International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)

Further development and implementation of an EU-level Forest Monitorng System (FutMon)

Forest Condition in Europe

2011 Technical Report of ICP Forests and FutMon

Work Report of the:

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2011 Technical Report of ICP Forests and FutMon

Richard Fischer, Martin Lorenz (eds.)

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United Nations Economic Commission for Europe (UNECE)
Convention on Long-Range Transboundary Air Pollution CLRTAP
International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)
www.icp-forests.org

Further development and implementation of an EU-level Forest Monitorng System (FutMon)
www.futmon.org

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Cover photos: Dan Aamlid (landscape, top), Richard Fischer (middle) Silvia Stofer (bottom)

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Preface

Forests provide a wealth of benefits to the society but are at the same time subject to numerous natural and anthropogenic impacts. For this reason several processes of international environmental and forest politics were established and the monitoring of forest condition is considered as indispensable by the countries of Europe. Forest condition in Europe has been monitored since 1986 by the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) in the framework of the Convention on Long-range Transboundary Air Pollution (CLRTAP) under the United Nations Economic Commission for Europe (UNECE). The number of countries participating in ICP Forests has meanwhile grown to 41 including Canada and the United States of America, rendering ICP Forests one of the largest biomonitoring networks of the world. ICP Forests has been chaired by Germany from the beginning on. The Institute for World Forestry of the Johann Heinrich von Thünen-Institute (vTI) hosts the Programme Coordinating Centre (PCC) of ICP Forests.

Aimed mainly at the assessment of effects of air pollution on forests, ICP Forests provides scientific information to CLRTAP as a basis of legally binding protocols on air pollution abatement policies. For this purpose ICP Forests developed a harmonised monitoring approach comprising a large-scale forest monitoring (Level I) as well as a forest ecosystem forest monitoring (Level II) approach laid down in the ICP Forests Manual. The participating countries have obliged themselves to submit their monitoring data to PCC for validation, storage, and analysis. The monitoring, the data management and the reporting of results used to be conducted in close cooperation with the European Commission (EC). EC co-financed the work of PCC and of the Expert Panels of ICP Forests as well as the monitoring by the EU-Member States until 2006.

While ICP Forests - in line with its obligations under CLRTAP - focuses on air pollution effects, it delivers information also to other processes of international environmental politics. This holds true in particular for the provision of information on several indicators for sustainable forest management laid down by Forest Europe (FE). The monitoring system offers itself for being further developed towards assessments of forest information related to carbon budgets, climate change, and biodiversity. This is accomplished by means of the project “Further Development and Implementation of an EU-level Forest Monitoring System” (FutMon). FutMon is carried out from January 2009 to June 2011 by a consortium of 38 partners in 23 EU-Member States, is also coordinated by the Institute for World Forestry of vTI, and is co-financed by EC under its Regulation “LIFE+”. FutMon revises the monitoring system in close cooperation with ICP Forests. It establishes links between large-scale forest monitoring and National Forest Inventories (NFIs). It increases the efficiency of forest ecosystem monitoring by reducing the number of plots for the benefit of a higher monitoring intensity per plot. This is reached by means of a higher number of surveys per plot and newly developed monitoring parameters adopted by ICP Forests for inclusion into its Manual. Moreover, data quality assurance and the database system are greatly improved.

Given the current cooperation between ICP Forests and FutMon, the present Technical Report is published as a joint report of both of them.

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

Susanne Iost[1], Pasi Rautio[2], Antti-Jussi Lindroos[3], Richard Fischer[1], Martin Lorenz[1]

4.1 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.

4.2 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).

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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 concept 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.

4.3 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).

4.4 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 (Tab. 4-1)

Table 4-1: Specific critical limits for nitrogen concentration in soil solution in different forest types (UNECE, 2007)

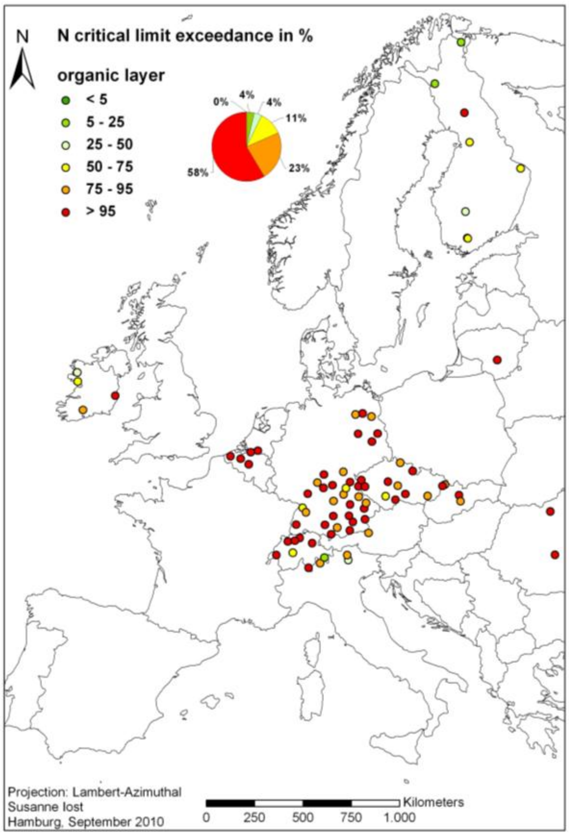
Effect	Chemical Criterion	Receptor
Nutrient imbalances	> 0.2 mg N / l soil solution > 0.4 mg N /l soil solution	Coniferous forests Deciduous forests
Elevated N leaching / N saturation	> 1 mg N / l soil solution	All forest types
Reduced fine root biomass /root lenght	> 3 mg N / l soil solution	All forest 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.

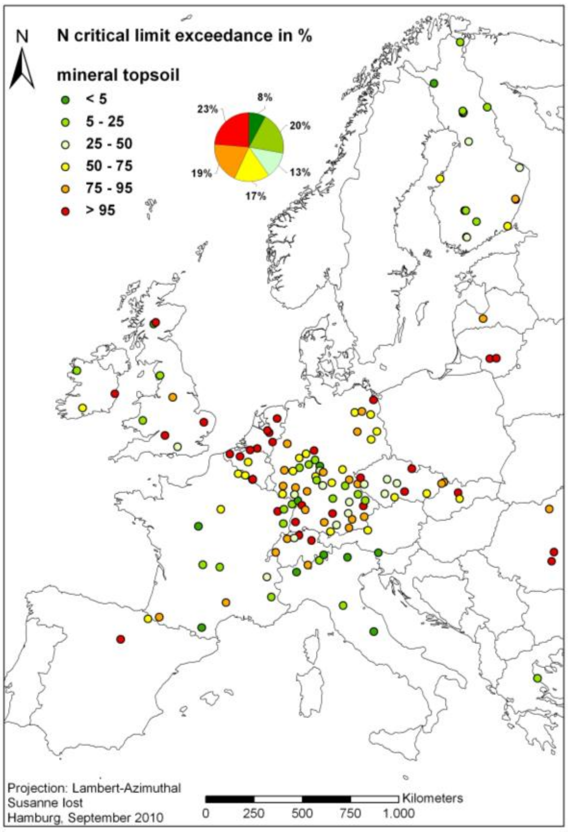
For the evaluation of temporal trends samplerwise exceedance frequencies were aggregated to annual plot means for organic layer, mineral top- and subsoil layers. Pearson correlation coefficients of annual plot means with number of years from the beginning of the measurements were calculated. Time trends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

4.5 Results

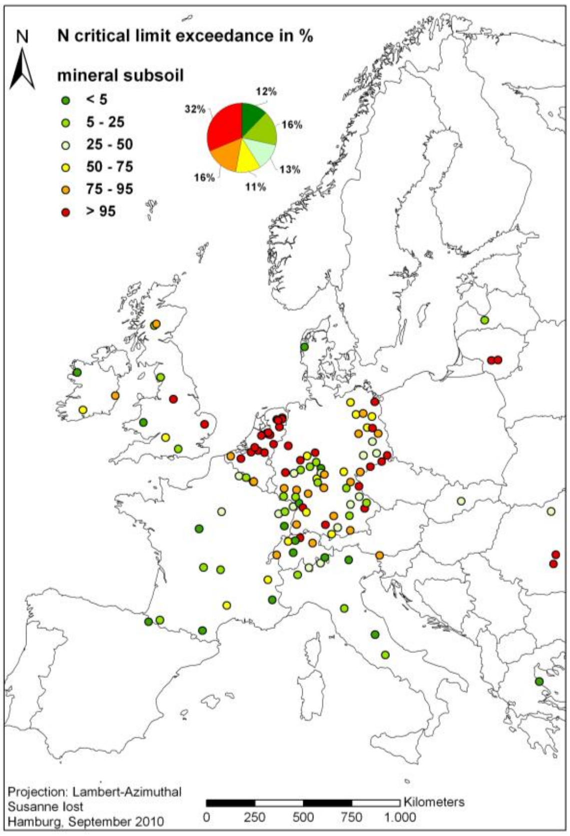
After data quality checks measurements from 1491 samplers on 173 plots in 17 countries were available for the analysis of nitrogen concentrations. On 93% of the plots CLim for nutrient imbalances in the organic layer were exceeded in more than 50% of the measurements (Fig. 4-1). For both, the mineral 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 (Fig. 4-2). The share of plots where CLimE for reduced fine root biomass (Fig. 4-3) or enhanced sensitivity to frost and fungi (Fig. 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

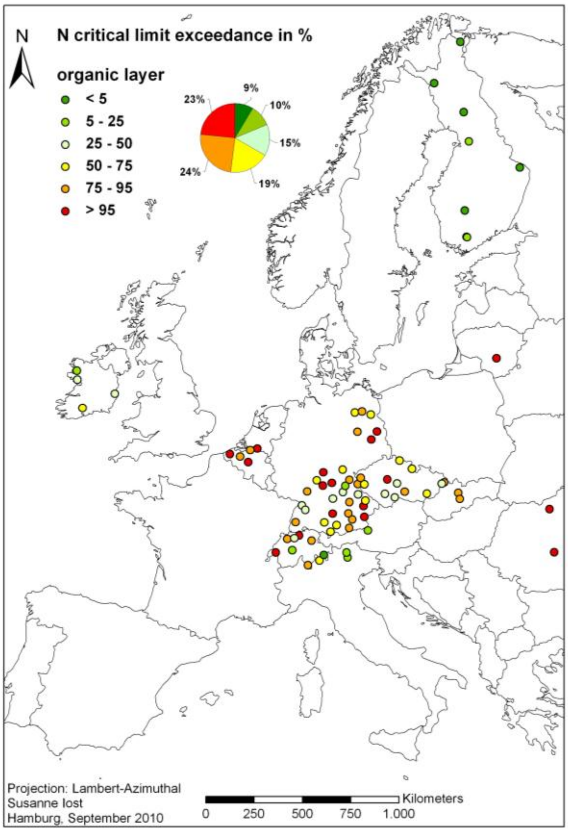


mineral topsoils

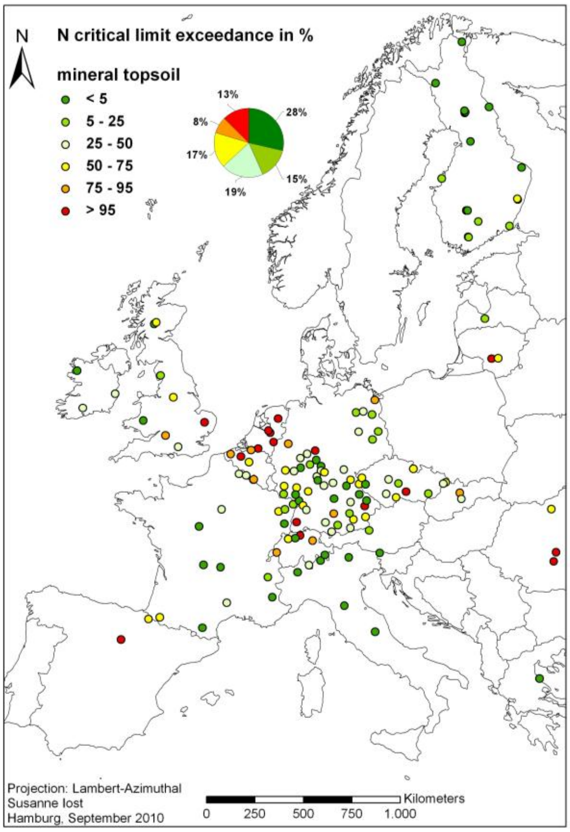


mineral subsoils

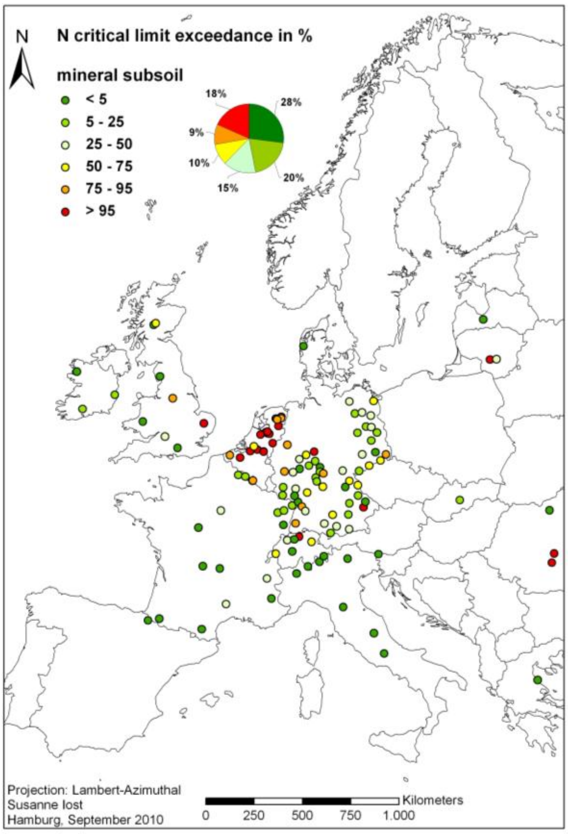
Figure 4-1: Frequency of N critical limit exceedances (CLimE) for nutrient imbalances in organic layers, mineral topsoils and mineral subsoils. Only plots with measurements in at least four consecutive years prior to 2006. Critical limits are >0.2 mgN/l for coniferous and >0.4 mgN/l for broadleaved forests. 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

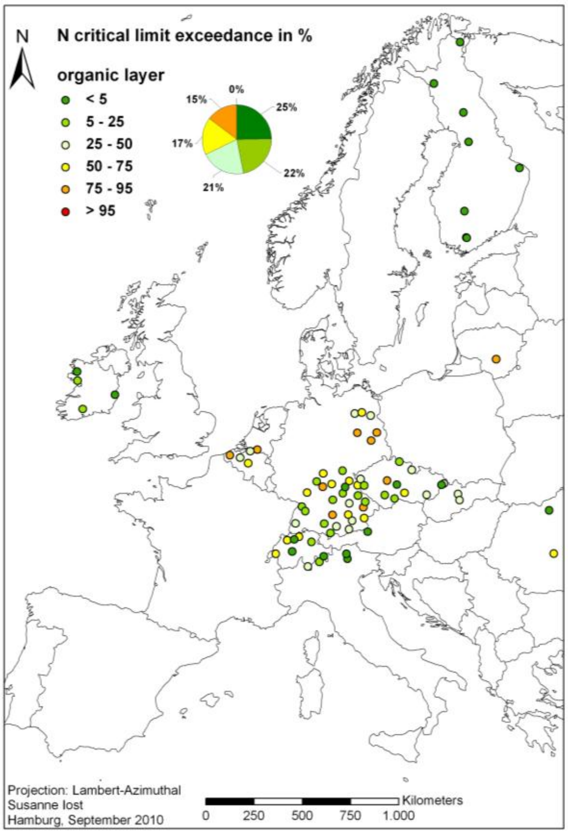


mineral topsoils

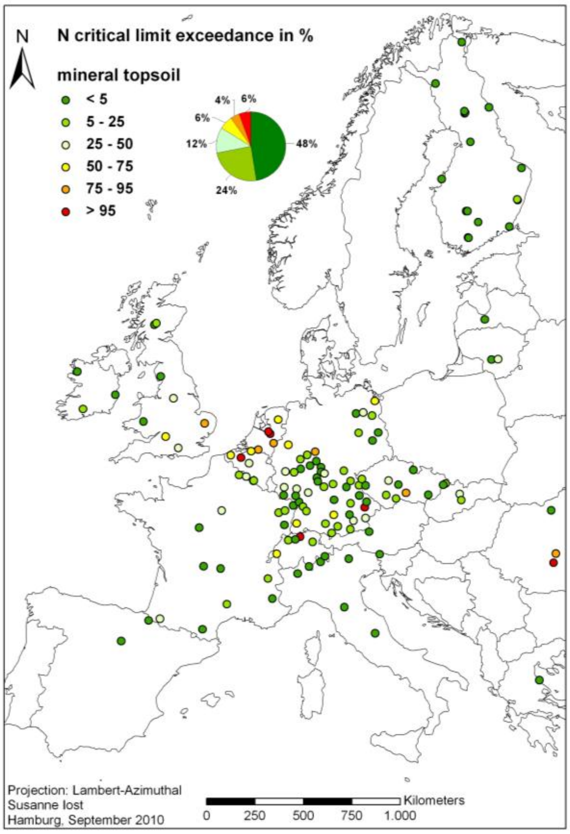


mineral subsoils

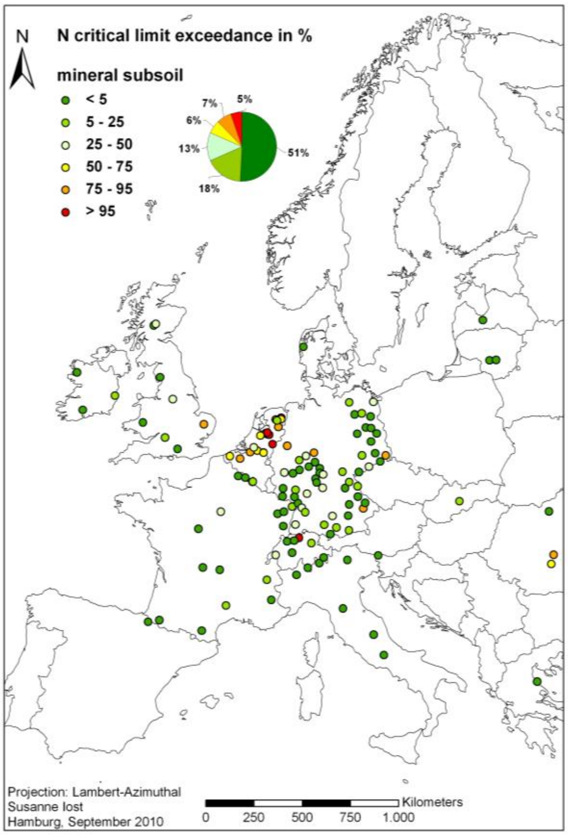
Figure 4-2: Frequency of N critical limit exceedances (CLimE) for N saturation / leaching in organic layers, mineral topsoils and mineral subsoils; Only plots with measurements in at least four consecutive years prior to 2006. The critical limit applied is >1 mgN/l; further details see Figure 4-1.



organic layers

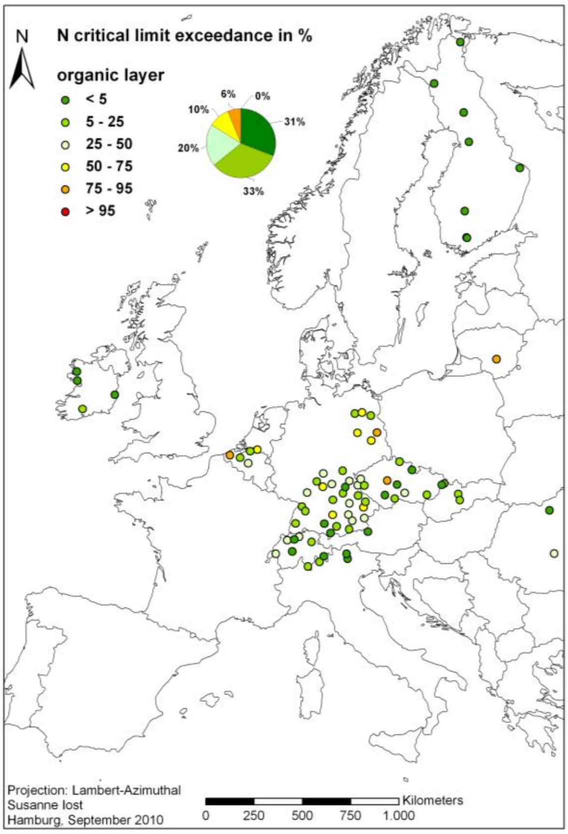


mineral topsoils

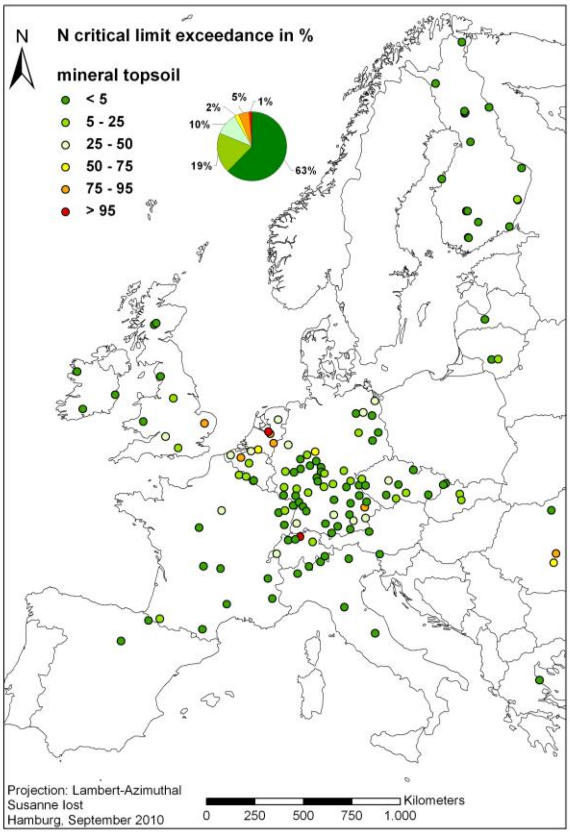


mineral subsoils

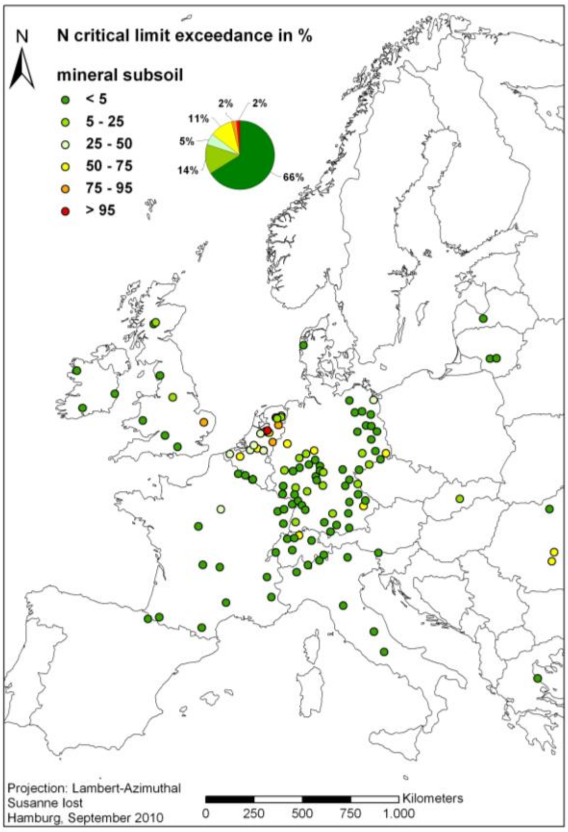
Figure 4-3: Frequency of N critical limit exceedances (CLimE) for reduced fine root growth in organic layers, mineral topsoils and mineral subsoils; Only plots with measurements in at least four consecutive years prior to 2006. The critical limit applied is > 3 mgN/l; further details see Figure 4-1.



organic layers



mineral topsoils



mineral subsoils

Figure 4-4: 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 4-2).

Table 4-2: 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 trend	in-crease	de-crease	no of of plots
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	

4.6 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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