mechanisms. The descriptive evaluations need to be continued and integrated into evaluations and datasets. Weather and site conditions are important information needed as insects and fungi themselves reflect changes in environmental conditions.

3.3. Recommendations for Future Monitoring

Johannes Eichhorn[1]

3.3.1. Introduction: The Significance of Tree Vitality in Forest Environment Monitoring

The assessment of tree and stand vitality range among the important criteria for sustainable forest management. This is shown by the MCPFE/Forest Europe process with resolution H1 (1993, 2003) which defines the criteria and indicators for sustainable forestry. According to criterion II "Health and Vitality" defoliation is the key indicator of tree vitality.

Since the middle of the 80ties defoliation time series were made on European scale on monitoring plots (Level I) as well as on intensive monitoring plots (Level II). Between 1998 and 2010 the feature 'defoliation' was recorded in 26 European countries using random samples from more than 3450 trial plots within the framework of the ICP Forests - Level I. No other key indicator of an environment monitoring system can look back onto such spatial representativeness and long-term observation.

The tree condition assessment procedure is set out in the ICP Forests Manual Part IV (Eichhorn et al., 2010). Since the beginning of the forest condition survey, defoliation is monitored in 5% steps and the results represented as median values and frequency distributions. The definition has hardly changed from that given in preceding manuals dating from the middle of the 80ties, thus permitting the analysis of trends.

Defoliation as a criterion for tree vitality is, however, frequently questioned (e.g. Innes J.L., 1988, 1993). Among the critical arguments that should be highlighted is, apart from the questions concerning the quality of tree assessment, the fact that defoliation does not really represent an integrative value of tree vitality and that hence defoliation cannot be directly equated with damage levels. In some reports damage levels are actually deduced from the degree of defoliation. Trees sporting a defoliation of 1-10% are regarded as 'undamaged', 10-25% as 'slightly damaged' and where defoliation is greater than 25% the tree is considered to be 'damaged'.

On the one hand, the sensible aspects of the feature 'defoliation' in the forest condition survey within the European forest condition inventory should be continued, while quality attaining measures should be developed further on the other. Also, the state of our present knowledge makes it necessary to improve the assessment of forest condition and forest vitality by using methods that are more integrative and use more quantitative values.

The recording of a tree's vitality may be important, but the carrying out of the survey for an inventory under forest field conditions is flawed by characteristic framework conditions. Among these the following deserve to be mentioned:

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- The vitality of trees can neither be measured nor observed directly with the aid of merely one indicator.
- Each assessment of vitality calls for the definition of a reference value (Dobbertin, 2005). Yet it is difficult to define reference values for tree vitality under forest ecosystem conditions.
- No ceteris-paribus conditions are available for practically natural forest ecosystems. Field methods such as assessing defoliation do not permit a cause/effect assignment and remain unspecific in their statement.
- Field assessment methods can, when not carried out properly, contain grave human errors.
- One must distinguish between the vitality of single trees and the vitality and stability of whole forests.

3.3.2. Recommendations

3.3.2.1. Criteria and indicators of tree vitality

Having regard to the methodological development and the procedures laid down in the Manual and the results of the FUTMON project, it is recommended that

(1) the FUTMON Manual serves as the methodological basis for future monitoring of tree vitality.

(2) the feature defoliation continues to be regarded as a key indicator for vitality assessment. However, levels of damage classes should not be judged solely by assessment of tree upper crown foliation intensity.

(3) the tree vitality triangle be considered as an operational appendage of integrative tree vitality assessment in connection with field surveys according to the ICP Forests Manual, part IV (Visual Assessment of Crown Condition and Damaging Agents).

(4) the vitality features listed in part IV of the Manual - particularly defoliation, apical shoot architecture, growth (part V), fruiting, removals, mortality and damaging agents - be applied because through operationally deployable indicators they permit the numerical implementation of the vitality triangle.

(5) a comparative consideration of tree growth be indispensable for an integrative assessment of tree vitality (Manual, part V: Growth).

(6) The assessment of biotic and abiotic diseases such as insects and fungi be indispensable for an integrative assessment of tree vitality.

(7) tree and stand age of sample trees should be recorded as accurately as possible as the features regarding tree vitality are often mainly dependent on the age of trees.

(8) long time series be considered with a view to applying the resilience concept. It should be checked whether recently published defoliation time-series with a large amount of data can be supplemented by older material possibly containing less data.

(9) In order to understand causes of tree vitality it is necessary to continue to juxtapose vitality indicators with environment indicators obtained within the framework of forest environment monitoring (Level I, Level II, core plots supplemented by scientific-experimental efforts).

(10) In addition to the classical approach of tree vitality assessment, stand related information on tree vitality such as Leaf Area Index (LAI) is needed for the use of modelling approaches. It is recommended for use of PCA measurements in Central European oak and beech stands: to measure spatially averaged gap fractions according to the field protocol with either the PCA-sensor or digital hemispherical photography; to calculate the effective leaf area index for three rings of the PCA-sensor; not to correct clumping or the contribution of woody surfaces. Optional: Collection of leaf litter samples for specific leaf area determination during the leaf fall period.

3.3.2.2. Quality measures

(1) The Manual part IV highlights measures to document and improve data quality. Recommendations:

- The photo ICC and field ICC methods should be temporally linked.
- The field ICC method should be repeated annually in all 3 European regions.
- The photo ICC method should be repeated in 2 yearly intervals
- The photo ICC should become an independent assessment using the common definition of the assessable crown.
- The photosets should be supported by further indicators of crown and tree vitality such as biotic agents (insects and fungi)
- The photosets should be further developed to increase the number of different age classes

3.3.3. Integrated system for surveying tree vitality

In particular, the following integrated system for surveying tree vitality shall apply:

Within the framework of the FutMon project, an integrative concept for the assessment of tree vitality was developed and partially introduced. The new concept of tree vitality is based on the “vitality triangle concept”. Gehrig's concept defines tree vitality as a criteria triangle. It includes (i) longevity, (ii) function and (iii) stress tolerance. “Trees or plants are defined as vital, if they use their energy to fulfil all three criteria in an optimal way” (Gehrig, 2004).

(i) Longevity

The criterion of longevity is implemented by the assessment of annual mortality of sample trees. It is supplemented by information about the cause of mortality such as in consequence of insect or fungus infestation (Manual IV: variables for damaging agents: 5.3).

(ii) Biological functions

Basic biological functions of trees are defoliation in the upper tree crown, growth (height and diameter growth) and reproductive structures (flowering, seed production). In addition, the indicators contribute to the biological key function of carbon storage and allocation.

(iii) Stress tolerance

The stress tolerance of trees is deduced by their resiliance after disturbances. Data is based on long time series of the above-mentioned vitality features as well as information on disturbances such as environmental influence on account of climatic variability.

A major innovative step in the FutMon project consists in a numerical implementation of the vitality triangle concept on the basis of vitality features that have been defined on an European scale in forest environment monitoring and have been regularly surveyed under field conditions. Thus Gehrig's theoretical concept is being implemented on an European scale on the basis of the inventory results derived from forest environment monitoring.

During the FUTMON project, the new concept of integrated tree vitality assessments was elaborated and discussed. The draft concept was circulated in 2009. FutMon D1 partners and beneficiaries were invited to join and to use the indicators during the field assessments. In 2010, after intensive discussion, the indicators were put into the new version of the ICP forests Manual part IV (Eichhorn et al., 2010). The formal decision to adopt the new Manual was taken by ICP Forests Task Force in May, 2010.

3.3.3.1. Longevity and annual Mortality

The longevity of sample trees can be deduced from the absence of mortality in the context of stand characteristics and tree age. In managed forests, the rotation period has to be taken into account.

The 16 km by 16 km grid pattern devised for the Level I random sample system enables one to document the annual mortality rate of sample trees representatively.

As biotic and abiotic reasons for the loss of trees are documented in Manual IV, it is possible to distinguish different causes of tree mortality regardless of the fact whether the tree is still standing or whether it has been removed.

With the partial rearrangement of the Level I random sample system to a common system of the National Forest Inventory (NFI), annual visits to sample trees are replaced by periodical ones. However, the surveyed sample trees are now no longer necessarily the identical ones to the time before. This reduces information on annual mortality as compared to the 16 km by 16 km grid pattern system of Level I.

Dobbertin (2009) suggests using defoliation values higher than 50% as an additional concept with regard to annual mortality. Since mortality is a rare occurrence (less than 0,3%

of sample trees in Europe) and furthermore because the connection with the net of the NFI impedes annual mortality analysis, the portion of trees showing more than 50% defoliation might be a useful estimator for risk assessment. However, own research in northwestern Germany shows that the correlation between high defoliation and mortality varies from tree species to tree species. While there is a strong correlation in the case of oak, this cannot be shown to be so as far as spruce, pine and beech are concerned.

3.3.3.2. Biological Functions

Defoliation and apical shoot architecture: Photosynthesis of the leaves is an important function of trees. This is indicated by defoliation in the upper crowns of sample trees (Manual Part IV 5.2.5: defoliation). The formation of leaves is largely governed by the ramification of the top crown. The manual gives definitions for the classification of the branching structure ('apical shoot architecture') using a beech tree as an example. (Part IV 5.2.9: Apical shoot architecture using Fagus sylvatica as an example).

Top crown apical shoot architecture ('apical shoot architecture', Manual 5.2.9.) is associated as growth potential with competition and survival ability in the struggle for light. The ramification pattern is, moreover, an important indicator of the tree's adaption potential to changing environmental conditions.

These considerations show the importance of an 'assessable uppper crown' definition to be used in the inventory (Manual Part IV 5.1.2: Assessable crown).

It is indeed so that 'assessable crown' definitions vary from country to country. This is partly justified by the different geographical regions. Thus the appearance of Scandinavian forests is quite different to that of Mediterranean ones. Yet there are also differences owing to the history of the inventories in the different countries. Since 2010, countries definitions of assessable crown have to be submitted annually to the data centre in addition to assessed data

Growth: Recording tree growth as an indicator of vitality necessitates at least an annual measurement of a tree's height and circumference. This is set down in the part V of the Manual under 'tree growth'.

With a view to vitality assessment it would make sense to divide the net primary production into various compartments such as leaves, fruit, twig- and stem biomass and root biomass. Investigation into the consequences of the exceedingly dry-warm year 2003 shows that in 2004 net primary production of beech trees in north-western Germany remained constant, but there was a shift from stem biomass to fruit biomass. Leaf biomass remained unchanged (Eichhorn et al. 2008). However, net primary production of the root systems has not been considered.

Fructification: The formation of flowers and fruit represents a further important factor for the natural regeneration of tree species. Particularly in the case of trees bearing large fruits such as oak and beech, fruit production can be considered a particular accomplishment of metabolism, which would also be of significance in a compartimentwise representation of net primary production (Manual Part IV, Flowering: 5.2.7; Fruiting 5.2.8; Manual Part XIII: Sampling and analyses of litterfall).

3.3.3.3. Stress Tolerance

Resilience: Resilience is the long-term capacity of a system to deal with change and continue to develop. “Resilience is defined as the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes” (Walker, 2004). “Sometimes change is gradual and things move forward in roughly continuous and predictable ways. At other times, change is sudden and disorganizing. Evidence points to a situation where periods of such abrupt change are likely to increase in frequency and magnitude.” *This challenges the adaptive capacity of ecosystems.* The resilience approach focuses on the dynamic *interplay between periods of gradual and sudden change* and how to adapt to and shape change (http://www.stockholmresilience.org).

In temporal development one must distinguish between variables owed to random sampling and other non - interpretable coincidences and those resulting from a reaction to disturbances. The criteria for the importance of a disturbance are, for example, the quantum of synchronisation of the change of the parameter values of comparable indicators or the duration or characteristics of a reaction. If there is a recovery after the disturbance, a reversion to the initial condition will take place - or not, as the case may be.

With the help of reaction patterns it is possible to carry out a comparative assessment of the sensitivity of vitality indicators and to define damage levels.

3.3.3.4. Causes and Effects

In order to record reaction patterns of vitality data it is necessary to juxtapose vitality indicators with environment indicators obtained within the framework of intensive monitoring. The echeloned system of forest environment monitoring (Level I, Level II, core plots supplemented by scientific-experimental efforts) offers the best preconditions for doing this.

3.3.3.5 Leaf Area Index (LAI) including LIDAR

Based on our measurement results and knowing that this result might not be valid for coniferous forests, where the degree of leaf clumping is higher, we derive the recommendations regarding LAI assessment (see.: Chapter 2).

3.3.3.5. Reasons

It still appears appropriate to us to gather further ground truth data on other forest stands in order to validate the results. The remaining insecurity is due to the small differences between the different possible evaluation methods. But since they all point into the same direction, the efforts for additional TRAC or PCA winter measurements may not be justified from this study. We recommend the alternative use of digital hemispherical photography, because this measurement provides a permanent record of the stand leaf distribution. The photos provide the same information as the PCA measurements and may still be used after years to correct for the clumped distribution of leaves, whenever this is suggested by new results on the relevance of clumping correction. These new results can most easily be achieved by leaf sampling for specific leaf area determination along with litterfall collections, when PCA measurements or hemispherical photographs are taken in the same stand.

The recommendation deviates from the field protocol in that only 3 rings of the PCA-sensor are used, with the effect that also smaller clearings are suitable for the above canopy reading. All other aspects with regard to PCA measurements are not affected.

Another deviation from the field protocol concerns hemispherical photography. Since not all available software programs enable the calculation of clumping indices, a program like the software *hemisphere* (Thimonier et al. 2010) or WinScanopy (Regent instruments inc.) is recommended. The use of hemispherical photography would also require further standardization in the field protocol.

The optional collection of litter samples for SLA determination during leaf litter collections is another deviation from the field protocol. All other aspects of the measurement methods are not affected.

3.3.4. Quality measures

3.3.4.1. International Calibration Courses

The New Manual highlights measures to document and improve data quality. Any quality concept on tree condition in Europe has to take into account

- A large natural variability of plot, stand, age and site conditions of tree species in Europe. This needs to be considered in national and in international control measures
- A large number of criteria and indicators, defined by the FutMon project. Quality measures have to consider all relevant indicators. This includes clear definitions, discussion, training and quality control.
- It has to be taken into account that a number of field experts represent a different level of experience. A remarkable number of experts are changing from year to year on the national and on the international level.

Year	Country	Tree species
2001	Czech Republic	Picea abies , Fagus sylv., Quercus robur
	Finland	Picea abies, Pinus sylv., Betula pub.
	Portugal	Pinus pinaster, Quercus suber
2002	Germany	Fagus sylv., Quercus robur
	Norway	Picea abies, Pinus sylvestris
	Spain	Pinus pinaster, Quercus ilex
2003	Germany	Picea abies, Fagus sylvatica
	Estonia	Pinus sylv. Betula pub.
	-	-
2004	-	-
	-	-
	-	-
2005	Czech Republic	Picea abies, Fagus sylvatica
	Finland	Picea abies, Betula pub.
	France	Pinus pinaster, Quercus ilex
2006	Slovakia	Fagus sylv., Quercus robur
	Norway	Picea abies, Pinus sylv. Betula pub.
	Spain	Pinus pinaster, Quercus ilex
2007	-	-
	Estonia	Pinus sylv., Betula pub.
	Greece	Abies cephalonica, Pinus halepensis
2008	-	-
	-	-
	-	-
2009	Finland	Pinus sylva. Betel pub.
	Czech Republic	Picea abies, Fagus sylv., Picea abies
	Italy	Pinus pinaster, Quercus ilex

Table 3.3.4.1-1: Field ICC from 2001 to 2009 and tree species

3.3.4.2. Photo International Calibration Courses (Photo ICC)

A special focus of the FutMon project was laid on concept development and a test phase of the European wide Photo Intercalibration Course in 2010 (Photo ICC).

3.3.4.2.1 Aims

The main aims of the Photo ICC method are:

1. Proof of temporal and spatial consistency of crown condition assessment

- to check that assessment consistency is maintained over a long period
- to ensure that assessment standards of an expert or of a team remain constant over long periods, even when there is a fluctuation among team members
- to check assessment consistency of a tree species in a given major European forest type covering different national and international regions
- to find out systematic or non - systematic assessment differences through a comparative analysis of different tree species and state of defoliation
- to check the assessment proficiency of individual experts or of a field teams
- to check out an individual's quality in relation to the team

2. Comparative appraisal of photographs with field pictures of the same trees and digital reference photographs, possibly in connection with field ICC courses.

3. Completion of the manual's criteria definitions through the addition of pictures that cover the complete range of main damaging symptoms, particularly those contained in the "national lists". Check assessment consistency in the face of characteristic biotic or abiotic criteria.

4. Regional photo guides for two to three tree species for each eco-region one are an essential help towards harmonizing tree assessment.

In 2010 the new Photo ICC method was developed and implemented for the first time. The 2010 test phase and the related recommendations mainly refer to the first of the mentioned aims.

3.3.4.2.2 Concept

The co-ordination office of the new photo ICC method at the Northwest Germany Forest Research Institute (NW FVA) Göttingen has been supported by experts taking responsibility for northern, central and southern European regions. Arthur Bauer, Inge Dammann, Jörg Weymar, (Germany), Ludmilla Bohacova (Czech Republic), Paloma Garcia P.(Spain) and Sören Wulff (Sweden) by acting as experts have greatly contributed to the acceptance of the method, and have been available to give advice. Continued use of this method greatly depends on the support of experts for the whole EU.

The newly developed method, first applied in 2010, was initially used on the most economically important and common tree species. For each of the species a forest scientist assessed a photoset which documented the differing vitality of the tree crowns. Care was taken to ensure that all types of crown were represented, for very well leaved or needled crowns to very poorly.

The photoset from each region and species was composed of 30 photographs. The 30 photographs were taken from a larger data set, and can vary for assessment to assessment. This is used to prevent any memory-effects of the photographs of the assessment teams.

To remove errors created by poor quality images of the crowns, only the best visible trees and the best quality photographs were used. As such, the use of these photosets does not reflect reality, where often in closed forests such easily visible trees are rare. To make the images of photosets comparable, the images were printed and sent to the assessment teams. After the assessment the photographs were returned to the co-ordination office.

The good acceptance of the photo ICC concept, the active participation, the high quality results, as well as the database of results and images developed at the NW FVA can be used as evidence that the quality assurance programme should continue.

3.3.4.2.3 Advantages of the Photo ICC concept

- A large number of photographs in the database ensure that for north, central and southern Europe a sufficient number of samples for all of the most important tree species in all degrees of defoliation are available.
- The definition of the assessable crown varies greatly between different European countries. Using the low cost photo ICC method it is possible for the first time to compare the country specific definitions with a European definition.
- Especially for pine using the European definition of the assessable crown greatly improved the comparability of the assessment of crown condition across Europe.
- Photosets used in 2010 can be used in the coming years. A comparison to these photographs provides a control to maintain a constant baseline for investigations carried out over many years.
- Easy access to the photographs ensures that many teams can take part in the assessment. Quality control can be carried out by a country team leader on assessments carried out by regional or temporary teams within that country.
- The use of photographs makes the quality control independent from plot and tree selection. It allows assessment of quality for both the classical Level 1 method using a 16 km x16 km grid, and for national inventories or intensive measurements. The method is even flexible enough to accommodate changes in methodology during the observation period.
- The databank developed contains the photographs, but also metadata of site, tree and assessment date. The assessment values are thus safely stored for a long duration.
- The photographic method is de-centralised, requires little time, and is high value for money.

3.3.4.2.4 Disadvantages of the Photo ICC concept

- The photographs are only two dimensional images of trees and forests
- The photographs are unable to provide an assessment of the crown combined with other relevant symptoms such as abiotic and biotic parameters. A holist assessment of tree vitality is lost.
- Up to now only the parameter defoliation is considered. The first advances are being made in a method that includes biotic indicators such as fungi and insects. In the future these will be included in the manual.

- The photographs do not allow the observer to include the status of the tree. Up till now no information about region, climatic conditions or position in the forest are given.
- The images abstract the crown condition taken under field conditions to an ideal image, which does not occur in real inventories. Any assessment carried out in the forest requires a translation of the photographs to reality.
- The photographs for the whole of Europe represent possibly only a small section of the real extent. For example, the Alps and the Netherlands are grouped into central Europe. In both the areas the same tree species can be found, but with certainty they differ in appearance.
- Until now mainly mature trees were used. Under real conditions trees are of all ages. The photo sets should be further developed to represent all age classes.
- The photograph concept is de-centralised, and does not provide a European platform for the exchange of experts. The essential exchange of ideas does not take place.

Recommendations regarding Photo ICCs are given in Chapter 2 (Quality measures).

The FutMon project contributed substantially to methods and quality measures of tree vitality assessment in the European environmental forest monitoring.

3.3.4.2.5 References

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4. Deposition of acidity and nitrogen

4.1. Temporal and spatial variation

Oliver Granke[1], *Volker Mues*[2], *Martin Lorenz*[2]

Abstract

Mean throughfall and bulk deposition data for the years 2005 to 2007 were analysed for between 215 and 288 intensive monitoring plots depending on the compound. Throughfall deposition was mostly higher compared to bulk deposition reflecting the air filtering function of forest canopies. Highest nitrogen and sulphur deposition occurred on plots in Central Europe. The lowest nitrogen deposition was observed in Scandinavia with values mostly below 1.8 kg per ha and year for $N\text{-}NO_3$ and below 1.6 kg per ha and year for $N\text{-}NH_4$. Plots with low sulphur deposition, i.e. with mean annual deposition below 3.3 kg per hectare, were found all over Europe. Deposition trends were calculated for the time period from 1998 – 2007 for around 160 plots. They show decreasing sulphur throughfall on half of the plots whereas for nitrogen compounds a decrease was only detected on between 10 and 20% of the plots.

4.1.1. Introduction

Air pollution impacts on forests have been known for about two millennia. The ancient Romans and Greeks described typical symptoms of air pollution damage in the immediate vicinity of their foundries. In the late 1970s and early 1980s, increasing forest decline observed in many parts of Europe was largely attributed to the impact of long-range transboundary air pollution (Schütt 1979, Manion 1981, and Ulrich 1981). This led to a continuous monitoring of air pollution and its effects on forest ecosystems in Europe by ICP Forests under CLRTAP. Despite air pollution control under CLRTAP and first indications of a recovery of forest soils and trees at several sites, air pollution continues to affect the structure and functioning of forest ecosystem in Europe and in other parts of the world. The interactions between air pollution including CO_2, the carbon budget, climate change, forest health and growth as well as biodiversity are still poorly understood. FutMon furnished a monitoring system which can contribute to the understanding of these interactions. Respective results of first analyses under FutMon are presented in this report. As data on air quality and atmospheric deposition assessed, submitted, and validated under FutMon became available only a few months before the end of the project, scientific studies under FutMon had often to rely on data assessed prior to FutMon by ICP Forests on the same plots. The present study aims at the description of spatial and temporal variation of the deposition of acidity and nitrogen. Its results give evidence of the success of air pollution control in Europe and constitute indispensable input data for further reaching studies on exceedances of critical loads and levels and their effects on forest vegetation. These studies are described later in the present report.

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4.1.2. Approach

Deposition data are collected on Level II plots in the open field ("bulk deposition") and under canopy ("throughfall"). Whereas bulk deposition is a basis for estimates of total atmospheric deposition rates in open fields, throughfall deposition typically differs from bulk deposition due to a) wash off of dry deposition from the forest canopy, b) element "leaching" from the tree crowns, and c) absorption of elements by the foliage, so-called "canopy uptake". The first two effects led to increased throughfall rates, the latter one, canopy uptake of elements by the crown foliage, reduces throughfall deposition compared to bulk deposition. Thus, throughfall deposition does not reflect total deposition but reflects the results of total deposition plus net canopy exchange. In addition, throughfall deposition may have been underestimated especially in beech stands because stemflow was not taken into account in the present study as it had not been measured continuously from 1998 to 2007 on most plots.

The observed annual mean throughfall deposition is interpreted always together with the respective bulk deposition in order to allow for an estimation of effective enriching and reducing canopy effects. The plot specific annual sums of bulk and throughfall deposition of nitrate (NO_3), ammonium (NH_4^+), sulphate (SO_4^{2-}), calcium (Ca^{2+}), sodium (Na^+), and chlorine (Cl^-) were basis for the evaluations. Bulk and throughfall depositions expressed in kg ha^{-1} yr^{-1} in the text and in the figures refer to the chemical element considered, e.g. to sulphur ($S\text{-}SO_4^{2-}$) instead of sulphate (SO_4^{2-}).

Data selection criteria and calculations follow the approach already described by LORENZ et al. (2005) for the calculation of deposition data from 1996 to 2001. The numbers of plots with available data fulfilling the selection criteria for mean annual deposition calculations from the year 2005 to 2007 are presented in table 4.1.2-1. In addition to mean annual deposition rates, the development of throughfall and bulk deposition over time was object of the present study. The slope of plot specific linear regression over the years of observation was used for mapping and quantifying the general temporal developments.

Table 4.1.2-1: Number of plots which fulfilled the selection criteria.

No. of observations		Na^+	Cl^-	Ca^{2+}	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	$S\text{-}SO_4^{2-}$
Trend 1998 – 2007	Bulk	155	156	155	155	156	151
	Throughfall	163	164	163	163	164	157
Mean 2005 – 2007	Bulk	288	288	288	288	288	288
	Throughfall	215	214	215	215	215	215
	Throughfall > Bulk	169 of 205	179 of 204	187 of 205	131 of 205	162 of 205	168 of 205

The slopes of the linear equations were statistically tested and depicted in maps according to the following classification:

- Decrease: negative slope, error probability lower or equal 5% (green)
- No change: negative slope with error probability greater than 5%, or same deposition in each year, or positive slope with error probability greater than 5% (yellow)
- Increase: positive slope, error probability lower or equal 5% (red)

Even with an enlarged time span of ten years, results must be understood as a mere description of the changes over time rather than a trend analysis which would require an even longer period of observation and respective statistical models for time series analyses.

Sulphate is an important constituent of sea salt, and in many coastal areas (e.g. western Norway) most sulphate in deposition may originate from sea salt rather than anthropogenic sources. As the relationship between chloride and sulphate in sea water is almost constant and assuming that chloride is almost entirely derived from sea salt and hardly affected by biogeochemical processes (which may not always be correct), measured sulphate concentrations can be easily corrected for the sea salt contribution using the formula

Non - marine $S\text{-}SO_4^{2-}$ = total $S\text{-}SO_4^{2-}$ - $(0.054 * Cl^-)$ (all values are in mg/l).

4.1.3. Results

4.1.3.1. Spatial variation

Mean annual throughfall and bulk deposition for the years 2005 to 2007 was calculated for 205 plots (204 plots for Cl) at which both deposition compartments were monitored (see Table 4.1.2-1). For all six compounds deposition was mostly higher in throughfall than in bulk deposition. This indicates the importance of dry deposition filtered from the air and washed off the leaves. Only for ammonium this observation is less clear and only on 131 of 205 plots throughfall deposition was higher than bulk deposition. This might suggest a more effective crown uptake of this element. National studies suggest that specifically on plots with rather low nitrogen deposition throughfall is below bulk inputs.

In Figure 4.1.3.1-1 bulk deposition of sulphur on 288 plots is mapped using the same class limits as for mapping of throughfall deposition in Figure 4.1.3.1-2 (215 plots). The pie diagrams in both maps and especially the higher throughfall deposition found for most plots in Germany and the Czech Republic show that sulphate is filtered from the air by the forest canopy. This dry deposition is then washed off from the air filtering leaves/canopies. Apart from a number of plots with very high sulphur depositions along the coastline (s. plots in Denmark, Spain, Italy, Norway, Belgium, The Netherlands, France), most plots with high sulphur deposition are located in central Europe (Poland, Germany, Czech Republic, Slovak Republic, Slovenia and Romania).

Sulphur deposition was corrected for sea salt. The respective maps of corrected bulk and throughfall deposition are presented in Figures 4.1.3.1-3 and 4.1.3.1-4. In analogy to respective maps for deposition of sodium and chlorine (not depicted) they underline the maritime influence on many of the plots. In addition to plots in central Europe also some plots in southern Europe (Spain, France, Italy) show relatively high sulphur deposition, especially in throughfall deposition.

The maps of bulk and throughfall deposition of nitrate and ammonium are presented in Figures 4.1.3.1-5 to 4.1.3.1-8. Highest deposition occurred on plots in Central Europe and in case of nitrate also in the south of France, north of Italy, and Spain. The lowest nitrogen deposition was observed on plots in Scandinavia with values mostly below 1.8 kg per ha and year for $N\text{-}NO_3$ and below 1.6 kg per ha and year for $N\text{-}NH_4$. Specifically for nitrate, throughfall fluxes were higher as compared to bulk inputs. This observation can be explained by the enrichment of throughfall deposition during the canopy passage due to the filter and wash off effect.

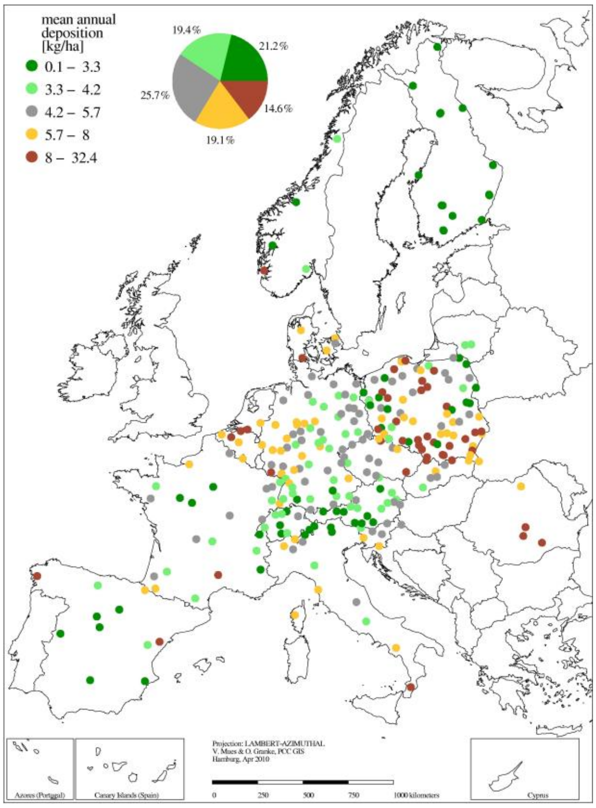

Figure 4.1.3.1-1: Mean annual sulphate sulphur ($S\text{-}SO_4^{2-}$) bulk deposition 2005 to 2007.

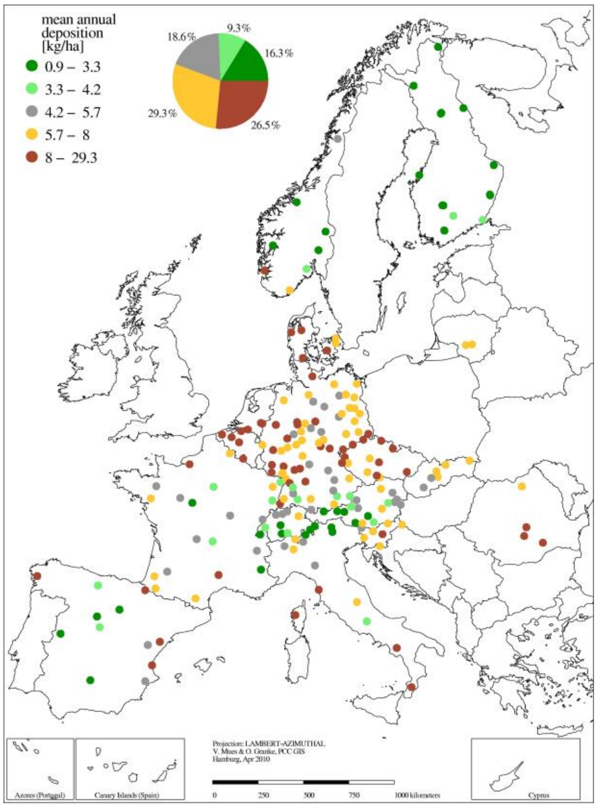

Figure 4.1.3.1-2: Mean annual sulphate sulphur ($S\text{-}SO_4^{2-}$) throughfall deposition 2005 to 2007.

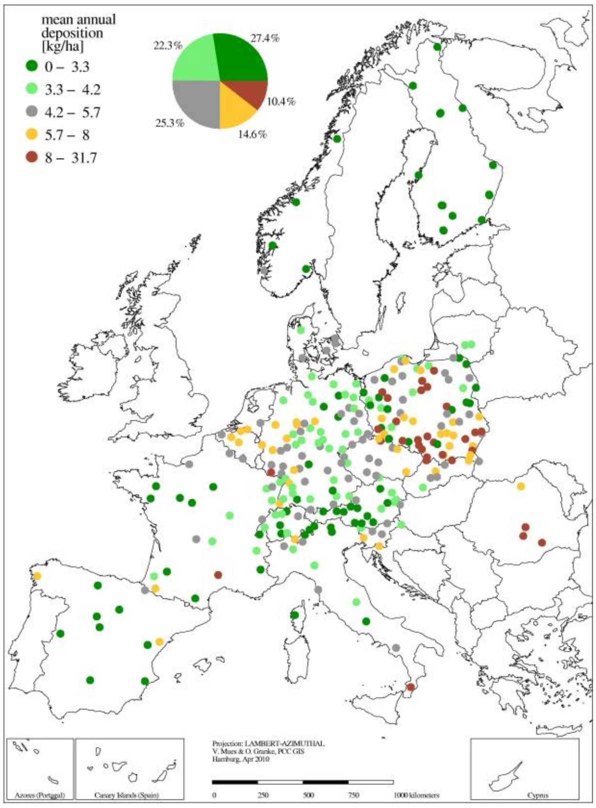

Figure 4.1.3.1-3: Mean annual sulphate sulphur ($S\text{-}SO_4^{2-}$) bulk deposition 2005 to 2007 (corrected for sea salt deposition).

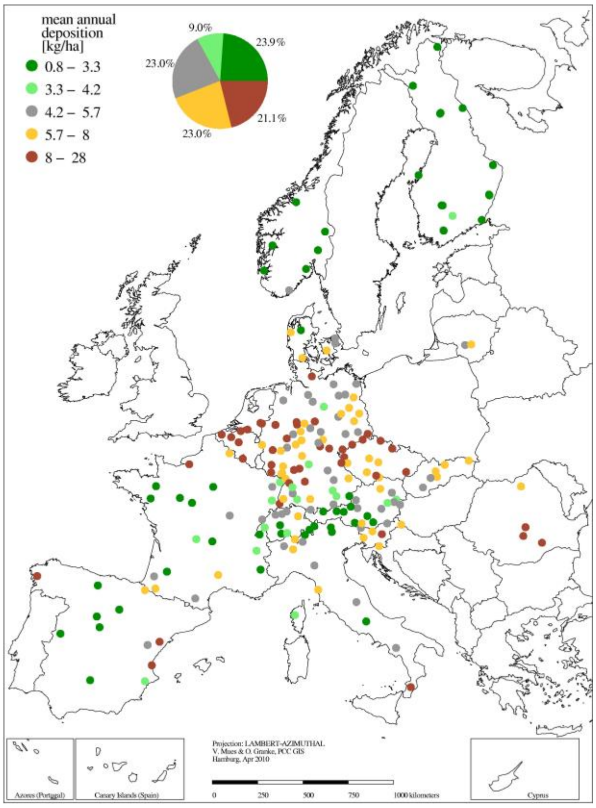

Figure 4.1.3.1-4 Mean annual sulphate sulphur ($S\text{-}SO_4^{2-}$) throughfall deposition 2005 to 2007 (corrected for sea salt deposition).

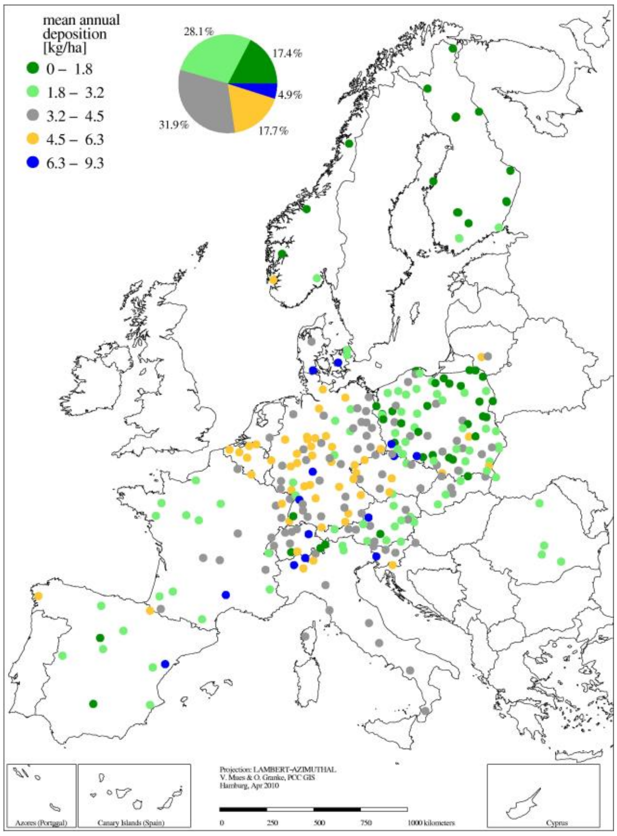

Figure 4.1.3.1-5: Mean annual nitrate nitrogen (N-NO_3^-) bulk deposition 2005 to 2007.

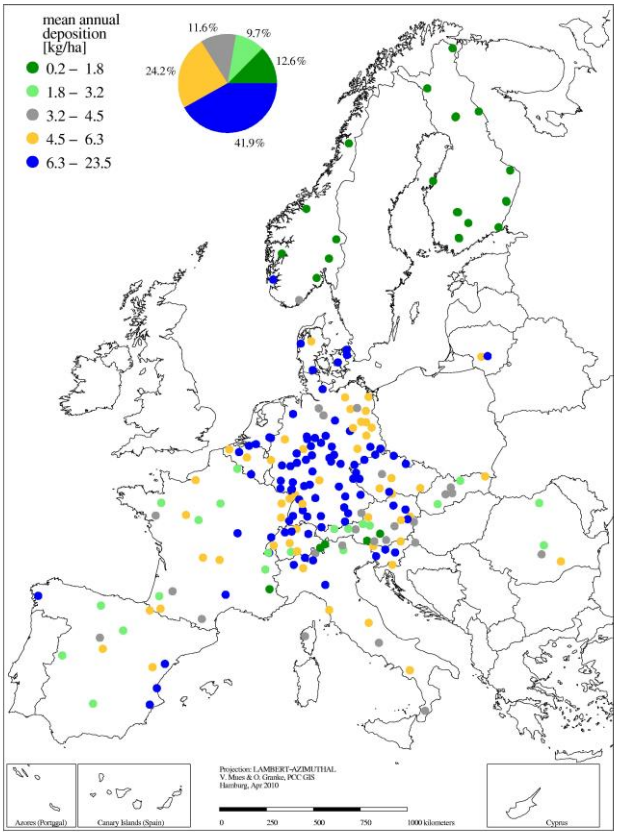

Figure 4.1.3.1-6: Mean annual nitrate nitrogen (N-NO_3^-) throughfall deposition 2005 to 2007.

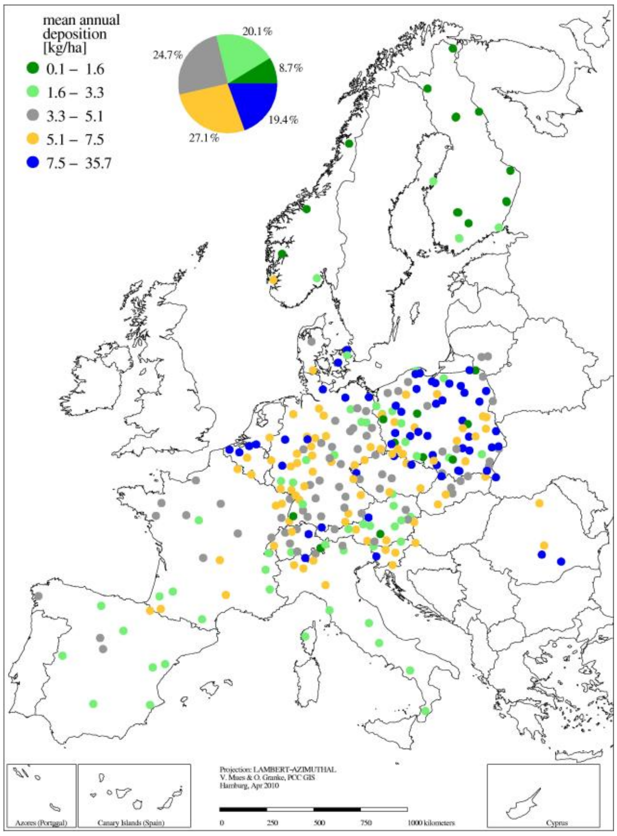

Figure 4.1.3.1-7: Mean annual ammonium nitrogen (N-NH_4^+) bulk deposition 2005 to 2007.

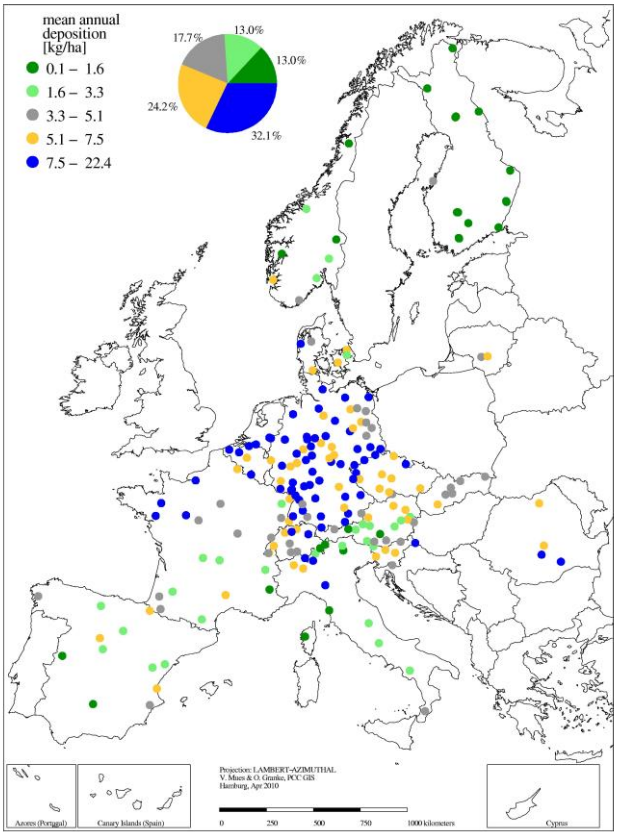

Figure 4.1.3.1-8: Mean annual ammonium nitrogen (N- NH_4^+) throughfall deposition 2005 to 2007.

4.1.3.2. Temporal variation

Earlier reports described a decrease in sulphur deposition based on periods of the last 6 available years with data submission. As nowadays also longer time series can be calculated without a significant reduction in number of observations compared to a six years period, the deposition in the 10 years from 1998 to 2007 was the basis for the present study. Figure 4.1.3.2-1 shows the decrease of mean annual sulphur deposition from 1998 to 2007. The strong decrease in sulphur deposition in the exceptionally dry year 2003 reflects its dependance from precipitation (not depicted). Nevertheless, the strong decrease in sulphur deposition from 1998 to 2007 (e.g. for sulphur throughfall deposition from 10.0 to 6.6 kg per ha and year) indicates a clear reduction of sulphur depsosition in this period. Thus, the influence of precipitation on deposition is considerable, but the observed decrease in deposition (see also Figures 4.1.3.2-3 and 3.2.2.2-4) over 10 years is not mainly a result of decreasing precipitation (LORENZ et al. 2008).

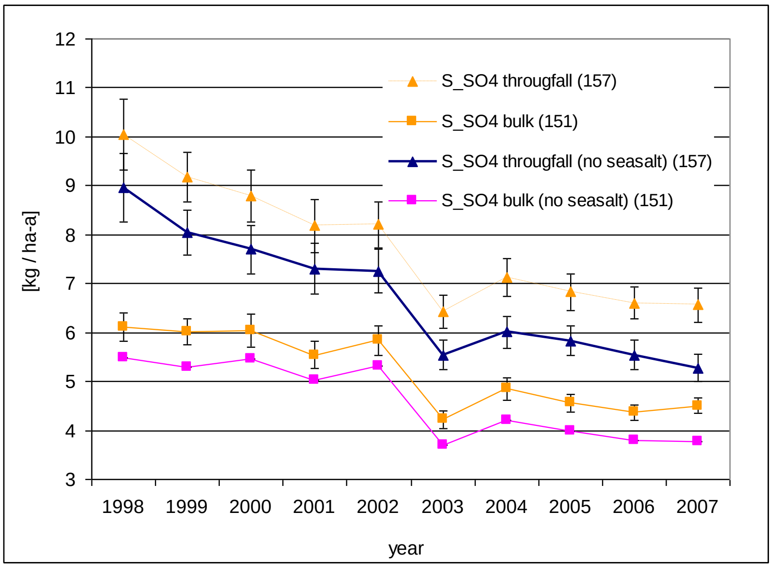

Figure 4.1.3.2-1: Changes in mean annual bulk and throughfall deposition (with standard error of the mean) of sulphate, with and without correction for sea salt, from 1998 to 2007.

The temporal development of ammonium and nitrate deposition is shown in Figure 4.1.3.2-2. Whereas for bulk deposition a more or less clear decrease in nitrogen deposition is observed, this is not the case for throughfall. This is as well reflected by the maps of the plot specific regression slopes in Figures 4.1.3.2-5 to 4.1.3.2-8. A significant increase in nitrogen throughfall deposition was even observed on some plots scattered across Europe.

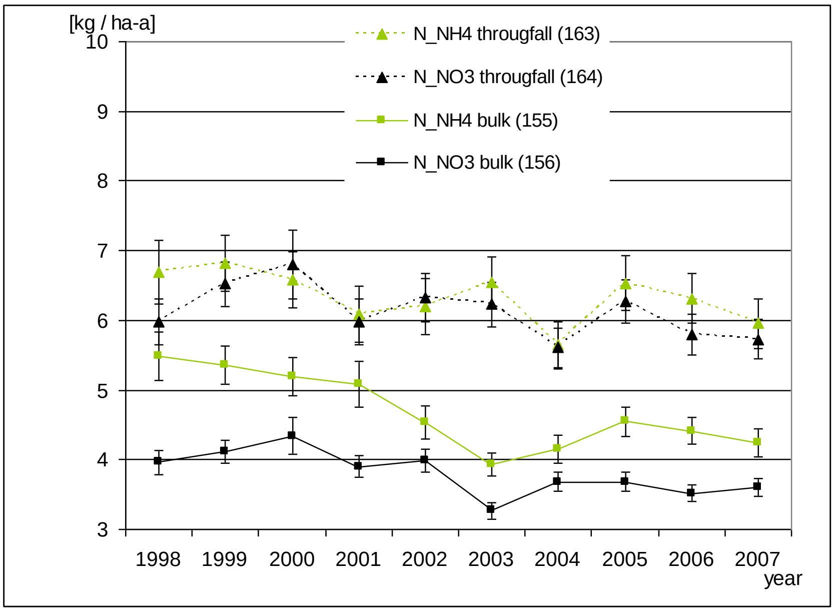

Figure 4.1.3.2-2: Changes in mean annual bulk and throughfall deposition (with standard error of the mean) of nitrate nitrogen and ammonium nitrogen from 1998 to 2007.

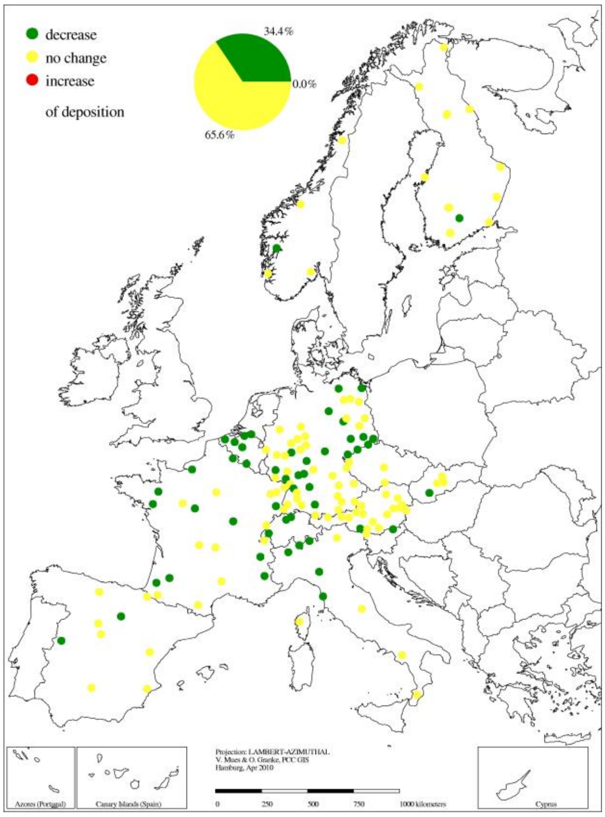

Figure 4.1.3.2-3: Trends in sulphur (S-SO_4^{2-}) in bulk deposition from 1998 to 2007.

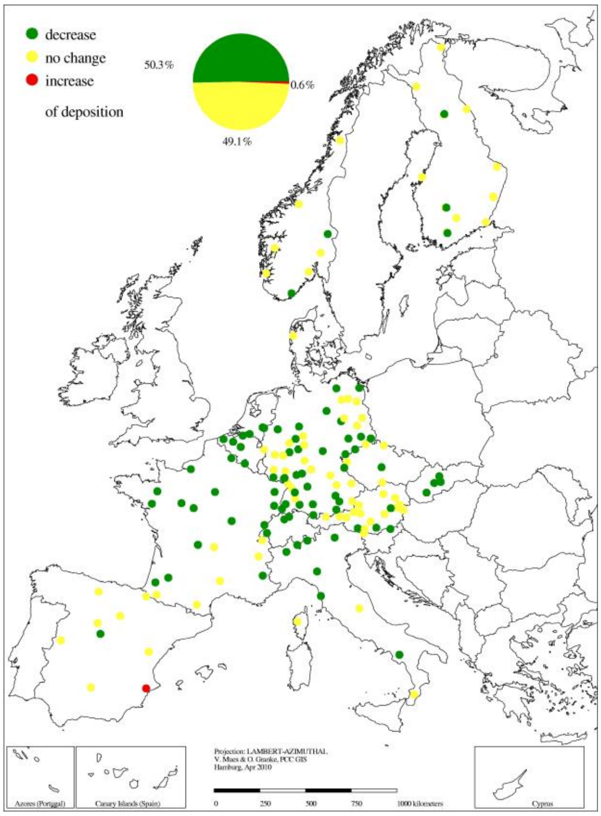

Figure 4.1.3.2-4: Trends in sulphur (S-SO_4^{2-}) in throughfall deposition from 1998 to 2007.

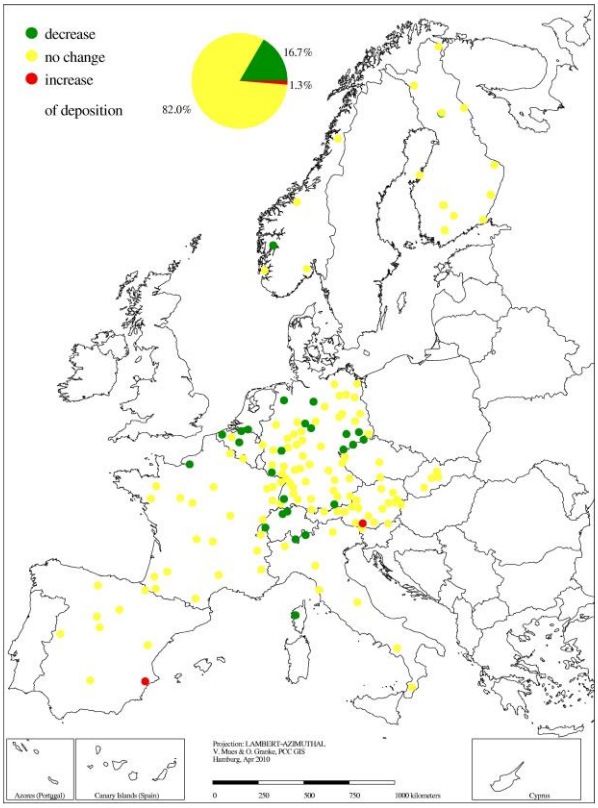

Figure 4.1.3.2-5: Trends in nitrate nitrogen (N-NO_3^-) in bulk deposition from 1998 to 2007.

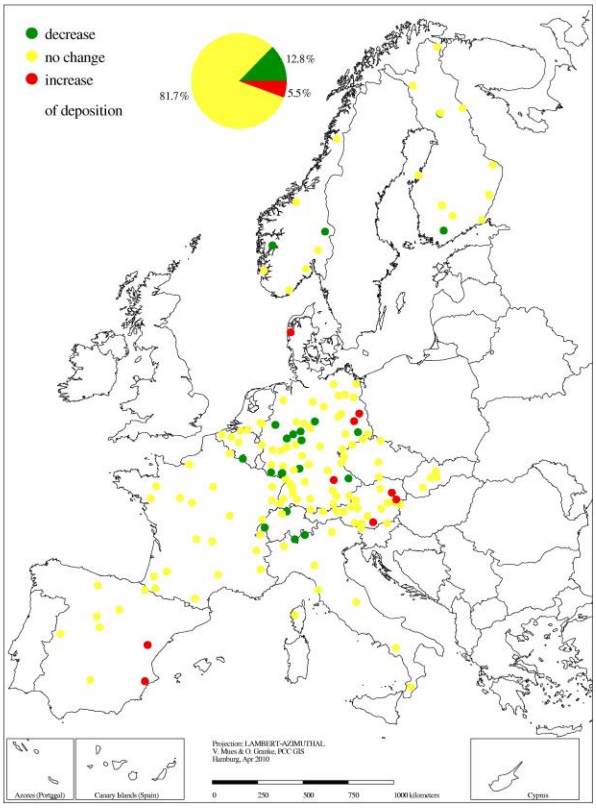

Figure 4.1.3.2-6: Trends in nitrate nitrogen (N-NO_3^-) in throughfall deposition from 1998 to 2007.

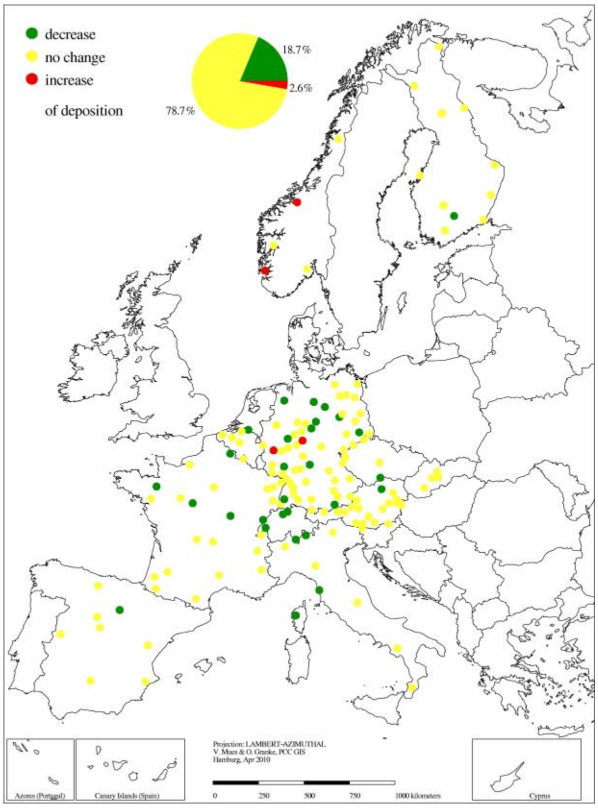

Figure 4.1.3.2-7: Trends in ammonium nitrogen (N-NH_4^+) in bulk deposition from 1998 to 2007.

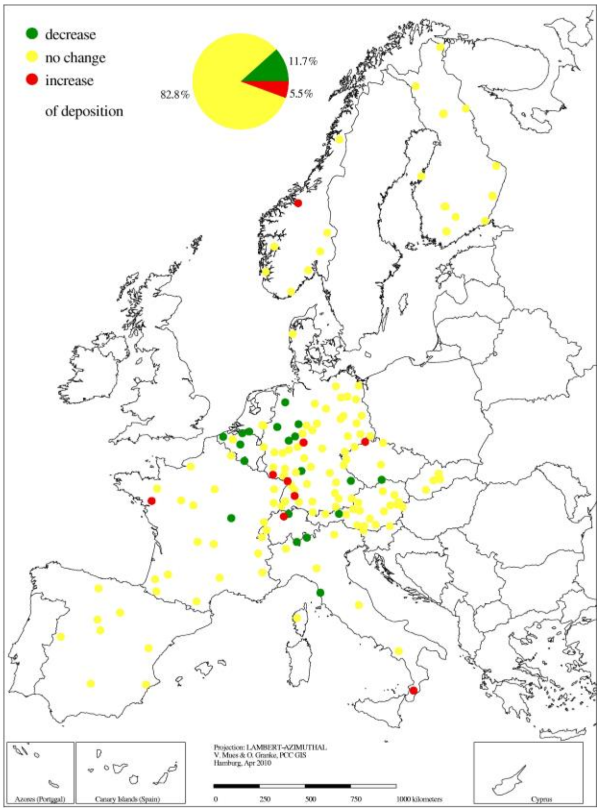

Figure 4.1.3.2-8: Trends in ammonium nitrogen (N-NH_4^+) in throughfall deposition from 1998 to 2007.

4.1.4. Conclusions

Forest monitoring at Level II shows clear pattern in the spatial distribution of deposition of sulphur and nitrogen. These spatial patterns reflect partly regional deposition situations. It seems that the Level II grid is dense enough to reveal spatial patterns of deposition, although it is designed for monitoring at the ecosystem scale rather than at the European-wide scale. This confirms results of earlier years (e.g. Lorenz et al. 2008, Lorenz et al. 2009). In general, atmospheric sulphur and nitrogen deposition is higher in central Europe and on some plots in southern Europe as compared to northern Europe and the alpine regions.

The length of the evaluation period showed a more comprehensive picture of the temporal development of deposition across Europe as compared to earlier evaluations based on shorter periods. Specifically for sulphur a very clear reduction of deposition was observed in the period from 1998 to 2007. This trend is less clear for nitrogen but also obvious at least in bulk deposition which is not influenced by canopy interaction effects. The small share of plots with decreasing nitrogen deposition is in line with Rogora et al. (2006) who investigated long-term deposition time-series from 1990-2002 and only found significant decreasing nitrate deposition trends for about half of the investigated sites in the Alpine Arc. It even seems obvious that at least in some regions of Europe an increase in nitrogen deposition is observed which should be analysed in more detail. All in all, the results of deposition measurements at Level II reflect the reduction of sulphur emissions (70% since 1980) under CLRTAP politics and the less pronounced reduction of nitrogen emissions in Europe (Sliggers and Kakebeeke 2004).

The plot related data calculated from the deposition measurements are indispensable for calculating exceedances of critical limits and loads of air pollutants for forest ecosystems, for assessing and predicting the effectiveness of clean air policies, and for studying relationships between air pollution, climate change, carbon fluxes, forest growth, forest health, and biodiversity.

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4.2. Comparison of measured and modelled deposition

Georg Becher[1]

Abstract

In the present study deposition data measured on Level II plots of ICP Forests were compared with the data modelled by EMEP. The measured and modelled data sets comprised sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) deposition for 2002 and 2003. In general, deposition measured on Level II plots of ICP Forests tends to be higher than deposition derived from EMEP models. The most pronounced and systematic differences were found with the nitrate deposition (NO_3^-). The differences found may rather arise from leaching effects in the canopy than from systematic underestimation of nitrate deposition by modelling since ICP Forests measured throughfall deposition whereas data available from EMEP models described total deposition. Regression analyses indicated that for nitrate up to a deposition load of 4 $kg/ha^{-1}/a^{-1}$ the modelled and measured deposition load was practically equal. From this amount on the deposition modelled does not increase anymore but the nitrate deposition measured on the plots of ICP Forests soars reaching values of about 20 $kg/ha^{-1}/a^{-1}$. In contrast to nitrate deposition nitrogen in form of ammonium (NH_4^+) resembled the modelled total NH_4^+ deposition, despite the possible canopy effects. As regards the spatial patterns concurring deposition loads derived from EMEP models and measured on Level II plots were found in Germany, Finland, Norway and Spain for sulphate (SO_4^{2-}). Higher measured NO_3^- deposition in contrast to the deposition modelled was found in Germany. The spatial analysis of NH_4^+ deposition confirmed agreeing values of measured and modelled deposition rates. The only exception is Austria where throughfall deposition on few ICP Forests plots lay below values derived from EMEP models.

4.2.1. Introduction

The air pollution and its effects on European forests have been monitored since 1986 under CLRTAP. In its beginnings the monitoring programmes concentrated on the assessment of the crown condition expressed in terms of defoliation. After having recognized that defoliation cannot be considered as caused by mono-specific factor forest monitoring has been extended by additional analyses of the most important compartments of forest ecosystem including soil, foliage and growth. These intensive monitoring activities pursued the question how the anthropogenic influences affect the state and functioning of the forest ecosystem over space and time. To analyse this problem different forms of deposition had to be monitored and put in relation to the parameter describing forest ecosystems monitored as well. Besides the scientific aspects methodological questions concerning the way of data collection were to be solved. To cover the extended forest areas in Europe and to gain data of a sufficient accuracy and at reasonable costs models and exact measurements were applied. In this context the present study aims at comparing the deposition exactly measured on the Level II plots of ICP

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Forests and modelled by the Cooperative Programme on the Long-range Transmission of Air Pollutants in Europe (EMEP). In detail, it was tried, to find out if there are any differences in deposition rates measured and modelled. If such differences were found, their magnitudes and other characteristics including the kind of their distribution were examined.

4.2.2. Database

The study is based on deposition data modelled by EMEP and data measured on Level II plots of ICP Forests in 2002 and 2003 for sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+). For the comparison of the both data sets the mean deposition rates calculated annually for each plot of ICP Forests were used. The EMEP deposition data were determined by the Eulerian multi-layer atmospheric dispersion model (BERGE and JAKOBSEN, 1998). Primarily, it is conceived for a horizontal resolution of 50 × 50 km^2. As the main species covered by the Level II network of ICP Forests are Norway spruce *(Picea abies)* and Common beech *(Fagus sylvatica)*, the evaluations are based on data derived from EMEP models for boreal and temperate forests. Comparable modelled and observed deposition data were available from Finland, Norway, Sweden, France, Ireland, UK, Germany, Italy and Spain. The number of Level II plots for which reliable deposition data were available varied between 244 and 289. Deposition data observed on these plots were compared with the EMEP data modelled in 50 × 50 km cells.

The spatial coincidence between deposition measured and modelled by EMEP was given only for the selected Level II plots of ICP Forests. In contrast to the spatial coincidence, there was not possible to compare the same kinds of modelled and measured deposition. Whereas from the EMEP models data on total deposition i.e. wet and dry deposition were available, only bulk and throughfall depositions measured on Level II plots of ICP Forests were used, which may impair the comparability of the both data sets. The limited comparability of the throughfall and total deposition is important for nitrate (NO_3^-) and ammonium (NH_4^+) since nitrogen is subjected to changes caused by the canopy effects. When passing canopy, nitrogen compounds can be enhanced by leaching from the tree crown, which leads to a higher throughfall nitrogen deposition. Besides leaching an uptake of nitrogen compounds can occur in the canopy of forest stands by absorption of nitrogen from precipitation water. In this process the amount of throughfall deposition is reduced as compared with total deposition. To what extent leaching and uptake modify the amount of throughfall deposition with the data used is unknown. For these reasons and other unknown factors random and systematic differences between measured and modelled deposition are expected, even if the measured and modelled deposition data coincide spatially.

4.2.3. Statistical analysis

Independent on how exact and how fine a model is, its capability to reflect and describe real objects remains limited. In view of this fact, the statistical analyses are aimed more at detecting discrepancies and dependencies expected between modelled and measured deposition than at absolute deposition rates. It is important to bear in mind that both modelled and measured data are prone to different errors such as inadequate model assumption, sampling errors, biased assessment, insufficient harmonisation of assessment and measurement methods, propagation error in calculating deposition, imperfect spatial coincidence between EMEP and Level II data and others. Although the main error sources are known, it is impossible to quantify their influence on the quality of both measured and modelled data. All these errors can contribute to a high variation of the EMEP and Level II deposition data which will be shown by statistical description of both data sets separately and by the regression analysis combining deposition data from EMEP models and data measured on Level II plots. Whereas the random errors cannot be ascribed to specific error sources, it is worth investigating if there are systematic differences between measured and modelled deposition data. Instead of statistical inference in form of significance tests the calculation of confidence intervals is preferred to show whether a given parameter is likely to be significant in the population considered and how exactly it is estimated by the data sampled. For becoming aware of the variation of the deposition data, scatter graphs are produced and data depicted in maps to visualize in which regions modelled and measured deposition data are conform and where not.

4.2.4. Results

As mentioned above the magnitude of the throughfall deposition results from total deposition modified by leaching or uptake processes in the forest canopy. When leaching prevails the throughfall deposition will be higher as compared with the total deposition unaffected by the canopy. In other cases i.e. when nitrogen compound passing the forest canopy are absorbed by the crowns of trees the throughfall deposition will be lower than the total deposition load. This means that the throughout deposition measured by ICP Forest can possibly be higher as total deposition modelled by EMEP. This will be the case when leaching is the prevailing process in the forest canopy. Also important for comparing the both data sets is the different spatial resolution of the modelled and measured data as the ICP Forests data reflect the local deposition rates whereas modelled deposition corresponds to an area of 2500 km^2.

4.2.4.1. Differences between measured and modelled deposition

Table 4.2.4.1-1 shows descriptive statistics of the differences between measured Level II and modelled EMEP data for 2002 and 2003.

Table 4.2.4.1-1: Descriptive statistics and **c**onfidence intervals (α = 0.05) for differences between measured (ICP Forests) and modelled (EMEP) deposition [kg/ha/a], N – number of plots

Deposition	Year	N	Min	Max	Mean	Lower limit	Upper limit
S-SO$_4^{2-}$ (bulk)	2002	244	-10.59	14.62	+0.51	+0.16	+0.85
	2003	**258**	**-10.34**	**15.78**	**+0.19**	**-0.16**	**+0.53**
S-SO$_4^{2-}$ (throughfall)	2002	274	-6.96	29.41	+2.16	+1.69	+2.64
	2003	289	-8.84	24.01	+1.92	+1.43	+2.41
N-NO$_3^-$ (bulk)	2002	244	-5.42	6.20	+0.37	+0.17	+0.57
	2003	258	-4.29	16.04	+0.28	+0.04	+0.51
N-NO$_3^-$ (throughfall)	2002	274	-3.66	17.73	+1.65	+1.28	+2.03
	2003	289	-3.13	17.44	+2.15	+1.76	+2.54
N-NH$_4^+$ (bulk)	**2002**	**244**	**-8.30**	**12.80**	**-0.36**	**-0.75**	**+0.02**
	2003	**258**	**-9.55**	**14.20**	**+0.12**	**-0.27**	**+0.52**
N-NH$_4^+$ (throughfall)	**2002**	**274**	**-9.19**	**11.23**	**+0.10**	**-0.25**	**+0.45**
	2003	289	-10.13	16.75	+1.27	+0.85	+1.69

The minimum values of these differences indicate that locally, i.e. for some data pairs, the modelled deposition is higher than the data measured but on statistical average based on sample sizes ranging from 244 to 289 the measured deposition is higher than the deposition modelled by EMEP. In these cases the lower and upper boundaries of the confidence intervals are positive indicating that models yield lower deposition rates than those obtained from the measurements on Level II plots of ICP Forests. Following the statistical interpretation of confidence intervals differences are unlikely to exist in the population investigated when a confidence interval contains null which obviously is the case with negative lower and positive upper confidence limits. As marked in Table 4.2.4.1-1 by bold type this holds true for N-NH_4^+ bulk deposition in both years and for N-NH_4^+ throughfall deposition in 2002. The same applies for S-SO_4^{2-} bulk deposition in 2003 where the mean difference in deposition measured and modelled of 0.19 kg/ha^{-1}/a^{-1} is not likely to exist since the respective confidence interval includes null. As regards nitrogen deposition in form of nitrate the confidence intervals are very wide but always positive implying that the troughfall deposition measured on the plots of ICP Forests is higher than total deposition modelled by EMEP**.**

4.2.4.2. Relationship between modelled and measured deposition

As already mentioned the most striking characteristic of the deposition data, no matter whether measured or modelled, is their large variation caused not only by diverse errors but also by unknown factors and laws governing deposition phenomena. Being aware of this it does not surprise that for some observations or their ranges the individual differences between measured and modelled deposition data may partly be positive, partly negative. This fact is not visible when only confidence limits for mean differences are considered. Thus, it is of advantage to plot both data sets to visualize their variation and to get the first impression on their relationship.

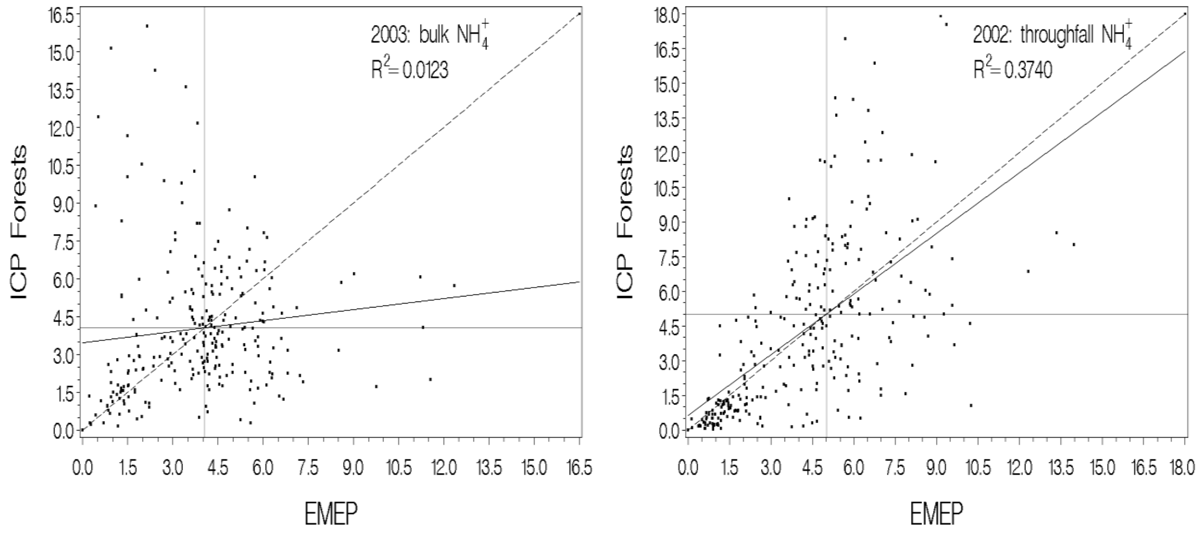

Figure 4.2.4.2-1: Scatter diagram and linear regression **y = a · x + b** (solid line) for deposition data [kg/ha^{-1}/a^{-1}]: **y** – measured deposition (ICP-Forests), **x** – modelled deposition, dashed line represents **y = x,** horizontal and vertical reference lines mark the intersection point between **y = a · x + b** and **y = x**

The above diagrams and regression lines look quite different but considered in a quantitative way both regressions indicate that on average the differences between both data sets do not exist. This **confirms** the conclusion drawn from the estimates of mean differences based on confidence intervals and specified in Table 4.2.4.1-1. However, although similar in quantitative terms, there is no linear relationship between the modelled and measured N-NH_4^+ bulk deposition. Looking closely at the left graph the measured deposition is up to 4 kg/ha^{-1}/a^{-1} higher than the deposition calculated by EMEP whereas large deposition rates resulting from EMEP models correspond with rather low deposition measurements. Since the negative and positive differences balance each other the mean difference between measured and modelled N-NH_4^+ bulk deposition tends towards null. This result cannot satisfy since there is a lack of relationship that would have to be expected with consistent data. Ideally, the regression line should widely resemble the y = x line which is the case with throughfall N-NH_4^+ deposition for 2002 (Figure 4.2.4.2-1, right). Moreover, the scattering of consistent data would have to be lower on either side of the ideal line and consequently the coefficients of determinations higher. Conclusions drawn from the scatter diagrams confirm the estimates of the slopes and intercepts of linear regression shown in Table 4.2.4.2-1.

Table 4.2.4.2-1: Linear regression analysis for deposition data [kg/ha^{-1}/a^{-1}]: **$y = a \cdot x + b$**, **y** – measured deposition (ICP-Forests), **x** – modelled deposition ($\alpha = 0.05$),

Deposition	Year	Slope			Intercept			R^2
		A	Confidence limits		B	Confidence limits		
S-SO_4^{2-}(bulk)	2002	0.58	+0.43	+0.74	+2.35	+1.60	+3.10	0.194
	2003	0.35	+0.19	+0.52	+2.71	+1.99	+3.43	0.064
S-SO_4^{2-} (throughfall)	2002	1.03	+0.81	+1.26	+2.01	+0.95	+3.07	0.235
	2003	0.70	+0.44	+0.97	+3.03	+1.91	4.15	0.085
N-NO_3^- (bulk)	2002	0.80	+0.65	+0.94	+1.01	+0.51	+1.51	0.329
	2003	0.45	+0.24	+0.66	+1.82	+1.19	+2.44	0.064
N-NO_3^- (throughfall)	**2002**	**1.79**	**+1.53**	**+2.04**	**-0.74**	**-1.59**	**+0.12**	**0.410**
	2003	**1.72**	**+1.35**	**+2.08**	**+0.20**	**-0.86**	**+1.26**	**0.231**
N-NH_4^+ (bulk)	2002	0.40	+0.27	+0.53	+2.33	+1.67	+2.99	0.135
	2003	**0.15**	**-0.01**	**+0.31**	**+3.45**	**+2.74**	**+4.17**	**0.012**
N-NH_4^+ (throughfall)	**2002**	**0.87**	**+0.74**	**+1.01**	**+0.64**	**-0.03**	**+1.30**	**0.374**
	2003	0.95	+0.74	+1.16	+1.45	+0.57	+2.33	0.221

Accordingly, the confidence intervals for the slope of the regression line between EMEP and ICP Forests NH_4^+ bulk deposition for 2003 include null indicating that there is no relationship between the modelled and measured deposition data. In contrast to NH_4^+ bulk deposition of 2003 the NH_4^+ throughfall deposition measured and modelled in 2002 imply agreeing magnitudes with insignificant intercept and slope confidence limits lying near to unity (see the corresponding bold typed lines in Table 4.2.4.2-1). As already stressed it is very difficult to interpret the results of such comparisons as both models and measurements show uncertainties. These are on the side of the EMEP approach the necessity of model assumptions simplifying or not accounting for all facets of the questions how the forest stands exert influence on the total deposition and to what extent leaching could enrich the amount of the elements in throughfall deposition. Also hardly quantifiable are uptake processes of nitrogen which maydiminish the deposition caught on the floor of forest stands. The reliability of the deposition measurements may be impaired by different field collectors, problems in precipitation assessments and, despite of extended harmonisation efforts, differences in data collection and analyses. As compared with SO_4^{2-} the measured and modelled nitrogen deposition in form of NO_3^- and NH_4^+ is relatively more correlated. In case of NO_3^- throughfall deposition the EMEP values are much lower than deposition measured on Level II plots of ICP Forests (Figure 4.2.4.2-2).

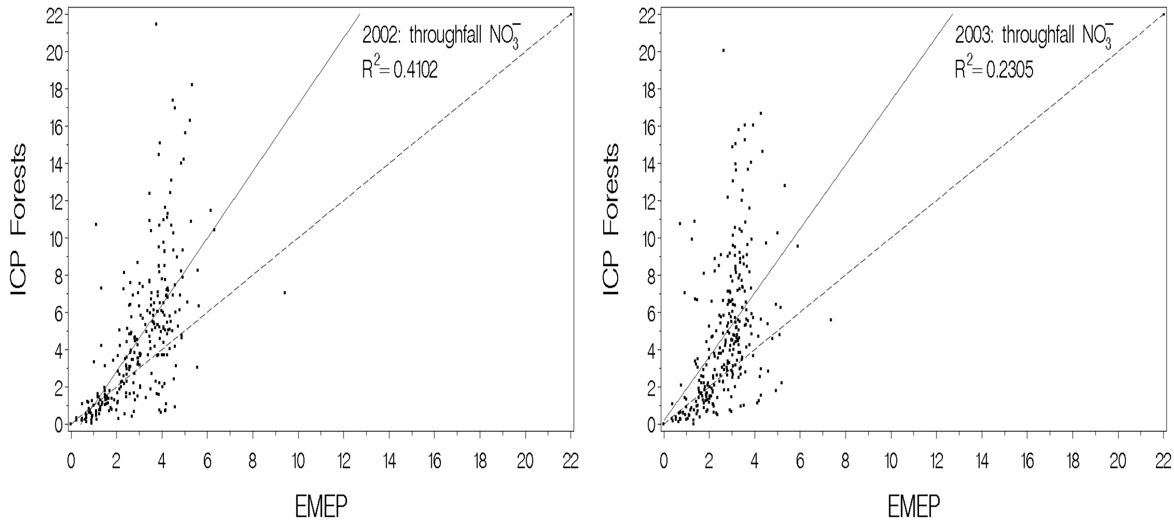

Figure 4.2.4.2-2: Scatter diagram and linear regression **y = a · x + b** (solid line) for deposition data (kg/ha^{-1}/a^{-1}): **y** – measured deposition (ICP-Forests), **x** – modelled deposition, dashed line represents **y = x**

Referring to the N-NO_3^- deposition only few values derived from EMEP models are larger than 5 kg/ha^{-1}/a^{-1}. In contrast, the spatially corresponding deposition rates measured on Level II of ICP Forests go up to almost 20 kg/ha^{-1}/a^{-1}. To arrive at a better fit to the data an equation like $y = ax^2$ with $a < 1$ may be more appropriate but this would not meet the objective of this study which is only aimed at quantifying possible differences between modelled and measured deposition data. Thus, linear regression was chosen as the simplest model to quantify the relation between the both data sets. For the graphs in Figure 4.2.4.2-2 slopes and intercepts are given in Table 4.2.4.2-1. Since the intercepts can be neglected only slopes and their confidence limits of the regression lines are relevant. Their means of 1.79 and 1.72 for 2002 and 2003 respectively are factors by which the ICP Forests NO_3^- throughfall deposition data are larger than the data modelled by EMEP. The shape of the scatter diagrams show very clear that there are more or less agreeing deposition rates between ICP Forests and EMEP, approximately up to 4 kg/ha^{-1}/a^{-1} followed by an increase of nitrate deposition based on Level II plots whilst the deposition calculated by EMEP remains unchanged. It is beyond all doubt that the nitrate deposition estimated by EMEP lies systematically below that of ICP Forests for deposition rates of about 3 kg/ha^{-1}/a^{-1} and more (see Figure 4.2.4.2-2). SIMPSON et al., 2006 found similar differences. In their opinion the different deposition rates arise from the problems with EMEP models and measurements of ICP Forests as well.

4.2.4.3. Spatial analysis of measured and modelled deposition data

Neither confidence intervals of mean differences nor regression equations calculated between deposition data of EMEP and ICP Forests make it possible to account for the spatial aspects of the deposition as measured or modelled variables. The regression analysis showed that differences between modelled approach and deposition derived by sampling may be confined to specific ranges of deposition loads (Figure 4.2.4.2-2). The question worth examining is whether the differences between deposition based on EMEP models and calculated from the measurements on plots of ICP Forests are randomly distributed or not. To embark on this question maps overlaying the measured and modelled deposition were produced. As regards the SO_4^{2-} the modelled and measured deposition are mainly conform in Germany, Northern Europe (Finland and Norway) and in Spain (Figure 4.2.4.3-1). A striking difference towards lower deposition based on ICP Forests can be seen in Italy whereas higher deposition rates as compared to EMEP can be found on some sites in the UK and Ireland. The lack of recognisable patterns and rather even distribution of both deposition estimates correspond with the result compiled in Table 4.2.4.2-1.

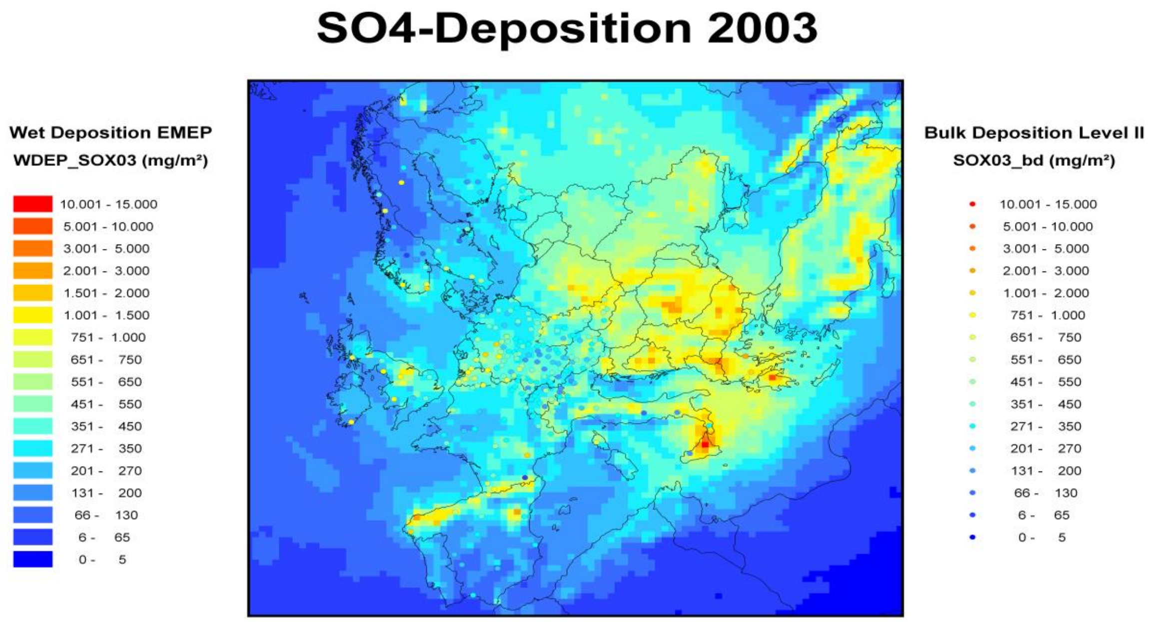

Figure 4.2.4.3-1: Patterns of sulphate deposition in 2003: EMEP wet deposition in 50 × 50 km grid and deposition based on Level II plots of ICP Forests.

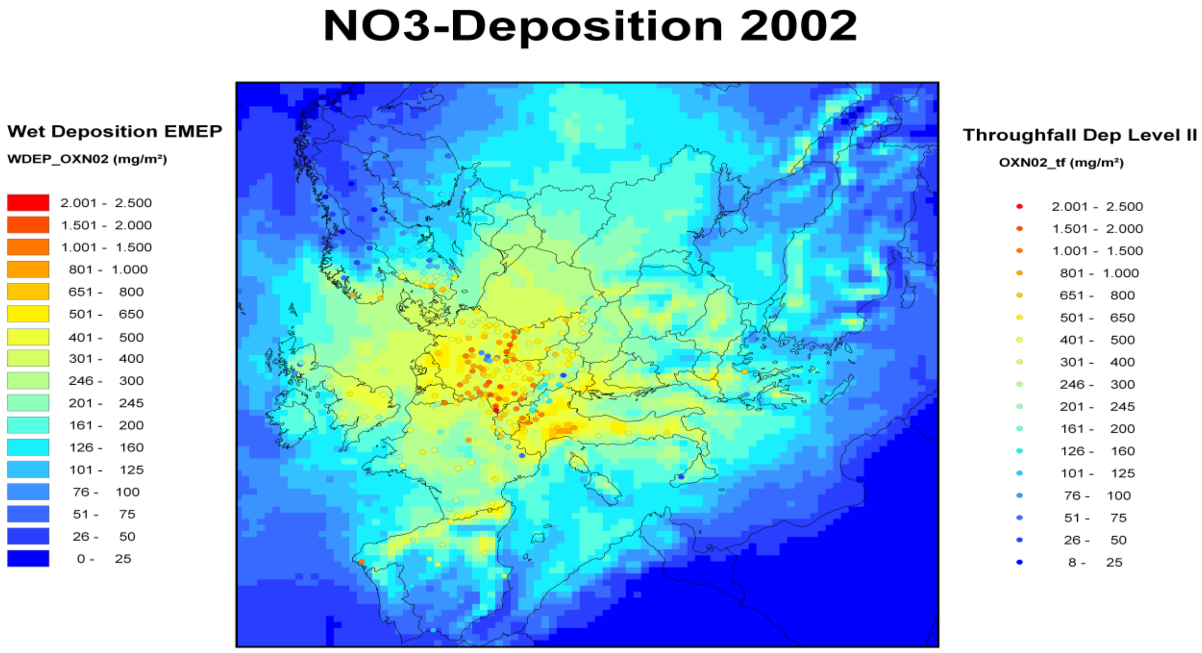

Figure 4.2.4.3-2: Patterns of the nitrate deposition in 2002: EMEP wet deposition in a 50 × 50 km grid and deposition based on Level II plots of ICP Forests.

As already shown by the regression analysis the measured NO_3^- throughfall deposition tends to be larger than the results obtained from EMEP (Table 4.2.4.2-1). The spatially investigated main areas (Figure 4.2.4.3-2) where models underestimate the measured deposition are in Germany and in the northern part of Italy. However, there are also a few plots of ICP Forests showing lower deposition rates than those based on EMEP models. Similar spatial patterns of NO_3^- throughfall deposition indicate that modelled data tend to be systematically lower than measured ones found in 2003 (Figure 4.2.4.3-3).

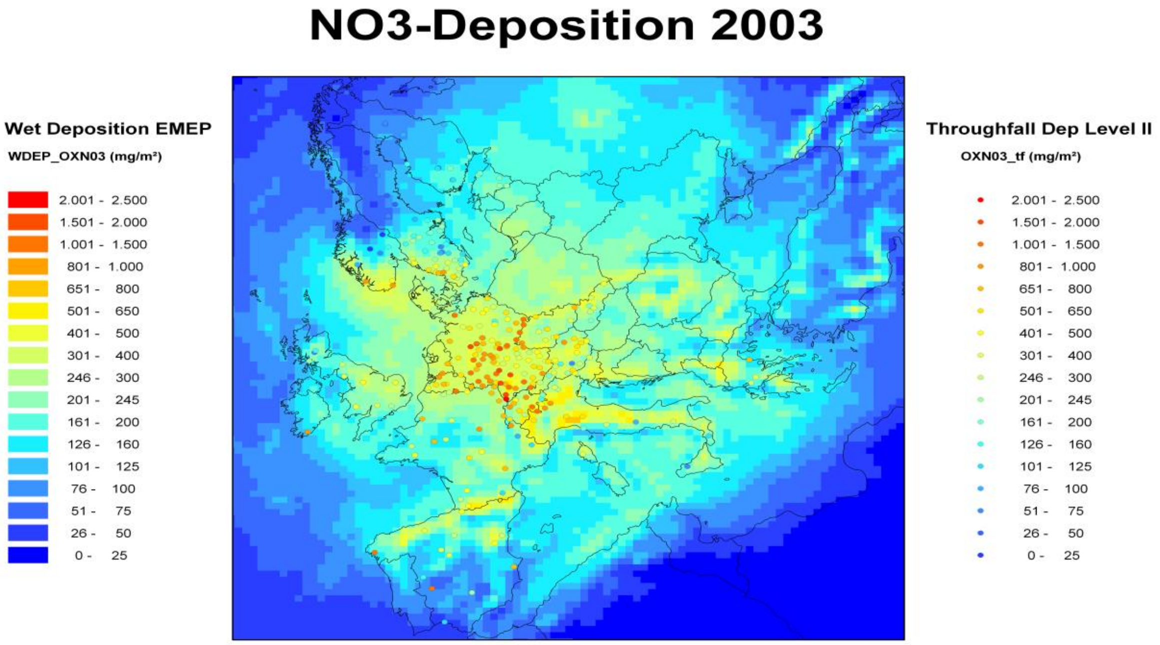

Figure 4.2.4.3-3: Patterns of the nitrate deposition in 2003: EMEP wet deposition in 50 × 50 km grid and deposition based on Level II plots of ICP Forests.

Out of all deposition kinds considered in this study the highest coincidence of measured and modelled data was found with ammonium throughfall deposition for 2002 (right graph in Figure 4.2.4.2-1). Even if the confidence limits for the slope of the regression line include unity indicating nearly perfectly coinciding deposition rates, the geographical visualization reveals strange discrepancies in NH_4^+ throughfall for 2002 in Austria where deposition on Level II plots tends to be much lower than deposition rates based on EMEP (Figure 4.2.4.3-4).

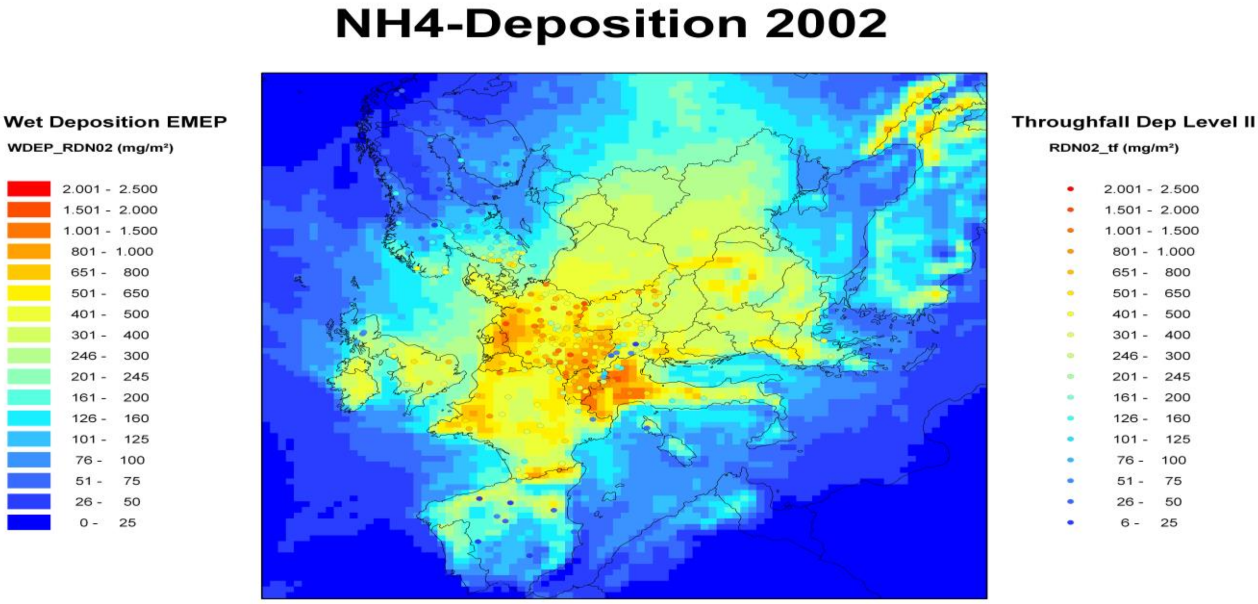

Figure 4.2.4.3-4: Patterns of the NH_4^+ deposition in 2002: EMEP wet deposition in a 50 × 50 km grid and deposition based on Level II plots of ICP Forests.

The reasons for these differences in a confined area do not necessarily lie on the side of models. Responsible for them may also be erroneous or biased measurements on the respective Level II plots.

4.2.5. Conclusions

The comparison of the spatial deposition data gained by measurements on Level II plots of ICP Forest and deposition modelled by EMEP for 2002 and 2003 showed that in most cases the deposition measured was higher than deposition derived from models. The most marked and systematic differences were found with the NO_3^- deposition. In contrast to nitrate the modelled and measured NH_4^+ depositions did not differ significantly.

Modelled deposition rates were linear regressed on the deposition measured showing that in case of nitrate deposition the modelled and measured values are almost equal up to 4 $kg/ha^{-1}/a^{-1}$. Higher values are scarce in modelled data whereas measured deposition went up reaching values of 18 $kg/ha^{-1}/a^{-1}$ and more.

As regards the spatial patterns agreeing deposition loads derived from EMEP models and measured on Level II plots were found in Germany, Finland, Norway and Spain for sulphate (SO_4^{2-}). The spatial analysis of NH_4^+ deposition confirmed the accordance of measured and modelled deposition gained from regression analyses. The only exception is Austria where throughfall deposition on few ICP Forests plots lay below values derived from EMEP models.

Taking up the point made by SIMPSON et al. (2006) that uncertainties may occur with both EMEP and ICP Forests data, it would be a challenging task to find out by what factors and to what extent the differences found are caused. In the first step deposition amounts obtained by EMEP and ICP Forests would have to be traced back separately attempting to detect and quantify all sources of possible errors and biases. On the side of models a detailed examination of model assumptions and their effects on the magnitude of deposition would have to be performed. Having information on EMEP models and measurements of ICP Forests, including the magnitudes and directions of possible errors and their sources, a thorough analysis of the discrepancies found between both systems could theoretically be performed.

4.2.6. References

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5. Status and development of forest soils

5.1. pH, base saturation, C/N ratio and C/N index

Bruno De Vos, Nathalie Cools[1]

Abstract

Between two European forest soil surveys there was an increase in pH and base saturation in the very acid forest soils but a decrease of soil pH and base saturation in the other soils. In the second soil survey, N deposition still causes disturbed organic matter and nutrient cycling on 14% of the observation plots, evidenced by a C/N index lower than 1. Especially the plots in Central-Western Europe are severely affected.

5.1.1. Introduction

In the period between 1986 and 1996 a first Pan-European forest soil condition survey was carried out on 5289 plots of the ICP Forests Level I grid (Vanmechelen et al. 1997). A second survey was conducted between 2004 and 2008 within the BioSoil project of the EU Forest Focus Regulation including 4928 plots. The results of this second survey were analysed within the FutMon project and presented in the Second European Forest Soil Condition Report (De Vos and Cools, 2011).

This chapter presents the status of four forest soil condition indicators (pH, base saturation, C/N ratio and C/N index) based on the measurements conducted within the BioSoil soil survey. Secondly the current situation is compared with the first inventory to show the development of the forest soil condition in Europe over roughly the past 20 years.
The soil pH is an indication of the degree of acidity or alkalinity of a soil. In both surveys the potential pH was measured in a $CaCl_2$ extract which is more stable than the actual pH measured in water.

The base saturation, calculated as the proportion of basic exchangeable cations (Ca^{2+}, Na^+, Mg^{2+} and K^+) to the total cation exchange capacity of the soil, is considered as a measure for the buffering capacity of the soil against soil acidification. The buffering capacity indicates how resistant the soil is to attempts of changing its pH. When the base saturation is depleted below levels of 10–20%, the remaining basic cations are more tightly held and are less available for counteracting soil acidification (Reuss and Johnson, 1986; Ulrich, 1995).

The ratio of the carbon-to-nitrogen concentration (C/N ratio) in organic layers and soils is a suitable indicator for the decomposition rate of organic matter, the availability of nitrogen and turnover of nutrients. As forest litter with a C/N ratio between 20 and 100 is decomposed, its ratio decreases gradually and stabilizes at 15-20 in mineral topsoil (0-10 cm) and about 10-

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15 in subsoil. Organic matter with a low C/N ratio will require less energy for decomposition, and the released nitrogen is sufficient to meet the demands of the micro-organisms, facilitating rapid decay and nutrient release. Decomposition rate is also influenced by climatic conditions and species specific litter quality, among other factors.

In healthy forests the C/N ratio of the forest floor is distinctly higher than in the mineral soil, and it further narrows with depth. However, in areas with a high nitrogen deposition load, the C/N ratio of the forest floor (C/N_{FF}) may become smaller than the C/N ratio of the mineral topsoil (C/N_{MIN}). Hence, the proportion of the C/N_{FF} over C/N_{MIN}, referred to as the C/N-index, is a valuable indicator for the imbalance induced by excess nitrogen input. If this index is less than 1, the organic matter and nutrient cycling is most likely disturbed and forest health and vitality may be at risk.

5.1.2. Current status of pH, base saturation, C/N ratio and C/N index

5.1.2.1. pH

The pH ($CaCl_2$) in the top 10 cm of the mineral forest soil ranges from 2.5 to 7.8 where 95% of the pH values are situated between 3.0 and 7.4. The median value is 4.0 and the mean 4.5, although most observations are comprised within the 3.75 – 4.0 class. The pH shows a bimodal distribution where the calcareous soils show a second peak within the pH 7.0 – 7.5 range which is seen on all depths. In the mineral soils, the pH gradually increases with depth. Figure 5-1 shows the geographical distribution across Europe of the pH($CaCl_2$) in the upper 10 cm of the mineral and peat soils. There is a clear gradient in increasing pH from Northwest to Southeast Europe except for some slightly calcareous areas in Estonia and Latvia.

5.1.2.2. Base Saturation

A gradient from very low base saturation in Northern Europe to low values in Central-Eastern Europe, over moderate base saturation in Central-Western Europe to high values in Southern Europe can be explained by natural conditions such as the presence of acidic Podzols in Northern Europe, sandy soils (Arenosols) in the Central-East of Europe (mainly Poland) and the calcareous parent material in Southern Europe. Figure 5.1.2.2-2 shows the status of the base saturation in the upper 10 cm of the mineral soil in the second soil survey. The classes with base saturation below 10–20% indicate forest soils with low buffering capacity against soil acidification.

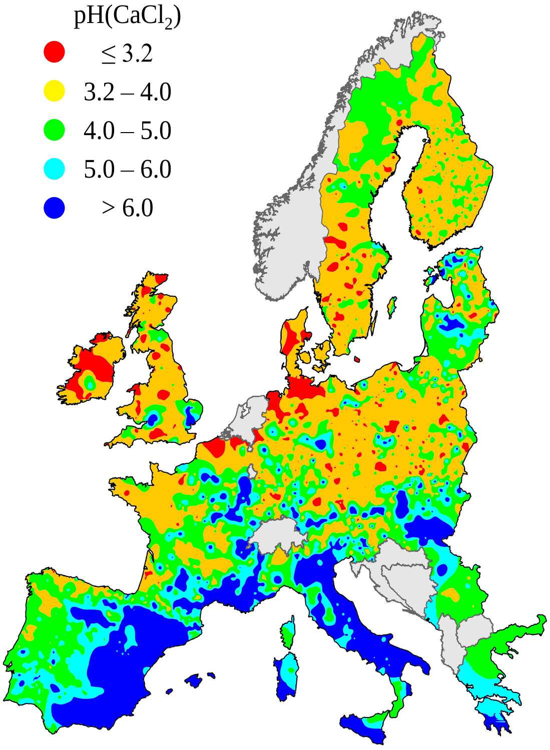

Figure 5.1.2.2-1: Kriged map of the pH(CaCl$_2$) in the upper 10 cm of mineral soils and peat soils of the Bio-Soil$^+$ Level I and Level II plots

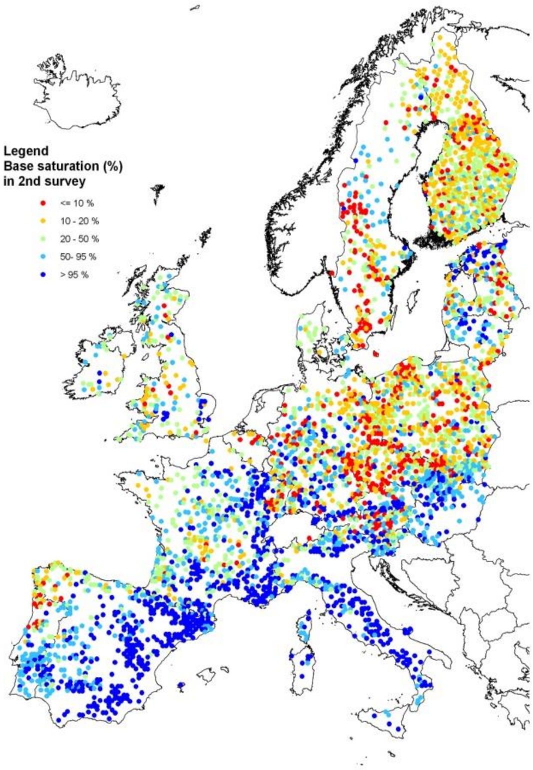

Figure 5.1.2.2-2: Base saturation in the upper 10 cm of mineral soils of the BioSoil$^+$ Level I plots

5.1.2.3. C/N ratio and C/N index

Country-based values for C/N ratios and index of the forest floor and mineral topsoil are given in Table 5.1.2.3-1. Note the low median and range values of the C/N index for the Central-Western European countries compared to those of the South-West. The countries Lithuania, Austria, Hungary, Slovakia, Slovenia, Portugal and Cyprus have minimum range index values above 1 and consequently less than 5 % of their plots are considered disturbed by N deposition during the second survey. The geographical extent of the affected area (in red) is illustrated in Figure 5.1.2.3-1, showing that the affected area is mainly situated in Central-Western Europe and parts of Central-Eastern Europe and the Baltic States.

Table 5.1.2.3-1: Country specific median and 95% range of C/N ratios in forest floor (C/N_{FF} of the forest floor) and in mineral topsoil (C/N_{MIN} 0-10 cm) and their respective proportion (C/N-index). The 95% range is comprised between the 2.5 and 97.5 percentiles.

	Country	No Plots	Forest floor C/N_{FF}		Mineral topsoil C/N_{MIN}		C/N-index C/N_{FF} to C/N_{MIN}	
			median	95% range	median	95% range	median	95% range
North Europe	Denmark (DK)	25	28.2	22.2 – 39.8	25.5	15.0 – 40.5	1.09	0.75 – 2.39
	Estonia (EE)	26	28.9	22.4 – 103	16.5	11.4 – 27.8	1.70	0.80 – 5.10
	Finland (FI)	493	30.1	18.8 – 44.7	22.2	14.4 – 31.4	1.31	0.94 – 2.45
	Latvia (LV)	70	24.2	16.1 – 47.2	19.6	9.21 – 61.9	1.02	0.44 – 2.15
	Lithuania (LT)	43	27.6	15.2 – 38.1	14.6	9.28 – 23.9	1.72	1.03 – 3.02
	Sweden (SE)	216	26.1	14.3 – 44.4	19.0	10.5 – 30.4	1.28	0.91 – 2.64
Central-West Europe	Austria (AT)	128	26.0	19.5 – 32.5	18.4	12.8 – 25.3	1.40	1.05 – 2.38
	Belgium (BE)	9	26.7	18.6 – 33.9	22.7	11.5 – 33.8	1.01	0.84 – 1.46
	France (FR)	133	22.5	16.7 – 39.0	16.6	12.0 – 34.8	1.12	0.74 – 1.56
	Germany (DE)	208	24.7	18.7 – 34.9	19.0	12.0 – 32.5	1.12	0.75 – 1.89
	Ireland (IE)	28	28.5	18.1 – 41.2	19.3	13.2 – 33.3	1.18	0.94 – 1.69
	United Kingdom (UK)	115	22.4	16.3 – 37.1	15.4	10.7 – 28.2	1.26	0.78 – 1.73
Central-East Europe	Czech Rep. (CZ)	145	21.7	14.3 – 30.8	18.6	11.1 – 27.3	1.14	0.90 – 1.78
	Hungary (HU)	19	22.3	13.8 – 31.6	13.2	10.3 – 20.1	1.42	1.05 – 1.97
	Poland (PL)	382	24.0	16.7 – 35.6	17.6	10.3 – 30.2	1.26	0.79 – 2.00
	Slovakia (SK)	70	22.5	16.1 – 31.0	14.3	10.3 – 21.6	1.49	1.02 – 2.23
South West	Italy (IT)	112	21.1	14.1 – 29.2	12.6	7.48 – 19.9	1.62	0.97 – 2.82
	Portugal (PT)	89	31.6	16.8 – 57.4	16.4	11.0 – 33.1	1.61	1.12 – 3.24
	Spain (ES)	384	26.8	14.0 – 47.9	14.6	6.00 – 29.3	1.70	0.94 – 7.07
South-East Europe	Cyprus (CY)	15	32.3	24.3 – 53.9	17.2	12.3 – 27.2	1.87	1.30 – 3.08
	Slovenia (SI)	28	24.1	17.4 – 30.6	16.3	12.1 – 22.2	1.31	1.02 – 1.81
	All countries	2738	25.3	15.9 – 43.4	17.4	9.75 – 32.4	1.32	0.80 – 2.82

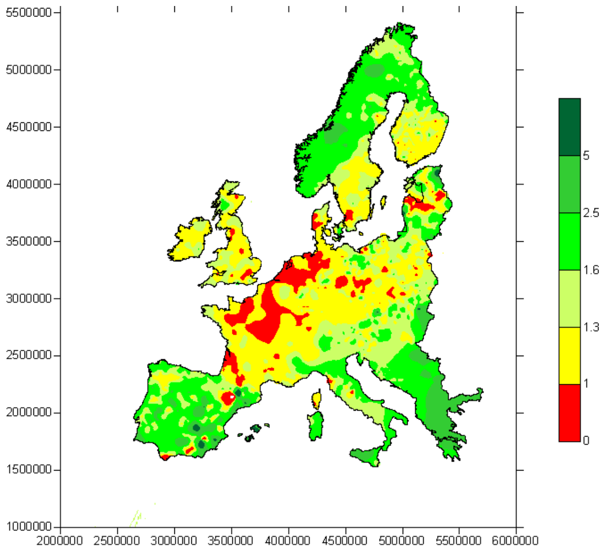

Figure 5.1.2.3-1: Kriged map of European areas with forest soil C/N-index based on the second soil survey. Affected area, where C:N index is less than 1, is indicated in red.

Forest growth is strongly stimulated by N deposition and by more narrow C/N ratios in the forest floor. However, if the forest soil cannot supply other nutrients (especially base cations like calcium and magnesium) in a balanced and sustainable way, impaired tree health is likely to occur.

Furthermore, it has been shown that when C/N ratio in the forest floor is narrow and N deposition is high (> 20 kg N ha^{-1} yr^{-1}), nitrate is leached from the soil into ground- and surface waters, leading to further eutrophication.

5.1.3. Development of pH, base saturation, C/N ratio and C/N index

5.1.3.1. pH

Figure 5.1.3.2-1 shows the evolution of pH on revisited observation plots across Europe. From the 2182 plots, 4 % are acidifying by more than 0.75 pH units, 21 % between 0.25-0.75 units, 57 % remained stable, 15% recovered between 0.25-0.75 units and 3 % recovered by more than 0.75 pH units. Considering all observations, soils are slightly acidifying by 0.03 pH units on average. However, in the acid forest soils (with pH below 4.0) pH increased significantly but it decreased in forest soils with pH above 4.0. This finding confirms the modelled recovery of the pH in soil solution where the recovery was indeed more pronounced at low pH values (Lorenz et al. 2007).

5.1.3.2. Base Saturation

Following the changes in pH, the base saturation increased in the acidified forest soils (with a base saturation below 20%) and decreased in forest soils with initial (first survey) base saturation values above 20%. The percentage of plots with low buffering capacity decreased from 48% in the first observation period to 28% in the second observation period. This again indicates a recovery from soil acidification at the European level on the most acid soils. Classified by the major reference soil groups according to the soil classification system of the World Reference Base for Soil Resources (IUSS Working Group on WRB, 2006), there is a statistically significant decrease in base saturation in the topsoil of Regosols, Arenosols and Stagnosols whereas a statistically significant increase is found in Luvisols and Gleysols (Figure 5.1.3.2-2).

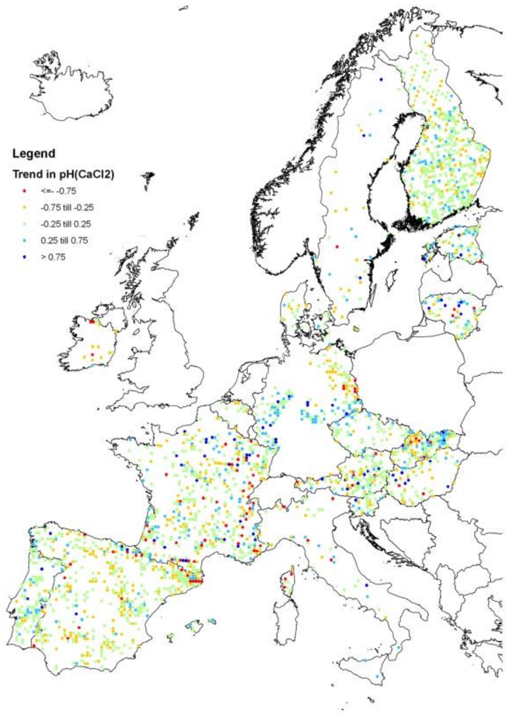

Figure 5.1.3.2-1: Changes in soil pH in the top mineral soil layer (0 – 10 cm) between the two surveys

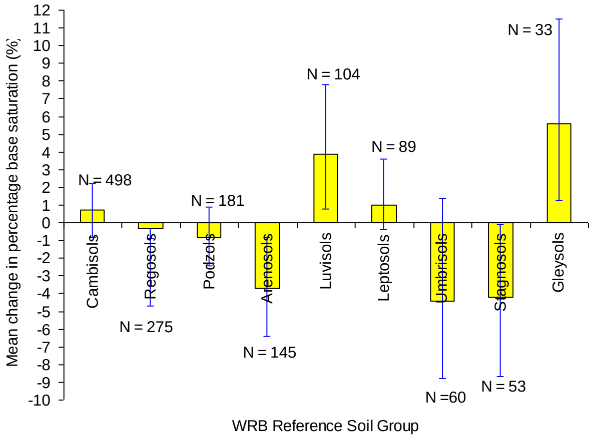

Figure 5.1.3.2-2: Mean change in percentage base saturation between the first and the second forest soil survey. When the error bars do not cross the 0 line, the change is statistically significant.

5.1.3.3. C/N ratio and C/N index

When compared with the status of the first survey, the percentage of affected plots (index < 1) increased for Belgium, Germany, Finland, France, Ireland and Italy but this might be slightly biased by differences in the observed set of plots. For instance for Belgium: only Flanders was resampled in the second survey and these plots are more severely affected than in Wallonia. Conversely, the percentage of affected plots decreased for Czech Republic, United Kingdom, Lithuania, Portugal and Sweden. On average, a slight decrease in percentage of affected plots is observed from 17 % to 14 % over the period considered. In the first soil survey 9 countries showed more than 20% affected plots whereas in the second survey only five countries (BE, DE, DK, FR and LV). However some countries were not reassessed (HR, LU, NO, NL) (Figure 5.1.3.3-1). This shows the importance of a systematic reassessment in all countries in order to draw stronger conclusions.

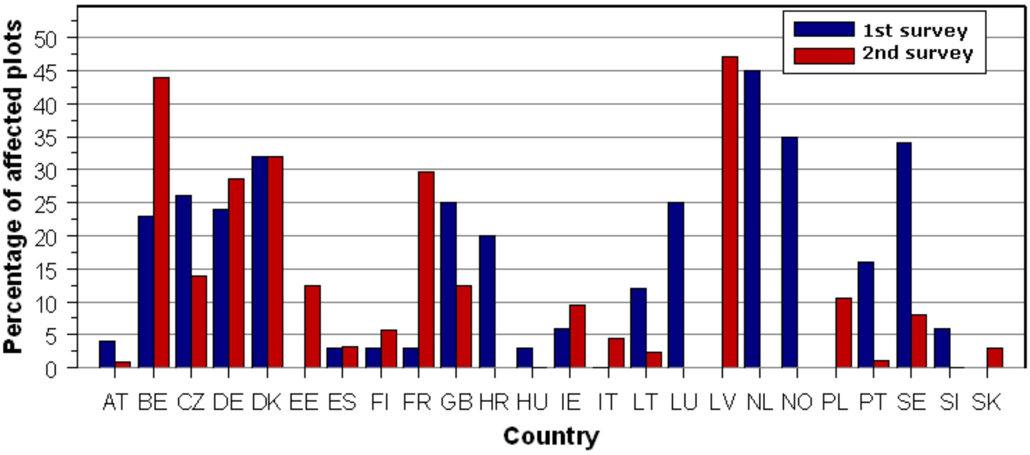

Figure 5.1.3.3-1: Percentage (%) of total plots per country (codes in Table 5.1.2.3-1) for which the C/N ratio of the mineral topsoil (0-10 cm) exceeds that of the forest floor. The percentages of the first survey are indicted in blue, the percentages of the second survey are indicated in red.

5.1.4 Conclusions

The evaluation of the results of the BioSoil soil survey allowed a substantially improved and more complete characterisation and evaluation of the forest soil condition in Europe compared to the first forest soil inventory. The continuous quality assurance and control programme for soil analysis and the regular update of the soil manual with harmonised methods contributed largely to the success of the soil survey and its evaluation.

Between the two soil surveys, there was an increase in pH and base saturation in the very acid forest soils but a further decrease of soil pH and base saturation in other forest soils.

In the second soil survey, N deposition still causes disturbed organic matter and nutrient cycling on 14% of the observation plots, evidenced by a C/N index lower than 1. Especially the plots in Central-Western Europe are severely affected.

5.1.5 References

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5.2. Exceedance of critical limits of nitrogen concentration in soil solution

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Abstract

Exceedances of critical limits for total nitrogen concentrations in soil solution were calculated based on samples from 171 Level II plots from the early 1990s to 2006. Mean concentrations were compared to critical limits that were available from literature. Results show that N concentrations in soil solution regularly exceed two widely used critical limits on the majority of ICP Forests intensive monitoring plots in Europe. On 93% of the plots critical limits for nutrient imbalances in the organic layer were exceeded in more than 50% of the measurements. On 67% of the plots critical limits for elevated N leaching in the organic layer were exceeded in more than 50% of the measurements. For the mineral topsoil and subsoil, the critical limits for elevated N leaching were exceeded on 38% and 37% of the plots, respectively, in more than 50% of the measurements. The respective share of plots where limits for reduced fine root biomass or enhanced sensitivity to frost and fungi were exceeded in organic layers were 32% and 16%. Exceedances in the mineral soil layers were lower. Data from 140 plots were available for the calculation of time trends of at least five years per plot. In most of the plots there was no temporal trend in the critical limit exceedance for nitrogen. In cases where trends could be documented they were usually decreasing. Nutrient imbalances and N saturation and leaching to deeper soil layers are expected consequences of these findings in large parts of Europe.

5.2.1. Introduction

Soil solution chemistry is an important indicator to monitor air pollution effects on forest ecosystems, as well as possible effects of air pollution abatement policies. Soil solution represents a medium for many chemical reactions in the soil like nutrient uptake by roots. In polluted soils, the same interface also enables the uptake of elements with harmful effects. Accordingly, the composition of soil solution has been one of the central indicators since the establishment of intensive monitoring plots of ICP Forests in the early 1990s.

Most important effects of acidifying deposition (i.e. sulphur, but also nitrogen) in soil solution (and as such on the solid soil phase) are a depletion of nutrient cations and the mobilisation of potentially toxic elements. This may change the buffer range and result in an unbalanced tree nutrition and nutrient deficiencies. These soil and soil solution mediated processes affect vegetation in terms of reduced growth resulting from impaired nutrient uptake, enhanced growth due to eutrophication, fine root dieback and general stress reactions of the vegetation like excessive flowering (Fischer et al., 2010; Koch and Matzner, 1993; Løkke et al., 1996).

An important tool to describe the potential risks of atmospheric pollution is the calculation of critical loads and their exceedances, aiming at the protection of forest ecosystems from harmful effects on forest structure or function (Augustin et al., 2005). The critical loads con-

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cept is accepted as the basis for effect-based air pollution abatement strategies, in order to reduce or prevent damage to the functioning and vitality of forest ecosystems caused by transboundary air pollution and acidic deposition (Løkke et al., 1996).

Model-based approaches for calculating critical loads aim at linking the deposition of air pollutants with its chemical or biological effects to the ecosystem. As the biological effects often are of complex nature, chemical criteria are mostly used to simplify the modelling. This calls for appropriate (soil) chemical criteria with proven (empirical) relationships to biological effects. For these chemical criteria values have to be defined that mark the threshold below which harmful effects on the specified biological indicator are not expected (UNECE, 2007).

Exceedances of these critical limits do not necessarily result in instant dieback of trees or ecosystems but do illustrate an enhanced risk for trees to be more susceptible to additional stressors. Exceedances may result in a loss of assimilation area, growth reductions and nutrient imbalances (Augustin et al., 2005). The critical loads are a function of the chosen chemical threshold values (critical limits) applied within the model (Hall et al., 2010).

The 2010 ICP Forests Technical Report (Fischer et al. 2010) presented critical limit exceedances for pH and for the base cation to aluminium ratio in the soil solution of Level II plots and evaluated these against well documented critical limits. In this year’s report, nitrogen concentrations in soil solution are presented in relation to different, widely used critical limits criteria that are used for the calculation of critical loads (UNECE, 2007).

The objectives of this study were to i) examine whether soil solution data from Level II sites show any exceedances with respect to different of critical limits criteria that are currently used in critical load calculations, and if so ii) find out about spatio-temporal trends in soil solution chemistry in relation to presented critical limits in Europe.

5.2.2. Data

For the years 1990 to 2006, soil solution chemistry data were available from 301 different plots in 26 countries. In 2006, soil solution data were collected at 226 plots in 21 countries. The number of samplers per plot varied, the maximum being 7 lysimeters per plot in the organic layer, 26 in the mineral topsoil and 12 in the mineral subsoil. The length of the measured temporal trend varied from plot to plot because samplers were installed in different years and a number of plots had to be abandoned for different practical reasons during the observation period. Earliest measurements started in 1990 but generally the monitoring was initiated between 1994 and 1997. The study includes data until the year 2006.

Field sampling and chemical analysis were carried out by the National Focal Centres of ICP Forests following harmonised methods developed by the ICP Forests Expert Panel on Soil and Soil Solution (Derome et al., 2002). On most plots, sampling took place at weekly to monthly intervals using non-destructive methods. 72% of the plots were equipped with suction cup lysimeters and 28% with zero tension lysimeters. In total, data were derived from more than 2000 samplers. After intensive data quality checks, data were submitted to the data centre of ICP Forests for central data storage and validation. Data were submitted either separately for each lysimeter or as plotwise means for each single soil layer.

In order to enable comparisons between different soil types, results were aggregated into three classes:

- organic layer (7% of the samplers)
- mineral topsoil 0 – 40 cm soil depth (51% of the samplers)
- mineral subsoil below 40 cm soil depth (42% of the samplers).

5.2.3. Methods

Analysis of critical limit exceedances of nitrogen was carried out for plots for which both nitrate and ammonium concentrations were available. Critical limits were applied based on published literature (Tabale 5.2.3-1)

Table 5.2.3-1: Specific critical limits for nitrogen concentration in soil solution in different forest types (UNECE, 2007)

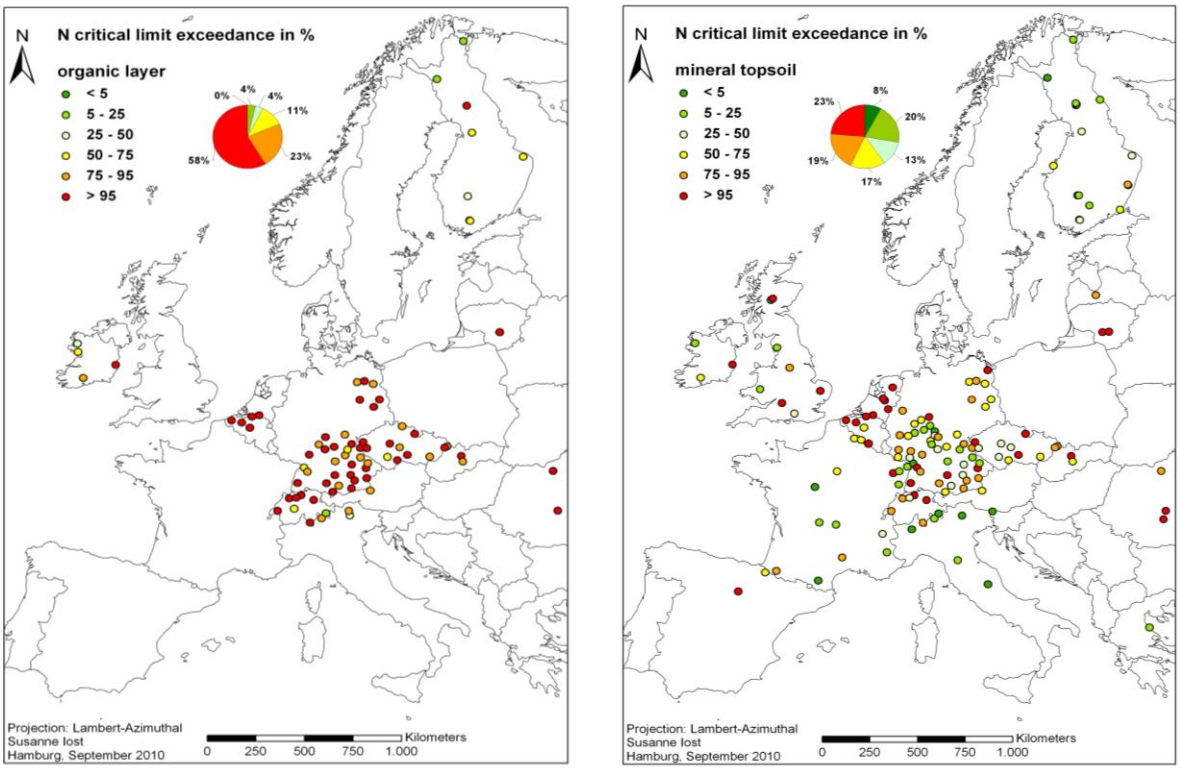
Effect	Chemical Criterion	Receptor
Nutrient imbalances	> 0.2 mg N / l soil solution > 0.4 mg N /l soil solution	Coniferous forests Deciduous forests
Elevated N leaching / N saturation	> 1 mg N / l soil solution	All forest types
Reduced fine root biomass /root lenght	> 3 mg N / l soil solution	All forest types
Enhanced sensitivity to frost and fungal diseases	> 5 mg N / l soil solution	All forest types

Critical limit exceedances are presented in relative frequencies per plot in order to be able to compare different geographical areas with different soils and tree species. Relative frequencies of critical limit exceedances were computed for each sampler (lysimeter) as the ratio of measurements that exceeded critical limits in all measurements over all available years. Using these samplerwise frequencies, a mean frequency for organic layer, mineral topsoil and mineral subsoil was computed for each plot. Plotwise frequencies for critical limit exceedances were classified into six groups.

For the evaluation of temporal trends samplerwise exceedance frequencies were aggregated to annual plot means for organic layer, mineral top- and subsoil layers. Pearson correlation coefficients of annual plot means with number of years from the beginning of the measurements were calculated. Time trends were only calculated for plots that had at least five years of continuous measurements. Temporal trends were regarded as significant for $r \geq 0.7$ and $p < 0.05$.

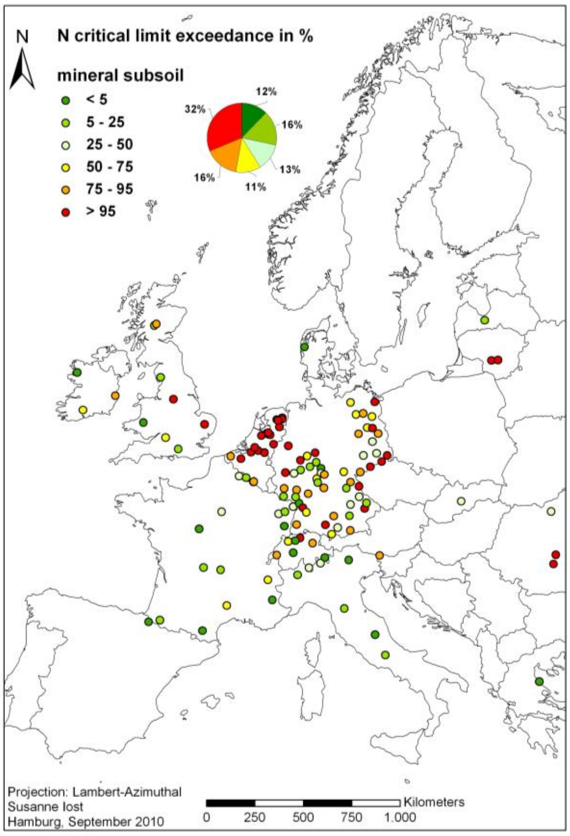
5.2.4. Results

After data quality checks measurements from 1491 samplers on 173 plots in 17 countries were available for the analysis of nitrogen concentrations. On 93% of the plots CLim for nutrient imbalances in the organic layer were exceeded in more than 50% of the measurements (Figure 5.2.4-1). For both, the mineral topsoil and mineral subsoil, such exceedances occurred on 59% of the plots. On 67% of the plots CLim for elevated N leaching in the organic layer were exceeded in more than 50% of the measurements. For the mineral topsoil and mineral subsoil such exceedances occurred on 38% and 37% of the plots respectively (Figure 5.2.4-2). The share of plots where CLimE for reduced fine root biomass (Figure 5.2.4-3) or enhanced sensitivity to frost and fungi (Figure 5.2.4-4) occurred in more than 50% of all measurements was 32% and 16% for organic layers, 16% and 8% for mineral topsoils and 18% and 15% for mineral subsoils.



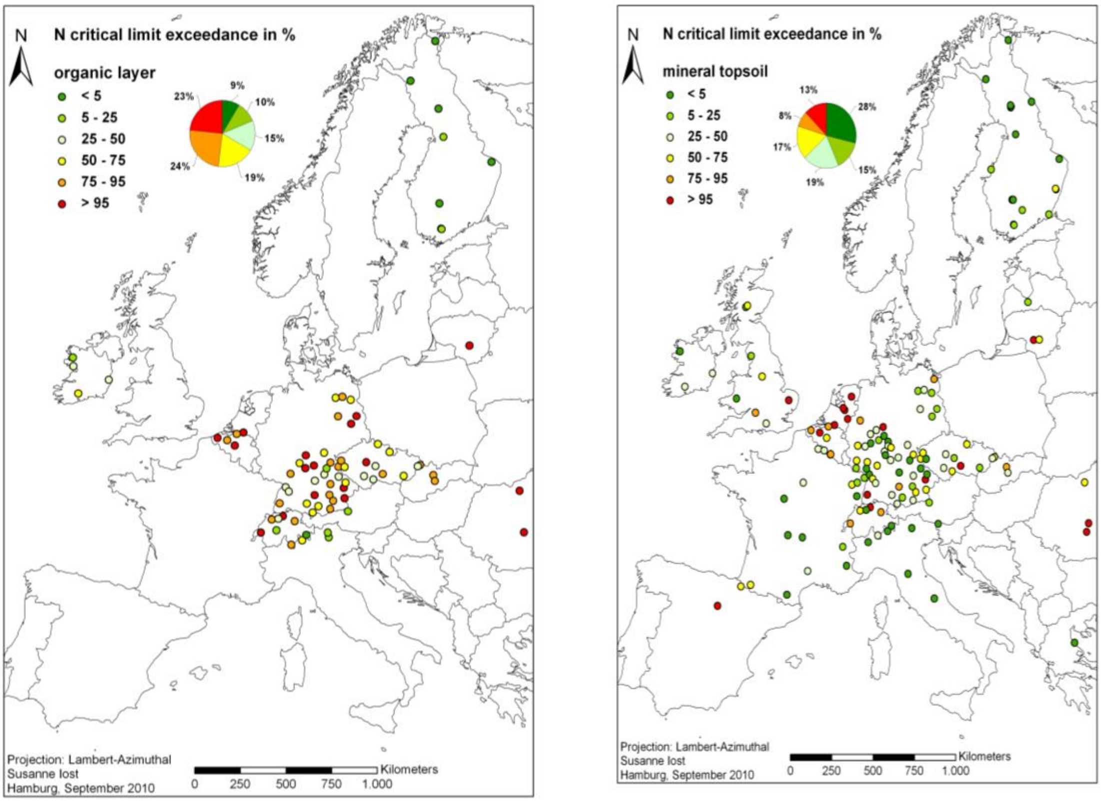
organic layers

mineral topsoils



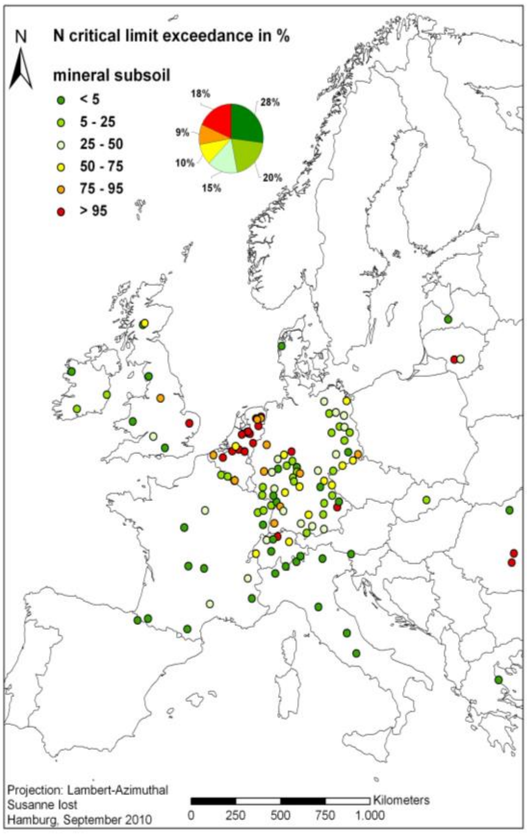
mineral subsoils

Figure 5.2.4-1: Frequency of N critical limit exceedances (CLimE) for nutrient imbalances in organic layers, mineral topsoils and mineral subsoils. Only plots with measurements in at least four consecutive years prior to 2006. Critical limits are >0.2 mgN/l for coniferous and >0.4 mgN/l for broadleaved forests. The colour of the plots display the proportion, e.g. <5% or ≥95%, of the measurements that have exceeded the CLimE (mean value per plot). The pie charts display the proportion of the plots that belong to the six categories



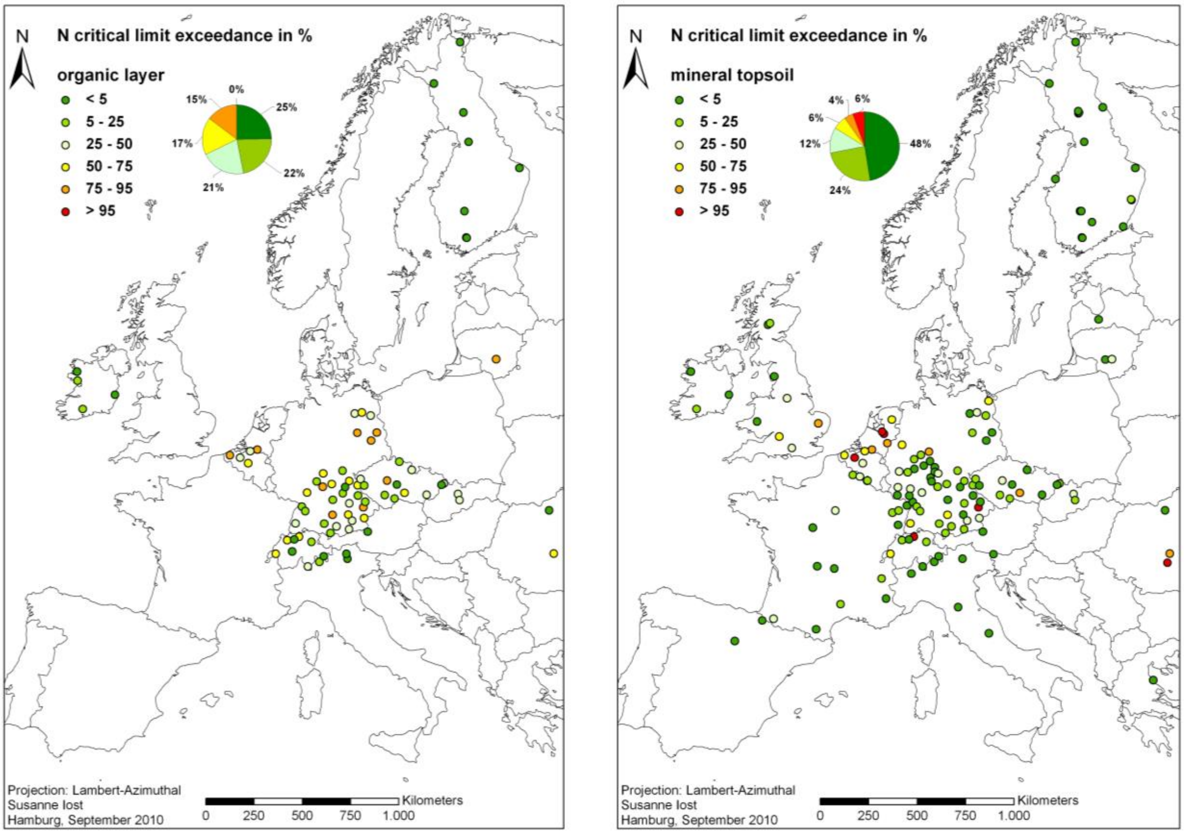
organic layers

mineral topsoils



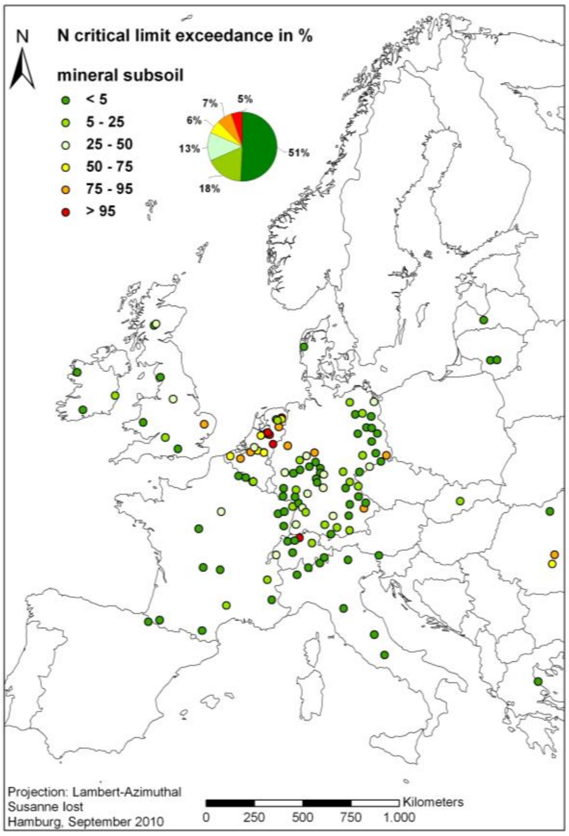
mineral subsoils

Figure 5.2.4-2: Frequency of N critical limit exceedances (CLimE) for N saturation / leaching in organic layers, mineral topsoils and mineral subsoils; Only plots with measurements in at least four consecutive years prior to 2006. The critical limit applied is >1 mgN/l; further details see Figure 4-1.



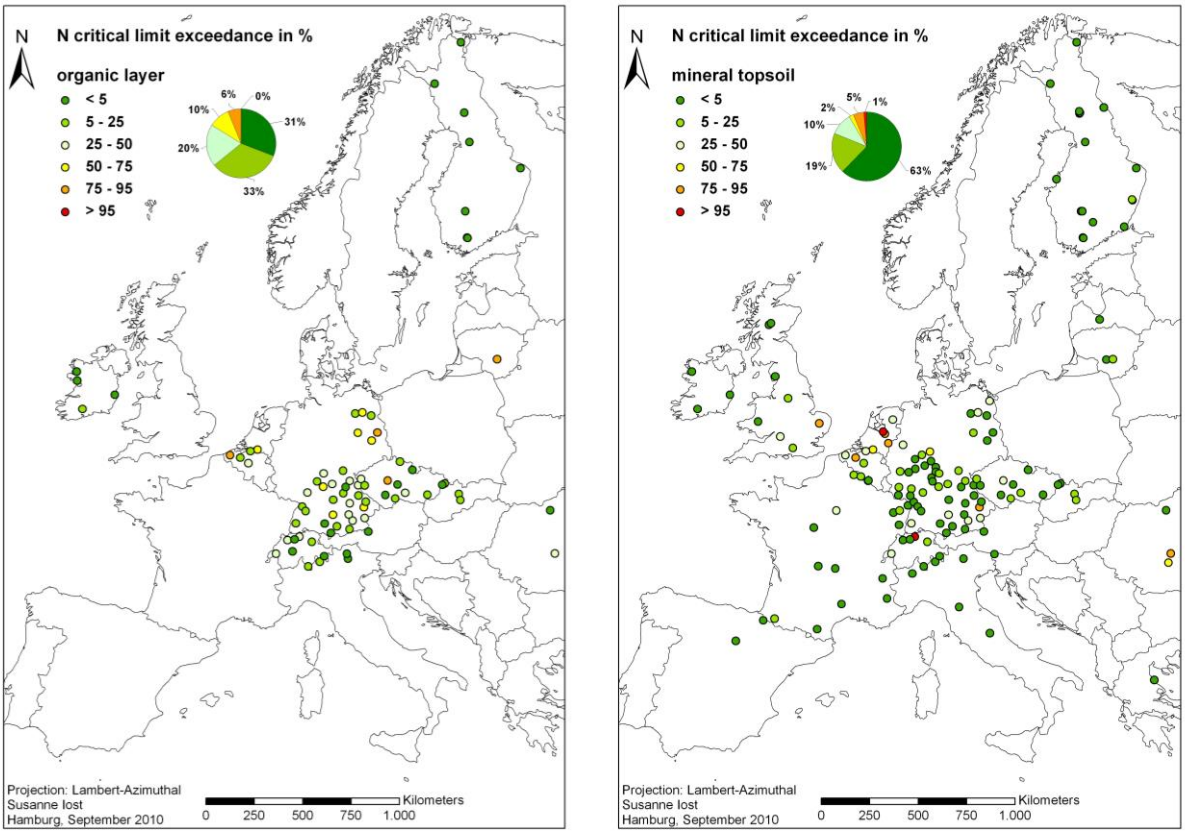
organic layers

mineral topsoils



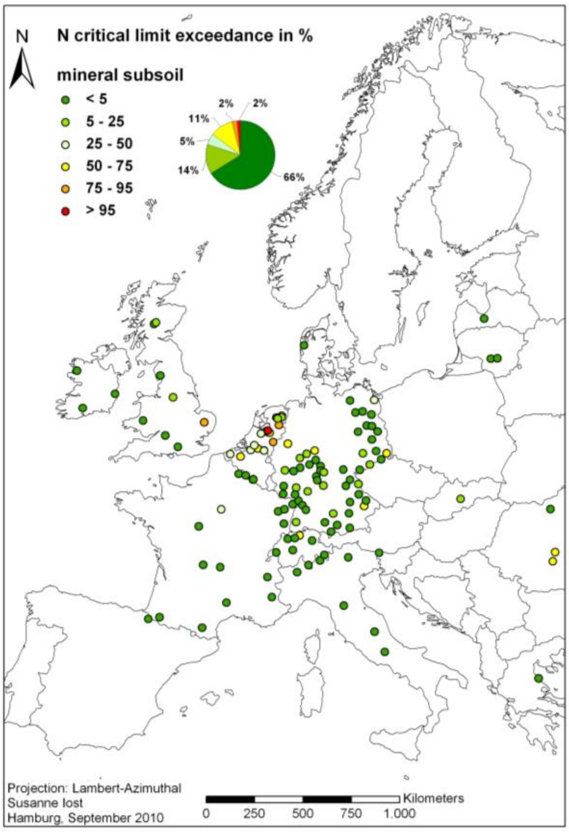
mineral subsoils

Figure 5.2.4-3: Frequency of N critical limit exceedances (CLimE) for reduced fine root growth in organic layers, mineral topsoils and mineral subsoils; Only plots with measurements in at least four consecutive years prior to 2006. The critical limit applied is > 3 mgN/l; further details see Figure 4-1.



organic layers

mineral topsoils



mineral subsoils

Frequency of N critical limit exceedances (CLimE) for enhanced sensitivity for frost and fungi in organic layers, mineral topsoils and mineral subsoils; The critical limit applied is > 5 mgN/l; further details see Figure 4-1.

Data from 140 plots were available for the calculation of time trends. In most of the plots there was no temporal trend in the CLimE for nitrogen. In cases where trends could be documented they were usually decreasing (Table 5.2.4-1).

Table 5.2.4-1: Temporal trends of Critical Limit Exceedances (CLimE) in different soil layers. The values indicate number of plots where strong ($r \geq 0.7$; $p < 0.05$) correlations between mean annual frequency of CLimE and time (years since the start of measurements) were detected. In case no trend was detected, in addition to the number of plots, also the number of plots where CLimE was never exceeded and where it was exceeded in every measurement is reported in brackets (X / X) (modified from Iost et al., 2011).

Layer	CLimE	Trend			Total no of of plots
		no trend	increase	decrease	
Organic	N > 0.2 / 0.4 mg l^{-1}	22 (0 / 5)	3	9	34
	N > 1 mg l^{-1}	12 (4 / 2)	6	16	
	N > 3 mg l^{-1}	19 (8 / 0)	2	13	
	N > 5 mg l^{-1}	20 (8 / 0)	5	9	
Mineral topsoil	N > 0.2 / 0.4 mg l^{-1}	33 (2 / 5)	6	26	65
	N > 1 mg l^{-1}	36 (5 / 1)	8	21	
	N > 3 mg l^{-1}	49 (21 / 0)	7	9	
	N > 5 mg l^{-1}	46 (29 / 0)	6	13	
Mineral subsoil	N > 0.2 / 0.4 mg l^{-1}	18 (3 / 6)	4	19	41
	N > 1 mg l^{-1}	24 (8 / 1)	3	14	
	N > 3 mg l^{-1}	23 (15 / 0)	6	12	
	N > 5 mg l^{-1}	28 (20 / 0)	5	8	

5.2.5. Discussion and conclusions

The present results show that the critical limits for nitrogen were constantly exceeded in major parts of Europe. On almost all the plots where data for the organic layer were available, the critical limit for nutrient imbalances in soil was exceeded in more than half of the measurements. And further, the exceedance of critical limits for nutrient imbalances was not restricted to organic layer, but was also seen in mineral soil layers. Even in the subsoil, nearly 60% of the plots exceeded this limit. However, if the critical limit for enhanced sensitivity to frost and fungi is regarded, only on a small proportion of the plots critical limits were exceeded. Elevated N concentrations in soil and soil solution can originate from deposition originating from anthropogenic sources (e.g. combustion of fossil fuels, fertilizers) or they are natural (Gundersen et al. 1998). It has been shown that N deposition has direct effects on N concentrations in soil solution (Mustajärvi et al. 2008). However, in this study the highest N concentrations were found in areas with the highest site fertility (C/N ratio). In the present study areas of high concentrations in soil solution often coincide with the areas that received high N deposition, for example during 2002-2004 (Lorenz et al. 2007).

The fact that on most of the plots no significant temporal change was seen, and that on the few plots where a trend was found this trend was decreasing, is in line with the deposition data reported by Fischer et al. (2010). They showed that in most parts of Europe there was no change in nitrate and ammonium deposition (bulk and throughfall) between 1998-2007. When a change was detected – as observed on less than one fifth of the intensive monitoring plots situated mainly in central-Europe - the change generally indicated a decreasing trend.

Results of VSD+ model applications (Chapt. 6) suggest that until 2050 eutrophic conditions, i.e. C:N ratios between 10 and 17, will dominate on the intensive monitoring plots studied. These results are not conflicting with the findings here. The critical loads for nitrogen are exceeded and the surplus of nitrogen will partly be stored in the soil. Also, Graf Pannatier et al. (2011) found no trend of inorganic N in the soil solution in most depths of Swiss long-term monitoring plots and concluded that soil solution reacts little to changes in atmospheric deposition. The absence of clearly decreasing trends in concentrations of inorganic nitrogen in soil solution and critical limit exceedances allows assuming continued critical limit exceedances at least with respect to nutrient imbalances possibly leading to further destabilisation of forest ecosystems. The continued exceedance of critical limits and related leaching of nitrogen implies a potential risk for future ground water quality.

In this study only inorganic forms or nitrogen (nitrate and ammonium) were used to calculate exceedances. In studies where a more specific fractioning of nitrogen forms in soil solution has been conducted it has been found that organic N is a considerable part of total N percolating through the soil (Mustajärvi et al. 2008). This is seen especially in the areas with relatively low N deposition. Because only inorganic forms of N were reported here, the present results might give a too optimistic picture on the status of critical nitrogen limit exceedances. Furthermore, N can accumulate especially in the organic layer from where it can, after certain threshold is reached or when site is prepared (e.g. soil scarification) after cutting, leach in accelerated rate to deeper soil layers.

The interpretation of the critical limit exceedances has in addition to take into account that the limits published in the UNECE manual were originally used to calculate the acceptable leaching of N below the root zone, thus their application to organic layers and mineral topsoils might yield a too negative picture for critical limit exceedances as in the rooting zone nitrogen uptake and nitrification occurs. The UNECE manual states that the low N critical limits may lead to critical loads that are lower than empirical data on vegetation changes.

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5.3. Exceedance of critical loads under different emission scenarios

Hans-Dieter Nagel[1], *Thomas Scheuschner*[1]

Abstract

For forest health and sustainable forest management the knowledge of stresses caused by atmospheric deposition is essential. Effect based thresholds are defined as critical loads and critical load exceedances indicate a risk of acidification and eutrophication. Applying this approach to about 4,600 forest monitoring sites the success of clean air policies is shown, starting in the 1980s with a clear reduction of sulphur emissions. For acidifying inputs the situation will considerably improve. In 2020, nearly all of the forest sites will be protected from acidification. For nitrogen inputs, however, the share of plots with exceedances decreased by 10% only between 1980 and 2000. The future scenarios show a further increase in the number of protected sites, but still would not protect all from risks through eutrophication. Studies including non-forest vegetation indicate that the total risk values are twice as high compared with risk for forest only. Dynamic modelling at forest monitoring plots allows taking into account the reaction and development of the system for the assessment of soil chemical changes over time. A summarizing, Europe wide interpretation for nearly 80 forest sites - each with specific conditions and soil reactions - is hardly possible. Thus, only basic and general trends can be discussed. An integrated interpretation of base saturation, pH and C:N ratio in soil solution shows (i) a decreasing C:N ratio is the dominant trend after about 1970; (ii) a full recovery of pH values to preindustrial times after 2010; (iii) a slight tendency towards low base saturation classes between 1960 and 2000, without a tendency of recovery after 2010. The intensive forest monitoring plots provide the basis for the risk assessment and for evaluating potential recovery of forest ecosystems under reduced atmospheric deposition and climate change. These future tasks require adaptation of forest management and nature conservation practices, continued observation of forest, monitoring and modelling.

5.3.1. Methods

Critical loads (CL) have been developed as a tool for determining the atmospheric deposition below which significant harmful effects do not occur under long term steady-state conditions. They are derived by combinations of chemical, physical, biological or geo-scientific indicators. While they reflect the state of present knowledge, they are subject to revision as science further develops. According to the general definition of critical loads as ecologically based environmental objectives for airborne pollutants, the magnitude of the critical load value should only be depending on the characteristics of the regarded ecosystems. Changes in the forest ecosystems which are due to pollutant deposition can be identified using parameters of the chemical composition of the soil solution. Significant damage can be expected to occur, when certain chemical parameters of the soil solution show a marked deviation from normal ranges. This will lead to destabilization of soil processes or to direct damage to the vegetation. The critical loads methodology is comprehensively described in the "Mapping Manual" of the ICP Modelling & Mapping, a revised version is presently elaborated (UBA 2004, ICP Modelling & Mapping 2010).

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Critical loads for acidification and eutrophication at Level I forest monitoring plots were calculated according to the Steady State Simple Mass Balance (SMB) method (ICP Modelling & Mapping 2010). The determination of critical loads for acidification requires the consideration of both sulphur and nitrogen deposition on the one side, and plant uptake, weathering, and biochemical immobilization processes on the other side. The deposition of acidifying sulphur and nitrogen exceeds a critical value if they alter the chemical characteristic of the soil solution. Indicators for the chemical characterization are aluminum concentration, base cations / aluminum ratio, pH value, base saturation of soils and acid neutralization capacity (ANC).

Applying the simple mass balance equations for the maximum critical load for sulphur-based acidity, $CL_{max}(S)$, and the maximum critical load for nitrogen-based acidity, $CL_{max}(N)$, thresholds for inputs of acidity were calculated.

The SMB approach for calculating critical loads for nutrient nitrogen assumes steady-state equilibrium of nitrogen input, acceptable storage and output. In this case, the nitrogen-fixing processes (immobilization, nitrogen uptake in the biomass) and nitrogen removal (denitrification, acceptable nitrogen leaching) should be in balance with the nitrogen deposition for steady-state conditions. With the mass balance equation the critical load for nutrient nitrogen, $CL_{nut}(N)$, were calculated. Taking into account the essential nutrient supply of nitrogen, $CL_{min}(N)$, a Critical Load Function (CLF) outlines the environmentally safe area. The CLF is a three-node line graph representing the acidity critical loads, and a four-node graph taking into account the effects of eutrophication as well. The intercepts of the CLF on the sulphur and nitrogen axes define the sulphur and nitrogen critical load values. (

Figure **5.3.**).

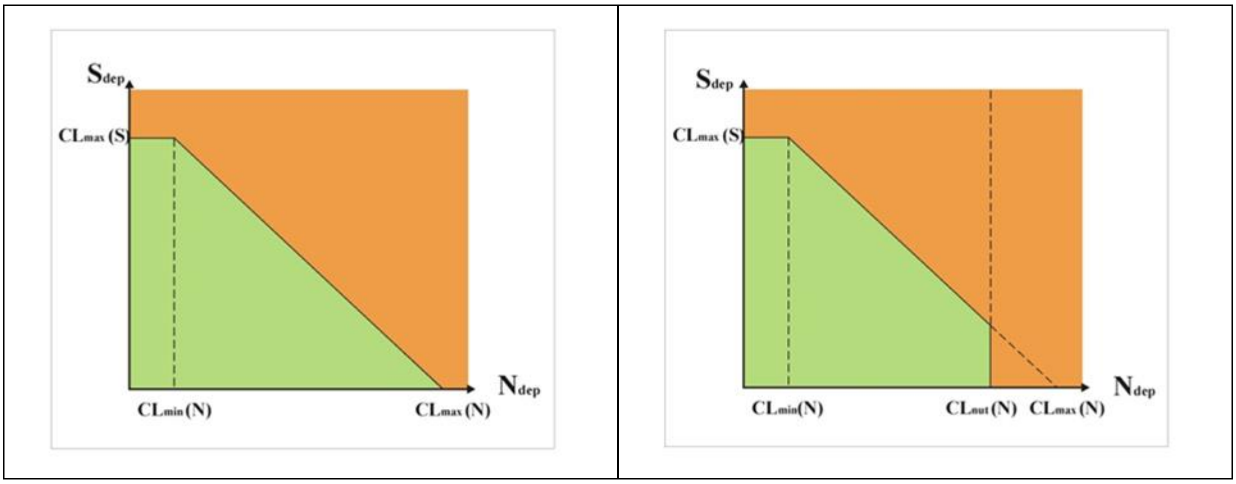

Figure 5.3.1-1: Critical load function (CLF) for acidification (left) and effects of acidification and eutrophication (right)

The amount of deposition above the critical load function is called the exceedance and the required reduction to reach ecosystem protection can be calculated for both, sulphur and nitrogen. Critical load exceedances were calculated by a comparison of critical loads with different deposition scenarios for a given year. The total sulphur and nitrogen deposition values were available for the 50x50km^2 grid cells of the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) and following scenarios were used:

EMEP1980 – deposition values of the year 1980 provided by EMEP[1];
NAT2000 – deposition values of the year 2000 derived from national projections;
COB2020 – deposition of the Cost Optimized Baseline scenario, former named as Current LEgislation (CLE) scenario;
Low*2020 / Mid*2020 / High*2020 – deposition of 3 scenarios with a different ambition level of emission reduction, e.g. a high ambition level of emission control means low values of deposition;
MFR – deposition assuming the Maximum (technically) Feasible Reduction of air pollutants emission.

All scenarios for the year 2020 and the MFR scenario are developed by the EMEP Centre for Integrated Assessment Modelling (CIAM) at the International Institute for Applied Systems Analysis (IIASA)[2] and provided by the Coordination Centre for Effects (CCE)[3] of the ICP Modelling & Mapping.

An assumption for critical load calculation according to the mass balance method is a long-term equilibrium (steady state), without any of the time-dependent and process-based dynamics. Therefore, internationally a number of dynamic models have been developed to enable a more accurate reflection of historical trends and predictions about the continued threat or a future recovery of ecosystems. Associated with the “call for data” the European Coordination Centre for Effects (CCE) provided the geochemical dynamic model VSD (2007 - 2009) and VSD+ (from 2010). The VSD model (Very Simple Dynamic Model) is a simple extension of the steady-state SMB model into a dynamic soil model by including cation exchange (Gaines-Thomas or Gapon) and time-dependent N immobilization (Posch M, Reinds GJ, 2009). It is confined to a few key processes in the ecosystem. The VSD model consists of a number of mass balance equations that describe the conditions of material inputs into the soil and to the soil solution. The soil solution chemistry depends on the net inputs from the atmosphere and the geochemical reactions in the soil (CO_2 balance, silicate and carbonate weathering, cation exchange). The interactions in the soil are modelled with mass-dependent processes such as plant uptake, weathering or by equilibrium reactions (e.g. cation exchange). The exchange of Al, H, Bc (Ca + Mg + K) is described by Gaines-Thomas or Gapon equations. Since 2010, with the extended model VSD+ (Bonten L, Posch M, Reinds GJ, 2011), the nitrogen and carbon transformation processes are considered. The model calculates the time steps of one year; seasonal fluctuations are not taken into account. The VSD+ model is based on a range of parameters, some are mandatory and others with proposed default values. Some parameters can be calibrated with an internal Bayesian Calibration if measured values are available. The VSD+ model is documented in the VSD+ manual published and distributed by the CCE[4].

The dynamic modelling requires data sets on major compartments of forest ecosystems. Such data were taken from the ICP Forests and FutMon data base as well as from the BioSoil+ data base (Table 5.3.1-2).

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[1] http://webdab.emep.int/Unified_Model_Results/

[2] http://gains.iiasa.ac.at/images/stories/reports/CIAM/CIAM2011-4-v1.pdf.

[3] http://www.rivm.nl/thema/en/themasites/cce/index.html

[4] http://www.rivm.nl/en/themasites/cce/methods_and_models/vsd-model/index.html

Table 5.3.1-2: Data availability for critical load computation and dynamic modelling

Type of data	Source of data	Number of plots
Soil survey	BioSoil+	114
Soil solution measurements	ICP Forests	298
Vegetation survey	ICP Forests	935
Litterfall	ICP Forests	211
Deposition measurements	ICP Forests	423
Modelled deposition	EMEP / CCE	whole Europe

Data preparation took as well into account vegetation data as a basis for subsequent modelling of vegetation species composition with the BERN model (Chapter 6). The data processing chain Figure 5.3.1-2 shows a continuous decrease in plot numbers when additional surveys were subsequently added in order to filter the data base for plots with complete data sets. Therefore a permanent task is tackling data gaps and in future the repetition of this study with a larger number of plots.

After screening and exploiting the ICP Forests and FutMon data base, 77 Level II plots in 17 countries were available for dynamic modelling (VSD+). As minimum input a comprehensive set of mostly mandatory data in the above mentioned surveys according the ICP Forests monitoring manual (ICP Forests 2010) is required. From the soil data all layers per plot were aggregated as VSD+ is a single soil layer model. Thus the soil thickness in the evaluation depends on the measurement depths of each single plot. 21 Level II plots were used to combine dynamic modelling results with the biodiversity model BERN (Chapter 6).

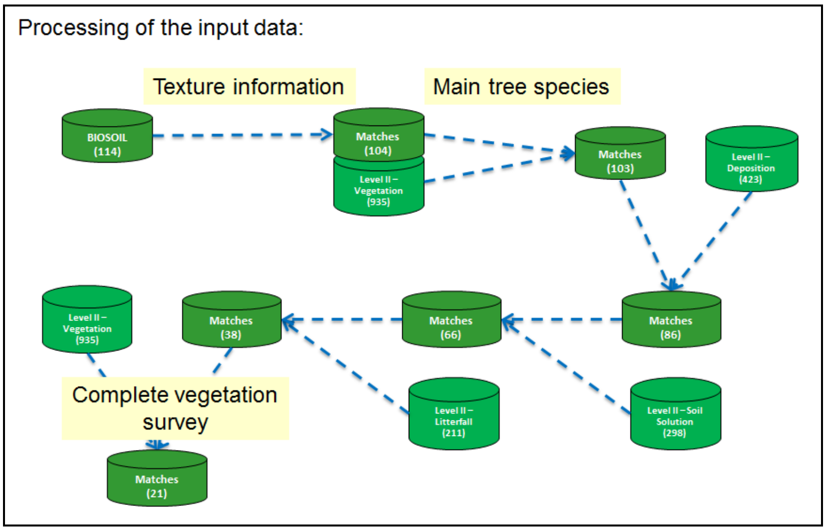


Figure 5.3.1-2: Flowchart of data processing chain

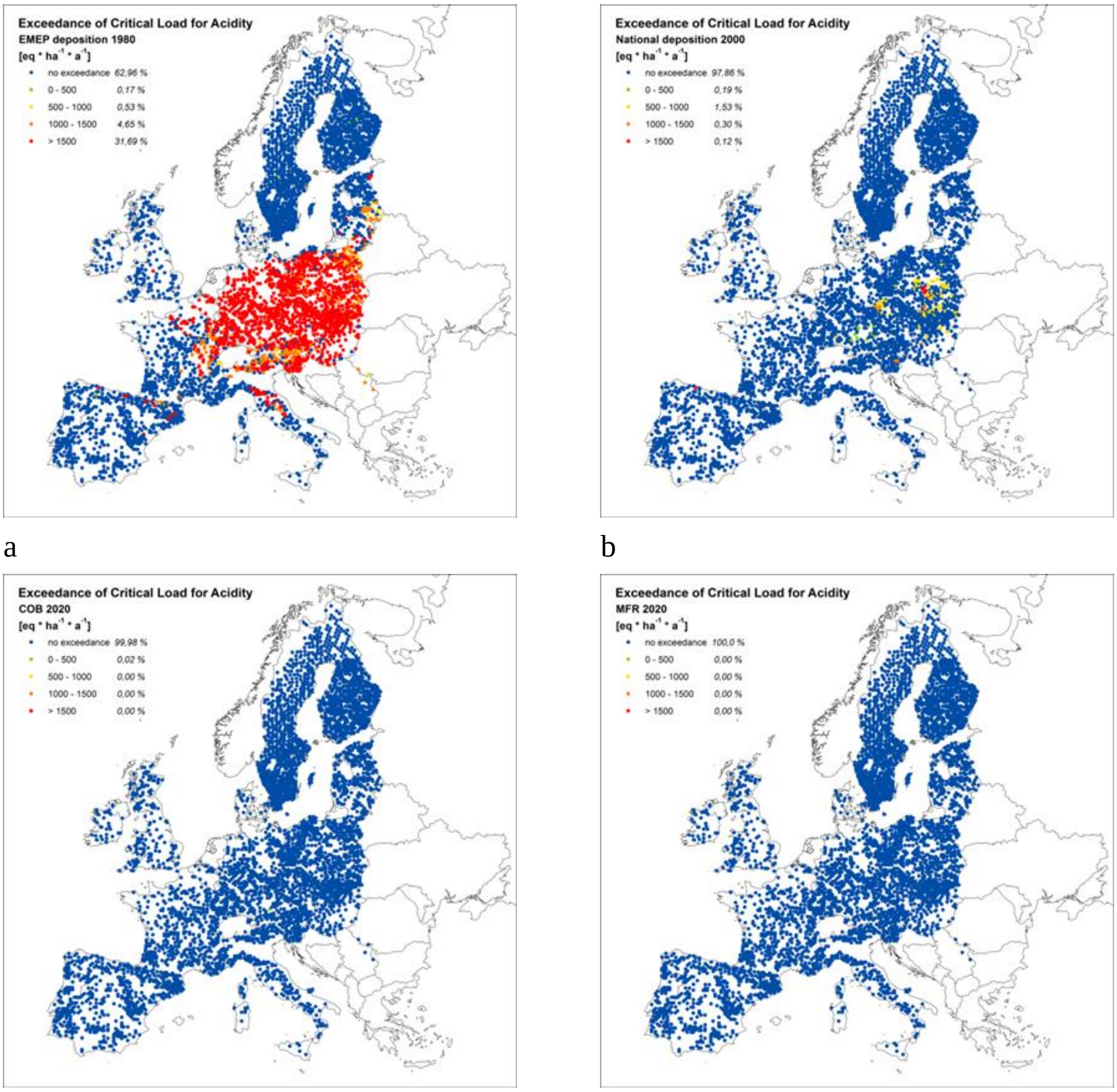
The outcome of this modelling relies on the models itself, but also on the accuracy, time consistency and continuity of the input data. Improvements in the database and the continuation of the measurements are essential for improving the output of advanced modelling.

5.3.2. Results

The comparison of present critical loads for acidity at Level I plots with modelled past sulphur and acidifying nitrogen deposition in 1980 (Figure 5.3.2-1a) shows exceedances mainly on plots in central Europe. The threat of acidification was widespread in the year 1980 and demonstrates potential for severe effects of air pollution in the central of Europe in the past. About 30% of the plots showed very high exceedances of the critical loads with more than 1500 eq ha^{-}1 a^{-1}. The situation improved considerably until 2000 when more than 97% of the Level I plots had no exceedances (Figure 5.3.2-1b). A continued positive future projection is clearly visible under all scenarios for 2020 (Figure 5.3.2-1c and d). Already the COB2020 scenario results in reducing the risk of acidification nearly complete (Table 5.3.3-1).

Table 5.3.2-1: Exceedances of critical loads for acidity at Level I sites

Forest Level I sites	EMEP 1980	NAT 2000	COB 2020	Low* 2020	Mid* 2020	High* 2020	MFR
No exceedances	62,96	97,86	99,98	100,00	100,00	100,00	100,00
>0 – 500	0,17	0,19	0,02				
>500 – 1000	0,53	1,53	0,00				
>1000 – 1500	4,65	0,30	0,00				
>1500	31,69	0,12	0,00				



a

b

c

d

Figure 5.3.2-1: Exceedances of critical loads for acidity at Level I plots by the acid deposition resulting from the scenario a) EMEP1980, b) NAT2000, c) COB2020, d) MFR. - Results are calculated for the plots and not to be confused with the area related maps calculated by ICP Modelling and Mapping.

Comparable to the recovery of forest ecosystems from acidification stresses a decrease of area at risk is expected for non-forest vegetation as well. Taking into account all types of ecosystem also a very small amount of 1% to 6% is expected to be at risk of acidification in 2020 (ECE 2011, Table 5.3.2-2).

Table 5.3.2-2: Area at risk of acidification in 2020 under different deposition scenarios

	COB2020	Low*2020	Mid*2020	High*2020	MFR
Forest Level I sites	< 1	0	0	0	0
All ecosystems, EMEP area	3	3	2	2	1
All ecosystems, EU 27	6	5	4	3	3

In 1980 the critical loads for nutrient nitrogen were exceeded on almost half of the Level I plots (Figure 5.3.2-2a). The exceedance of the critical loads implies a high risk of eutrophication for the forest ecosystems. Even though the exceedances were mostly lower in 2000 (Figure 5.3.2-2b), the share of plots with exceedances decreased by 10% only over two decades. The future scenarios show similar results for the year 2020, i.e. a further increase of the protected sites to approximately 80% (COB2020) or 90% of the plots (High*2020). Maximum (technically) feasible reductions (MFR) will improve the situation with the best results, but still would not protect all sites from risks through eutrophication (Table 5.3.2-3).

Table 5.3.2-3: Exceedances of critical loads for nutrient nitrogen at Level I sites

Forest Level I sites	EMEP 1980	NAT 2000	COB 2020	Low* 2020	Mid* 2020	High* 2020	MFR
no exceedances	53,67	63,71	81,05	86,18	87,27	88,88	89,43
>0 – 500	21,03	27,36	17,72	13,31	12,29	10,70	10,15
>500 – 1000	15,96	8,15	0,96	0,45	0,38	0,38	0,38
>1000 – 1500	7,94	0,53	0,25	0,06	0,06	0,04	0,04
>1500	1,40	0,25	0,02	0,00	0,00	0,00	0,00

By comparison with the area at risk for eutrophication computed with all ecosystems, it is obvious that the forest is not the most sensitive receptor for nitrogen inputs. All scenarios for the year 2020 based on critical load exceedances for all ecological receptors indicate that the risk values are twice as high or higher compared with risk for only Forest Level I sites (ECE 2011, Table 5.3.2-4).

Table 5.3.2-4: Area at risk of eutrophication in 2020 under different deposition scenarios

	COB2020	Low*2020	Mid*2020	High*2020	MFR
Forest Level I sites	19	14	13	11	11
All ecosystems, EMEP area	37	32	28	25	21
All ecosystems, EU 27 area	58	52	46	42	36

However, it should be noted that the critical loads data on which these exceedance calculations are based, are derived from steady-state mass balance methods, which are used to define long-term critical loads for systems at steady-state. Therefore, exceedance is an indication of the potential for harmful effects to systems at steady-state. This means that current exceedance does not necessarily equate with damage. In addition, achievement of non-exceedance of critical loads does not mean the ecosystems have recovered. Chemical recovery will not necessarily be accompanied by biological recovery; and the timescales for both chemical and biological recovery could be very long, particularly for the most sensitive ecosystems.

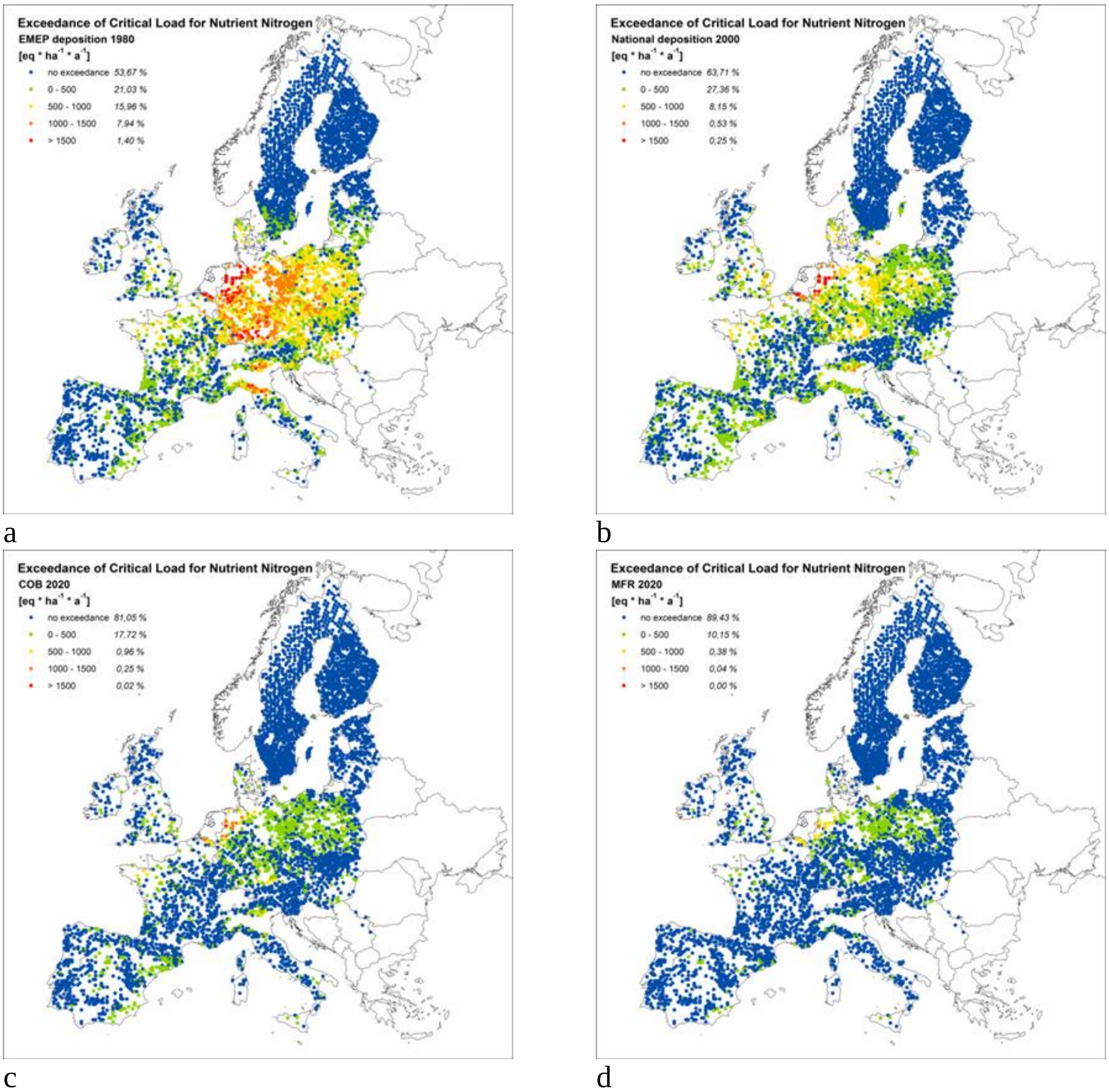


Figure 5.3.2-2: Exceedances of critical loads for nutrient nitrogen at Level I plots by the deposition resulting from the scenario a) EMEP1980, b) NAT2000, c) COB2020, d) MFR. – Results are calculated for the plots and not to be confused with the area related maps calculated by ICP Modelling and Mapping.

Single plot wise results from the dynamic modelling with VSD+ at Level II sites show time trends for major geochemical parameters like pH value, carbon pool, acid neutralization capacity (ANC), C:N ratio and base saturation (EBc) based on the underlying deposition scenarios. Deposition curves of site 40301 (Luess in Germany Figure 5.3.2-3), are typical for many central European sites with sulphur and NOx showing a peak between 1970 and 1980 and a decreasing trend starting 1990. Base cation deposition peaked slightly in 1980 and remains rather unchanged from the year 2000 onwards. The model output shows the response of soil and soil solution to deposition. Measurements of the C:N ratio and base saturation were used for model calibration so that the figures include the measured values as well.

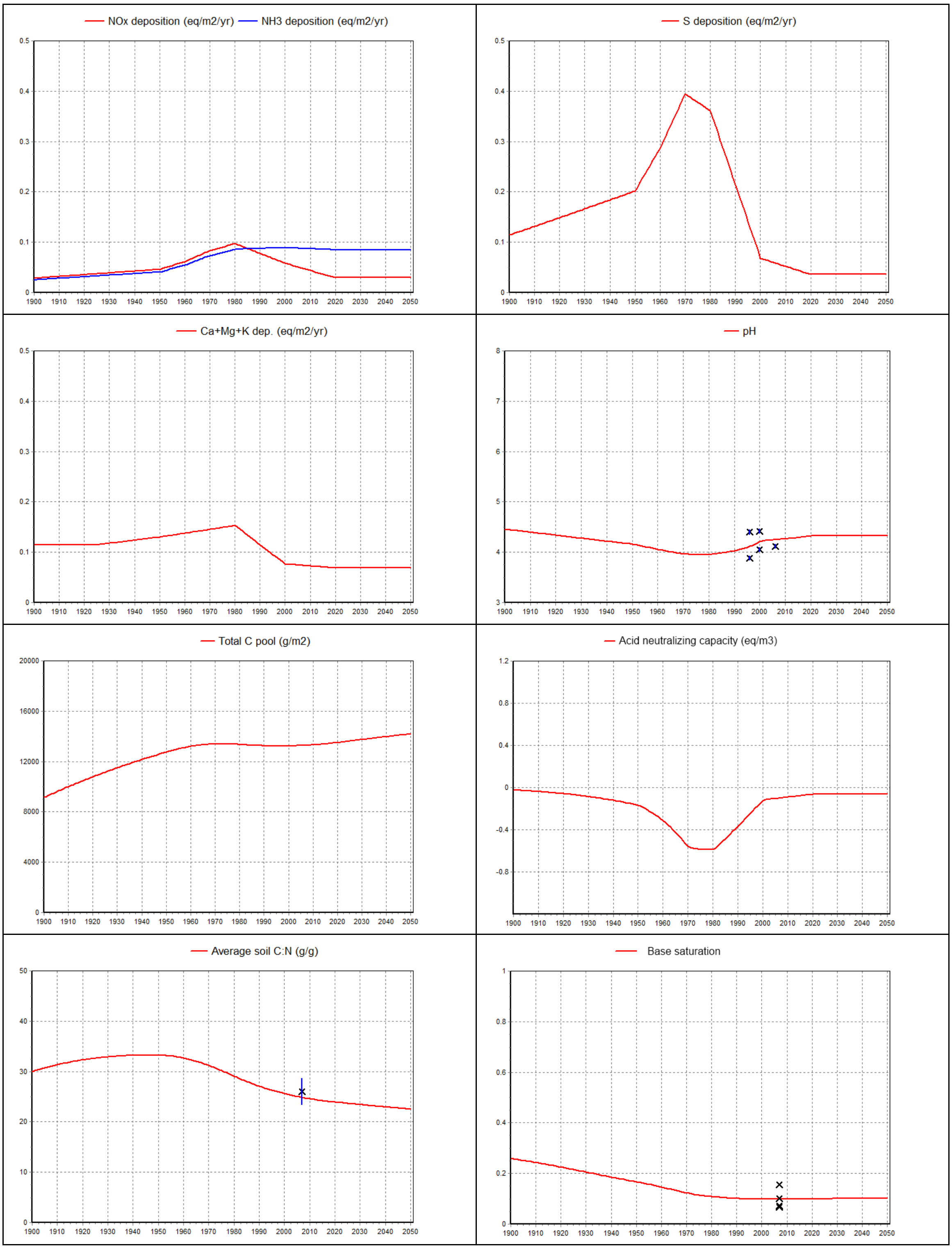


Figure 5.3.2-3: Dynamic change of geochemical parameters, modelled with VSD+ (red/blue lines) and measured / observed values (blue dots); example for Level II site 40301, Luess in Germany

At the selected 77 Level II plots the results of VSD+ calculations show the pH-value as an indicator of acid deposition. Modelled pH values (Figure 5.3.2-4) were grouped into ranges according to ULRICH (1981): 2,4 – 3,8 iron buffer range, 3,8 – 4,2 aluminium buffer range, 4,2 – 5,0 exchanger buffer range, 5,0 – 6,2 silicate buffer range, 6,2 – 8,6 carbonate buffer range. In all years the exchange buffer range dominates on most plots.

Major changes occurred between 1950 and 2000. These changes include an increase in the share of plots with extremely low pH values in the 1970s and 1980s and a recovery from 1990 onwards.

Most severe acidification was observed around the year 1980 suggesting a strong link with SO_2 emission peaks. Between the years 2000 and 2050 there is hardly any change visible on most of the plots. Results confirm that pH in soil solution is rather directly linked to increasing or decreasing acid deposition. Solid soil chemistry may react much slower and its recovery can take decades.

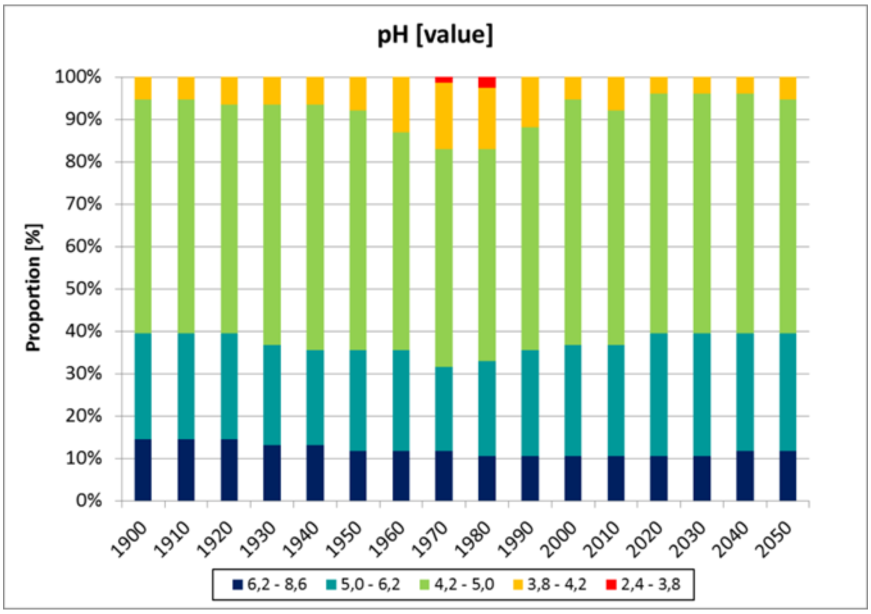


Figure 5.3.2-4: Overall trend modelled by VSD+ for pH values classified by buffering classes (ULRICH 1981)

The trend for base saturation Figure 5.3.2-5 is heterogeneous as the site conditions differ also. Nevertheless, a slight tendency towards low base saturation classes can be assumed. Statistical analysis of the model results suggests that most changes in base saturation occurred between 1960 and 2000 when acidification was most widespread. In this period, the share of plots with low base saturation, i.e. below 20%, doubled from 10% to 20% of the observed plots, at the expense of the share of plots with a base saturation between 20% and 40%. After 2010, the model predicts hardly any changes on more than 90% of the plots. Model runs over longer time periods reveal similar results. The spatial analysis shows a tendency towards low base saturation for plots in central and eastern / north-eastern Europe, the region where acidification had been most pronounced.

The carbon to nitrogen (C:N) ratio Figure 5.3.2-6 is an indicator for the nutrient status of the plots. Until 1970 a modelled increase in the share of nutrient poor plots (C:N > 24) is visible while the share of mesotrophic sites (C:N 18 – 24) decreases. The eutrophic plots (C:N 10 – 17) show an increasing trend since 1920. Starting in 1980, a clear trend towards more nutrient rich conditions is observed, indicated by shares of constantly increasing eutrophic and even hypertrophic plots. At the same time the share of plots with mesotrophic conditions shows no longer a clear trend but varies. The general increase in C:N ratios at the beginning of the observation period is attributed to a sharp increase in sulphur deposition at unchanged base cation and nitrogen supply. The resulting decrease in pH Figure 5.3.2-4 has probably led to reduced microbial activity in the soil and to an accumulation of carbon rich and slowly decomposing humus in the topsoil layer. But for several plots also another overlapping process needs to be considered. The fact that the supply with base cations in some regions was on a higher level at the beginning of the last century than today while simultaneously the nitrogen input was much lower might have led to a depletion of nutrient nitrogen. The increased nitrogen deposition starting in the middle of the 20th century put an end to nitrogen shortage and the reduced acidification at the end of the last century led to decomposition of previously accumulated organic matter. Decreasing C:N ratios clearly indicate the changed nutrient supply. Eutrophic conditions that are prevailing at the end of the observation period bear risks for the water filtering function of forest soils, may lead to shifts in species composition and are an indicator for nutrient imbalances that may destabilize forest ecosystems.

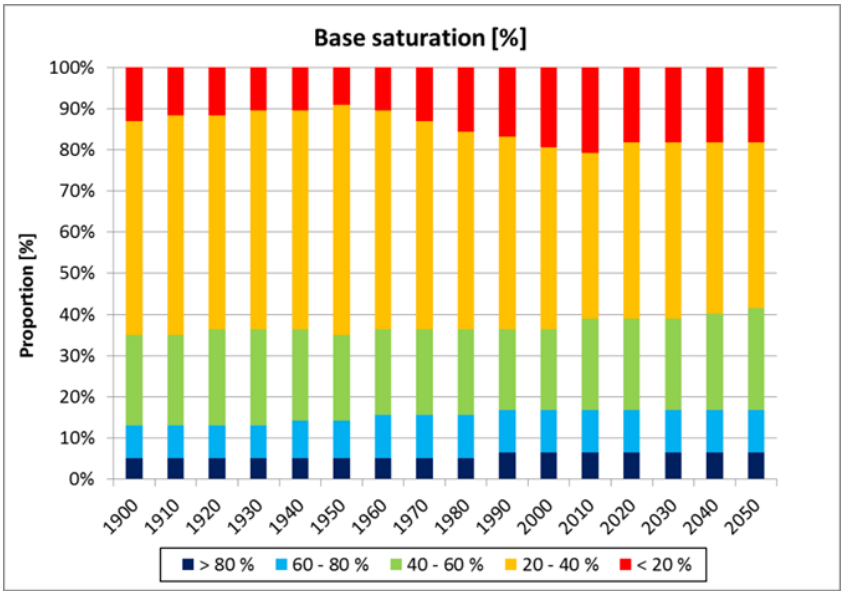


Figure 5.3.2-5: Overall trend modelled by VSD+ for base saturation classes

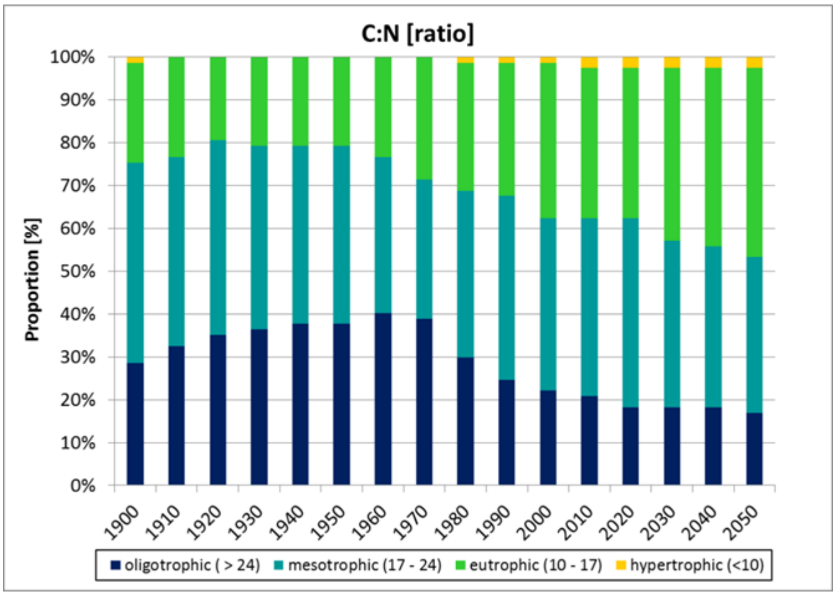


Figure 5.3.2-6: Overall trend modelled by VSD+ for C:N ratio, classified by nutrient levels

Of course from dynamic model results only trends of development and not locally reliable predictions can be derived. But dynamic models offer insight into the general development of soil and soil solution chemistry which is dynamically reacting to changed deposition inputs. Therefore the results offer important decision support in the field of environmental protection and for evaluating measures of clean air policies.

5.3.3. Conclusions

The widespread and clear reduction of sulphur deposition starting in the 1980s shows the success of the clean air policies under the UNECE and the EU. For nitrogen inputs, however, the monitoring data (Chapter 4) and model values reveal less change. By relating past, present and future deposition scenarios to present stand and soil condition, critical load exceedances offer an important tool to assess deposition effects and their potential for damage to forest ecosystems. Results suggest that for acidifying inputs the situation will considerably improve: in 2020, nearly all of the forested sites will be protected from acidifying inputs. But even assuming full implementation of national legislation (COB2020) approximately 20% of the forest sites will still receive eutrophying nitrogen inputs above the critical loads according to the models. Studies including non-forest vegetation also indicate that the total risk values are twice as high or higher compared with risk for Forest Level I sites only.

The VSD+ model allows for the assessment of soil chemical changes over time taking into account the reaction and development of the system. A summarizing, Europewide interpretation for nearly 80 forest sites - each with specific conditions and soil reactions - is hardly possible. Thus, only basic and general trends can be discussed. An integrated interpretation of base saturation, pH and C:N ratio in soil solution shows:

A decreasing C:N ratio is the dominant trend after about 1970. Such a decrease occurs on half of the plots; a full recovery of pH values to preindustrial times after 2010; a slight tendency towards low base saturation classes between 1960 and 2000. After 2010, the model predicts hardly any changes on more than 90% of the plots.

Previous soil acidification is still a burden to forest soils. Soil solution pH shows an astonishingly quick recovery. A comparison with measured data shows that critical limits for soil acidification are still exceeded on around half of the ICP Forests samplers (FISCHER et al. 2010) and the measurement periods available are not long enough to confirm the modelled recovery. In contrast to soil solution the recovery of soil solid phase takes decades. The comparison of soil solid phase pH on over 2000 Level I plots between a first survey end of the 1990s and a second survey in the years 2004 to 2008 even showed further decrease of the pH on plots with pH above 4.0 and significant recovery only on the strongly acidified soils with pH below 4.0 (De VOS and COOLS 2011). In addition, emissions of nitrogen compounds from traffic, industry and households affect the forests. The ammonia depositions, especially in regions with intensive husbandry, indicate the need for further emission reductions. Current national legislation should be amended taking into account higher technically feasible reductions.

The intensive forest monitoring plots provide the basis for the risk assessment and for evaluating potential recovery of forest ecosystems under reduced atmospheric deposition. Critical loads of acidity and nutrient nitrogen as well as assessments of their exceedances contribute to the scientific basis for UNECE and EU air pollution prevention policy. Together with results of dynamic modelling they support optimized control strategies in the ongoing review of the Gothenburg Protocol. The long-term intensive monitoring data of ICP Forests also enable the derivation of trends in soil condition. This information is used to validate recovery effects predicted by dynamic models. The effects on forest vitality and biodiversity reveal a considerable delay after changes of soil conditions which also occur with some delay after the impact of atmospheric pollution. Influences of climate change might become more important in the future. This all requires adaptation of forest management and nature conservation practices, continued observation of forest, monitoring and modelling.

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6. Climate change, air pollution, and impact on biodiversity

6.1. Linking climate model result to Level II plots

Konstantin Olschofsky[1]

Abstract

Methodology for linking global climate scenario simulations to Level II plots as basis for modeling studies under consideration of metrological plot measurements and other measured meteorological auxiliary data.

6.1.1. Introduction

The discussion on climate change led to the calculation of a number of climate scenarios (IPCC, 2000). In order to allow for the calculation of forest models based on FutMon data it is necessary to link the climate scenario data to the Level II plots. Two dimensional or three dimensional interpolations of the coarse global climate scenario data led to a reduction of variance. Hence, the linkage of the climate scenario data is based on a calibration with the measured meteorological data from the Level II plots in terms of a bias correction. In case of missing or incomplete measured FutMon data additional data from the CRU database were applied.

Modeling of weather dependent forest parameters, e.g. growth or water budget, requires meteorological data in high temporal resolution. The FutMon study “Modeling of the Carbon Budget of Forests on Level II Plots with Biome-BGC” („Chapter 7.3 of the present report“) and the modeling of critical loads for future climate scenarios required the regionalization of those high resolution meteorological scenario data for a period from 1990 to 2100.

The implemented method for linking the global climate scenario data to the Level II plots on basis of measured meteorological data is described in this section.

6.1.2. Applied Data

The SRES climate scenario data B1 and A1B were calculated with the climate model ECHAM 5 (MPI 2003, 2004) and were regionalized with a climate local model (CLM) for Europe (M & D 2008). In addition measurement data from Level II and from the CRU data base which are used for the calibration of the scenario data are described in this section.

SRES Scenarios:

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IPCC defined scenarios of potential economic and social global development in the Special Report on Emission Scenarios (SRES, IPCC 2000):
"The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income"(IPCC 2000). The A1B Scenario assumes technological emphasis balanced between fossil and non-fossil energy sources. Various computer climate models projected for the period 2090 to 2099 an increase of temperature by 2.8°C (varying between 1.7°C and 4.4°C) compared to the period 1980 to1999 (IPCC 2007).

"The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives." (IPCC 2000) Various computer climate models projected for the period 2090 to 2099 an increase of temperature by 1.8°C (varying between 1.1°C and 2.9°C) compared to the period 1980 to1999 (IPCC 2007).

6.1.3. Climate model echam

ECHAM is a Global Climate Model developed by the Max Planck Institute for Meteorology. It was created by modifying global forecast models developed by ECMWF to be used for climate research and has spatial ground resolution of 3°. Detailed description can be found in MPI Report No. 349: The atmospheric general circulation model ECHAM5, Part I: Model description (MPI 2003) and MPI Report No. 354: The atmospheric general circulation model ECHAM5 Part II: Sensitivity of simulated climate to horizontal and vertical resolution (MPI 2004).

The results of the global ECHAM5 mode run l for the IPCC A1B and B1 scenarios as well as the reconstruction of the last four decades of the 20th century are dynamically scaled down to grid cell size of about 18×18 km2 by the climatic local model CLM (M & D 2008) .

6.1.4. Level II Meteo data

The measurements of meteorological data on Level II plots mainly started between 1994 and 1996. The latest data of the Level II data base used here were measured in 2009/2010. For some plots longer time series from former projects exist. The Level II data base contains measured meteorological parameters from the open field at sites close to the forest area, from tower measurements above the canopy, or from a nearby weather station.

6.1.5. CRU data

The Climate research unit of East Anglia (CRU) collects meteorological observations worldwide and derives gridded data sets. For the calibration monthly mean temperature and precipitation sum with 0.5º latitude by 0.5º longitude resolution are used. Further details about this data can be found in a Tyndall Centre Technical report (Tyndall 2004).

6.1.6. Methodology for plot wise calibration

The linkage of coarse climate A1B and B1 (SRES) scenario data to Level II plots has to be done. The process of calibration consists of linking scenario data to a plot coordinate, bias correction of temperature and adjustment of precipitation patterns.

For each plot the data in a surrounding area of a 30 km buffer zone are extracted from the ECHAM5 CLM dataset. From these scenario data the area weighted daily mean temperature and daily precipitation is calculated. For the bias correction the monthly mean temperature from the scenario data set is calculated and is compared to the observed monthly mean temperature from the Level II database or CRU database in case of data lags. The process of area weighted averaging leads to flattened precipitation distribution compared to the observation. Therefore the plot specific observed frequency and distribution of monthly precipitation is extracted and used for calibration of the modeling results.

6.1.7. Results and Examples

By means of the described method coarse climate models were linked to 190 Level II plots, which are used within the FutMon project for modeling studies („Chapter 7.3 of the present report“). One example of the calibration process is given in the following figure.

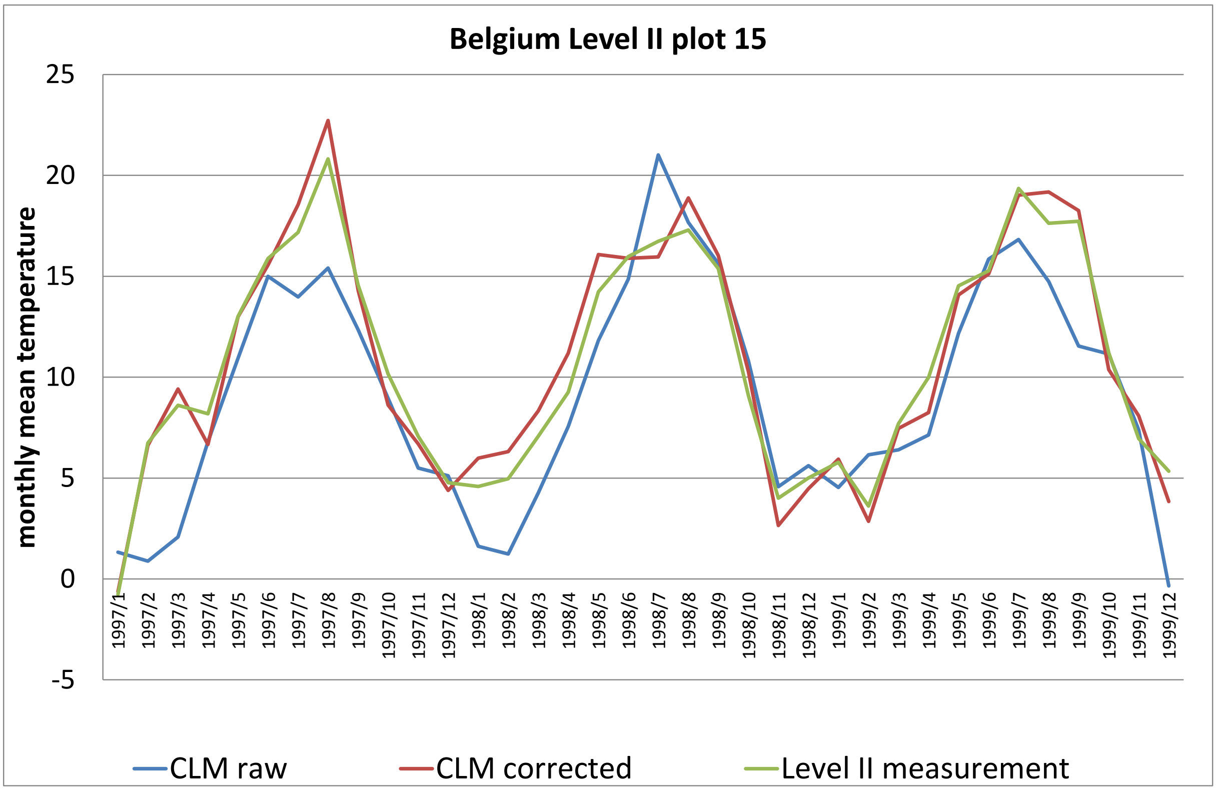

Figure 6.1.7-1: Calibration of mean monthly temperature of climate (CLM) to Level II plot observation for the Belgium Level II plot 15 over three years. CLM corrected shows the mean monthly temperature from the climate model after calibration.

6.1.8. References

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6.2. Epiphytic lichen diversity in relation to atmospheric deposition

Paolo Giordani [1], Vicent Calatayud [2], Silvia Stofer [3], Oliver Granke [4]

Abstract

Epiphytic lichens are among the most sensitive bioindicators for different environmental stress factors including nitrogen deposition. On 80 % of the plots assessed during the ForestBiota test-phase, lichen species composition indicates unsustainably high nitrogen deposition. The sample dimension (12 tree per plot) recommended in the protocol used during the survey is adequate to ensure a robust estimation of the lichen diversity.

6.2.1. Introduction

Lichens have been considered to be among the most sensitive groups of organisms at the ecosystem level for several types of pollutants (Nimis et al., 2002). They have been recently used for revising the critical levels for NH_3 in sensitive ecosystems (e.g. Geiser et al., 2010) and they have also been used for defining critical loads (e.g. for forest habitats) under the Air Quality Directive and UNECE/CLRTAP. Besides their use for evaluating effects in sensitive ecosystems, they can be used in other ecosystems as early-warning indicators since they are most likely the first species group to react. In this chapter, the question of the minimum number of trees that should be used in lichen diversity surveys at a large scale in different types of forest is tackled, and the possible relations of lichen functional groups with different levels of nitrogen deposition are explored. The results of this study will improve the knowledge on the effects of N on lichens for contributing to Critical Levels, Critical Loads and Critical Limits in different forest ecosystems throughout Europe.

6.2.2. Methods and data

The evaluations here are based on a dataset of 292 epiphytic lichen species determined on 1155 trees at 83 Level II plots. The data were collected between 2004 and 2006 in ten countries according to the ForestBIOTA sampling protocol (Stofer et al. 2003).

6.2.2.1. Nitrogen deposition and lichen functional groups

142 species corresponding to 49 % of all species determined were classified as oligotrophic. 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 (Nimis and Martellos 2008). 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 methodology for the calculation of mean deposition follows Fischer et al. (2010).

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6.2.2.2. Lichen diversity

The minimum number of trees that have to be sampled in order to obtain reliable estimates of lichen diversity in terms of species number and species composition was evaluated using a Jackknife approach. Rarefaction curves were calculated to determine the increase in the number of species sampled when the number of studied trees per plot increased (i.e., subsamples of 1 to n-1 trees, species present in all the studied trees per plot = n trees). The first-order jackknife estimator was used for estimating species richness of an area subsampled with smaller sample units (Palmer 1990):

$$\text{Jackknife} = S + r1(n-1)/n$$

Where S = the observed number of species, r1 = the number of species occurring in one sample unit (tree in this case), and n = the number of sample units (trees).

6.2.3. Results: method development

An evaluation of the adequate number of trees to be sampled for obtaining reliable estimations of lichen diversity was carried out, in order to provide suggestions for increasing the cost-effectiveness of future sampling efforts and the overall quality of the results.

6.2.3.1. Representativeness of sampled trees

Jackknife analyses showed that a sample of 12 trees per plot is enough for ensuring a sufficient sampling effort/species catching ratio in the considered forest types in Europe. On average, such a sample allowed to catch 77% of the total number of species estimated by Jackknife. This percentage did not increase significantly by adding more trees (Figure. 6.2.3.1-1, left). Moreover the results were quite stable both considering conifer and broadleaved forests (Figure. 6.2.3.1-1, right) and no relevant differences have been observed between countries.

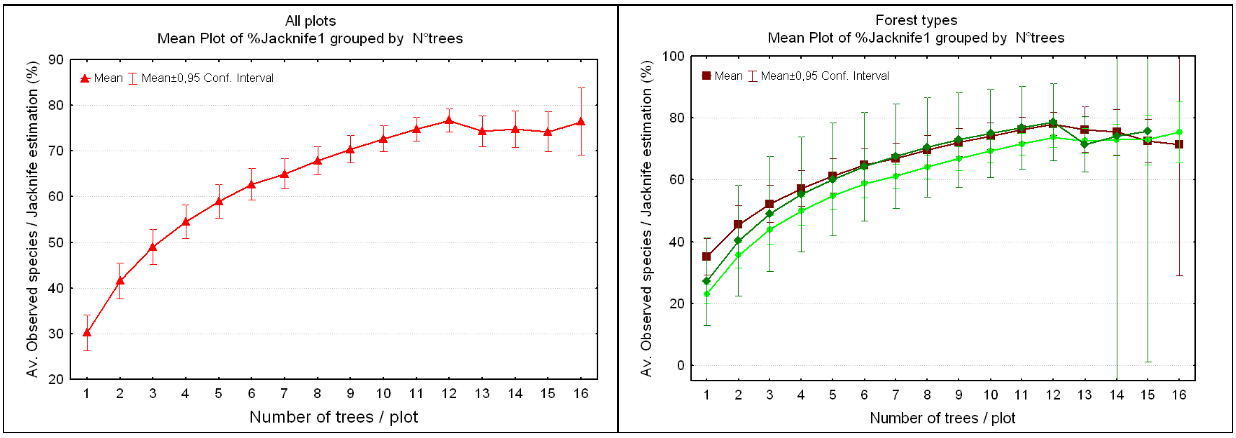

Figure 6.2.3-1-1: Trend of the observed/estimated species ratio, in relation with the number of the number of sampled trees in the plot; left: all 83 plots; right: disaggregated analysis per forest type (light green: deciduous broadleaves forests; dark green: evergreen broadleaves; brown: conifers).

6.2.4. Results: effects of nitrogen deposition

6.2.4.1 Relation between nitrogen deposition and % oligotrophic macrolichen species

A total of 292 epiphytic lichen species was determined on 1 155 trees of the ForestBIOTA plots. 142 species corresponding to a share of 49% from all determined species were classified as oligotrophic. A value of 40% of all lichens species on a plot being oligotrophs has been considered a critical threshold for nitrogen deposition (Geiser et al. 2010). When evaluating the percentage of oligotrophic macrolichens on the evaluated plots, a throughfall nitrogen deposition of ≈ 3.8 kg ha^{-1} yr^{-1} was related to the threshold of 40% oligotrophs (Figure 6.2.4.1-2). As expected, the effects of nitrogen compounds were closely related to the amount of throughfall precipitation (Figure 6-6.2.4.1-2). Although the correlation was always statistically significant, in drier plots a nitrogen deposition of > 9 kg ha^{-1} yr^{-1} led to a complete disappearance of oligotrophic species, whereas, given the same amount of nitrogen deposition, a modelled percentage of 20% oligotrophic species is still expected in plots with higher annual precipitation.

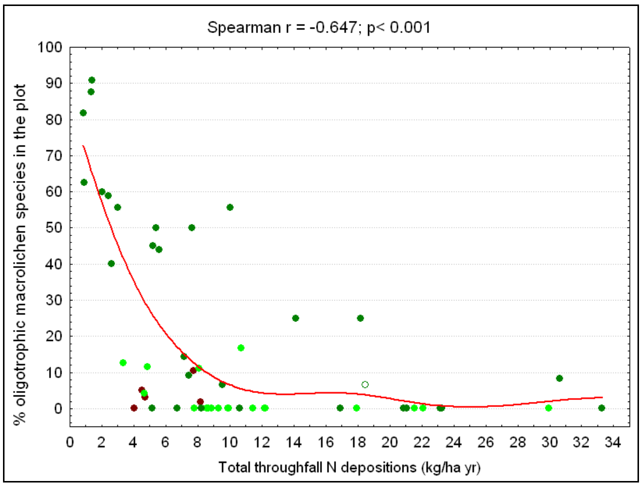

Figure 6.2.4.1-1: Biplot of the % oligotrophic macrolichens as a function of the total throughfall nitrogen deposition at plot level. The fitting line is a distance weighted least square function with stiffness = 0.25.

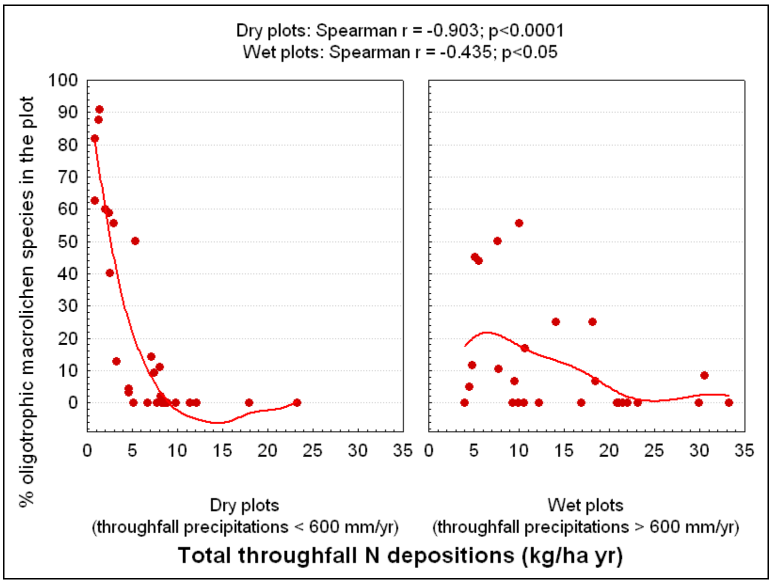

Figure 6.2.4.1-2: Percentage of oligotrophic macrolichens as a function of the total throughfall nitrogen deposition at plot level, I relation with the amount of precipitations. Left: dry plots; right: wet plots. The fitting line is a distance weighted least square function with stiffness = 0.25.

6.2.4.2 Mapping of the percentage of oligotrophic lichens

Based on the relative share of oligotrophic macrolichen species at plot level, it was shown that approx. 80% of the ForestBIOTA Level II plots are affected by an unsustainable throughfall nitrogen deposition (Figure. 6.2.4.2-1), that can be suspected to cause a significant change of the expected composition of epiphytic lichen vegetation, together with a significant decrease in total lichen diversity, as well. About 58% of the plots, mainly located in Germany and other central European countries, showed a very low occurrence or even a complete lack of oligotrophic lichen species.

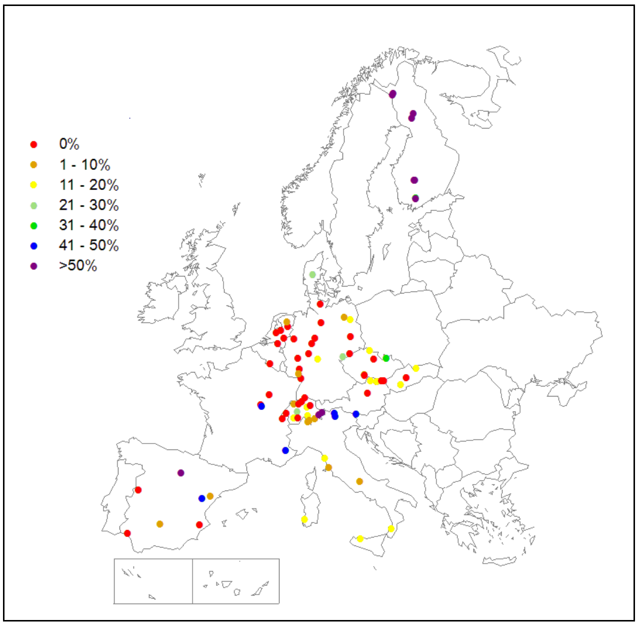

Figure 6.2.4.2-1: Percentage of oligotrophic macrolichens on the total number of species on selected ICP Forests Level II plots.

6.2.5 Conclusions

Based on the statistical analysis of the ForestBIOTA dataset, a number of conclusions for large-scale lichen biodiversity studies can be drawn as a basis for future lichen assessments on forest monitoring plots.

Jackknife analyses showed that the sample dimension (12 tree per plot) recommended in the protocol used during the survey is adequate to ensure a robust estimation of the lichen diversity.

For the determination of critical thresholds of nitrogen deposition and for the further use of epiphytic lichens as bioindicators the following conclusions are relevant:

- The occurrence of oligotrophic lichen species provided information on the actual impact of reduced nitrogen compounds (mainly ammonia). A percentage of 40% oligotrophs seemed to be related to throughfall nitrogen deposition of approx. 3.8 kg ha^{-1} yr^{-1}. The results for European ForestBiota Level II plots are in accordance with those in Pacific North West of USA.

- Based on these findings, the use of lichens as bioindicators is recommended for inclusion in the monitoring activities both on Level I and Level II plots, in order to quantify effects of nitrogen atmospheric deposition on sensitive forest ecosystems components even on plots without direct measurements of nitrogen deposition. Possible interactions between the effects of nitrogen on lichens and those caused by other pollutants and/or climatic factors have been mainly explored at local scale (e.g. Giordani 2006) and should be taken into account in forthcoming applications of this approach at European scale.

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6.3 Exceedance of critical limits and their impact on tree nutrition

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6.3.1 Introduction

The atmospheric deposition of sulphur (S) and nitrogen (N) compounds affects forest ecosystems through several processes. For N limited stands, enhanced N supply may stimulate the production of above-ground biomass. However, in excess, N loads may lead to nutrient imbalances and sensitivity to frost, insects, and fungi may increase (N saturation hypothesis, postulated by Aber et al., 1989). When N availability exceeds the capacity of the ecosystem to retain N, nitrate leaching from the rooting zone is enhanced. The release of acid anions such as nitrate (NO_3^-) and sulphate (SO_4^{--}), balanced by base cation leaching, may contribute to the acification of soils and surface waters (acidifcation hypothesis, postulated by Aber et al., 1989). In acid soils, aluminium (Al) can be mobilized from the soil complex and have adverse effects on fine roots. Both, loss of base cations and the toxic effect of aluminium may further contribute to an unbalanced mineral nutrition of the trees.

The long-term effects of atmospheric deposition on ecosystems can be assessed using the concept of "critical loads" and "critical levels" (CL). These critical values are defined as a

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quantitative estimate of an exposure to loads or levels below which significant harmful effects on specified sensitive elements of the environment do not occur according to current knowledge (Nilsson & Grennfelt, 1988).

The BC/Al molar ratio, where BC corresponds to the sum of the base cations Ca2+, Mg2+ and K+, is the most widely used criterion for estimating CL for acidity (ALBIOS project, Cronan et al., 1989; ICP-Modelling and Mapping, Spranger et al., 2004; ICP-Forests Technical Report 2010, Iost, 2010).

For nitrogen, CL have been defined with three approaches: the first approach gives a range of typical critical loads for each ecosystem type, e.g. for forests 10 to 20 kg ha^{-1} a^{-1} (empirical CL, Achermann & Bobbink, 2003). The second approach assumes that the leaching of N below rooting zone should not exceed an ‘acceptable’ level. The third approach uses a values of N concentrations in the soil solution as a criterion for e.g. nutrient imbalances, N saturation or enhanced sensitivity to frost and fungal diseases (Sverdrup & de Vries, 1994; Lorenz et al., 2008; Technical Report 2011, Iost et al., 2011).

Commonly, a steady state approach (SMB) is used for the European-wide mapping of critical loads exceedances: It is assumed that the ecosystem will reach a steady state and the maximal acceptable load under a certain criterion is estimated for this state (cf. Mapping Manual, \Spranger, 2004 #3741; level I and II plots \Nagel, 2011 #4860}. The base cations to aluminium ratio (BC/Al) in the soil solution and the ‘acceptable’ N leaching are among the criterion typically used to define CL for acidity and nutrition N.

On ICP Forests plots ecosystem responses to deposition are monitored and this data seems to be suited to investigate tree response to critical loads exceedances. However, plots marked on the maps as having CL exceeded may not yet have reached the steady state and changes of soil solution and related effects are thus expected to appear in future only.

In this context, ICP Forests allow to investigate the actual N saturation and acidification status of plots with CL exceeded as well as the tree response to exceedances of critical limits in soil solution.

6.3.2 Objectives

This study aims on investigating the following relations based on the level II network

- Relations between indicators for actual N saturation and soil acidification status and exceedances of critical loads
- Relations between tree responses and exceedance of critical limits for soil solution

6.3.3 Methods

This study has been carried out on the plots from the countries shown in Table 6.3-1 of the level II network of ICP-Forests programme (Fischer et al., 2010), i.e. the intensive monitoring plots of the FutMon project of the LIFE+ programme based on measurements and assessment carried out during 2006-2009.

Table 6.3-1: Study sites and number of plots for combinations of critical loads calculations (CL_{SMB}), the deposition (DP), soil solution (SS) and foliar (FO) analyses and assessment of light green to yellow discolouration or Mg deficiencies (damage cause assessment, DCA) in the years 2007 to 2009.

COUNTRY	CL_{SMB}>SS	DP>SS	SS>FO		DP>FO	yellowing			Deficencies
	plots	plots	plots	species	plots	plots	species	n	n
France	9	14	14	1	24				
Belgium	4	7	7	1	9	11	1	111	18
Netherlands		1	1	1	4				
Germany	5	59	53	1.2	62	31	1	281	122
Italy	7	9	9	1.1	22	20	1.8	78	
United Kingdom	1	6	5	1.2	5	5	1	22	
Ireland	2	2							
Greece	3	3	3	1	4	3	1	10	
Spain		3	3	1	14	34	1.1	805	
Sweden						5	1	19	
Austria				1.1	20				
Finland	15	17	17	1.0	18	15	1.1	58	
Switzerland		7	7	1.6	12				
Hungary		1	1	1	8	5	1.8	12	
Romania		3							
Poland		1	1	1.0	1	18	1	32	
Slovak Republic	3	3	4	1.2	6	6	3.8	205	
Norway				1	8	6	1.2	29	
Lithuania				1	3	4	1.3	4	
Czech Republic	8	11	11	1	12	14	1.1	73	
Estonia		3	3	1	7	5	1	30	
Slovenia				1	6	7	1	15	
Russian Federatio		3							
Bulgaria				1	3				
Latvia		1	1	1	1				
Cyprus				1	2	2	1.5	51	

CL_{SMB}>SS: plots for which CL_{SMB} and SS were determined, etc.
yellowing: reporting of occurrence of symptom ‘light yellow to green discoloration’
deficiencies: reporting of occurrence of cause ‘nutrient deficiencies’.
plots: number of plots, species: number of tree species, n: number of trees.

The measurements and assessments have been carried out according to the Manual of ICP-Forests (ICP-Forests, 2010). For detailed additional descriptions refer to e.g. Thimonier (2010) [list of national studies, to be extended]. The QA/QC measures included checks within the countries, as well as consistency checks during the submission of the data to the data centre at the Programme Coordination Centre (PCC).

Bulk deposition (BD) and throughfall deposition (TF) were continuously collected with weekly to monthly sampling intervals. Annual deposition was calculated as described in the ICP Forests Technical Report (Granke & Mues, 2010), using continuous sampling during at least 333 days as completeness criterion. Volume of bulk deposition was used to derive precipitation quantity.

Soil solution was sampled generally with suction cup lysimeters in same intervals as deposition and analysed chemically in laboratory. Annual mean concentration of the samples as well as the ratio of samples exceeding critical limits were calculated for each depth and depth classes aggregated as described in the Technical Reports (Iost, 2010; Iost et al., 2011)

(Table 6.3-2, Table 6.3-3). For the comparison of critical loads exceedance and soil solution a generic critical BC/Al=0.8 was used, while for comparison of soil solution and foliar nutrition the tree species specific values in Table 6.3-3 were applied. The values of the lowest lysimeter are referred to as ‘bottom’ hereafter.

Table 6.3-2: Critical limits for N in soil solution (Mapping Manual, Spranger et al., 2004; ICP-Forests Technical Report 2010, Iost, 2010).

Effect	critical limit N (mg N/L)	forest type	depth class used	Indicators compared
Nutrient im-balances	0.2	Coniferous	mineral topsoil	Foliar N, Mg and K nutrition, symptoms of ‘light green to yellow discolouration’ and cause ‘Mg deficiency’.
	0.4	Deciduous		
N saturation	1	All	lowest lysimeter	(exceedance of critical loads)
enhanced sensitivity to frost and fungal diseas	3	All	mineral topsoil	Cause ‘fungal deseas’ on foliage

Foliage samples were taken from the upper third of the tree canopy from branches fully exposed to sunlight. Foliage was sampled from at least five trees of the main tree species on the plot. In case of deciduous species, foliage was sampled during full development of the leaves, i.e. in the end of growing season before autumn yellowing. Evergreen foliage was sampled during dormancy period. The ranges of optimal nutrition and the species group compiled by the Expert Panel of Foliage FSCC (Stefan et al., 1997) were used to classify the nutrient concentrations in foliage into ‘low’, ‘in’ and ‘high’ (Table 6.3-3).

Table 6.3-3: Ranges of optimal nutrition for tree foliar concentration (mg/kg) of nitrogen (N), phosphorous (P), sodium (K), calcium (Ca) and magnesium (Mg) of optimal nutrition compiled by FSCC (Stefan et al., 1997) and critical values of the molar ratio of base cations to total aluminium (BC/Al_{crit}) in the soil solution according to Sverdrup et al. (1994)and Lorenz et al. (2008) .

Species group	N	P	K	Ca	Mg	BC/Al_{crit}
Spruce	12 – 17	1 - 2	3.5 - 9	1.5 - 6	0.6 - 1.5	1.2
Silver Fir	12 – 17	1 - 2	3.5 - 9	1.5 - 6	0.6 - 1.5	1.2
Pine	12 – 17	1 - 2	3.5 - 10	1.5 - 4	0.6 - 1.5	1.2
Douglas	12 – 17	1 - 2	3.5 - 10	1.5 - 4	0.6 - 1.5	0.3
other conifers	12 – 17	1 - 2	3.5 - 10	1.5 - 4	0.6 - 1.5	1.2
Beech	18 – 25	1 - 1.7	5 - 10	4 - 8	1 - 1.5	0.6
Birch	18 – 25	1 - 1.7	5 - 10	4 - 8	1 - 1.5	0.8
Oak	15 – 25	1 - 1.8	5 - 10	3 - 8	1 - 2.5	0.6
other broadleaves	15 – 25	1 - 1.8	5 - 10	3 - 8	1 - 2.5	0.6

The Damage Cause Assessment can be carried out and reported in various level of detail, e.g. only symptom and cause class or Latin name of causing insect. Assessment of a specific symptom detail has been assumed to be carried out if it has been reported at least once in a country and year. Based on this assumption, the proportion of trees showing the symptom has been computed for each year.

Critical loads for nitrogen as nutrient N_{nut} (CLN_{SMB}) and for acidification (CLA_{SMB}) have been calculated as described in Nagel et al. (2011), based on the measurements described above as well as on soil analyses, using the methods recommended in the Mapping Manual (Spranger et al., 2004). On plots without steady-state mass balance (SMB) calculations, empirical critical loads for N_{nut} (typically in the range between 10 to 20 kg N ha-1 a-1, Achermann & Bobbink, 2003) were used as a reference to classify N loads. Throughfall N deposition was used for calculation of critical loads exceedances.

Means of annual values of the period from 2006 to 2009 have been calculated per plot and tree species. The means of the exceedances of critical loads and critical limits and the means of foliar nutrition and occurrence symptoms per tree species were compared hereafter.

Relations were investigated comparing the percentage of plots using contingence tables and the chi-square test. In addition linear mixed effects models (LME, Pinheiro & Bates, 2011) were applied on annual means from 2006 to 2009. Foliar N and Mg concentrationss were used as response variables and the concentrations in soil solution of N and Mg, as well as precipitation, altitude and latitude as explanatory variables. Fixed effects of species group and random effect of survey year nested per plot were included into the regression modelling using the maximum likely hood method.

6.3.4 Results

Figure 6.3.4.-1 illustrates the changes of the concentrations of dissolved inorganic nitrogen (NH_4^++ NO_3^-) in the water on its path through the ecosystem as already shown earlier by e.g. de Vries et al. (2003). Despite direct uptake of N from the canopy, the precipitation below canopy (throughfall) often has higher N concentrations than above (values typically close to the bulk deposition), due to dry deposition on the foliage that is washed out with the precipitation. Subsequent concentrations in soil solution are the net result of various processes including immobilisation of nitrogen in the solid phase, nutrient uptake by vegetation, nutrient release from decomposed biomass and water volume changes through e.g. transpiration.

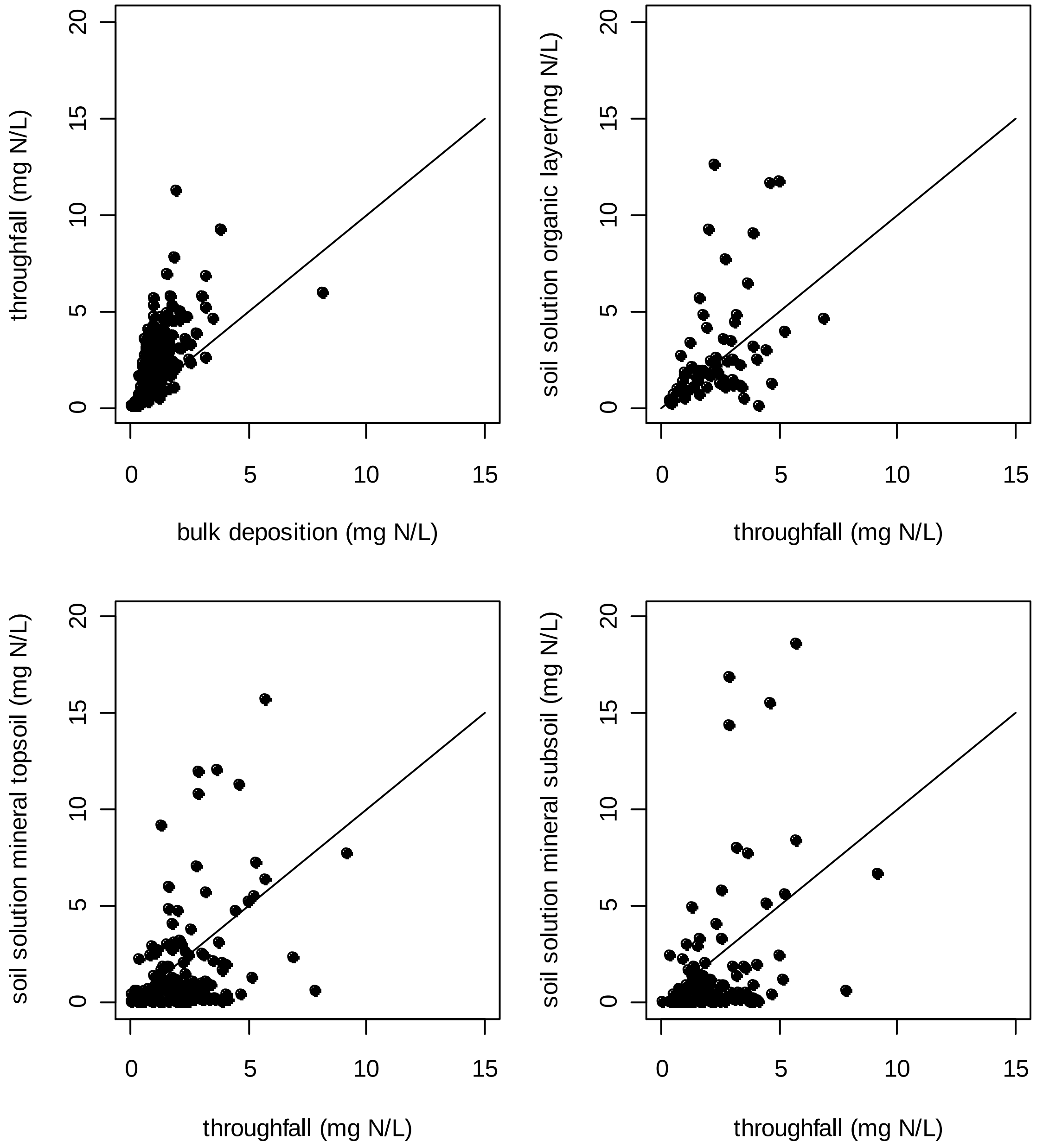

Figure 6.3.4.-1: Concentration of dissolved inorganic nitrogen (NH_4^+ + NO_3^-) in bulk precipitation, throughfall precipitation, and soil solution (top right: organic layer, bottom left: mineral topsoil 0-40 cm and bottom right: mineral subsoil 40-80 cm) on selected ICP-Forests level II plots.

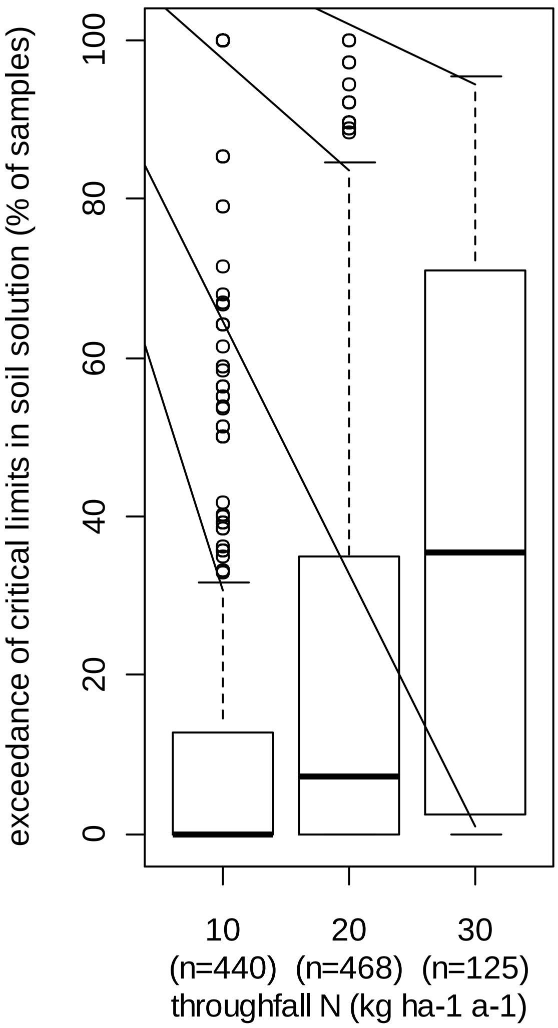

Figure 6.3.4-2: Percentage per plot of soil solution samples from the lowest lysimeter with exceedance of critical limits for N saturation. Boxplots showing the 25th, 50th and 75th percentiles, bars showing the 95th percentiles and circle showing single higher values for plots with throughfall N deposition less than 10 (10), between 10 and 20 (20) and exceeding 20 kg N ha^{-1} a^{-1} (30).

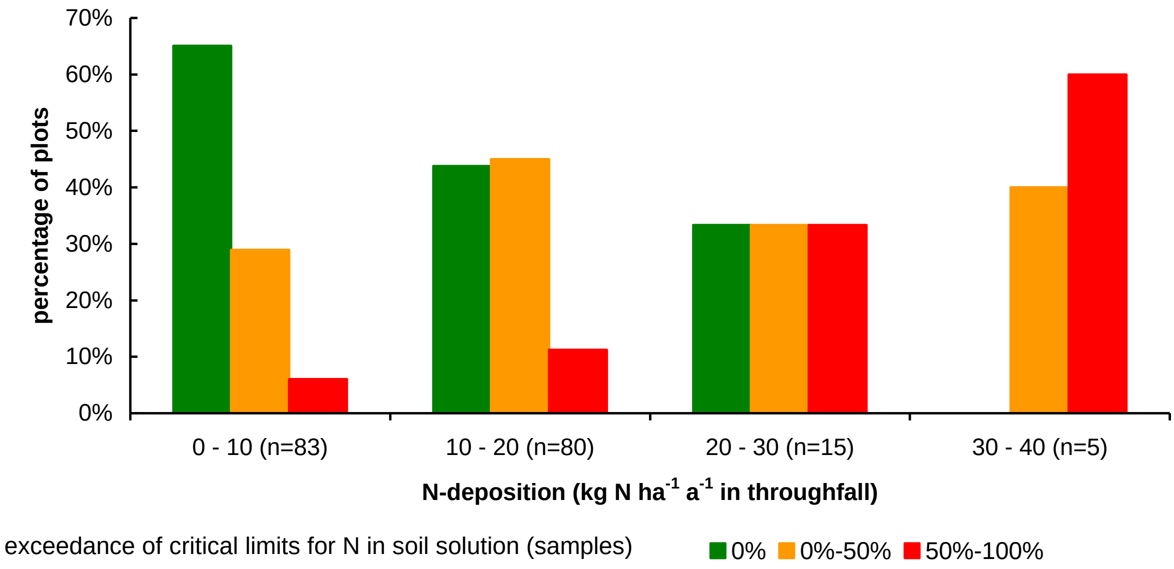

Figure 6.3.4-3: Percentage of plots with exceedances of critical limits for N saturation in soil solution of the lowest lysimeter (>0% of samples) for plots with throughfall N deposition less than 10, between 10 and 20 and exceeding 20 kg N ha^{-1} a^{-1}.

The capacity of ecosystems to accumulate nitrogen depends on the N saturation state that is affected by various processes (Gundersen et al., 1998; MacDonald et al., 2002; Gundersen et al., 2006; Gundersen et al., 2009). Figure 6.3.4-2 shows that on plots with higher N throughfall (>20 kg N ha^{-1} a^{-1}) nitrate concentrations in the soil solution samples from the lowest lysimeters more often exceeded critical limits for N saturation. Regarding the SMB concept, we may interpret that about half of the plots with critical loads exceeded already show indication of N saturation while the other half may still be in the phase of accumulation and reach saturation later (Figure 6.3.4-3, Figure 6.3.4-4).

Table 6.3.4-4: Percentage of plots with exceedances of critical limits for BC/Al in soil solution in more than 80% of the soil solution samples for plots with and without exceedances of critical loads for Acidity CLA$_{SMB}$. The critical BC/Al ratio of 0.8 was used for all plots regardless the tree species composition on the plot.

depth class	CLA$_{SMB}$	BC/Al < 0.8		
		<80%	>80%	n
0-20cm	not exc.	65%	35%	(57)
	exceeded	82%	18%	(11)
20-40cm	not exc.	74%	26%	(35)
	exceeded	50%	50%	(6)
40-80cm	not exc.	46%	54%	(28)
	exceeded	38%	63%	(8)
below 80 cm	not exc.	64%	36%	(14)
	exceeded	50%	50%	(2)

Similarly, proportion of plots with BC/Al criterion exceeded (BC/Al<0.8 in more than 80% of the samples) seems to be higher among the plot with exceedance of critical loads of acidity than among the plots without exceedance of critical loads for acidity (**Table 6.3.4-4**). Laboratory determination of the Al speciation showed, that the most toxic form, Al3+, typically is about 30% to 100% of total dissolved aluminium, but can also be much lower (Graf Pannatier et al., 2011).

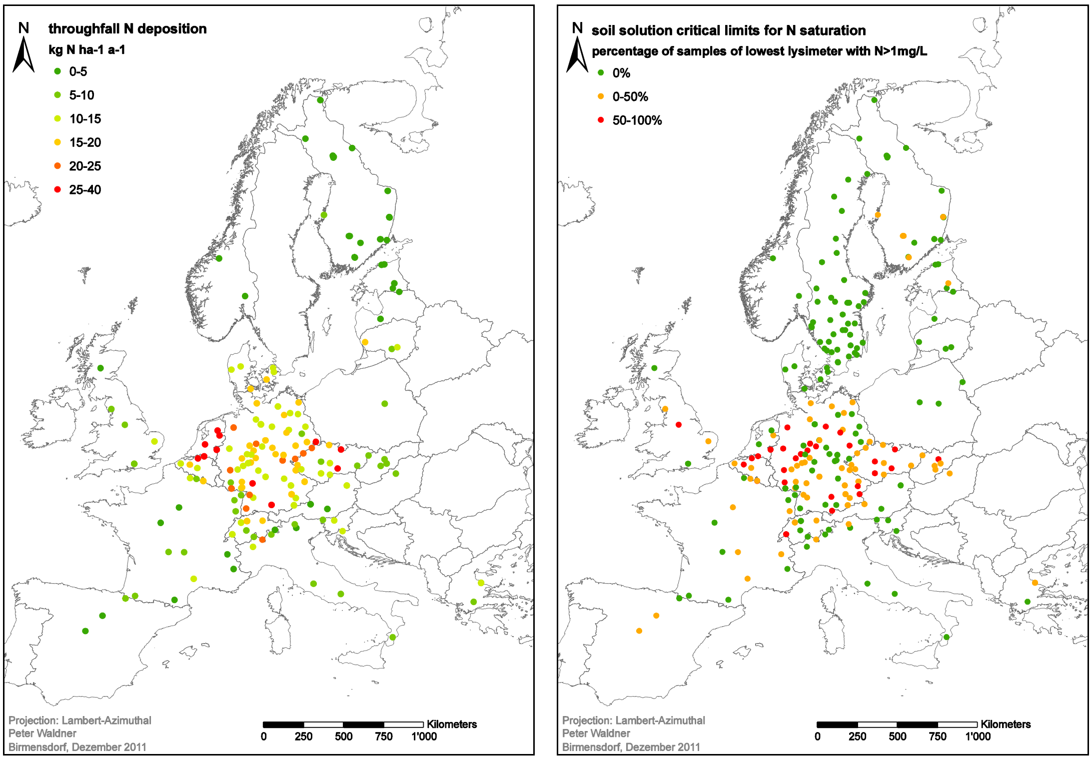

Figure 6.3.4-4: Throughfall N deposition measurements (left) and exceedances of critical limits of N in soil solution (percentage of samples from lowest lysimeter with sum of concentrations of NO_3^- $+NH_4^+$ >1 mg N/L) for N saturation (right) on ICP-Forests level II plots. Mean of annual deposition with at least 330 day of continuous measurement of the year 2006 to 2009.

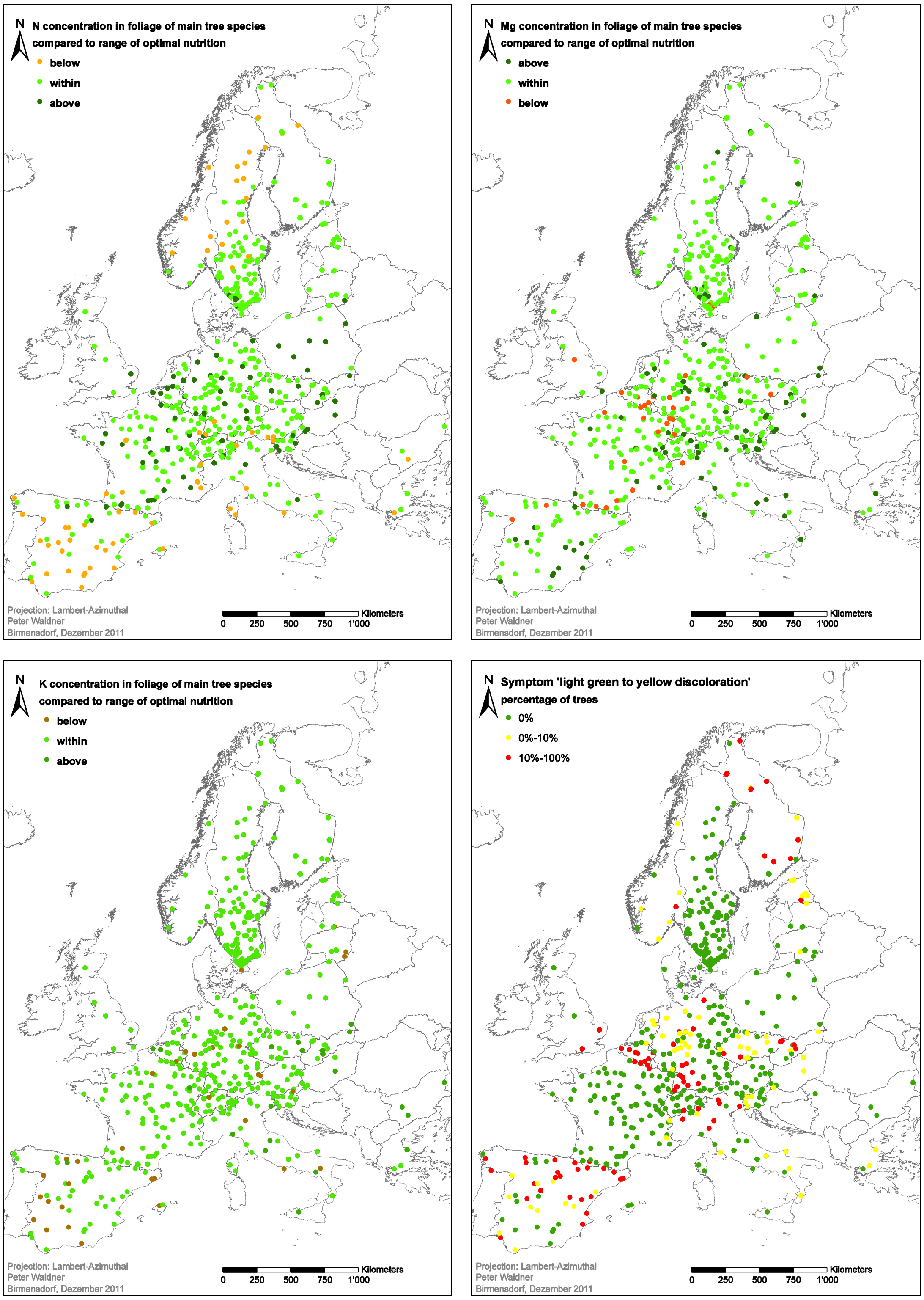

Figure 6.3.4-5: Foliar nutrition class (FSCC, Stefan et al., 1997) for N (top left) and Mg (top right) concentrations of the main tree species, and occurrence of the symptom 'light green to yellow discoloration' of foliage reported within the Damage Cause Assessment (bottom right). Means of available values of the years 2006 to 2009 for ICP-Forests level II plots are shown.

The relation between the exceedance of critical limits in soil solution for nutrient imbalances and the class of nutritional status as indicated by the foliar concentrations are shown in Table 6.3.4-5 and Table 6 (see also Figure 6.3.4-4, Figure 6.3.4-5). Tree species had been summarized to tree species groups in Table 6.3-3.

Table 6.3.4-5: Relation between exceedance of critical limits for NO$_3^-$ in soil solution sampled in the mineral topsoil (0-40 cm depth) (TR, Iost, 2010) and foliar nutrition classes (FSCC, Stefan et al., 1997) assigned to foliage samples from 2007 to 2009. Percentages of plots with mean foliage concentrations of N, Mg, and K below, in or above the range for optimal nutrition for plots with soil solution critical limits for nutrient imbalances exceeded in 0% and more percent of soil solution samples from the mineral topsoil, respectively.

Species group	NO3-N (mg N/l)		N				Mg				K			
			low	in	High	n	low	in	high	n	low	in	high	n
Spruce	0.2	not exc.	**38%**	62%	0%	(13)	0%	79%	21%	(14)	7%	93%	0%	(14)
		exceeded	**7%**	93%	0%	(42)	2%	93%	5%	(42)	7%	93%	0%	(42)
Pines	0.2	not exc.	**22%**	67%	11%	(9)	0%	89%	11%	(9)	0%	100%	0%	(9)
		exceeded	**0%**	79%	21%	(34)	6%	94%	0%	(34)	0%	100%	0%	(34)
Fir	0.2	not exc.	0%	100%	0%	(1)	0%	0%	100%	(1)	0%	100%	0%	(1)
		exceeded	20%	80%	0%	(10)	10%	60%	30%	(10)	0%	100%	0%	(10)
Beech	0.4	not exc.	0%	71%	29%	(7)	10%	30%	60%	(10)	0%	100%	0%	(10)
		exceeded	0%	72%	28%	(39)	36%	33%	31%	(39)	3%	85%	13%	(39)
Oak	0.4	not exc.	0%	83%	17%	(6)	0%	100%	0%	(6)	0%	83%	17%	(6)
		exceeded	0%	35%	65%	(17)	0%	100%	0%	(17)	0%	76%	24%	(17)

bold: p-value<0.05 with chi-square test.

Table 6.3.4-: Relation between exceedance of critical BC/Al ratio in soil solution sampled in the mineral topsoil (0-40 cm depth) (TR, Iost et al., 2011) and foliar nutrition classes (FSCC, Stefan et al., 1997). Percentages of plots with mean foliage concentrations of N, Mg, and K below, in or above range for optimal nutrition for plots with BC/Alcrit exceeded in less and more than 80% of soil solution samples, respectively.

Tree species	crit. BC/Al	exceed. (sampl.)	N				Mg				K			
			low	in	high	n	low	in	high	n	low	in	high	n
Spruce	1.2	<80%	20%	80%	0%	(35)	0%	86%	14%	(36)	3%	97%	0%	(36)
		>80%	5%	95%	0%	(20)	5%	95%	0%	(20)	15%	85%	0%	(20)
Pines	1.2	<80%	0%	84%	16%	(19)	5%	95%	0%	(19)	0%	100%	0%	(19)
		>80%	8%	71%	21%	(24)	4%	92%	4%	(24)	0%	100%	0%	(24)
Fir	1.2	<80%	14%	86%	0%	(7)	0%	57%	43%	(7)	0%	100%	0%	(7)
		>80%	25%	75%	0%	(4)	25%	50%	25%	(4)	0%	100%	0%	(4)
Douglas Fir	0.3	<80%	0%	0%	0%	(0)	0%	0%	0%	(0)	0%	0%	0%	(0)
		>80%	0%	100%	0%	(1)	0%	0%	100%	(1)	0%	100%	0%	(1)
other conifers	1.2	<80%	0%	0%	0%	(0)	0%	0%	0%	(0)	0%	0%	0%	(0)
		>80%	0%	0%	0%	(0)	0%	0%	0%	(0)	0%	0%	0%	(0)
Beech	0.6	<80%	0%	76%	24%	(34)	36%	31%	33%	(36)	3%	89%	8%	(36)
		>80%	0%	58%	42%	(12)	15%	38%	46%	(13)	0%	85%	15%	(13)
Oak	0.6	<80%	0%	47%	53%	(19)	0%	100%	0%	(19)	0%	79%	21%	(19)
		>80%	0%	50%	50%	(4)	0%	100%	0%	(4)	0%	75%	25%	(4)
Birch	0.8	<80%	0%	100%	0%	(2)	0%	0%	100%	(2)	0%	100%	0%	(2)
		>80%	0%	0%	0%	(0)	0%	0%	0%	(0)	0%	0%	0%	(0)
other broadl.	0.8	<80%	0%	50%	50%	(2)	0%	75%	25%	(4)	0%	75%	25%	(4)
		>80%	0%	0%	0%	(0)	0%	0%	0%	(0)	0%	0%	0%	(0)

BC/Al$_{crit}$: growth reduction to 80% of mean according to (Sverdrup & de Vries, 1994; Lorenz et al., 2008) (no data for Sitka Spruce, few data only), n: number of plots.

However, generally, coniferous species more often have N values falling into the nutrition class ‘low’ than the broadleaves. This may be related to the fact that conifers are the naturally abundant in higher altitudes and latitudes, both regions with lower N deposition (Thimonier et al., 2010).

When comparing plots with exceedance to plots without exceedance there seems to be a shift to higher classes for N for Spruce, Pines and Oak and a shift to lower classes for Mg for Spruce, Pines, and Beech. For the groups of Spruce and Pines the in the percentage of plots with foliar N concentrations s below optimal range is significantly lower for plots with critical limits exceeded. For conifers, Mg concentrationss below optimal ranges were only recorded on plots with critical limits exceeded. For Beech, the percentage of plots with low Mg values is higher for plots with critical limits exceeded. For these later observations, statistical significance was not reached with the chi-square test. However, the LME analyses resulted in a significant positive effect of the N concentration in soil solution on the N concentrations in foliage ($p<0.000$) and negative effect on Mg concentrations ($p=0.01$) and Mg/N ratio ($p<0.000$). For Spruce, Pines and Beech it seems likely that there might be a tendency towards less optimal Mg/N ratios with increasing exceedances of critical limits for N in soil solution.

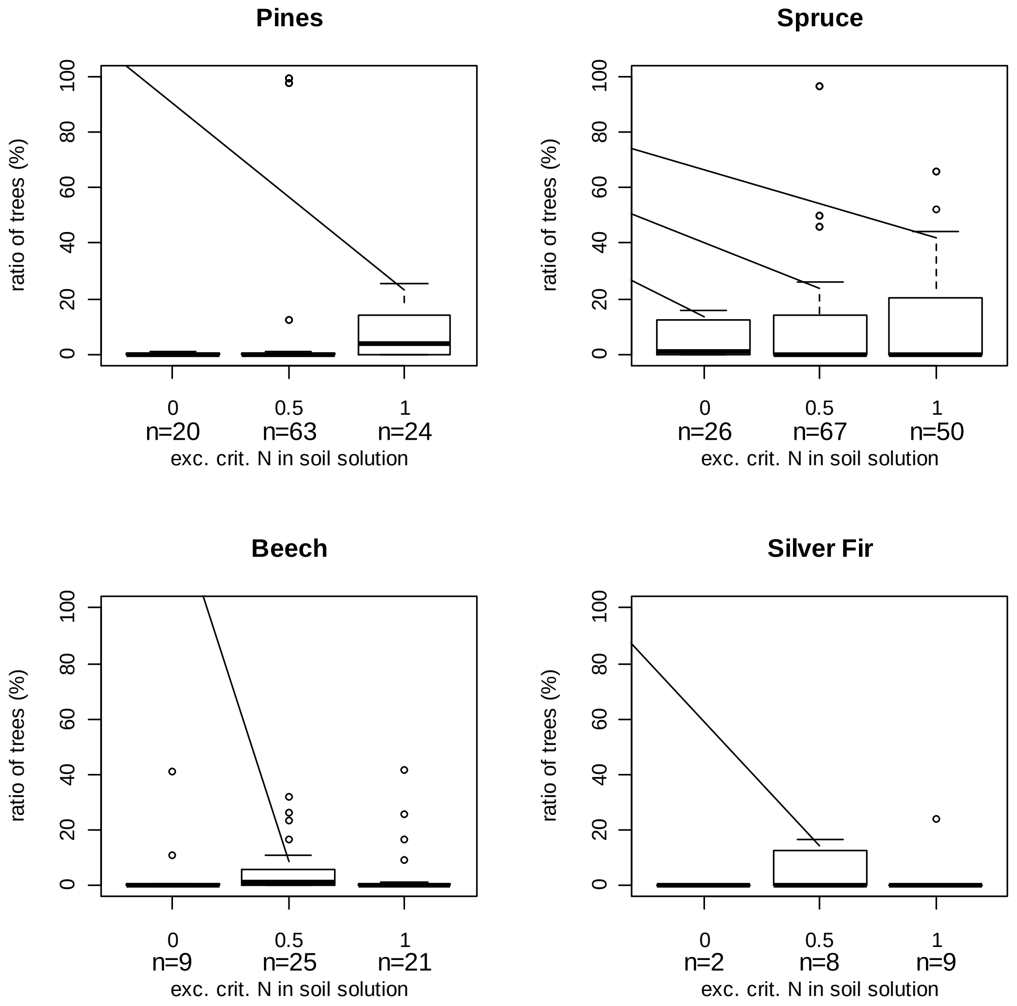

Figure 6.3.4-6: Percentage of trees with symptom ‘light green to yellow discolouration’ for plots with critical limits for N in soil solution for nutrient imbalances exceeded in >0%, between 0% and 50%, and >50% of the samples from the mineral topsoil. The relation is shown for the species groups ‘Spruce’ (top left), ‘Pines’ (top right), ‘Beech’ (bottom left), and ‘Silver Fir’ (bottom right) (n: number of plots).

The symptom of ‘light green to yellow discolouration’ and the cause ‘nutrient deficiency’ have not been assessed on all plots. The assessment does not completely cover the full range of foliar concentrations found in the whole dataset. Symptoms reported from a plot might have appeared on trees not sampled for foliage analyses. However, foliar Mg concentrationss of sampled trees on plots from which symptoms were reported are in the lower part of the concentration range of the tree species (not shown).

Figure 6.3.4-6.3.4-6 shows that reported ratio of trees with the symptom is higher on plots with soil solution critical limits for nutrient imbalances exceeded.

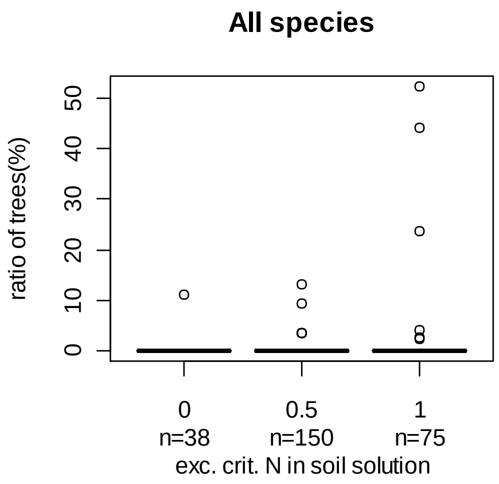

Figure 6.3.4-7: Percentage of trees with symptom cause ‘nutrient deficiency’ reported for plots with critical limits for N in soil solution for nutrient imbalances exceeded in >0%, between 0% and 50%, and >50% of the samples from the mineral topsoil (n: number of plots).

Similar relations have been found between exceedance of BC/Al ratio and ratio of trees with reporting of cause ‘insects’, but not for cause ‘fungal disease’ on foliage, with the current set of assessment based on the assumptions mentioned in the method sections.

6.3.5 Discussion

A correlation or a relation between to variables does not necessary mean that there is a cause effect relationships. There might be confounding factors. In this study the influence of e.g. soil condition, tree age, tree density, management, and drought stress has not been considered.

Critical loads are a concept to prevent long-term effects. Absence of immediate effects of critical loads exceedances is thus fully in accordance with the concept. We built classes of plots with throughfall N using the lower and upper values of empirical critical loads. However, throughfall N generally is lower than the total N deposition that also includes nitrogen taken up in the crown. Hence, it is very likely that critical loads exceedances are more frequent than the >10 or >20 kg N ha^{-1} a^{-1} classes may suggest.

For the critical limit for soil solution that indicates N saturation, we investigated exceedance based on the concentrations of inorganic nitrogen in soil solution samplers of the lowest lysimeters. This was based on the assumption that the lowest sampler is installed more or less at the in the lower end of the rooting zone and that the magnitude of variation is much higher for the N concentration than for the water fluxes. However, for a more precise determination (i) the effective depth of rooting zone should be crosschecked with the profile descriptions and (ii) the leaching should be estimated with a water balance model.

About half of the plots with exceedance of critical loads for N_{nut} already show signs of N saturation and N leaching. It is likely that the other plots may still be in a phase of N accumulation and tend towards saturation. However, we recommend that the N balances are investigated in a later study.

Regarding critical loads of acidity (CLA_{SMB}), the proportion of samples with BC/Al ratio in the soil solution of the mineral soil (20-80 cm depth) exceeding the critical limit (<0.8) tends to be larger on plots with CLA_{SMB} exceeded than on other plots. As for nitrogen, it cannot be stated that BC/Al is exceeded when CLA_{SMB} is exceeded. We note that the proportion of plots with critical loads exceeded is relatively small (20-30%), while the $BC/Al<0.8$ criterion is frequently exceeded in soil solution of the mineral soil on about two third of the plots, suggesting soils being acidified. However, we suggest that proportion of toxic Al^{3+} within total dissolved Al is considered in further assessment of ecological risks. The relationship between BC/Al ratio and foliage nutritional was not very obvious: The Mg and K concentrations in foliage of conifers tend to be lower on plots with BC/Al ration exceeded, indicating a possible depletion in base cations due to soil acidification. No such tendency was observed for broadleaves.

6.3.6 Conclusions

Most of the relations found in this study are not in contradiction of the postulated hypothesis on N saturation and acidification effects and the recommendations for calculation of critical loads and limits. Further investigations will be needed to establish cause-effect relationships based on the level II data independent data that

6.3.7 References

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6.4 Exceedance of critical loads and their impact on biodiversity

Angela Schlutow[1]

Abstract

Deposition of sulphur and nitrogen has a continuous influence on soil-chemical properties and nutrient availability of soils. This will affect the vitality of single plants and whole ecosystem. Since the vitality or functionality of ecosystems is crucial for the protection of the biodiversity the focus of this study is the biological response of plant species and plant communities. The results of the dynamic modelling of soil chemistry (with VSD+) were coupled with the BERN model. The BERN model allows an evaluation of the current plant composition and an outlook for future development of regeneration abilities of plant communities. On basis of the BERN results forest management measures can be recommended for 10 plots.

6.4.1 Methods

The BERN model has been designed to integrate ecological cause-effect relationships into environmental assessment studies and for deriving critical loads for acidification and eutrophication. More than 38.000 empirical vegetation data sets and data from related soil surveys form the basis of the BERN model. One of the central presumption of the BERN model is that nearly all biological components in a natural or semi-natural ecosystem are adapted to a long-term evolutionary status of relations between essential nutrients, such as nitrogen (N), phosphorus (P), carbon (C), and base cations (Na, Ca, Mg, K), as well as water supply, solar radiation and temperature conditions. Therefore a typical plant composition should occur on sites with undisturbed soil condition in a longer perspective. Since such a natural or semi-natural plant community offer the highest level of information regarding ecosystem services and self-regeneration capabilities as extent of potential risks the BERN is actually focused on modelling the possibility of whole plant communities. But the starting point is the plant species level. So a crucial preliminary step for designing the BERN model was the analysis of the empirical data regarding plant composition and plant occurrence related to site conditions. Such “blurred” relationship can be characterized by using so called fuzzy-logic (ZADEH 1978) and should represent and describe all possible combinations of plant species and site factors. Therefore the definition of these fuzzy functions for each plant species and each site factor is of prime importance for the BERN model.

The collection of the fuzzy functions for the site factors represents the so called fundamental niche and was derived by analyzing the vegetation surveys mentioned before. This fundamental niche - also called “possibility field” - is defined by a range of parameters in which each plant species can exist. This range of occurrence possibilities is determined by the physiological and genetic properties of the plant species and is rather unchangeable (DIERSCHKE 1994). The fact that the focus of the used vegetation relevés was on undisturbed sites underlines the efforts of the BERN model to describe a fundamental niche of plant spe-

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cies within natural or semi-natural conditions. Because the information about the most extreme site condition on which a plant can augmentable survive has only limited value for the analysis of healthy ecosystems. Currently fundamental niches of 1996 plant species are defined by fuzzy thresholds for site variables (base saturation, C:N ratio, soil moisture, length of vegetation period, climate water balance, temperature and solar radiation) in the BERN database.

The combination of the site factors which influence the vegetation vitality results in defined possibility function for plant existence. The actually existing combinations of site factors are classified to site types. All site parameter ranges have to lie within the physiological niche width of a specific plant community. Thus the combination of the fundamental niches of the plant species results in typical realistic niches of plant communities at a specific site type. The problem of unknown competition is solved by using knowledge on existing plant species abundance in a balanced equilibrium in combinations. The realistic niche is thus a result of the social properties and is determined by the competitive power and reproductive fitness of the species in connection with all other existing species at the site (WHITAKER et al. 1973). Realistic niches of 547 plant communities are integrated by combining the fundamental niches of the consistent plant species using fuzzy logic gamma operator. A distribution function of possibilities (DFP) is the mathematical expression of the realistic niche of a plant community. The n-dimensional DFP reaches a maximum at the point where most constant species building up the community have their highest possibility values. The regeneration ability of a plant community is assumed to be in an optimum when the DFP reaches its maximum. The results of the DFP as function of the site factors stands for possibility degrees for the existence of recent plant communities, and can be grouped into classes of different regeneration abilities at given plots in relation to a reference condition. The possibility class “no regeneration abilities” indicates non-natural disharmonious conditions for a plant community with high risks to lose its self-regeneration capabilities. The possibility class “low regeneration abilities” indicates that a certain plant community can exist, but degradation is most likely to happen. The possibility class “full regeneration ability” is equal to the ecological niche where a plant community can reach its highest functionality. In this case the plant community can develop well and is fully capable of providing ecosystem goods and services. With decreasing site suitability the competition capacity for the respective plant community also decreases, leading to reduced resistance against environmental influences like windfall, snow damage, frost, damaging insects and pests.

The BERN scenarios for predicted possibility degrees of the recent main tree species were driven by the modeled C:N ratio and base saturation in the years 2000 and 2050 as output of the VSD+ model (Chapt. 5.3). Changes in C:N ratio and base saturation are based on a deposition scenario assuming full implementation of current national legislation in the EU (COB scenario, see Chapt. 5.3). The current application of the BERN model assumes constant climate. Additional runs of the model taking into account climate change scenarios are ongoing.

The knowledge on the optimum natural plant community offers additional information on main tree species with the potentially highest vitality. Therefore, in a next step, the main tree species of the “natural” or optimum plant communities for a specific site was compared to the main tree species of the presently occurring species composition as indicated by the recent vegetation surveys. This approach is based on the assumption that there is mostly a clear link between the vitality and regeneration potential of the main tree species and the possibility degrees for existence of recent plant communities to which the trees belong. Not only competition drives the vitality but also the cooperation between the species, including trees. The comparison of recent main tree species with the dominating tree species of the optimum plant communities results in recommendations for forest management measures to alter future plant composition.

6.4.2 Results

The evaluated plots show a wide variety of plant species communities and related presently occurring main tree species (Table 6.4.2-3). From the 21 analyzed sites 12 had "high regeneration abilities" of the presently occurring plant species composition, indicating that species composition was rated as adapted to the presently occurring geo-chemical site conditions. On 6 sites regeneration ability was rated as low and on the remaining three sites there was "no regeneration ability" in a long term perspective indicating the currently occurring vegetation composition is not well adapted to present site conditions (Figure 6.4.2-1). On 12 plots the presently occurring main tree species was assessed to have full regeneration abilities and therefore no elevated risk of suffering from natural diseases. On 8 plots the current main tree species was assessed with "low regeneration ability" or respectively a low risk and on one plot the model assumes "no regeneration ability" which indicates an elevated risk. When relating the presently occurring main tree species to geo-chemical site conditions predicted by the VSD+ model assuming the COB deposition scenario for the year 2050 regeneration abilities changed on several plots. On two plots the potential risk for natural diseases increased while on other three plots the risk decreased to a level of "no risk" (Figure 6.4.2-2).

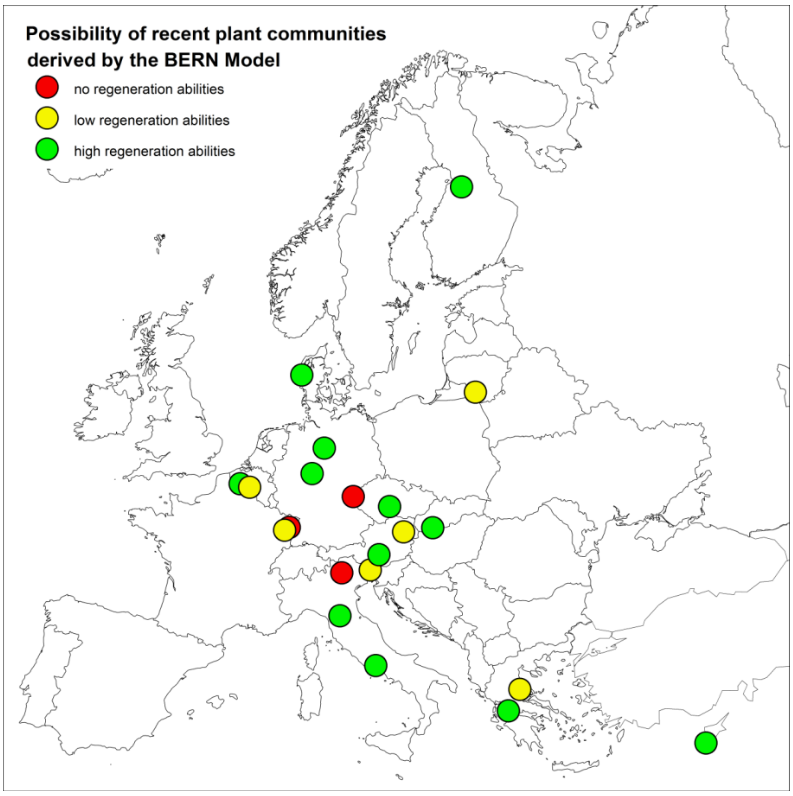

Figure 6.4.2-1: Possibilities of recent plant communities

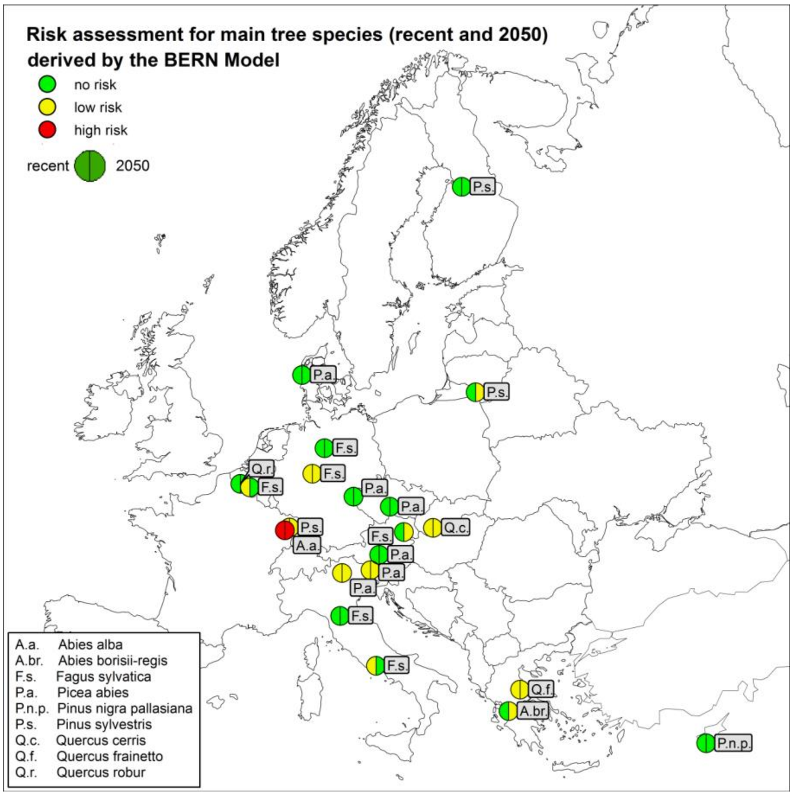

Figure 6.4.2-2: Risk assessment for main tree species (recent and 2050).

The condition doesn’t change on 16 plots but 7 of them are still classified as having low or even high risks. On 9 out of 21 plots the main tree species maintain “full regeneration abilities” and therefor they are classified as plots with no elevated risks.

The 3 plots with decreasing suitability and the 7 sites with constantly low site potential were analyzed regarding recommendations for new main tree species (Table 6.4.2-3). Four types of measures can be distinguished and these types can be described as “no measure”, “mix the stand”, “main tree shift” and “main tree exchange”. Type “no measure” needs no further explanation. Type “mix the stand” means that the vitality of the stand can be improved by encourage tree species that are already in lower vegetation layers. This can be done by thinning the recent main tree species so the result will be a mixed forest including the recent main tree species. This is true for plots 20016, 20021, 40606, 140009 and 560003. Type “main tree shift” means the site has the potential for a natural rejuvenation by supporting the plant tree species in the shrub or herb layer. But the resulting plant composition doesn’t necessarily include the recent main tree species. This is true for plot 10098 and 50008. The type “main tree exchange” represents plots with limited potential for a natural rejuvenation described above. Thinning the recent main tree species and supporting the species in the understory vegetation will be necessary. Additionally some new plant tree species should be planted in order to reach a suitable and sustainable composition of tree species. This is true for plot 10084 and 90002. Of course all measures of these should be performed according to guidelines of good forest management.

Table 6.4.2-3: Recent plant communities and tree species for the Level II plots, tree species in bold letters are the main tree species, tree species in italic letters are present at the site (according the vegetation survey) but not in the tree layer

Level II plot	Recent plant community 2000	Recent tree species	Plant community with optimum in 2050	Main tree species with optimal vitality in 2050
10084	Dicrano-Cultopinetum	*Betula pendula* **Pinus sylvestris** *Quercus petraea*	Betulo-Quercetum	Fagus sylvatica *Support for natural regeneration is needed for:* *Quercus petraeae* *Betula pendula*
10098	Vaccinio-Abietetum	**Abies alba** *Pinus sylvestris* *Quercus petraea*	Viscario-Quercetum	*Support for natural regeneration is needed for:* *Pinus sylvestris* *Quercus petraea*
20016	Fraxino excelsi-Aceretum pseudoplatani	**Fagus sylvatica** *Quercus robur* *Acer pseudoplatanus* *Castanea sativa* *Fraxinus excelsior*	Fraxino excelsi-Fagetum sylvatici	*No changes required* *But support for natural regeneration is needed for:* *Fraxinus excelsior*
20021	Fraxino excelsi-Fagetum sylvatici	*Acer pseudoplatanus* **Fagus sylvatica** *Fraxinus excelsior*	Fraxino excelsi-Fagetum sylvatici	*No changes required* *But support for natural regeneration is needed for:* *Fraxinus excelsior* *Acer pseudoplatanus*
40606	Fraxino excelsi-Fagetum sylvatici	**Fagus sylvatica** *Acer pseudoplatanus* *Acer platanoides* *Ulmus glabra* *Fraxinus excelsior*	Fraxino excelsi-Fagetum sylvatici	*No changes required* *But support for natural regeneration is needed for:* *Fraxinus excelsior*
50001	Calamintho grandiflorae-Fagetum sylvatici	**Fagus sylvatica** *Acer platanoides* *Acer pseudoplatanus*	Calamintho grandiflorae-Fagetum sylvatici	*No changes required*
50006	Daphno laureolae-Fagetum sylvatici	**Fagus sylvatica** *Acer platanoides*	Daphno laureolae-Fagetum sylvatici	*No changes required*
50008	Helleboro nigri-Abieti-Fagetum sylvatici	**Fagus sylvatica** **Abies alba** **Picea abies** **Larix decidua**	Deschampsio flexuosae-Fagetum sylvatici	*Support for natural regeneration is needed for:* *Fagus sylvatica*
50017	Vaccinio myrtilli-Piceetum	**Picea abies** **Pinus cembra**	Vaccinio myrtilli-Piceetum	*No changes required*
80011	Vaccinio-Abietetum	**Picea abies**	Vaccinio-Abietetum	*No changes required*
90002	Quercetum frainetto-brachyphyllae	*Quercus pedunculiflora* **Quercus frainetto** *Castanea sativa*	Quercetum frainetto-cerris macedonicum	*Addition in superstructure:* *Quercus dalechampii* *Quercus cerris*
90004	Abietetum cephalonicae	*Abies cephalonica* **Abies borisii-regis**	Abietetum cephalonicae	*No changes required*
140009	Fraxino excelsi-	**Fagus sylvatica**	Fraxino excelsi-	*No changes required*

Level II plot	Recent plant community 2000	Recent tree species	Plant community with optimum in 2050	Main tree species with optimal vitality in 2050
	Fagetum sylvatici	*Acer pseudoplatanus* *Fraxinus excelsior*	Fagetum sylvatici	*But support for natural regeneration is needed for:* *Fraxinus excelsior*
140016	Calamagrostio villosae-Piceetum	**Picea abies**	Calamagrostio villosae-Piceetum	*No changes of main trees required*
150009	Empetro nigri-Pinetum sylvestris	*Populus tremula* **Pinus sylvestris**	Empetro nigri-Pinetum sylvestris	*No changes required*
540201	Quercetum dalechampii-cerris	**Quercus cerris** *Quercus petraea* *Acer platanoides*	Quercetum dalechampii-cerris	*No changes required*
560003	Dicrano-Quercetum roboris	**Pinus sylvestris** *Quercus robur*	Dicrano-Quercetum roboris	*No changes required* *But support for natural regeneration is needed for:* *Quercus robur*
580521	Vaccinio myrtilli-Piceetum	**Picea abies** *Betula pendula* *Quercus petraea* *Quercus robur*	Vaccinio myrtilli-Piceetum	*No changes required*
582161	Vaccinio myrtilli-Piceetum	**Picea abies** Betula pendula	Vaccinio myrtilli-Piceetum	*No changes required*
660102	Staehelino-Pinetum pallasianea	**Pinus nigra pallasiana** *Pistacia terebinthus*	Staehelino-Pinetum pallasianea	*No changes required*

6.4.3 Conclusions

The 21 selected plots of the pilot study show different degrees of adaptability of the tree species and associated plant communities. Deposition leads to changes in soil properties (see Chapter 5.3) and these changes affect the vitality of plants differently. But on a number of plots plant species composition will remain adapted also to future site conditions.

On several plots the present site conditions do not match requirements of the presently occurring main tree species, or the present tree species will be less adapted in future. With decreasing site suitability there is a risk for higher latent mortality and for the need of sanitary felling. In addition to reduced economic benefits the stability of the stands may be at risk.

To encounter such situations in forest management, changes in main tree species might be a suitable management target. Such measures are necessary where such changes are required were the current tree species are not optimally adapted to site conditions. This might be due to questionable past tree species selection or because site conditions have already been changed during the life time of the existing stand e.g. by atmospheric deposition, climate change or past silvicultural treatment. But only a few plots need such straight measures most plots only need efforts of encourage the trees that are already present at the site in lower vegetation layers.

Even though the number of plots available for this pilot study is quite low and not representative for whole Europe, the methodology of this study offers a wide range of estimating future effects and ways of management adaptions to these effects. The BERN model can be used as a tool for the estimation of deposition effects and for operational forest management recommendations. In future studies plot numbers need to be increased and the influence of climate change should be included as well.

6.4.4 References

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7 Climate change, carbon fluxes, water and growth

7.1 Forest growth and its relation to deposition and climate

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Abstract

Based on existing long-term and intensive forest monitoring data forest growth has been evaluated for 822 plots in 30 European countries. Data include information on breast height diameter of all trees, heights of selected trees and plot area. For nearly 600 plots re-measurements were available within different measurement intervals. In addition to the data quality checks routinely applied in the context of data submission to the central data base, accuracy of the data and the calculations were checked by independent re-measurements on selected plots and by applying national form functions to a test data set provided to national experts.

Results show stocking wood volumes between 300m³/ha and 600m³/ha for most plots with higher volumes for plots in the Alps and lower volumes in the northern and southern regions. Basal area and stem volume increments show similar spatial patterns. Low increments are located in the south and north whereas the plots in Spain show very low increments. Moderate increments are observed on the plots of central and eastern Europe and high increments are found in the western region. The results provide a unique overview on forest growth based on standardized measurements. They are a valuable basis for future validation, refinement or creation of forest growth models, for the determination of growth responses to site and environmental conditions and their changes and for the estimation of harvestable wood and potential stocking biomass in European forests under different management scenarios.

The calculated forest increment for the first five year period (1994-1999) was used to test if current growth deviates from the expected growth based on stand site condition, stand density and stand age and if environmental factors, such as nitrogen deposition or temperature increase, can explain these growth deviations. Nitrogen deposition and above-average temperature had a positive effect on tree growth. However, on soils with already higher nitrogen content nitrogen deposition had almost no effect. Whether continuous high nitrogen deposition may eventually lead to nutrient imbalance and growth decline will be examined in further studies.

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7.1.1 Introduction

The growth of trees is a key ecological parameter of forests and thus of high importance as an indicator of forest condition. Increment is defined as the growth of trees (shoots in coppice forests) and stands within a defined period and can be expressed as increment of diameter, basal area, height and/or volume. On Level II plots of the ICP Forests programme growth assessments are carried out on fixed plots, thus the calculation of area related estimates is possible. These parameters can be linked to external as well as internal factors serving as a proxy parameter for the reaction of trees and stands to management, as well as changes in site and environmental conditions. The advantages compared to other proxies lie in their direct economical and ecological importance of growth parameters.

A first evaluation carried out already in 2003 focusing on carbon pools (de Vries et al., 2003) presented first results of growth assessments on intensive monitoring plots. First remeasurement data for the period 1994-1999 were also used in studies on the effect of atmospheric deposition and climate on growth (Laubhann et al. 2009, Solberg et al. 2009, de Vries et al. 2008, 2009). Following the latest remeasurement of 2009/2010 an evaluation based on all information available up to 2011 and based on intensified data quality checks now allows improved and updated evaluations. Revised data of stocking biomass and main increment information are now available for further use within the intensive monitoring.

7.1.2. Data Evaluations

Evaluations are based on a Level-II plot database export created in March 2011. It contains data from 822 plots in 30 countries. Some plots have been established in 1991 already and are still observed. These plots have been observed for up to 18 years. On the other hand, more than 250 more recently established plots have still not been remeasured which does not allow their use for a growth examination. The total area of all observed plots amounts to around 250 ha. In addition to the total period covered by the observations at specific plots the remeasurement interval is as well of importance. On the evaluated plots, most intervals are in a range of up to 6 years, which is a suitable basis for calculating and interpreting increments.

Most of the plots have a size of or around 0.25 hectare. Plot size also has an influence on the growth analysis: small plots have larger deviations and biases than larger plots as imprecise measurements have a larger effect when only few trees are measured. On the other hand, the variation of site condition is increasing with plot size as well as the error in plot size determination.

Height curves show considerable differences between different plots (Fig. 7.1.1). Ideally these functions should be derived for each species, plot and observation year separately. But this is only possible if there are enough height observations. Also it can be observed that there is much variation in measured heights around such a height curve. As the influence of height on the tree volume is not linear, estimated heights from height curves may result in a bias in volume calculation.

All spatial data is shown in aggregated raster cells of 1°x2/3° size which prevents the overlap of neighbouring plots in the maps. Many plots have been observed repeatedly. Therefore the data have been spatially and temporally aggregated. Most of the grids contain less than 4 plots (Fig. 7.1.2).

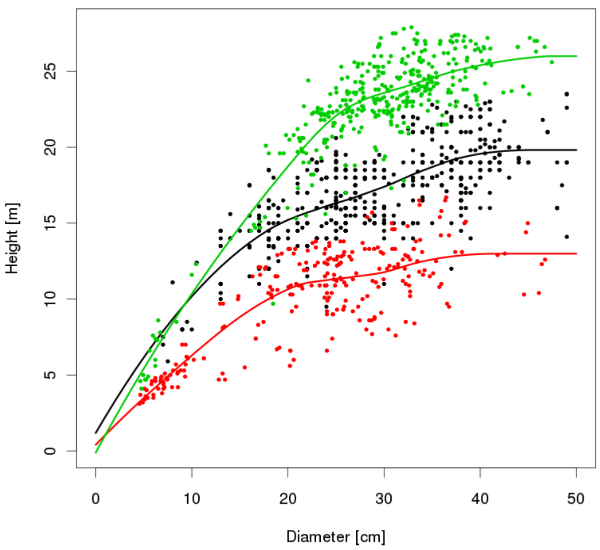

Fig. 7.1.1: Height curves of Pinus sylvestris on three Level II plots.

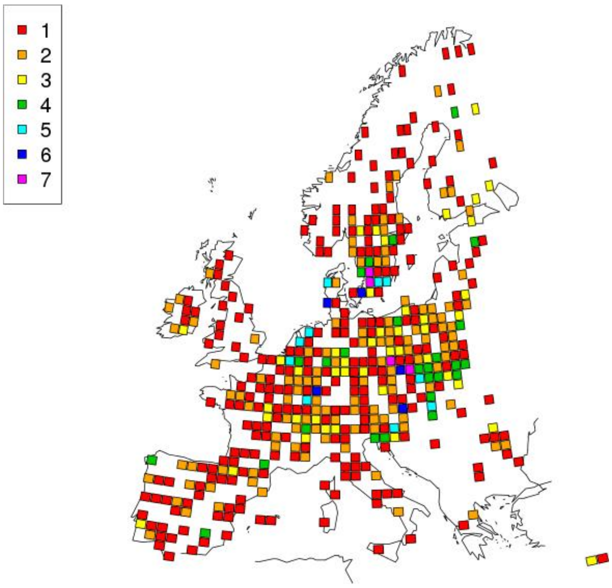

Fig. 7.1.2.: Number of plots per grid.

7.1.2 Data accuracy

The ICP Forests Manual (ICP Forests, 2010) requires for the two most important measured variables an accuracy of 90% of the values to be within +/- 1% of the mean (true) diameter, to be within +/- 2% of the mean tree height measurement for conifers and to be within 5% of the mean tree height for broadleaves. Independent remeasurements from seven sites in Austria and Switzerland were used to analyze if the desired accuracy was reached. The remeasurements show that the limits are reached for diameter, but not always for height assessments, especially in broadleaved stands.

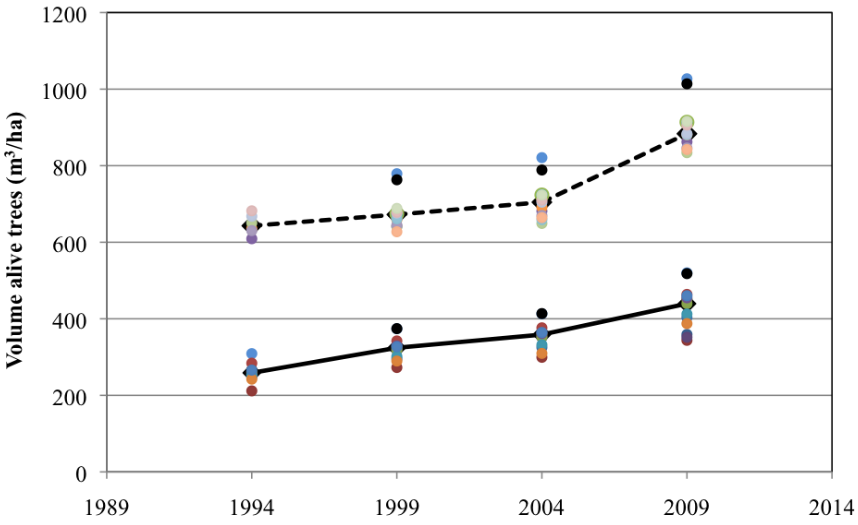

Figure 7.1.3-1: Calculated standing volume for two stands in the ring test. Lines represent the median value. Dots show different participating countries.

In addition to the measurement errors in the field, forest stand parameters (stand density, stocking volume and its increment) are prone to typing errors (e.g. wrong digits used or digits switched, misnumbered trees, switched species) and calculation differences. Calculation differences occur when different form functions are used and missing tree heights are substituted with regression estimates. To test how these calculations differ, a test data set for two sites with 4 subsequent inventories was compiled using two existing plots from Austria. Measurement errors, missing tree heights, mortality and removal codes and switched tree numbers were added to the data set. The last survey was modelled and thus not prone to measurement errors. The data set were sent around to the participating countries and the experts were asked to provide the key forest stand and increment parameters for each inventory as required for in ICP Forests. Experts were asked to use there own form functions to calculate tree volume and in addition to use the Austrian form functions. Thirteen countries participated in the ring test. Most countries used only their own form functions. It was tested how many estimates were within +/- 10 % of the median value. As expected for basal area per ha agreement was very high. All values were within +/- 10% and more than 90% of all values were within +/- 1% of the median value. For standing volume on average 80% of the calculated volume was within +/- 10 % of the median volume (Fig. 7.1.3). Usually the ordering of the volume estimate stayed the same for the subsequent inventories. This indicates that the main reason for the different orderings were the form functions applied. Volume increment is much smaller than volume stocks and therefore has a higher relative variability. Here, only 40% of the increment values were within +/- 10% of the median values.

7.1.3 Forest Growth

The basal area increment for the Level II plots was calculated with:

$$\text{Basal area increment/ha/Year} = \frac{\dfrac{ba_{t1}}{area_{t1}} - \dfrac{ba_{t0}}{area_{t0}} + \dfrac{ba\ removals_{t0t1}}{area_{t0}}}{t1 - t0}$$

where *ba* is the basal area, *area* the plot size, *t0* observation time of the first and *t1* of the second observation. Removals are all trees which have no dbh in the following survey or have a code describing their removal and mortality. As trees are not growing constantly over the year the dates of observation are related to the vegetation period. The time between two surveys was calculated using their observation date and assuming that there is a linear increment between day 120 and day 240 of the year.

Typically the wood volume is either related to total stem volume or to merchantable volume (above a certain diameter threshold). For this analysis the functions from Pollanschütz (1974) have been used to calculate stem wood and those from Kennel (1973) to calculate merchantable wood. The form factor of trees with a broken or forked crown were not calculated separately.

Measured diameters at breast height (dbh) range from 1cm to 120cm, with an average of 23cm. Heights range from 1m to 45m and show an average of 18m. Observed stem numbers are between 8 and 5000 trees per hectare, basal area ranges between 0.2 and 105m^2/ha and stocking stem volume between 1.5 and 1200m^3/ha. The average basal area increment is approximately 1m^2/ha/year and the average stem volume increment is 5.6m^3/ha/year.

The basal area increments of all plots and remeasurement intervals cover a wide range but most observations show an increment of basal area between 0 and 2 m^2/ha/year. Stem volume increment mostly ranges between and 0 and 20 m³/ha/year. Outliers are caused e.g. by short observations intervals, small areas or errors in the data.

The spatial distribution of the stocking stem volume shows higher volumes for plots in the Alps and lower volumes in the northern and southern regions (Fig. 7.1.4). Many plots have a volume between 300m³/ha and 600m³/ha. As there are many plots and many time periods which provide data, this information has been reduced in spatial and temporal dimension.

Diameter deviation on the plots can be used as an indicator of the homogeneity (low deviation) or heterogeneity (high deviation) of the trees on a plot. Plots in central Europe show more deviation than the others, indicating larger diameter- and a higher stand structural-diversity (Fig. 7.1.5).

Basal area and stem volume increments show similar spatial patterns (Fig. 7.1.6). Low increments are located in the south and north whereas the plots in Spain show very low increments. Moderate increments are observed on the plots in central and eastern Europe and high increments are found in the western region.

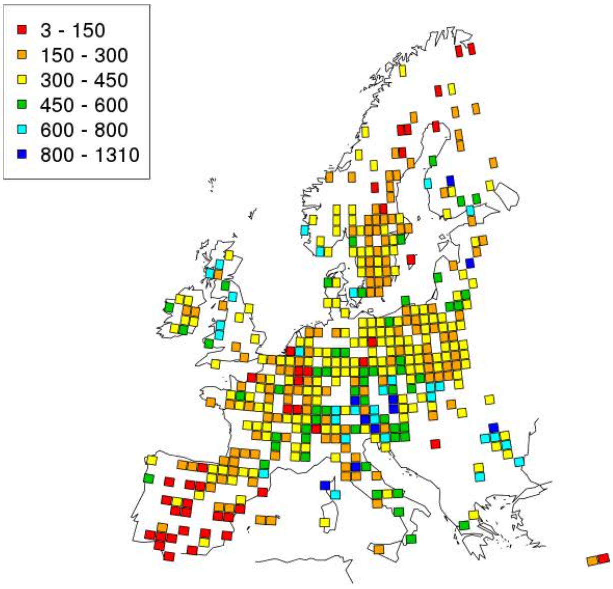

Figure. 7.1.4-1: Stocking stem volume [m³/ha]. Plot data averaged to means per grid cell.

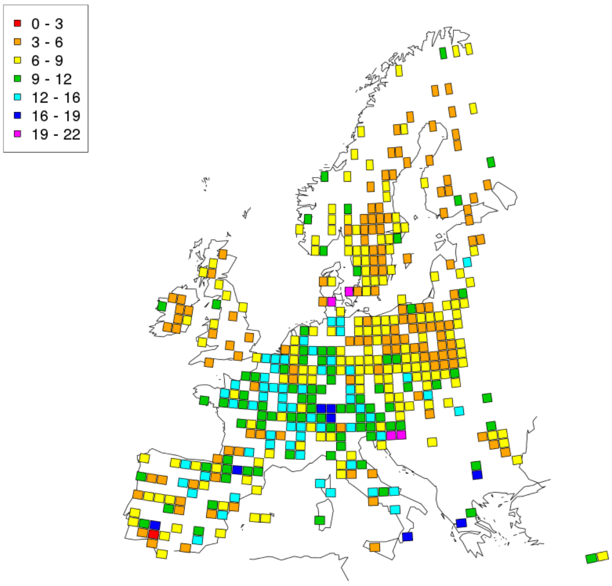

Figure. 7.1.4-2: Average dbh-deviation [cm]. Plot data averaged to means per grid cell.

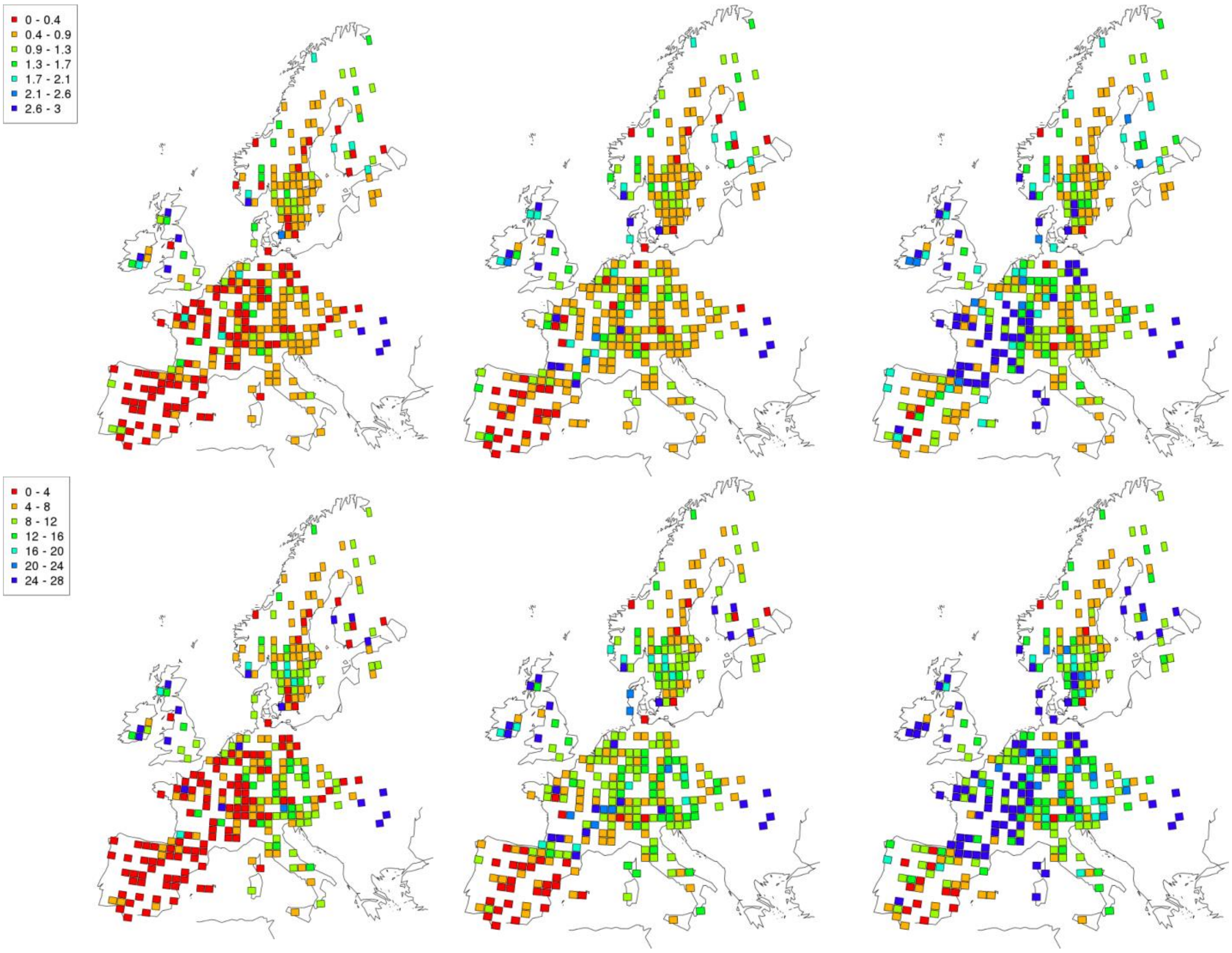

Figure 7.1.4-3: Basal area (top in m2/ha/a) and stem volume (bottom, in m3/ha/a) increment Left: lower 10%; Middle: median; Right: higher 90% of the observations.

7.1.4 The effect of atmospheric deposition and temperature on tree growth

In order to evaluate how atmospheric deposition and temperature change effect tree growth the first growth period 1994-1999 had been used and analysed. For this purpose even-aged leve II sites with at least one species being dominant had been chosen for the four main tree species Norway spruce (Picea abies), Scots pine (Pinus silvestris), common beech (Fagus sylvatica) and sessile and pedunculate oak (Quercus robur and petrea). More than 360 level II plots could be used. Taking the top height of the stand (i.e. the height of the 100 biggest trees per ha) and the stand age the site index (i.e. the height obtained at age 50 years) was estimated. Using the site index and a set of species-specific yield tables the expected volume growth for the given age and stand density (i.e. basal area per ha) was obtained for each site (Solberg et al. 2009). Altogether four such estimates were obtained per species using different yield tables. The deviation of the actual measured growth for the period 1994-1999 was calculated and used to identifiy the envrionmental factors that are currently influencing tree growth that are independent of the stand and site conditions, such as acidic and nitrogen depostion, deviation of temperature and precipitation form the long-term mean at the given site etc.

Between 18 and 40% of the current growth was explained by site index, stand age and stand density. The residuals of the site index models were used in analysis of covariance and multiple regression models using the environmental variables as predictors. For Norway spruce and Scots pine all models showed a significant positive effect of nitrogen deposition on growth. The same trend was found for common beech and oak, but the models were not always statistically significant. Acidic deposition and sulphour deposition were not negatively corrrelated with growth residuals. A deposition of 1 kg nitrogen per year and ha resulted on average in an increase of rougly 1% volume growth (Table 7.1.1, Solbeg et al. 2009, Laubhann et al. 2009). However, when the soills were grouped into nitrogen saturated (ratio of C to N smaller or equal to 25) versus nitrogen limitted sites (C/N ratio > 25) only on nitrogen limitted soils such a positive effect was found (Fig. 7.1.7).

Table 7.1.5-1 Range of modelled volume growth increase per 1 kg N deposition per year for the four main tree species in Europe for the various models used (in bold significant at p = 0.05, Solberg et al. 2009).

Tree species	Growth increase per 1 kg N
Norway spruce	+ **0.8 - 2.0 %**
Scots pine	+ **0.9 - 1.1 %**
Common beech	+0.3 - 1.0 %
Oak spec.	-0.4 - **1.6 %**
All combined	+ **1.2 %**

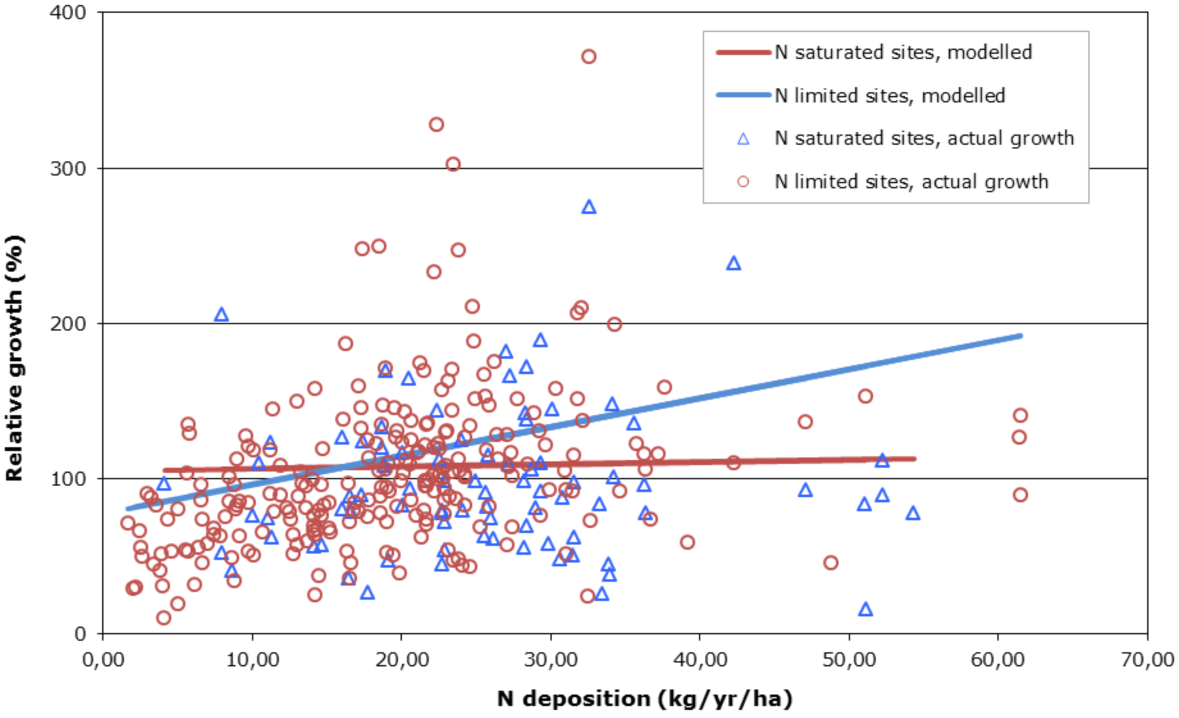

Figure. 7.1.5-1. Relative growth increase of all species combined on N saturated sites and N limited sites with modelled trend based on an analysis of covariate (Solberg et al. 2009).

For Norway spruce, Scots pine and common beech growth was significantly higher than expected when the growth period was warmer than usual (Fig. 7.1.8). Drought condition during the five year period tends to have a negative impact on tree growth, but this was only significant for Scots pine.

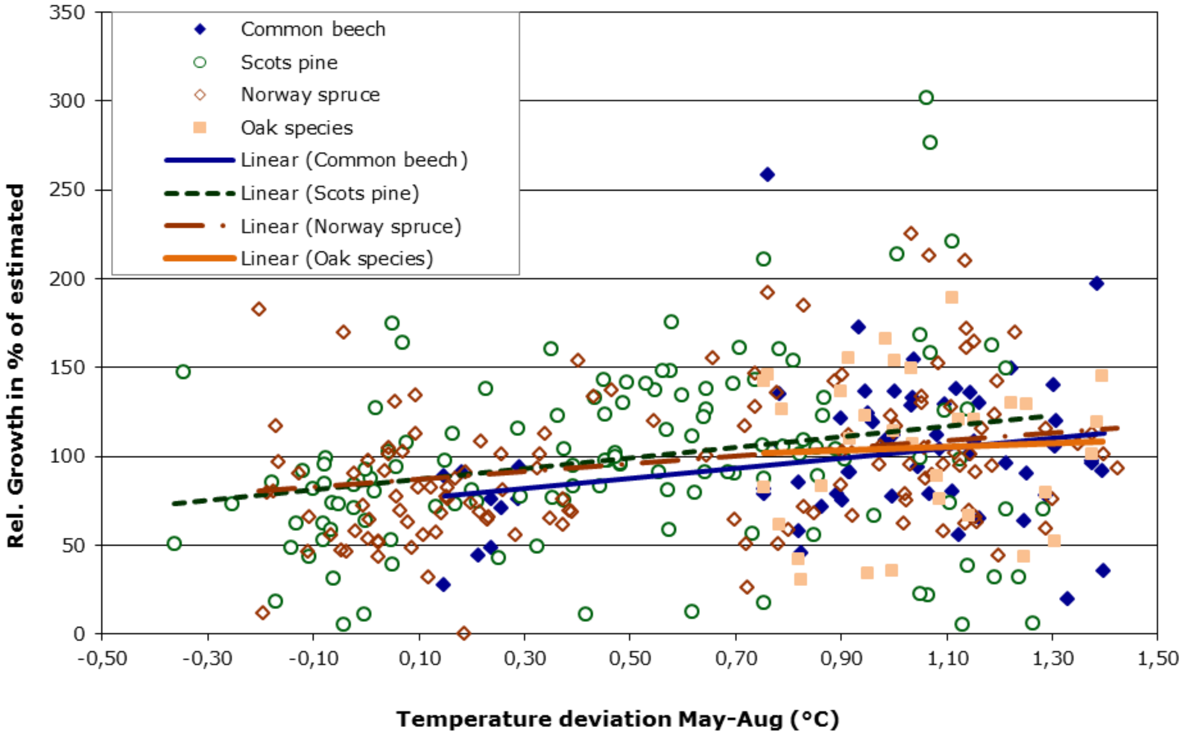

Figure. 7.1.5-3. Relative tree growth (1995-1999) against temperature deviation of the period 1993-2000 from the long-term mean for the main European species (Solberg et al. 2009).

7.1.5 Discussion and conclusions

The collected growth data provides a unique source of forest growth information for Europe. The various growth parameters can be linked to external as well as internal factors serving as a proxy parameter for the reaction of trees and stands to management, changes in site and environmental conditions. Furthermore they can be used e.g. for:

- Validation, refinement or creation of forest growth models.
- Observation of the geographical extension and growth response of specific species in relation to site and environmental conditions and their changes (soil, climate, deposition, pest and diseases).
- Estimation of harvestable wood and potential stocking biomass in European forests for different management (species selection, thinning, and harvest) and environment scenarios.

The highly aggregated results provide a first and general overview on forest growth in Europe. More specific investigations for single tree species will be essential to exploit the full benefit of the data set.

The current dataset includes more than 250 Plots which have not been remeasured up to now. For those plots no increment can yet be calculated, but first remeasurement data are expected soon. The longer the observation time of a plot is, the higher is the value of such data if the remeasurement interval is in the range of 5 years. To estimate volume increments at least tree height is essential. There are many ways to estimate tree heights using the measured diameter but none of them is as good as a measured height. Hasenauer and Monserud (1997) have reported that usage of estimated (smoothed) tree heights will lead to biased predictions. The tree volume is typically calculated using form factor functions based on diameter(s) and height (de Vries et al. 2003). Currently there exists no paneuropaen form factor function for different tree species. Such functions would allow the consistent volume estimates for European forests (de Vries et al. 2006). In addition e.g. terrestrial laser scanners could be used to observe the taper form of the trees (Klemmt and Tauber 2008).

In general the tree measurements are fairly precise. Diameter measurements are commonly more reproducible - compared to the observed size - than height assessments. The diameter is usually measured with a calliper or a circumference tape which will diverge if the stem has no circular shape. The basal area is calculated using the measured diameters. These calculations are usually done by assuming a circular stem diameter. Unbiased diameter observation will lead to a biased basal area calculation if the diameter has random measurement errors. The measurement error should be considered in the basal area calculation. Volume estimates including basal area, tree height and estimated form factors are necessarily prone to lower accuracy. Changes (increment) in basal area or stocking volume are influenced by two error components resulting from two measurements and are therefore less reliable than parameters describing actual condition like stocking volume. The magnitude of change variables is also normally smaller and measurement errors have a larger impact. Although volume estimates are more (economical) important, the separate analyses of basal area (e.g. stand density) and tree height (e.g. site index) and their changes are ecologically more relevant and more precise. The calculated forest increment for the first five year period (1994-1999) was used to test if current growth deviates from the expected growth based on stand site condition, stand density and stand age and if environmental factors, such as nitrogen deposition or temperature increase, can explain these growth deviations. Nitrogen deposition and above-average temperature had a positive effect on tree growth. No negative effect of acidic deposition could be detected. However, on soils with already higher nitrogen content nitrogen deposition had almost no effect. Whether continuous high nitrogen deposition may eventually lead to nutrient imbalance and growth decline will be examined in further studies. Warmer temperature increased forest growth. Drought tended to reduce growth, but was usually not found to be significant.. For future studies better drought indices incorporating water storage capacities of the soil and the potential transpiration of the forest stands should improve to identify the forest sites most sensitive under future climate change.

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7.2 Water budgets

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Abstract

The water budget of forests is one of the most important factors concerning tree vitality and forest condition. Moreover, the determination of soil water fluxes is of major importance in understanding a number of physiological processes like nutrient uptake, growth and response to biotic stress factors. The impact of environmental stressors like drought, physiological water shortage and elevated ozone concentrations may result in reduced tree growth, increased occurrence of pests and diseases as well as deterioration of crown condition. Especially in a changing climate, water availability together with nutrient supply and the detection of drought stress are important issues for forest health. However, water fluxes in forests are difficult to measure. Therefore, important fluxes such as transpiration, interception loss, soil evaporation, and drainage, are usually calculated using deterministic water budget models. While it is possible to directly assess evaporation, transpiration and seepage on a few forest investigation sites with intensive monitoring facilities using eddy flux, xylem sap flow, intensive soil water measurements, hydrographs in catchments, or large scale lysimeters, the determination of water fluxes on monitoring plots with more basic equipment and on a regional scale has to be based on results from water budget models.

In general, well designed water budget models are capable to give realistic and site specific results. These models use climate data (temperature, humidity, precipitation, solar radiation, wind speed) and information specific to the respective forest stand and soil. However, parameterization and the experience of model users are crucial for the quality of model results.

7.2.1 Improvement of water budget modelling

In order to be able to assess water availability in European forests, a standardized calculation of water budget components is necessary. Therefore, a water budget model comparison was the first step in this action. From this recommendations and guidelines for the appropriate use of standardized water budget modelling on European forest stands were derived.

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Table 7.2.1-1: European Level II sites used in water budget model comparison

Site	country	tree species	location	altitude	mean annual temperature	mean annual precipitation
Celerina	Switzerland	Swiss pine, Europ. Larch	09°53’23’’E 46°29’37’’ N	1850 m	1.9 °C	860 mm
Freising	Germany	European beech	11°39’22’’E 48°24’29’’ N	508 m	8.39 °C	860 mm
Juupajoki	Finland	Norway spruce	24°18’45’’E 61°51’05’’ N	177 m	4.39 °C	760 mm
Monte Rufeno	Italy	Turkey oak	11°53’51’’E 42°49’39’’ N	690 m	12.09 °C	970 mm
Solling	Germany	European beech	09°34’ E 51°46’ N	504 m	7.09 °C	1210 mm
Solling	Germany	Norway spruce	09°34’ E 51°46’ N	508 m	7.09 °C	1210 mm

Table 7.2.1-2: Water budget models used in model comparison

Water budget model	Reference	Number in Figure 7-1
ArcEgmo	Becker et al. 2002	1
BiomeBGC (version ZALF)	Thornton 1998, White et al. 2000, modified by Jochheim et al. 2007, Puhlmann & Jochheim 2007	2
LWF-Brook90	Federer and Lash 1978, modified by Hammel & Kennel 2001	3, 4, 5
Coupmodel	Jansson and Karlberg 2004	6, 7
Theseus	Wegehenkel 2000	8
Watbal	Starr 1999	9, 10

Six European Level II core plots (table 7.2.1-1) were used to validate different water budget models (Table 7.2.1-2) applied by different users. Due to the installation design of the plots, model validation was restricted to dynamics in throughfall and soil water content. Although basic plant and soil parameters as well as the climatic input data were the same for all model runs, the results showed high differences (Figure 7.2.1-1). The discrepancy between the model results was independent from site, model and user. However, an objective approach to estimate impacts of forest management and climate change on water budgets, especially drought stress and the amount of seepage, needs accurate results with a low dependency from the applied model or user.

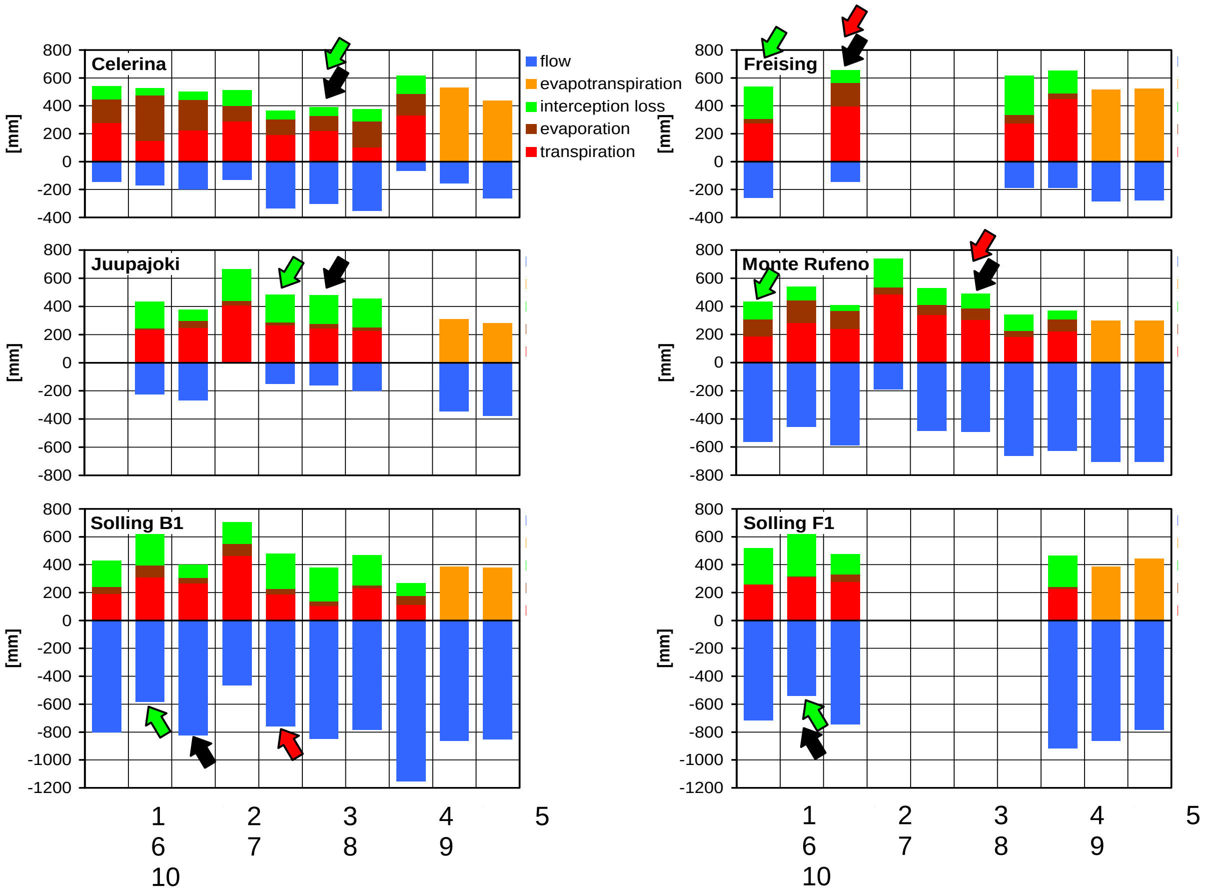

Figure 7.2.1-1: Comparison of mean annual water budgets for different model-user combinations (numbers at the x-axis see table 7.2.1-2). Arrows mark the best results from validation using measured time series of throughfall and soil water content (black: water content, green: throughfall; red: transpiration - only available for Freising, Monte Rufeno, Solling B1).

As a consequence the following recommendations should be considered:

Plausibility-check of meteorological input data
Plausibility-check of measurements used for model calibration/validation
Plausibility-check of soil water characteristics
(model soil water retention curves (SWRC) should correspond to measured soil water content)
Plausibility-check of model results (balanced water budget, literature)
Validation of measured and modelled throughfall
Validation of measured and modelled soil water content with respect to
-available soil water
-decrease due to transpiration

In addition, model validation can be improved using measured soil water flux rates (catchments hydrographs, large scale lysimeters) and transpiration rates (xylem sap flow, eddy correlation, daily differences in soil water content during drought) if available.

However, even well working and well validated water budget models for some thoroughly equipped plots throughout Europe will not automatically lead to realistic water budget modelling on a regional scale. An approach is needed to standardize model application, to eliminate user influence and to obtain important model input values from data available on regional level or at least for a large number of inventory plots (e.g. European Level 1 plots). With respect to climate, input methods as described in Chapter 6.2 can be used.

Model parameters relevant for the calculation of water flux through the soil profile are usually taken from pedotransfer functions (PTF) deriving hydraulic properties from the particle size distribution (texture) in the soil. Due to a lot of soil inventories throughout Europe, information on texture is comparatively well available. However, the use of different PTFs influences water budget model output (Figure 7.2.1-2). Especially in dry conditions, soil water flux and transpiration can differ by up to 100 % (in our example some 100 mm per year). Results from a couple of Level 2 plots suggest that the PTF HYPRES (Wösten et al. 1999) is well applicable for a wide range of loamy soils. However, sandy soils are probably better matched by other PTFs (e.g. Russ & Riek 2011). A pan-European evaluation for best choice of pedotransfer function or a new improved PTF is strongly recommended. The measurements of soil water characteristics on all D3 plots provide an ideal data basis.

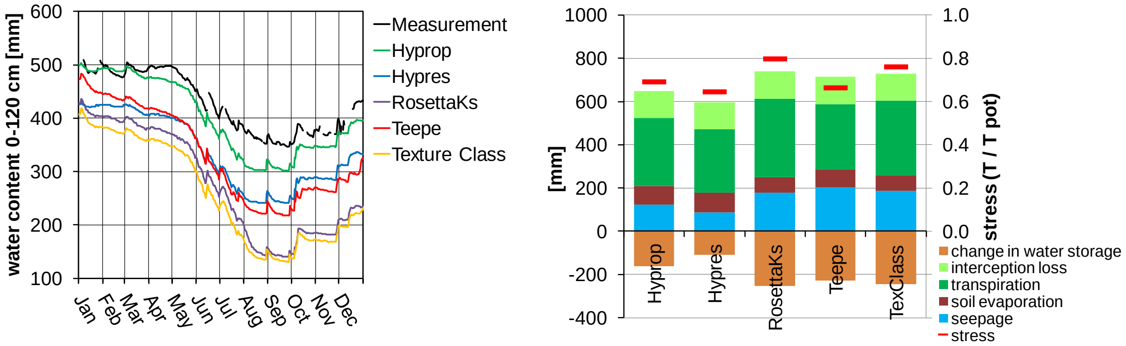

Figure 7.2.1-2: Impact of pedotransfer functions on soil water content and water fluxes. (plot 913, Oak, loam; Hyprop: measurement method of SWRC and hydraulic conductivity; other labels: different PTFs)

Crucial for correct water budget modelling is the calculation of transpiration, interception loss (evaporation from tree crown) and soil evaporation. Simplified, transpiration is driven by leaf area and leaf conductivity, interception loss by the evaporating leaf and stem area. Leaf area for deciduous trees can be derived from annual litter fall. Leaf and stem area is determined either by biomass investigations or by indirect measurements based on photographs or radiation properties. Values of leaf area and conductivity as well as stem area in literature cover a surprisingly wide range, both between tree species and for specific species (e.g. Breuer et al. 2003). Therefore, LAI was determined on all D3 plots within the FutMon project.

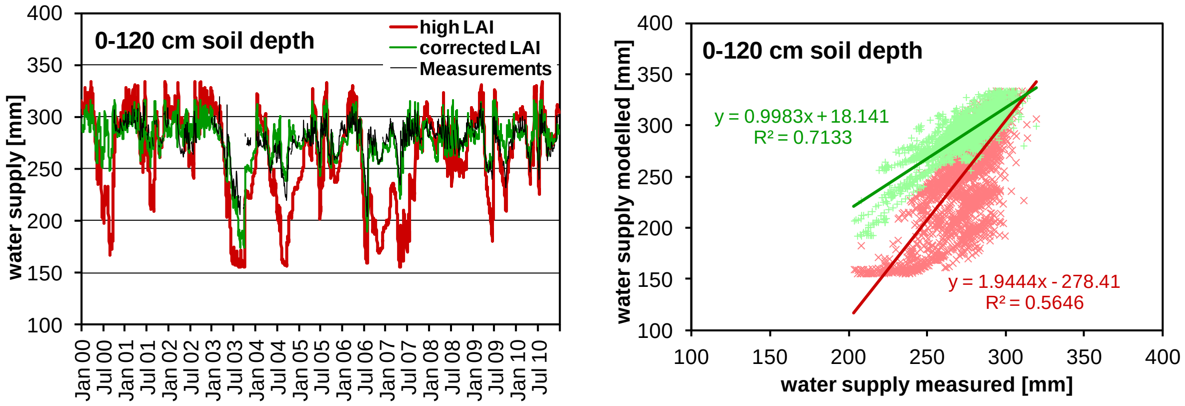

Figure 7.2.1-3: Validation of modelled soil water supply (plot 906, Norway spruce) using a high LAI from literature erature and a corrected LAI from plot specific needle biomass and specific needle area. Left side: measured and modelled soil water supply; right side: quality of model results expressed by linear regression (good results show a slope and R² close to 1).

A consistent approach of model parameterization was tested for five D3 plots with complete, long-term data sets for climate, stand and soil characteristics as well as soil water content. We used species specific values of leaf conductivity from literature, leaf area index of broadleaves from litter fall measurements, LAI of conifers and stem area index (SAI) from biomass studies. The biomass investigations relate tree dimensions (dbh, height) to leaf mass and stem area. A validation example is shown in Figure 7.2.1-3 comparing measured and modelled soil water content. Weighted R² in linear regression was used for validation index as proposed by Krause et al. 2005. For all five plots, weighted R² was well acceptable - independent of tree species, soil and climate (table 7.2.1-3).

Table 7.2.1-3: Quality of water budget modelling: modelled versus measured water supply in soil profile

Level 2D3 plot	tree species	soil	temperature/ precipitation	□R² 1998-2010	□R² dry year 2003
906	Norway spruce	loam/clay laom	7.5°C/1010 mm	0.71	0.74
908	Norway spruce	sandy loam	6.2 °C/960 mm	0.70	0.81
911	European beech	sandy (clay) loam	5.6°C/1570 mm	0.54	0.66
913	Common oak	silt/clay loam	8.0°C/740 mm	0.77	0.77
919	European beech	loam/clay laom	8.1°C/840 mm	0.66	0.83

$$\omega R^2 = \begin{cases} |b| \cdot R^2 & \text{for} \quad b \le 1 \\ |b|^{-1} \cdot R^2 & \text{for} \quad b > 1 \end{cases}$$

b: slope in linear regression (modelled versus measured values)
R²: coefficient of determination in linear regression

A similar approach was used to calculate stand and soil specific water budgets of forests throughout Bavaria, Southern Germany (8 x 8 km grid, figure 7.2.1-4). Soil texture, tree dimensions and stand characteristics were taken from soil and forest inventories. Provided that European databases offer sufficient information on regional climate, tree dimensions, stand, and soil, this approach can be extrapolated to all of Europe for tree species with available biomass studies for LAI and SAI determination. Nevertheless, further validation on core plots covering a wider range of climates, tree species, and soil properties is recommendable. Only then, a reliable assessment of water budgets under present and future climate conditions both applicable to large regions and sufficiently specific to real forest sites will be appropriate.

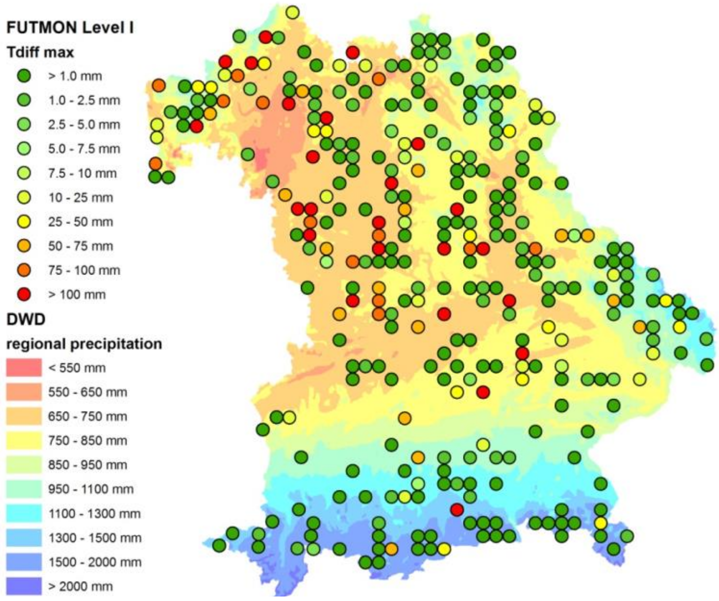

Figure 7.2.1-4: Drought stress (reduction of annual transpiration due to soil drought) in Bavaria, Southern Germany based on water budget modelling using soil and forest inventory data

7.2.2 Significant changes of water availability from 1960 to 2009 – a long-term study for the Level II plot Solling.

Apart from the balance of water fluxes, water budget models may also be used to provide information on the actual soil water availability for trees and its variation over time. These simulation results may directly be judged by comparison to measured data that are available on plots of the Level II net.

Changes of water availability in forests are expected to be most pronounced in mountainous regions, where the storage capacity of soils is lower due to shallow soils with relatively high stone content. The above mentioned Level-II plots in the Solling mountain range (Tab. 7-1) are two well investigated examples for this type of forest and provide soil moisture measurements since 1968. The time series of measured soil water content was elongated and gap-filled with LWF-Brook90 simulations based on local climate measurements and the results are presented here.

Soil water availability in the summer months decreased significantly by 13% (beech) and 7% (spruce) over the 50 years from 1960 to 2009 (Fig. 7.2.2-1). Significance of this trend was tested with the Mann-Kendall test and yielded an error probability below 1%. Despite this significant decrease of soil water availability, two very wet summers occurred during the last decade. But also the 5 driest summers occurred during the last 20 years of the investigation period. Soil water availability was highest in the summer of 1981 and lowest in summer 2003.

In contrast to this decrease, soil water content in the winter months (December, January, and February) increased by 2% under spruce and by 4% under beech, significantly on the 10% level. The three driest winters were found in 1963, 1970 and 1977, while the three wettest winters with regard to soil water content occurred in 1995, 2000, and 2004.

Climate projections for the Solling area (IPCC 2007) expected increasing precipitation for the winter months and decreasing precipitation in summer. The actual data seem to confirm these projections and show that changes in climate do affect forest soil water availability.

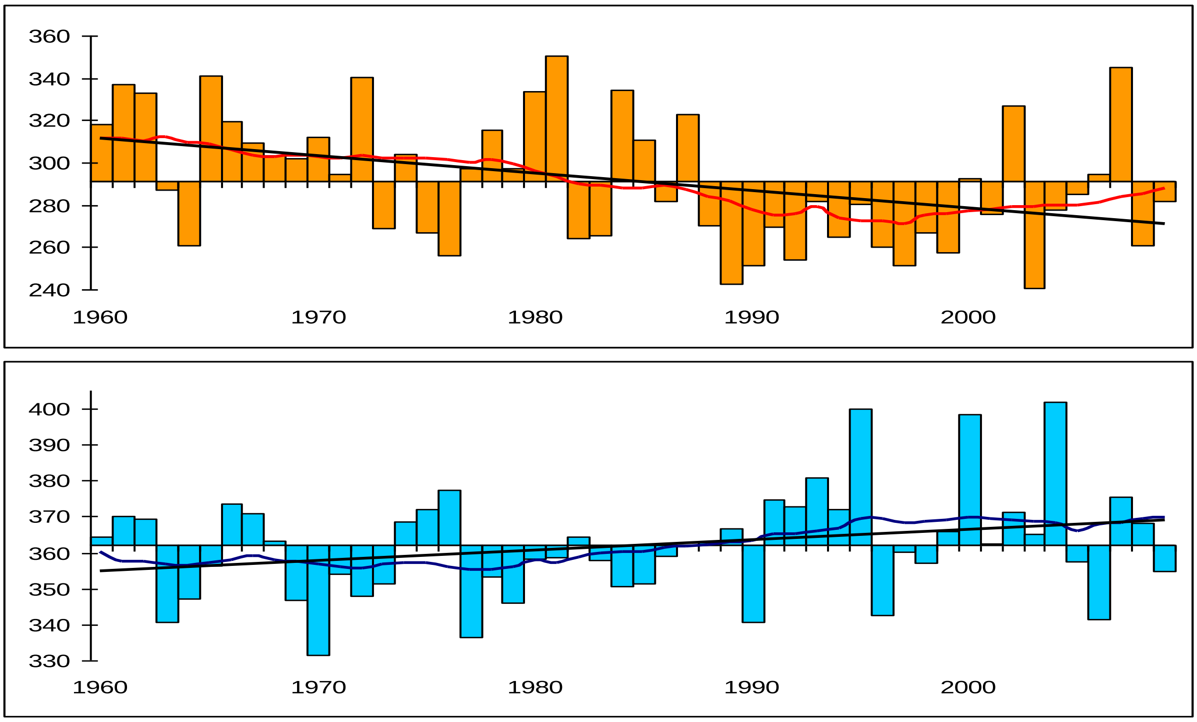

Figure 7.2.2-1: Deviation of the mean soil water content in summer (above) and winter (below) for the Level II plot Solling (beech)

7.2.3 Effects on tree growth

How did soil water availability affect tree growth in these 50 years? The answer has to consider that the influence of soil water content strongly depends on the seasonal activity of trees: While high soil water content in winter causes anoxia and subsequent dieback of roots, it is – in spring – the precondition for strong growth and formation of large vessels. A lack of soil water in this phase is usually more critical than in summer or autumn, since it affects tree growth over the whole year. Extremely dry soil conditions over longer periods in summer or autumn lead, however, to destruction of larger vessels, and may affect growth in several following years. The analysis of soil water effects must, therefore, be based on the time course of soil water content over each year and the specific characteristics it exhibited in comparison to other years.

Tree growth rings of 20 co-dominant beech trees at the Solling site were evaluated for this analysis and compared to soil water content (Figure 7.2.3-1).

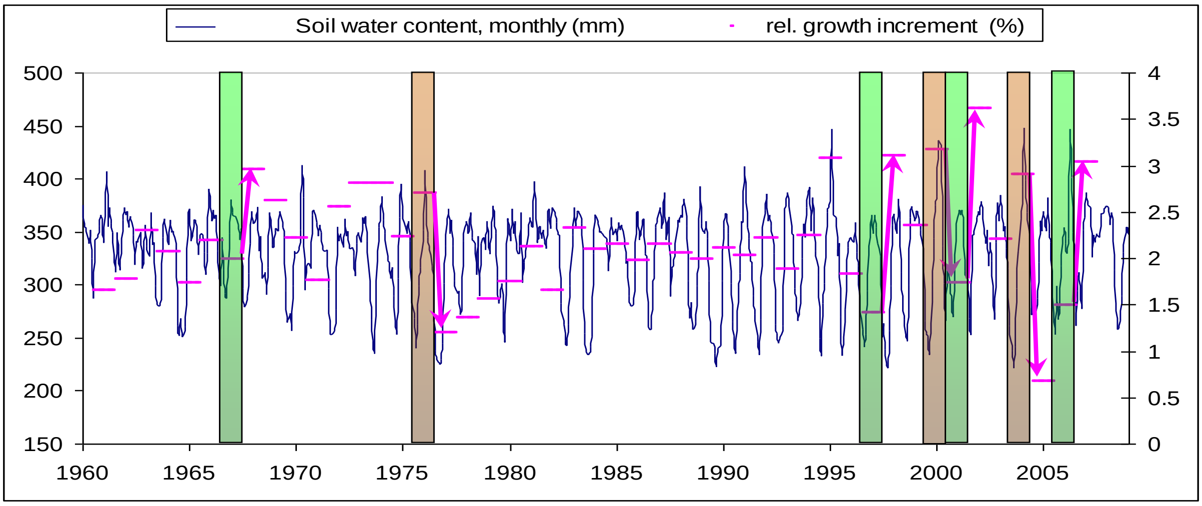

Figure 7.2.3-1: Development of soil water content (scale on the left) over 50 years in comparison to annual tree growth (scale on the right).

Their severest growth reductions occurred in 1976, 2000, and 2004 and this was typically after extreme and sudden changes in soil water content during spring and in the months before (indicated by brown rectangles in Figure 7.2.3-1). Extremely dry summers in the year before were followed by extremely wet winters and water content in spring decreased more sharply than usual.

On the other hand side, soil water content changed comparatively slowly in 1967, 1997, 2001, and 2006, when the strongest growth increments were recorded (indicated by green rectangles). The summer seasons in the year before were not very dry and the winters till mid of March not extremely wet. The soil dried rather slowly in spring, staying moderately moist till end of June.

With respect to all years since 1960, tree growth was affected by the velocity of changes in water content as well as by the most extreme values reached during the time course of a year: When the factors water availability of the preceding summer, water content in the preceding winter, and velocity of soil drying in spring are combined to one hydrological index, they can explain more than 50% of the measured variability of tree growth rates of beech and spruce trees in the Solling. Thus, though beech trees do grow well at much drier sites, their growth at this site reacts strongly to locally unusual soil water conditions.

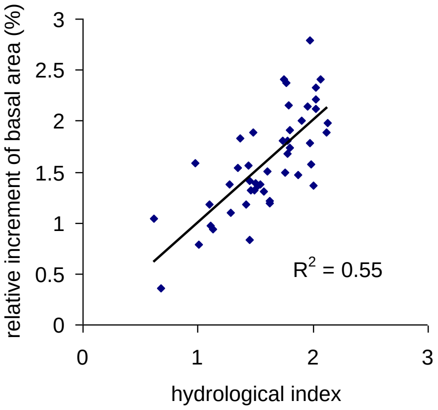

Figure 7.2.3-2: When the time course of soil water content changes is considered, hydrology may explain 55% of the variability in tree growth.

7.2.4 Effects of climate change

The IPCC climate projections expect for nearly all parts of Europe at least either rising precipitation rates in winter or lowered precipitation rates in summer, and a substantial part of Central and Western Europe is expected to face both changes at the same time. Most precipitation changes lie in the range of 10% to 20%. Additionally, temperatures are expected to rise everywhere in Europe and the world.

The most probable consequences of these changes for tree growth are alarming:

1. The changes in precipitation will most probably lead to more extreme conditions on both ends of the scale of soil water content: More extended anoxic periods in winter and more extended drought periods in summer would be the consequences.

2. Driven by the larger gap between both extremes in soil water content, soil water content would have to rise and fall more sharply than today.

3. Rising temperatures may as well enhance the extremes, since they lead to increased water losses in summer and higher water infiltration in the winter months (due to rain instead of snow).

All 3 effects are potentially severe risks for tree growth, if other trees react in the same way as in this investigation. Other effects of rising temperatures (acceleration of growth processes, elongation of the vegetation period, increased respiration losses) may in part counteract these developments.

7.2.5 Future application of water budget modelling

These are only a few examples for a possible characterisation of water budget and drought stress calculation of many Level II plots. They demonstrate the applicability of water budget modelling within the European forest ecosystem monitoring programme. This work will be continued in the future beginning with the water budget modelling for the core plots (FutMon D3 plots). Later on also other Level II and Level I plots could be included. This will be a substantial contribution for the monitoring of effects of climate change on forest ecosystems in Europe.

7.2.6 Conclusions

7.2.6.1 Degree to which the goal of the study was reached

All objectives of the study were reached,
Update of manual for meteorological measurements
Field protocol for determination of SWRC
Field protocol for LAI measurements
Literature study on correction methods of precipitation measurements
Water budget model validation and comparison
Modelling of water availability and drought stress for selected Level I and Level II plots

7.2.6.2 Scientific and political implications

Water budget can be calculated by the use of deterministic models for Level I and Level II plots reliably. Thorough model validation and site specific parameterization are essential. Thus, forest susceptibility to drought can be addressed under present and future climate conditions and recommendations for forest management adaption are possible.

7.2.6.3 Perspective for future work

Pan European modelling of water budget for all Level I plots

A pan-European evaluation for best choice of pedotransfer function or a new improved PTF is strongly recommended.

Parameterisation , calibration and run of a water budget model for core plots using measured SWRC, LAI, stand precipitation and soil moisture data
Developing a transfer function for LAI and SAI (using results of FutMon D1 and D3)
Parameterisation, calibration and run of a water budget model for all standard Level II plots and Level I plots

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7.3 The carbon budget under current and future climate

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Abstract

The carbon budget of 28 selected European FutMon / ICP Forests level II plots was simulated using the simulation model Biome-BGC (version ZALF). Data for the initialisation and calibration mainly originated from the level II database and from national forest institutes. They covered the topics meteorology, stem growth, litterfall, phenology, leaf area index, soil respiration, stand precipitation, soil water content, and soil temperature. As result of the model calibration 22 plots could be identified as carbon sinks and 6 plots as carbon sources between 1996 and 2009. Climate projections for the time periods 2040-2059 and 2080-2099 from the FutMon CLM dataset (CLM data, adapted to level II plots) were used for assessing future development. In general, the carbon sink function was simulated to increase under expected future climate conditions.

7.3.1 Introduction

Global change has the potential to modify the relation between biomass assimilating and dissimilating sub-processes and to change the resulting carbon sequestration. The politically relevant tasks in this context are to understand the sub-processes of the carbon budget of forest ecosystems, to assess the source-sink relationship for carbon under current and future climate conditions, and to find measures for carbon mitigation by forest management. Within the FutMon / ICP Forests level II program, the aboveground parts of the carbon balance were assessed by measurements. Modelling can be used to link different kinds of measured data in order to calculate the complete carbon budget of the investigated plots and to give estimates for future development of the carbon budget by applying climate scenarios. This requires a huge amount of information, of which most parts started to be measured at “core plots” of the FutMon project. Based on the level II database and additionally available data sources it should be evaluated whether the measurements carried out at level II plots are suitable to investigate the carbon budget of the forests. In the present study a modified version of the Biome-BGC model is used to calculate the carbon budget of selected level II plots and to simulate the impact of future climate conditions on the carbon budget.

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7.3.2 Methods

7.3.2.1 Investigated sites

In this investigation Biome-BGC was applied to 28 ICP Forests level II plots. They cover Germany (16), Italy (7), Slovakia (2), Austria (1), Belgium (1), and Greece (1). Within these countries, their altitude ranges from planar to alpine. The annual mean air temperature ranges from 4 to 12 °C, the mean precipitation from 580 to 1680 mm a^{-1}, and the mean nitrogen deposition from 3 to 44 kg N ha^{-1} a^{-1}. The dominant tree species on the plots are Pinus sylvestris L. (9), Picea abies [L.] Karst. (9), Fagus sylvatica L. (7), Quercus cerris L. (1), Quercus frainetto Ten. (1), and Quercus robur L. / petraea [Matt.] Liebl. (1). Full tree species names are abbreviated by the terms pine, spruce, beech, and oak in this text. The trees mainly belong to older stand age classes between 60 and 160 years.

7.3.2.2 Data for model application

The main sources of input data used for model application are listed below:

- FutMon / ICP Forests level II database (processing status: 08.06.2011), supplied by Thünen Institute for World Forestry, Hamburg
- Some additional data of German level II plots received from German Forest State Institutes (Bayerische Landesanstalt für Wald und Forstwirtschaft (LWF), Landeskompetenzzentrum Forst Eberswalde (LFE), Nordwestdeutsche Forstliche Versuchsanstalt (NW-FVA))
- Evaluated data on forest growth of level II plots, supplied by ICP Forests Expert Panel on Forest Growth
- Soil profile data from the BioSoil project, supplied by the Forest Soil Co-ordinating Centre at INBO and the European soil database (ESDB)
- Historical meteorological data from the NCEP/NCAR reanalysis dataset (2.5° grid) and E-OBS data (0.25° regular grid (version 5.0) and station data)
- Future climate projections from the FutMon_CLM dataset provided by the Thünen Institute for World Forestry, Hamburg (Olschofsky, 2011)

Based on our experience we classified the input data needed for initialisation, parameterisation, calibration, and validation of Biome-BGC concerning their necessity into the groups:

1. absolutely necessary for model application (meteorology, N deposition, initial values of stem and soil organic carbon pools, physical and hydrological soil parameters),
2. highly needed for model calibration (forest growth, litterfall, soil respiration, initial root depth and distribution, stand precipitation, canopy transpiration, soil moisture, phenology),
3. Useful for model calibration (LAI, time series of litter, CWD, and soil carbon pools, C:N ratios, specific leaf area, soil temperature, tree ring analysis).

Gaps in ICP Forests meteorological data were filled using the E-OBS dataset (version 5.0, 0.25° regular grid) for temperature and precipitation. Global radiation was derived from sunshine duration or cloud cover fraction of the closest E-OBS station. Relative humidity was taken from the NCEP/NCAR reanalysis dataset (2.5° regular grid). In order to shift the external data to the level of measured plot data, monthly means of external data and measured data on the plot were correlated and the linear regression parameters were used to correct the daily external data.

Climate projection data of the FutMon_CLM dataset (Thünen Institute for World Forestry, Hamburg) originate from the CLM dataset on basis of the IPCC-SRES emission scenarios A1B and B1 and the global climate model ECHAM5-MPIOM of the Max Planck Institute for Meteorology, Hamburg. The FutMon_CLM dataset was calibrated for level II plots by measured values on plots and the CRU dataset. The dataset consists of a calibration run (C20) for 1961-2000 and future projections for 2001-2100 for the emission scenarios A1B and B1.

The climate conditions of future simulation periods (see chapter “Simulation scenario setup” below) are compared to the reference scenarios (1990-2009). In the simulation period 2040-2059 the temperature increases by 1.1 °C and 1.6 °C for B1 and A1B, respectively, compared to the reference period, whereas the shift for the periods 2080-2099 is larger (2.4 °C, 3.6 °C for B1 and A1B, resp.). In the climate projections a shift of precipitation from summer to winter time is predicted. Increasing winter precipitation overcompensates the reductions in summer resulting in increasing annual precipitation sums (76 – 107 mm a^{-1} = 8 - 11 %, depending on period and scenario).

7.3.2.3 The simulation model Biome-BGC (version ZALF)

The biogeochemical model Biome-BGC (vers. 4.2) (Thornton et al., 2002) was developed for simulating the dominant processes of water, carbon and nitrogen dynamics in generalised biomes in a daily resolution and is applied mainly at regional to global scales. The model considers natural forests, but not managed ones. Complete sets of input parameters for major natural temperate biomes are provided (White et al. 2000) and for tree species growing in Central Europe (Churkina et al., 2003; Cienciala and Tatarinov, 2006; Jochheim et al., 2009; Pietsch et al., 2005).

The extended version of the model Biome-BGC (version ZALF; Jochheim et al., 2007; Puhlmann and Jochheim, 2007) allows for the simulation of managed forest stands, considers species specific phenology, and was extended by a multi-layered soil module for water and carbon budget calculation.

7.3.2.4 Scenario simulation setup

The calibration periods using measured meteorological data start between 1976 and 2001 and end in 2009 or 2010 depending on the availability of meteorological and stem growth data (Figure 7.3.2.4-1). In case of measurements starting later than 1990, which applies to most plots, a pre-simulation period of ten years was introduced in order to reduce model inherent trends during the calibration period before the actual simulation starts.

For the investigation of climate change effects the simulation results of two future periods were compared with those of a reference period. The reference period equals the calibration period keeping initial values, model parameters, and N deposition constant, but use climate projection data (C20/B1 or C20/A1B) from the FutMon_CLM dataset instead of measured climate data. For the future periods under changed climate the reference periods were shifted by 50 and 90 years and two emission scenarios B1 and A1B are distinguished (Figure 7.3.2.4-1).

For comparability of the plotwise simulation results the periods were truncated to 1996-2009 for the calibration period and to 1990-2009, 2040-2059, and 2080-2099 for the reference and future simulation periods.

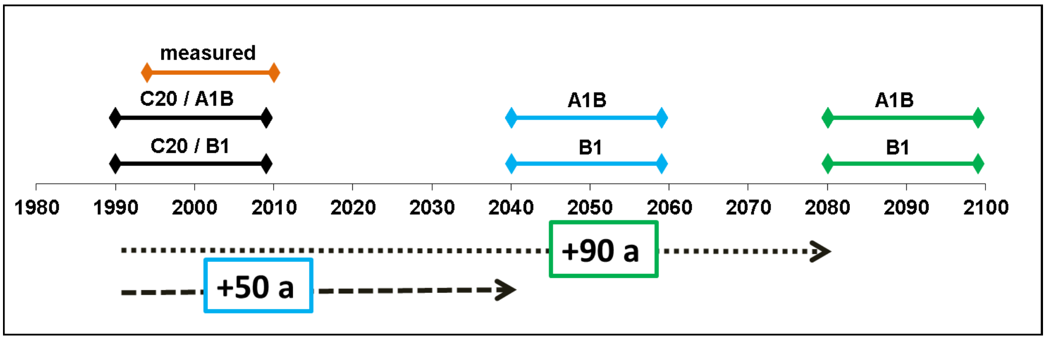

Figure 7.3.2.4-1 Schematic diagram of the time scales of simulation periods for the calibration using measured meteorology and the climate change projections with the reference periods of the past and two future periods

7.3.3 Results

7.3.3.1 The carbon budget under current climate

The comparison of simulation results with field measurements show, that the aboveground carbon and water budget (not depicted) can be displayed by Biome-BGC, whereas the belowground parts of the carbon balance (e.g. soil respiration) remain uncertain).

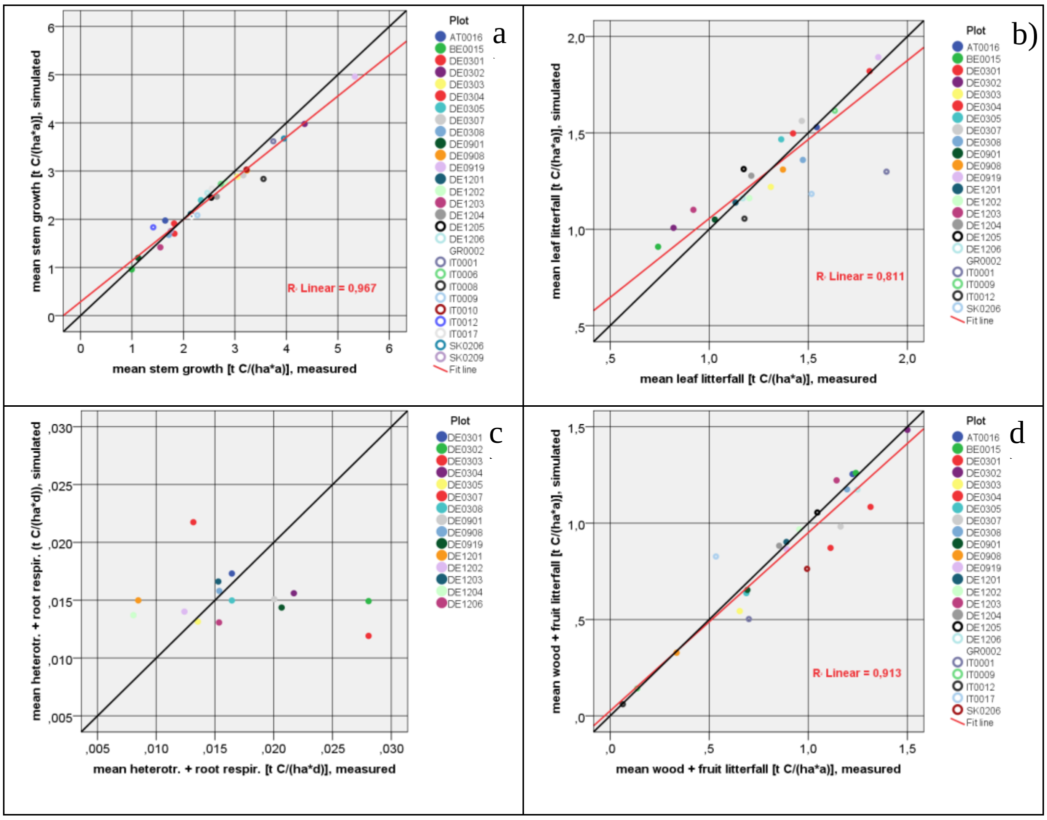

Figure 7.3.3.1-1 Regression between simulated and measured averages of stem growth (a), leaf litter fall (b), soil respiration (c), and wood+fruit litter fall (d)

For the year 2009, in our simulations on average a total carbon stock of 323 t C ha^{-1} was calculated for the forest ecosystems of the investigated plots with the main fractions in soil down to 100 cm depth (152 t C ha^{-1} = 47 %) and stem, branch and twigs wood (125 t C ha^{-1} = 39 %), followed by leaf + root litter including coarse woody debris (22 t C ha^{-1} = 6.9 %), coarse roots (18 t C ha^{-1} = 5.4 %), needle/leaves (3.9 t C ha^{-1} = 1.2 %), and fine roots (1.8 t C ha^{-1} = 0.6 %) (Figure 7.3.3.1-2).

The carbon balance can be expressed in terms of processes, by which the carbon leaves the ecosystem or is stored in different compartments (Figure). In terms of carbon balance the rate of photosynthesis is called gross primary production (GPP) and is simulated to a rate of 14.4 t C ha^{-1} a^{-1} for the investigated plots. The plant respiration, averaging 53 % of the GPP, is the largest process of carbon losses from the forests, consisting of maintenance respiration (39 % of GPP) and growth respiration (14 % of GPP). The rest (6.7 t C ha^{-1} a^{-1} = 47 % of GPP) amounts to the NPP, that is regarded as short term carbon balance. 28 % (= 4 t C ha^{-1} a^{-1}) of the fixed carbon is lost in the process of heterotrophic respiration (HR), leading to a NEP of 2.7 t C ha^{-1} a^{-1} as the medium term carbon balance. Taking into account the rate of exported carbon by harvest (0.91 t C ha^{-1} a^{-1} = 6.4 % of GPP) results in an average value of 1.8 t C ha^{-1} a^{-1} (= 13 % of GPP) for the NBP, that is seen as the long term carbon balance. The NBP corresponds to the sum of annual change rates of the carbon pools in vegetation (1.4 t C ha^{-1} a^{-1}), leaf and fine root litter (0.26 t C ha^{-1} a^{-1}), coarse woody debris (0.15 t C ha^{-1} a^{-1}), and soil organic matter (-0.07 t C ha^{-1} a^{-1}).

Negative NEP was computed for plot BE0015 that was induced by a high heterotrophic respiration rate. Six plots show negative NBP values corresponding to strong harvest actions (Figure 7.4.3.1-4).

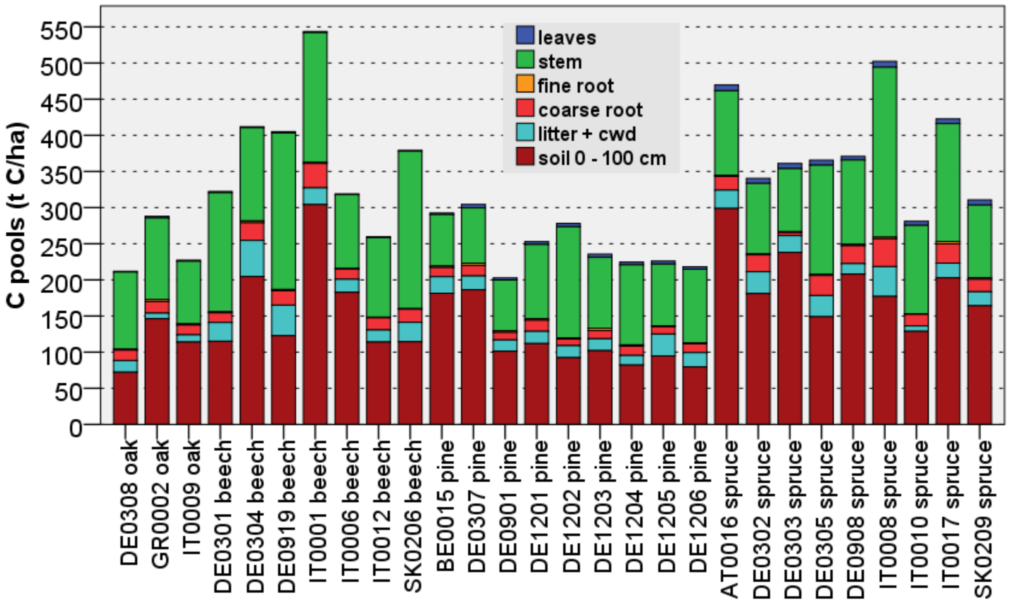

Figure 7.3.3.1-2 Carbon pools of forest ecosystems at level II plots as simulated for 2009 using measured climate data. Soil carbon includes humus layer and mineral soil (0-100 cm).

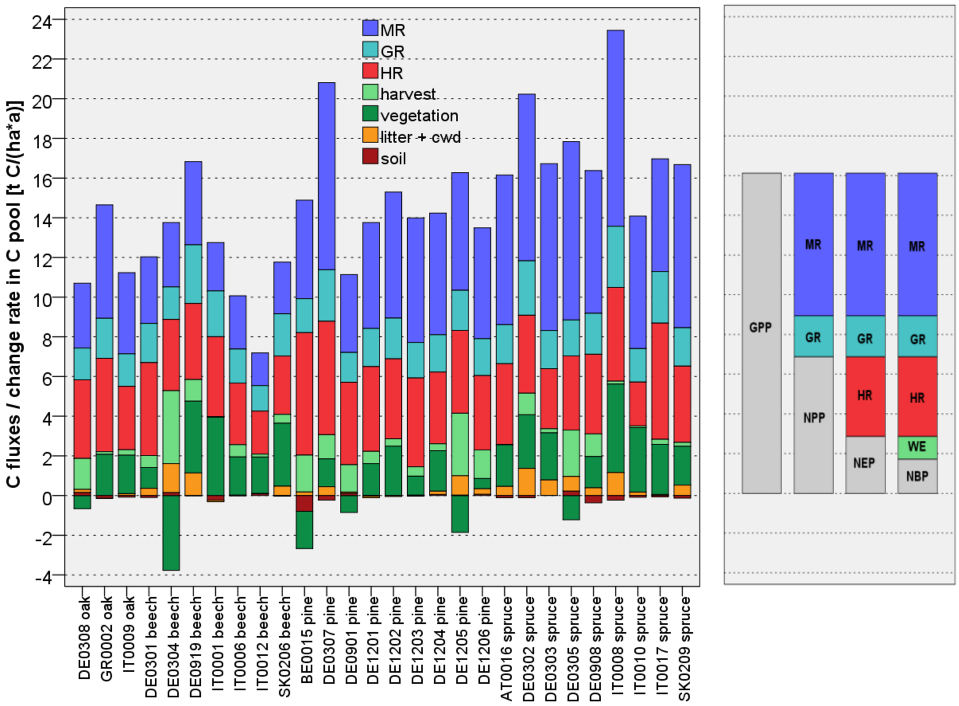

Figure7.3.3.1-3: Simulation results on carbon losses and change rates of carbon pools in vegetation, litter + coarse woody debris, and soil of forest ecosystems at level II plots between 1996 and 2009. The right part of the figure explains the different carbon balances and its composition.

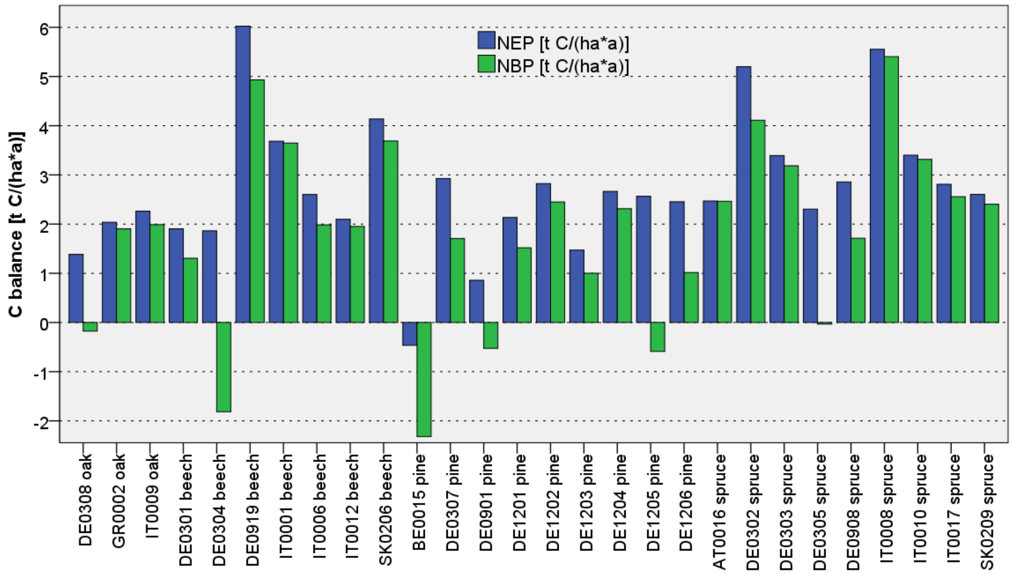

Figure 7.3.3.1-4: Simulated NEP and NBP of investigated plots using measured climate data over 1996-2009.

7.3.3.2 The carbon budget under changing climate

Compared to the reference period (1990-2009), gross primary production (GPP) was simulated to increase by 1.2 – 4.8 t C ha^{-1} a^{-1} or 9 – 35 % depending on the selected future period (2040-2059 or 2080-2099) and emission scenario (B1 or A1B). The low GPP for plot BE0015 is a result of erroneous climate scenario data, because the short wave radiation is lowered by 40% for both the reference period and future periods compared to measured values.

Similar to the GPP all respiratory processes are increased, too. The proportional increase of maintenance respiration (MR) ranges between 12 and 55 %. The increase of growth respiration (GR) is 7 – 22 %, those of the heterotrophic respiration 6 – 20 %. The indicators of the carbon balances (NPP, NEP, and NBP) as the difference of GPP and carbon losses are simulated to rise under future climate conditions. The NPP amounts to 6.4 t C ha^{-1} a^{-1} on average between 1990 and 2009 and rises by 0.5 to 1.4 t C ha^{-1} a^{-1} (7 – 22 %). Lower change rates were simulated for NEP (0.2 – 0.7 t C ha^{-1} a^{-1}, 10 – 26 %). NBP shows little increase in absolute terms (0.2 – 0.6 t C ha^{-1} a^{-1}) under future climate, but the relative changes are higher (13 – 359 Stem growth and similarly the litterfall rates of leaf, wood + fruit, and roots are accelerated under changing climate.

Under the climate reference scenarios for 1990 to 2009 the net change rates of carbon pools are calculated to 1.4 t C ha^{-1} a^{-1} for vegetation, to 0.25 t for leaf + fine root litter, and to 0.14 t for CWD pool, whereas the soil carbon pool decreases by 0.14 t C ha^{-1} a^{-1}. Compared to the reference period, the annual vegetation C pool change rates are enhanced by 0.22 – 0.66 t C ha^{-1} a^{-1} (15 – 47 %). The leaf + fine root litter C pool is enhanced by 10 – 20 %. The accumulation of CWD is diminished by 8 – 28 %. The carbon loss from soil is accelerated under future climate conditions by 13 – 64 %

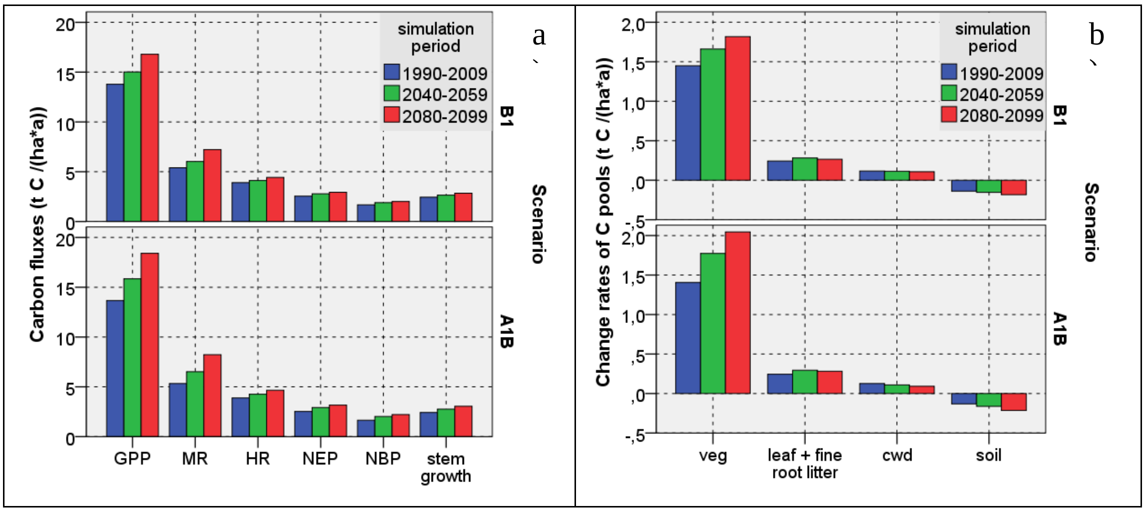

Figure 7.3.3.2-1: Simulation results on carbon fluxes and balances (a) and on change rates of carbon pools (b) of the periods 2040-2059 and 2080-2099 compared to the reference period (1990-2009) are shown as averages over all plots.

Table 7.3.3.2-1: Simulation results on carbon fluxes, balances, and change rates of carbon pools as average over all plots. The carbon fluxes of the reference period (1990-2009) and the absolute and relative differences of these fluxes or of change rates (Δ) of C pools of the periods 2040-2059 and 2080-2099 compared to the reference period (1990-2009) are shown.

		value in 1990-2009 (t C ha^{-1} a^{-1})	**difference to 1990-2009 (t C ha^{-1} a^{-1})**		**change (%) compared to 1990-2009**	
			2040-59	**2080-99**	**2040-59**	**2080-99**
Gross primary production (GPP)	B1	13.71	1.23	3.02	9.0	22.0
	A1B	13.58	2.20	4.76	16.2	35.1
Maintenance respiration (MR)	B1	5.35	0.63	1.83	11.8	34.2
	A1B	5.27	1.20	2.90	22.7	55.1
Growth respiration (GR)	B1	1.93	0.14	0.28	7.2	14.3
	A1B	1.92	0.23	0.43	12.1	22.4
Net primary production (NPP)	B1	6.43	0.46	0.92	7.2	14.3
	A1B	6.39	0.77	1.43	12.1	22.3
Heterotrophic respiration (HR)	B1	3.89	0.22	0.53	5.6	13.5
	A1B	3.87	0.37	0.78	9.6	20.1
Net ecosystem production (NEP)	B1	2.55	0.24	0.39	9.6	15.4
	A1B	2.52	0.40	0.65	16.0	25.8
Wood export by harvest (WE)	B1	0.88	0.02	0.05	2.2	6.1
	A1B	0.88	0.03	0.07	3.6	8.3
Net biome production (NBP)	B1	1.67	0.22	0.34	13.4	20.3
	A1B	1.65	0.37	0.58	22.6	35.1
Stem growth (SG)	B1	2.43	0.21	0.40	8.4	16.4
	A1B	2.41	0.35	0.63	14.3	26.2
Leaf litterfall	B1	1.35	0.09	0.19	6.8	14.3
	A1B	1.35	0.15	0.28	11.0	20.9
Wood + fruit litterfall	B1	0.74	0.02	0.05	2.7	7.1
	A1B	0.74	0.03	0.07	4.4	9.4
Root litterfall	B1	1.68	0.10	0.21	5.8	12.7
	A1B	1.68	0.16	0.30	9.5	18.2
Vegetation	B1	1.43	0.22	0.38	15.4	26.5
	A1B	1.39	0.38	0.66	27.5	47.4
Litter (leaf + fine roots)	B1	0.25	0.03	0.02	12.9	9.5
	A1B	0.25	0.05	0.04	20.4	17.4
Coarse woody debris	B1	0.13	-0.01	-0.02	-7.8	-13.5
	A1B	0.14	-0.03	-0.04	-18.1	-28.3
Soil	B1	-0.14	-0.02	-0.05	13.1	33.4
	A1B	-0.14	-0.04	-0.09	27.1	63.5

7.3.4 Discussion

7.3.4.1 Assessment of simulation results

7.3.4.1.1 Carbon budget under current climate conditions

The simulated aboveground biomass carbon stocks, coarse woody debris and soil carbon exceed the values from literature, while simulated coarse and fine root carbon stocks are in the range of reported values (Luyssaert et al., 2007; Nabuurs et al., 2003; Oehmichen et al., 2011; San-Miguel-Ayanz et al., 2010; Wirth et al., 2004). Higher aboveground biomass C value of the present simulation study may be explained by an over-representation of forests with high tree age in the plot selection compared to the other studies and the fact, that the selected plots are not representative for the whole area of Germany or Europe. The high value of the simulated CWD carbon can also be explained with different definitions of this pool. While the German forest inventory only considers wood with a diameter higher than 10 cm, the so called CWD carbon pool of Biome-BGC additionally includes other dead wood fractions from branches, twigs, bark and coarse roots. Concerning the soil C, it has to be considered that partly different soil depths were used for the estimation of soil carbon stocks.

The simulated carbon fluxes GPP and the NPP with its fractions foliar, wood, and root growth as well as the rates for autotrophic and heterotrophic respiration are in the range of the considered literature values (Bellassen et al., 2011; Luyssaert et al., 2007; Nabuurs et al., 2003; Vetter et al., 2005). Some lower NPP of pan-European area-representative estimations compared to our simulation results can be explained by the fact, that in the presented simulation forests with lower productivity due to climatic limitations are missing.

At the level II plots usually only the carbon fluxes litterfall and tree growth are measured. Application of a dynamic model can add estimations of not measured carbon fluxes. The close correlation of the plotwise means of simulated versus measured values of these variables document the successful calibration of the model. In contrast to stem growth and litterfall, for soil respiration a successful model calibration was not possible. On average, the same magnitude was computed, but the plotwise means did not correlate at all. Possible reasons can be seen in a mismatch of measured SOC used as initial values and the steady-state SOC. In this context, alternative methods for model initialisation and calibration have to be tested.

In order to answer the key question if the forest ecosystems react as carbon sources or sinks, the temporal scale has to be taken into account. NPP is regarded as short-term, NEP as medium-term, and NBP as long-term carbon sink (Grace, 2005).

While our simulated average NEP is still in the range of comparable values, the NBP exceeds the considered literature values (Bellassen et al., 2011; Karjalainen et al., 2003; Luyssaert et al., 2007; Nabuurs et al., 2003). With simulation periods of 11 to 34 years, the simulated carbon fluxes do not cover a whole rotation period and are therefore only valid for the considered time period. Especially wood harvest that mainly takes place at the end of the rotation period is computed considerably below the literature values that refer to the whole rotation period. This explains why the NBP obtained from the present study is significantly higher compared to a NBP that is representative for larger areas.

The NBP reflects the change of carbon pools in vegetation, litter, CWD, and soil. This balance cannot be verified with measured data from the level II plots, because no time series for these carbon pools exist.

Similar to NBP, the change rates of the vegetation, litter, and CWD carbon pools were higher than comparable values of the German greenhouse gas inventory (Oehmichen et al., 2011). Only the simulated change rate of soil carbon is smaller than the considered literature values.

7.3.4.1.2 Carbon budget under changing climate conditions

The simulation results presented here show that for the 28 selected level II plots the changed climate conditions lead to an accelerated carbon turnover in the whole forest ecosystem. The results on an 8-26 % enhanced wood increment under climate change conditions are in accordance with analyses of growth trends of the past (Boisvenue and Running, 2006; Spiecker et al., 1996) and simulation studies for future development (Eggers et al., 2008; Lasch et al., 2002).

For the calibration period the simulated stem growth was sensitive to changes in summer precipitation (not shown). Plants react to drought by closing their stomata (Irvine et al., 1998). This reduces water loss via transpiration and can reduce photosynthesis because the leaf conductance for CO2 decreases at the same time. Despite the fact that the simulation results predict an increase of summer drought stress for the future (not shown), stem growth rates, NEP and NBP were increasing (Figure 7). The summer drought effect on future growth development is not visible because it is overcompensated by the fertilizing effect of CO2 (Ceulemans and Mousseau, 1994). With higher atmospheric concentrations the demand for CO2 during photosynthesis can be fulfilled with lower stomatal conductance. This may lower transpiration rates and increases the water use efficiency (Leuzinger and Körner, 2007). Additionally, during spring and autumn the reduction of stomatal conductance is simulated to be weakened under future climate conditions (not shown) because of less frequent frost events (Delucia, 1987). Taking as well into account the improved water supply in spring, this leads to an overall enhanced annual GPP.

The length of the vegetation period also influences annual stem growth rates. Under the predicted future climate conditions higher air temperatures lead to an increase of the photosynthetic rate (Hyvönen et al., 2007) and an elongation of the vegetation period (Menzel et al., 2006). Similarly, our simulation results predict an extension of the vegetation period under future climate conditions by 5 % (B1) and 7 % (A1B), respectively, for the simulation period 2080-2099 (not shown).

In contrast to the mentioned studies above, simulation studies on pine stands in the federal state of Brandenburg, Germany predict a reduced productivity under climate change (Lasch and Suckow, 2007). From studies along climate gradients (north – south, maritime – continental) different growth reactions are expected depending on the climate zone. While the growth limiting effect of low temperature will be reduced under future climate in the boreal zone, an increase of the growth limiting drought effect is expected for the Mediterranean zone (de Vries et al., 2007; Kellomäki et al., 2005). Both effects are documented in our investigation, even if no regional differentiation was carried out.

The simulated increase of forest growth under future climate results in higher vegetation carbon pools. But despite higher inputs into the litter + cwd and soil carbon pools the simulation results show an accelerated decrease of SOC stocks on the investigated sites. The reason is, that HR is simulated to increase even stronger than the carbon input into the soil under future climate. Due to higher primary production more substrate becomes available for HR from leaf, wood, and root litterfall (Hyvönen et al., 2007). These substrates then undergo a stronger a stronger decomposition and HR because of increased temperature, unless strong changes in the soil water content may inhibit the respiration due to dry conditions or stagnant moisture.

The development of precipitation as part of the climate scenarios often determines the simulation result on forest growth. While the precipitation of the STAR scenarios (Orlowsky, 2007) is decreasing, corresponding to the simulated reduction of primary production (Lasch and Suckow, 2007), in our investigation the FutMon CLM scenarios predict increasing annual precipitation.

7.3.4.1.3 Reliability of simulation results

A comparison of several simulation studies on the future development of carbon stocks in European forests under climate change conditions led to widely differing results (Nabuurs et al., 2007). The simulation results and their reliability are determined by a large number of factors that can be classified into model assumptions, approaches for model initialisation and calibration, and the quality of model input or calibration data. In case of the application of climate scenarios consequences of the used simulation setup and the quality and source of projections on environmental conditions have to be considered. The results are restricted to the investigated level II plots and are hence not representative for European forests.

7.3.4.2 Limits of model assumptions

The model does not consider carbon pools for flowers and fruits. In order to account for the associated carbon fluxes of flowering and fructification they are subsumed under wood turnover that had to be increased. Consequently, the temporal dynamic of the competing carbon sinks stem increment and fructification (Mund et al., 2010) cannot be displayed adequately. Possible carbon losses caused by disturbances like wind throw, forest fire, insect attacks, or pollutants are not considered by the model. For this reason the simulated carbon balance has to be interpreted as potential carbon sequestration. On the other hand parts of these carbon losses are compensated as they are included in the underlying calibration data. Vertical relocation of soil organic carbon for example due to bioturbation or leaching of dissolved organic carbon is not considered by Biome-BGC. This may lead to an unrealistic accumulation or depletion of SOC in deeper soil layers. The turnover of ground vegetation biomass as possible pathways of organic matter into the litter layer is neglected by the model.

7.3.4.3 Quality of input data for model calibration

The quality of data used for model calibration may affect the simulation results. For some plots the data are relatively uncertain, for example for the gap filled measured meteorological data, soil parameters, and the fractionation of litterfall. Uncertainties may originate from the use of different methods, for example when measuring leaf area index, applying biomass expansion factors, or calculating total nitrogen deposition. Reliable data on initial coarse woody debris, vertical distribution, depth, and biomass of roots were mostly missing and had to be estimated.

7.3.4.4 Consequences of simulation setup for climate scenario application

For simulating the climate change effects we decided to keep the initial values and all other boundary conditions constant with the exception of climate data and the atmospheric CO2 concentrations. This avoids an overlaying effect of changing tree age during a simulation period of 110 years. Thus, the simulation results have to be attributed to a comparable "model stand" under changed climate. But the simulation results do not take into account the age development and clear cut of the forest stands. This would require knowledge on silvicultural scenarios, e.g. from the applicable yield tables, that was not available. It could also draw the focus on forest management effects instead of climate change.

The effect of the missing stand development is most apparently visible concerning the NBP, because the major part of the wood harvest takes place at the end of the stand development. Therefore the results from the present study are not comparable to long-term balances.

The effect of changing nitrogen deposition on future primary production and priming effects were not considered in this investigation.

7.3.5 Conclusions

By calibrating the simulation model Biome-BGC with level II data, a well-founded calculation of the carbon budget of forest stands is achievable. Furthermore, based on successful calibration the modified Biome-BGC model is a useful tool to assess climate change effects on forest ecosystems.

Under current climate conditions the investigated forests act mainly as carbon sinks. With one exception a positive NEP (on average 2.72 t C ha^{-1} a^{-1}) was simulated, denoting the forests as carbon sinks. Taking into account the carbon export by harvest, an average NBP of 1.81 t C ha^{-1} a^{-1}) was calculated.

Under future climate conditions the carbon sink function of the ecosystems was simulated to increase. Depending on the climate scenario applied and the regarded period, a plus of 0.2 – 0.6 t C ha^{-1} a^{-1} for NEP corresponding to 10 – 25 % and a plus of 0.2 – 0.6 t C ha^{-1} a^{-1} for NBP equivalent to 13 – 34 % was calculated.

Carbon losses caused by ecosystem disturbances like diseases, insect attacks, wind throw, or forest fire are not considered by the model. For this reason the simulated carbon balance has rather to be regarded as potential carbon sequestration.

Considering the availability and quality of the data and as the general reflection of the application of simulation models the following conclusion can be drawn: The simulation results on water budget and on the aboveground parts of carbon budget can be described adequately by the model for the current climate conditions, because the model could be calibrated by a number of measurements. The simulation results on the belowground part of the carbon budget have to be regarded as relatively uncertain because only few calibration data were available. Concerning the impact of climate change on the carbon balance of forests, uncertainties from the variation of different climate scenarios have to be considered. Additionally, the global radiation of the reference period of regionalised climate scenarios systematically deviates from measured meteorological data.

The monitoring data from the ICP Forests level II program, especially including the extensions at “core plots” during the FutMon project provide valuable information for calibration of dynamic simulation models for calculating the carbon budget of European forest ecosystems. The carbon budget cannot completely be measured, but modelling can contribute to fill these gaps. Simulation of carbon budgets using measured data presupposes an intensive analysis of data and helps to find inconsistencies and to improve data quality.

The results offer valuable input for further model development.

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8. Conclusions

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The implementation of the LIFE project "FutMon" by a consortium of 38 partners in 22 EU-Member States shows that the responsible Ministries and research centres in Europe are highly motivated to carry out forest monitoring based on a harmonized pan-European system which was further developed to comply with latest information needs of environment politics. Results of the further development are

- A revised large-scale (Level I) forest monitoring involving an increased number of plots of national forest inventories (NFIs) and contributions to the NFI harmonisation;
- A revised forest-eocsystem scale (Level II) monitoring involving a new set of about 250 plots featuring higher monitoring intensity than ever before with newly developed surveys permitting assessments of relationships between forest condition, forest growth, climate change, carbon fluxes, air pollution, and biodiversity;
- An improved quality assurance programme involving laboratory ringtests, field intercalibration exercises, as well as data compliance, conformity, and uniformity checks.
- An innovative database with on-line data submission, automated data validation, automated validation reports, data storage, interactive Web-GIS, and a data dissemination module.

The further development has greatly increased the scientific impact of forest monitoring as is shown by more than 100 articles based on Level I and Level II data published in peer-reviewed journals within the last three years. Several of the scientific results described in the present report prove the compliance of the system with recent information needs of environmental politics:

- Forests on the investigated Level II plots act as a carbon sink under current climate conditions. Under future climate conditions the carbon-sink function of forests will increase.
- Recent above-average temperatures and nitrogen deposition caused an increase in forest growth. This, however, does not mean that nitrogen deposition is generally of benefit as is shown by other data analyses under FutMon (see below).
- Nitrogen concentrations in the soil solution exceed critical limits on the majority of Level II plots. On 93% of the plots critical limits for nutrient imbalances in the organic layer were exceeded in more than half of the measurements. On 67% of the plots critical limits for elevated nitrogen leaching were exceeded in more than half of the measurements.
- The species diversity of epiphytic lichens was notably reduced on those forest ecosystem plots receiving high nitrogen deposition.
- CLRTAP and EU clean air politics have positive effects. There are first signs that the decrease in sulphur deposition is followed by a decrease in nitrogen deposition to forests. If current legislation is continued to be implemented, this will be of benefit for forest ecosystems in future years. Using Level I forest soil condition data, relationships found at Level II could for the first time be up-scaled to Level I. On 4600 Level I plots, the share of plots with critical load exceedances for nitrogen will decrease from 36% in the year 2000 to 9% in 2020.

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The scientific results prove that the forest monitoring system, in particular after its further development, is suitable for deriving cause-effect relationships from forest ecosystem data, for modelling forest ecosystem processes, and for up-scaling processes from the ecosystem scale to the large scale. This is in many cases a prerequisite for interpreting results of large-scale forest monitoring. Large-scale forest monitoring can describe the spatial and temporal variation of a number of parameters. That number of parameters, however, is mostly limited because of the high costs incurred by the high numbers of plots. This is why any future EU-level forest monitoring must rest on two pillars, namely large-scale and ecosystem scale surveys. This is also suggested by the 2012 report of the ad-hoc Working Group on Forest Information and Monitoring to the Standing Forestry Committee (SFC) of EC. For the same reason ICP Forests has taken over the system of standard and core Level II plots, the new surveys, and the database management system developed by FutMon. The revised monitoring system in connection with the database management system have boosted scientific data analyses by ICP Forests as was shown by its last two Science Conferences in Warsaw (2012) and in Belgrade (2013). Results show that the Level I and Level II monitoring data of ICP Forests are a basis for the verification of large-scale air pollution models as well as for risk assessments by means of modelling critical loads and their exceedances. They also permit the description of nutrient, carbon and water cycling in forest ecosystems and contribute to assessing risks from e. g. nutrient imbalance, climate change and drought. Their analyses contribute to a better understanding of carbon fluxes as well as the development of forest health and species diversity under different forest management, climate change, and atmospheric deposition scenarios. This enables ICP Forests to verify the effectiveness of clean air policies and to supply information to various policy processes. Besides meeting its obligations under CLRTAP, ICP Forests contributes data to LULUCF and CBD. Moreover, it contributes information to Forest Europe (FE, the former MCPFE). Relevant data are available for the following indicators: Carbon stock, forest damage, tree species composition, introduced tree species, deposition and air pollution, soil condition, and defoliation.

Future studies under preparation on Level I and Level II plots with emphasis on protected areas include

- Assessments of relationships between climate change, carbon fluxes and forest growth;
- Assessments of nitrate leaching into the groundwater;
- Prediction of the impact of climate change on the exceedance of critical loads for nitrogen;
- Assessments of invasive species;
- Assessments of threatened species;
- Prediction of the development of threatened species under climate change and air pollution;
- Predictions of the suitability of future site conditions to currently growing tree species;

These studies are also of priority for the new forest monitoring system planned by EC DG Environment. This shows that the monitoring system revised under FutMon with its combination of fully harmonised large-scale and ecosystem-scale assessments becomes available at the right time.

Annex I: Acronyms and abbreviations

Al	Aluminium
AMT	Annual mean air temperature
ANC	Acid neutralization capacity
AWC	Available soil water capacity
Bc	Base cation
BD	Bulk deposition
BE	Belgium
C	Carbon
C/N	Carbon-to-nitrogen
C/NFF	Carbon-to-nitrogen ratio of the forest floor
C/N_{MIN}	Carbon-to-nitrogen ratio of the mineral topsoil
Ca	Calcium
$CaCl_2$	Calcium chloride
CCE	Coordination Centre for Effects
CIAM	Centre for Integrated Assessment
CL	Critical loads
Cl	Chlorine
CLA	Critical loads for acidification
CLC	Corine Land Cover
CLE	Current legislation
CLF	Critical load function
CLM	Climate local model
CLmax(N)	Critical load for nitrogen-based acidity
CLmax(S)	Critical load for sulphur-based acidity
CLN	Critical load for nitrogen
CLnut(N)	Critical load for nutrient nitrogen
CLRTAP	Convention on Long- range Transboundary Air Pollution
CO_2	Carbon dioxide
COB	Cost Optimized Baseline
CORINE	Coordinanted Information on the European Environment
COST	European Cooperation in Science and Technology
CRU	Climate Research Unit
DBH	Diameter at breast height
DCA	Damage cause assessment
DE	Germany
DFP	Distribution function of possibilities
DG	Directorate General
DK	Denmark
DP	Deposition
DQL	Data quality limit
DQRs	Data quality requirements
EC	European Commission
ECE	Economic Commission for Europe
EMEP	European Monitoring and Evaluation Programme
ESDB	European Soil Database
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FR	France

FSCC	Forests Soil Coordinating Centre
GIS	Geographic Information System
GPP	Gross Primary Production
GR	Growth respiration
H	Hydrogen
HR	Heterotrophic Respiration
ICC	International Calibration Course
ICP Forests	International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovermental Panel on Climate Change
ISBN	International Standard Book Number
IT	Italy
IUSS	International Union of Soil Science
K	Potassium
KDE	Kernel density estimate
LAI	Leaf area index
LFE	Landeskompetenzzentrum Forst Eberswalde
LME	Linear mixed effects models
LT	Lithuania
LU	Luxemburg
LV	Latvia
LWF	Landesanstalt für Wald und Forstwirtschaft
MCPFE	Ministerial Conference for the Protection of Forests in Europe
MCPFE/FE	Ministerial Conference for the Protection of Forests in Europe/ Forest Europe
MFR	Maximum (technically) feasible reduction
MPI	Message passing interface
MQOs	Measurement quality objectives
MR	Maintenance respiration
N	Nitrogen
Na	Sodium
NAT2000	Natura 2000 Networking Programme
NBP	Net biome production
NDEP	Nitrogen deposition
NEP	Net ecosystem production
NFI	National Forest Inventory
NH_4	Ammonium
NL	The Netherlands
NO	Norway
NO_2	Nitrogen dioxide
NO_3	Nitrate
NO_X	Nitrogen oxides
NPP	Net primary production
NW FVA	Northwest German Forest Research Institute
O_3	Ozone
OWL	Other wooded land
P	Phosphorous
PCC	Programme Coordinating Centre
pH	Logarithmic measure of hydrogen ion concentration
PREC	Annual precipitation

PTF	Pedotransfer functions
QA	Quality assurance
QC	Quality control
RO	Romania
S	Sulphur
SAI	Stem area index
SDEP	Sulphur Deposition
SFC	Standing Forestry Committee
SG	Stem Growth
SLA	Service Level Agreement
SMB	Simple Mass Balance
SO_2	Sulfur dioxide
SO_4	Sulphate
SOP	Standard Operating Procedure
SRES	Special Report on Emissions Scenarios
SS	Soil solution
$S\text{-}SO_4$	Sulphate sulphur
ST	Soil types
SWRC	Soil water retention curves
TI	Thünen Institute
TF	Throughfall deposition
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
USA	United States of America
VSD	Very Simple Dynamic Model
WE	Wood export by harvest
WRB	World Reference Base

Annex II: Partners under the FutMon consortium

Austria
Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW)

Belgium (Flanders)
Research Institute for Nature and Forests (INBO), (EV INBO)

Bulgaria
Ministry of Environment and Water, Environmental
Executive Agency, Monitoring of Land, Biodiversity and Protected Areas Department (Ex-EA)

Cyprus
Ministry of Agriculture, Natural Resources and Environment, Department of Forests

Czech Republic
Forestry and Game Management Research Institute
(VULHM)

Denmark
Forest and Landscape Denmark, University of Copenhagen

Estonia Forest Service, Department of Agriculture, Fisheries and Food (DAFF) Forest Service, Department of Agriculture, Fisheries and Food (DAFF) Forest Service, Department of Agriculture, Fisheries and Food (DAFF)
Estonian Centre of Forest Protection and Silviculture (EEIC)

Finland
Finnish Forest Research Institute, (METLA)

Germany
Johann Heinrich von Thünen – Institut (TI)

Germany (Baden-Württemberg)
Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg (LVA)

Germany (Bayern)
Bayerische Landesanstalt für Wald und Forstwirtschaft (LWF)

Germany (Brandenburg)
Landesforstanstalt Eberswalde (LFE)

Germany (Hessen, Niedersachsen, Sachsen-Anhalt, Schleswig-Holstein)
Nordwestdeutsche Forstliche Versuchsanstalt (NW-FVA)

Germany (Mecklenburg-Vorpommern)
Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz (LU M-V)

Germany (Nordrhein-Westfalen)
Landesamt für Natur, Umwelt und Verbraucherschutz NRW, Fachbereich Monitoring, Effizienzkontrollen, Dezernat Forstliches Umweltmonitoring (LANUV)

Germany (Rheinland-Pfalz)
Forschungsanstalt für Waldökologie und Forstwirtschaft Rheinland-Pfalz (FAWF RP)

Germany (Saarland)
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Thüringer Landesanstalt f. Wald, Jagd u. Fischerei (TLWJF)

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Ministry of Rural Development and Food, General Directorate for the Development and Protection of Forests and Natural Environment (GDF)
National Agricultural Research Foundation (NAGREF), Forest Research Institute of Athens

Hungary
Central Agricultural Office (CAO), Forestry Directorate

Ireland
Forest Service, Department of Agriculture, Fisheries and Food (DAFF)

Italy
CONECOFOR OFFICE, National Forest Service (DIV. VI)
Agriculture Research Council (CRA)
National Research Council (CNR)

Latvia
Latvian State Forest Research Institute (SILAVA

Netherlands
Ministerie van LNV, directie Kennis, Ministry of Agriculture, Nature and Food Quality (LNV)

Poland
Forest Research Institute (IBL)

Romania
Forest Research and Management Institute ICAS)

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