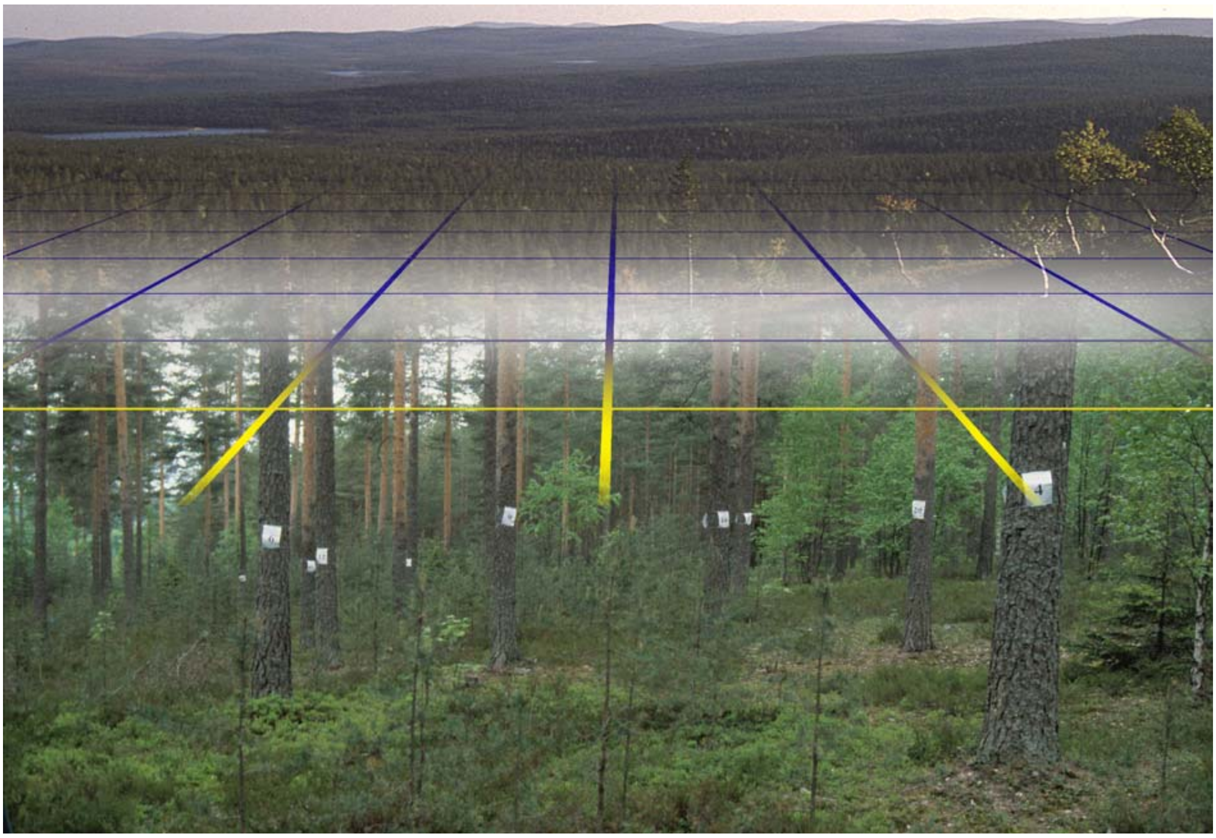
CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION
INTERNATIONAL CO-OPERATIVE PROGRAMME ON ASSESSMENT AND MONITORING OF AIR POLLUTION EFFECTS ON FORESTS

United Nations
Economic Commission
for Europe

Up-scaling of results from forest ecosystem monitoring to the large-scale

Peter Schall
Walter Seidling



May 2004

Federal Research Centre for Forestry and Forest Products (BFH)

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1 Background

Forest condition in Europe has been systematically and continuously monitored by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) of the United Nations Economic Commission for Europe (UN/ECE) and under the Scheme on the Protection of Forests against Atmospheric Pollution of the European Union (EU) for 15 years. Based on harmonised sampling methods the monitoring is carried out by up to 34 countries at two different levels:

- At Level I, extensive annual assessments of crown condition are conducted on a systematic European-wide grid comprising more than 6000 sample plots. On many of these plots soil condition and foliage chemistry has also been assessed.
- At Level II, intensive monitoring of crown condition, soil condition, foliage chemistry and tree growth is conducted on 860 plots. On many of these plots, meteorological conditions, ambient air quality, atmospheric deposition, soil solution chemistry and ground vegetation are also assessed.

Results by DE VRIES et al. (1998, 1999, 2000, 2001, 2002) show that statistical approaches within Level II can deliver conclusive statistical models for relevant ecosystem relationships. The transfer of such results and relationships from Level II to the less intensive but more representative Level I (spatial up-scaling) is one of the goals of the Level II approach (DE VRIES et al. 1997) and part of the strategy of ICP Forests (HAUßMANN et al. 2000) as well as the European Commission (EC).

The linkage of results and processes from Level II and Level I will have twofold stimulus:

- The results achieved at ecosystem level will be supplemented by information on their spatial relevance.
- The results achieved at the large scale (Level I) will be better understood in causal terms.

The spatial extrapolation from the Level II plots to the Level I plots can in certain cases be seen as a validation process with a database representative for the European-wide scale (LORENZ et al. 2000). It is not only the higher spatial representativeness of the Level I grid that might enable the consolidation of hypotheses concerning large-scale forest condition, but it is also the longer observation period which may allow for an evaluation of relationships and their time trends. In addition Level I plots could probably be a basis for further, large-scale transboundary interpolations (regionalisation) of results derived from integrated process-based models. These interpolations can hardly be based on Level II plots, due to their low spatial density. The development and testing of appropriate methods for up-scaling from detailed investigations to large areas is thus of enormous interest.

At its 17th meeting, the Task Force of ICP Forests asked its Programme Coordinating Centre (PCC) to continue its efforts towards the realisation of an up-scaling project in cooperation with the National Focal Centres (NFCs) and the Forest Intensive Monitoring Coordinating Institute (FIMCI). This gave rise to the present study of an up-scaling project by the Federal Research Centre for Forestry and Forest Products (BFH) which hosts PCC.

2 Objectives

Statistical analyses within Level II delivered conclusive statistical models for relevant ecosystem relationships. These are describing important information and allow computation of ecosystem parameters, which both are yet not available at Level I. Thus, the aim of this pilot study is to transfer these findings to Level I monitoring net.

When successful, such a transfer is scaling up the original Level II findings to area representative assessments.

3 Approach

Up to now correlative inter-plot studies have been the most frequently applied studies. Most of the statistical relationships within Level II at the European level were established by FIMCI (DE VRIES et al. 1998, 1999, 2000, 2001, 2002). Therefore, it was most promising to concentrate up-scaling efforts on findings published in these Technical Reports.

3.1 Screening for relationships

In a first step, relevant publications were screened for results that are of special interest for up-scaling. This material has to be evaluated systematically with respect to underlying data and methods. Especially the range of definition is of importance in this context, which can be distinguished in a mathematical (functional) and a geographical component. The analysis of these ranges allows to determine the Level I plots for which an information transfer is appropriate.

Model type and data availability are the criteria for selection and combination of techniques for transfer of those relationships. Thus, a thorough analysis of the relationships found is a precondition for further steps.

3.2 Techniques (Up-scaling toolbox)

Techniques for transferring relationships (i.e. statistical models) can basically be grouped into two categories: (i) **condensing** and **aggregating** the models in order to minimise or adapt the data requirement or (ii) supplying the necessary data via estimation methods (e.g. spatial interpolation). In this project techniques of the category (i) ‘function transfer’ will be followed up. With respect to category (ii) ‘data estimation’ only available and tested estimation results or methods will be regarded, for instance from DE VRIES et al. (2001), but no own estimations will be conducted making the approach complementary to efforts of FIMCI.

3.2.1 Model aggregation

Statistical models (described for Level II) which need to be transferred can be expressed in the following general form:

$y = f(x_{1 \dots n} , u_{1 \dots m})$

where:

y = response variable which is not available for Level I, but obtained for Level II

u = explanatory variable which is not available for Level I, but obtained for Level II

x = explanatory variable which is available for both, Level I and Level II

n, m = number of explanatory variables of types u and x, respectively

This expression states that: One or more explanatory variables which are available only for Level II (type *u*) and none, one or more explanatory variables which are available for both levels (type *x*) determine the value of the response variable, which is only obtained for Level II. Aggregating such models means that all explanatory variables which are exclusively available at Level II, type *u*, will be either expelled or substituted by variables of type *x*.

Dropping variables of type *u* is an appropriate method when these contribute only in a minor extent to explained variance and, additionally, no substitution is possible. However, dropping is the second choice always.

The chance for **substituting** variables of type u constitutes on a phenomenon frequently observed in large data-sets: intercorrelations among variables. Intercorrelations of explanatory variables, a typical problem in regression analysis, in fact can facilitate function transfer. If an explanatory variable of type *u* is intercorrelated with one or more variables of type *x*, there is an increased probability that one of those variables might replace the original variable (within the model) without loosing too much accuracy. Provided that the adapted regression model is sufficiently substantiated within Level II, it is not imperative that this 'transfer' variable is part of a cause-effect relationship. Rather, it should be understood as an auxiliary variable which represents the variable of the original regression model. In some cases also the introduction of a latent auxiliary variable from principal component analysis or another multivariate technique might be promising, if there is a relationship with the original predictor. An example for such an auxiliary variable could be elevation, which might substitute meteorological parameters or even deposition in mountainous regions.

3.2.2 Spatio-functional analysis of relationships

In any case, before conducting any function transfer efforts, the established regression models have to be comprehensively analysed, both in functional and geographical terms. Therefore, the established regression models will be recalculated on the data-set or stratum reported, with the methods reported, in order to determine: global significance, partial significance, partial contribution to explained variance, and model parameters. Additionally, the range of definition with respect to each explanatory variable will be determined in statistical and geographical terms. The statistical range of definition will be assessed with means of frequency distribution of explanatory variables and the respective confidence intervals. The geographical range of definition will be assessed by delineating the circumference of the data-set or stratum based on point maps.

3.2.3 Global versus regional (stratified) transfer

The model analyses also will retrieve indication whether **global** or **regional** transfer is more appropriate. Global transfer means that any treatment of explanatory variables of type *u* (dropping, substitution) fully applies to the original statistical model. Regional transfer means that explanatory variables will be treated separately for stratums or geographical regions, and consequently, the original regression model will be split in several models with regional range of definition. Global transfer will be the method of first choice, because it preserves the original data context of the finding. However, for (i) relationships based on (pre-)stratification and (ii) spatially biased relationships a regional transfer might be preferred.

For regional stratified transfer, initially the Level I plots have to be selected which meet the stratification criterion (e.g. plots with a pH-value below 4.5). If the stratification variable itself is not available for Level I (type *u*), this might be accomplished by analysing the difference between Level II strata with multivariate methods using only variables of type *x*, and an subsequent assignment of Level I plots to one of the groups by means of discriminant analysis.

In case of uneven spatial distribution, the target areas for transfer (i.e. regions) will be circumferenced by means of multivariate or geostatistical methods, or a combination of both.

3.2.4 Validation

In case the screening reveals regression models which include only explanatory variables of type *x* and additionally describe response variables which are available for Level I an empirical quality assessment is possible. Such models can be directly applied to Level I plots without function aggregation and, therefore, allow a comparison of transferred (estimated) and measured values of ecosystem parameters at Level I. This characteristic facilitates validation of the 'non aggregation' part of the transfer approach. Especially the quality of the methods for determination of target plots, i.e. mathematical and a geographical range of definition, may be assessed.

4 Results of screening

This chapter reports the results of the initial screening of the Technical Reports on "Intensive Monitoring of Forest Ecosystems in Europe" elaborated by FIMCI. After outlining integrity checks and general evaluation strategies for the Level II monitoring (DE VRIES et al. 1997), from 1998 onwards, Technical Reports concentrate on thematic evaluations (DE VRIES et al. 1998, 1999, 2000, 2001, 2002). The authors limited the evaluations to “key effect parameters” resp. “relevant” relationships. The major hypotheses comprised of natural stress, direct air pollution impacts, soil acidification, and soil eutrophication. Regression models were kept to be the most powerful means. Response parameters and predictors were selected according to theoretical considerations.

The main results with respect to up-scaling are grouped according to environmental sectors: (1) Foliar element concentrations, (2) chemical soil conditions (solid phase), (3) soil solution chemistry, and (4) deposition regime. Data about meteorology, tree growth, crown condition, and ground vegetation were used as predictors only, or respective regression models did not reach selection criteria for up-scaling approaches.

(1) Foliar element concentrations should respond to both: site characteristics and the ambient air conditions. Foliar element concentrations and reasonable ratios are put into relation to stand and site characteristics as well as to deposition levels, in addition to a documentation of ranges (DE VRIES et al. 1998, 2000) and comparisons with Level I data. Foliar N and S seem to correlate with deposition level, while foliar P is related to its availability within soils. Soil type is a significant predictor for foliar Ca, but not for Mg or K. Tree species is often a good predictor like in a model were foliar N is explained by tree species and climatic region with an R^2_{adj} of 79% (see Table 6). The model can be enhanced, if N deposition and the C/N ratio in the organic layer are added (DE VRIES et al. 2000, see Table 7 and Table 8).

(2) Soil factors are of crucial interest due to its influence on tree growth and its memory properties for past depositions. They exhibit distinct depth functions. C/N ratios in the organic layer can be lower than in the mineral layer caused by external N inputs. However, the ratio is not a general indicator for high N inputs (DE VRIES et al. 1998). In 22% of the soils with base saturation is less than 10%. Acidic inputs are buffered by release of Al. Pb and Cd contents in soils decrease with depth and may mainly result from atmospheric inputs. Regressions show that Pb and Cd are significantly predicted by region and altitude (see Table 3), while e.g. Cu is predicted by soil type.

Tree species, soil type, climatic region, and altitude explain 40 to 50% of the nutrient contents in the organic layer, except for P (DE VRIES et al. 1998). Since litterfall is the main source of input to the organic layer, the significance of tree species is plausible. Except for Mg, deposition also influences significantly the respective element in the organic layer. Element contents within the mineral topsoil are explained by 30 to 50% by the same predictors, however, tree species, soil type and climatic region all play a significant role. Heavy metal concentrations are less explained, except for Pb where 53% is explained. Element pools in the soil can be explained with 30-50% by various stand and site characteristics, precipitation, temperature and pH with the meteorological part mostly playing the greatest role. Only the S pool is explained with more than 50% (DE VRIES et al. 2000, see Table 2).

(3) Soil solution chemistry is highly dynamic. Generally spatial variations of major ion concentrations are better explained by atmospheric deposition rather than by meteorological condition or soil solid phase chemistry (DE VRIES 1999). Deposition of NH_4 had a significant positive impact on N compounds, base cations, Al and a negative impact on pH in the soil solution. Dissolved Al in mineral top- and subsoil was strongly correlated to SO_4 and NO_3 in soils with base saturation < 25%. Under these circumstances acid inputs are neutralized by release of Al. Calculated free Al was strongly related with pH. Explained variation in element

concentration varied between 45 and 75% (DE VRIES et al. 1999). The molar ratio [Al]/([Ca]+[Mg]+[K]) exceeded unity in 30-39% of the plots (DE VRIES et al. 2000). Variation in concentrations of major ions within the soil solution is largely explained by atmospheric deposition of corresponding compounds. Furthermore, meteorological parameters esp. precipitation have significant influences (see Table 4 and Table 5).

(4) Bulk, throughfall (+ stemflow) deposition is directly measured at Level II plots, however, different models have to be used to calculate total deposition. Dry deposition is at least 1/3 of total deposition for S and N compounds and slightly lower for base cations (DE VRIES et al. 1999). KLAP et al. (1997) used an EDACS model and EMEP estimates for ambient air concentrations to calculate site specific deposition rates. Modelled and measured total fluxes correlate considerably for NH_x (r = 0.72), moderate for SO_x (r = 0.49) and almost not for NO_x (r = 0.13). N and S deposition was calculated even for Level I plots with site specific data (tree species, tree height) and EMEP estimates. This up-scaling was done (i) by validation of a process-based model on a limited number of plots and (ii) application at Level I plots.

Based on 402 plots DE VRIES et al. (2000) estimated atmospheric deposition with an adapted canopy budget model (DRAAIJERS et al. 1994). Altitude correlates negatively with all compounds of deposition, except NO_3 and Ca. S leaching from the soil is mainly related with S deposition, however on a number of plots with high historical S inputs leaching is greater than deposition. N leaching is negligible in comparison to N inputs. Only at higher N input rates leaching increases. Leaching fluxes of base cations and Al was found to increase significantly with increasing S input.

Throughfall fluxes (SO_4, NH_4, NO_3, N, Ca, Mg, K) are influenced by most site and stand characteristics (R^2 = 42 – 70%, DE VRIES et al 1998). N input in bulk deposition equals S deposition. NH_4 to NO_3 varies widely in Europe. Ca and SO_4 were found to be significantly correlated. At 50% of the plots the deposition of N + S is buffered by inputs of base cations (ratio BS/(S+N) > 1) (DE VRIES et al. 2001). A strong correlation was found between soil solution nitrate and throughfall N (broadleaves: r^2 = 0.65, conifers: r^2 = 0.59) and between throughfall and bulk deposition (broadleaves: r^2 = 0.33, conifers: r^2 = 0.64). There is also a significant correlation between C/N ratio in the organic layer and throughfall N (broadleaves: r^2 = 0.14, conifers: r^2 = 0.19). The same is true for the significant but rather loose relationship between foliage N and C/N within the organic layer (conifers: r^2 = 0.16, see Table 9). Better expectations exist for the relationship for conifers between foliage [N] and troughfall [N] (r^2 = 0.40).

Critical Loads (CL) refer to deposition limits of air pollutants "below which no adverse effects on ecosystems are expected in a steady-state situation". They have reached great importance in pollution reduction endeavours. In regression studies they have only limited value.

4.1 Method & Criteria

In a first step, the Technical Reports were screened for results that are of special interest for up-scaling. This material was evaluated systematically with respect to underlying data and methods.

Criteria for the selection of the individual models have been:

- Response variable not mandatory at Level I (optional variables were appreciated, for validation)
- Predicting variables either mandatory at Level I or accessible via tested estimation methods (i.e. methods already used by FIMCI for Level II)
- Meaningful and interpretable

- Relative high explanation. In case several models were published within a specific study (i.e. element pool in organic layer), the "best" meaningful model was selected.
- Based on large number of observations

Criteria for the selection of the set of models have been:

- Reflect the range of studies conducted
- Reflect the range of model types, i.e. bivariate and multivariate, linear and non-linear models
- Reflect the range of accessibility of predicting variables, i.e. only mandatory variables at Level I, mix of mandatory at Level I and "to be estimated" variables, "to be estimated" variable

4.2 Models selected

The eight relationships selected are summarized in Table 1. These models describe relationships between variables of different ecosystem compartments or between ecosystem compartments and site/stand characteristics. Several types of regression models applied in analyses of Level II data are included.

Three models use only mandatory variables at Level I as predicting variables. Five models include predicting variables not measured at Level I, mostly variables originating from the deposition survey.

Table 1: Statistical models and origin of predicting variables

Response variables	**Statistical models and origin of predicting variables**	
	Site/stand characteristics & soil condition survey	Site, stand and soil characteristics plus **Deposition survey**
Soil chemistry	$S_{org\ layer}$ = f (tree species, + temperature, - pH-CaCl) [Pb] = f (tree species, climatic region, altitude)	
Soil solution		$[SO_4]_{topsoil}$ = f (tree species, + $SO_{4,throughfall}$, - precipitation) $[NO_3]_{topsoil}$ = f (tree species, + $NH_{4,throughfall}$, - precipitation)
Foliar	$[N]_{foliar}$ = f (tree species, climatic region) $[N]_{foliar,\ conifers}$ = f (+ $N/C_{organic\ layer}$)	$[N]_{foliar,\ P.\ abies}$ = f (+ $N_{deposition}$, - $C/N_{organic\ layer}$, + altitude – stand age) $[N]_{foliar,\ P.\ sylvestris}$ = f (+ $N_{throughfall}$)

4.3 Models selected in detail

In the following the regression models selected are reported in detail. The models are structured in chapters according the source of the response variable.

Description of tables:

- N: size of sample
- $R^2_{adj.}$: explained variance
- Variable:
  bold: response variable
  (h): highly significant
  (s): significant
- Source: variable measured in …
- L II:
  m/o: variable mandatory/optional at Level II
  external: variable not from monitoring network
- L I:
  m/o: variable mandatory/optional at Level I
  +: variable not measured at Level I, but fairly accessible
  -: variable not measured at Level I and hardly accessible
- p.n.: value not published

4.3.1 Soil condition survey

Table 2: Sulphur pool in the organic layer

Sulphur pool in the organic layer

$S_{org\ layer}$ = f (tree species, + temperature, - pH-CaCl)

N = 68 $R^2_{adj.}$ = 72

Source: Tech. Rep. 2000: 125, Chapter "Soil condition"

Variable	Source, cf. p. 117	L II	L I
$S_{org\ layer}$	Soil condition survey	o	-
Tree species (h)	Stand characteristics	m	m
Temperature (h)	interpolated, cf. p. 117	external*	+
pH-CaCl (h)	Soil condition survey	m	m

* data from LEEMANS & CRAMER 1991

Table 3: Lead concentration in the organic layer

Lead concentration in the organic layer

$[Pb]_{org\ layer}$ = f (tree species, climatic region, altitude)

N = 122 $R^2_{adj.}$ = 53

Source: Tech. Rep. 1998: 108, Chapter "Soil condition"

Variable	Source, cf. p. 17ff	L II	L I
$[Pb]_{org\ layer}$	Soil condition survey	o	o
Tree species (h)	Stand characteristics, cf. p. 19	m	m
Climatic region (h)	10 climatic regions, cf. p. 22	external*	+
Altitude (s)	Plot location	m	m

* according UN-ECE (1996)

4.3.2 Soil solution chemistry survey

Table 4: Sulphate concentration in the topsoil

Sulphate concentration in the topsoil

$[SO_4]_{topsoil}$ = f (tree species, + $SO_{4,throughfall}$, - precipitation)

N = 99 $R^2_{adj.}$ = 63

Source: Tech. Rep. 2000: 145, Chapter "Soil solution chemistry"

Variable	Source, cf. p. 137	L II	L I
$[SO_4]_{topsoil}$	Soil solution chemistry survey	m	-
Tree species (h)	Stand characteristics	m	m
$SO_{4,throughfall}$ (h)	Deposition survey	m	-
Precipitation (h)	Deposition survey	m	-

Table 5: Nitrate concentration in the topsoil

Nitrate concentration in the topsoil

$[NO_3]_{topsoil}$ = f (tree species, + $NH_{4,throughfall}$, - precipitation)

N = 90 $R^2_{adj.}$ = 58

Source: Tech. Rep. 2000: 145, Chapter "Soil solution chemistry"

Variable	Source, cf. p. 137	L II	L I
$NO_{3,topsoil}$	Soil solution chemistry survey*	m	-
Tree species (h)	Stand characteristics	m	m
$NH_{4,throughfall}$ (h)	Deposition survey	m	-
Precipitation (h)	Deposition survey	m	-

4.3.3 Foliar condition survey

Table 6: Nitrogen concentration in the foliage

Nitrogen concentration in the foliage

$[N]_{foliar}$ = f (tree species, climatic region)

N = 423 $R^2_{adj.}$ = 79

Source: Tech. Rep. 1998: 109, Chapter "Foliar condition"

Variable	Source, cf. p. 17ff	L II	L I
$[N]_{foliar}$	Soil condition survey	m	o
Tree species (h)	Stand characteristics, cf. p. 19	m	m
Climatic region (h)	10 climatic regions, cf. p. 22	external*	+

* according UN-ECE & EC (1996)

Table 7: Nitrogen concentration in the foliage; Picea abies

Nitrogen concentration in the foliage; Picea abies

$[N]_{foliar,\ P.\ abies}$ = f (+ $N_{deposition}$, - $C/N_{organic\ layer}$, + altitude – stand age)

N = 91 $R^2_{adj.}$ = 58

Source: Tech. Rep. 2000: 100, Chapter "Foliar condition"

Variable	Source, cf. p. 92	L II	L I
$[N]_{foliar,\ P.\ abies}$	Foliar condition survey	m	o
$N_{deposition}$ (h)	Deposition survey*	m	-
$C/N_{organic\ layer}$ (h)	Soil condition survey	m	m
Altitude (h)	Plot location	m	m
Stand age (h)	Stand characteristics	m	m

* Throughfall, cf. p. 100, fig. 7.7; p. 78 & 79

Table 8: Nitrogen concentration in the foliage; Pinus sylvestris

Nitrogen concentration in the foliage; Pinus sylvestris

$[N]_{foliar,\ P.\ sylvestris}$ = f (+ $N_{throughfall}$); bivariate - non-linear

N = n.p. $R^2_{adj.}$ = 60?

Source: Tech. Rep. 2000: 100, Chapter "Foliar condition"

Variable	Source, cf. p. 92	L II	L I
$[N]_{foliar,\ P.\ sylvestris}$	Foliar condition survey	m	o
$N_{throughfall}$ (h)	Deposition survey	m	-

Table 9: Nitrogen concentration in the foliage; Conifers

Nitrogen concentration in the foliage; Conifers

$[N]_{foliar,\ conifers}$ = f (+ $C/N_{organic\ layer}$); bivariate - linear

N = n.p. $R^2_{adj.}$ = 16 y = 21,2 – 0,21 * x

Source: Tech. Rep. 2001: 167, Chapter "Annex 6"

Variable	Source, cf. p. 160	L II	L I
$[N]_{foliar,\ conifers}$	Foliar condition survey	m	o
$C/N_{organic\ layer}$ (h)	Soil condition survey	m	m

4.4 Overview on origin of predicting variables

Here, the models selected are summarised with respect to the source of the predicting variables.

Table 10: Origin of predicting variables

Response variables	Origin of predicting variables				
	Plot location	Stand characteristics	Soil condition survey	Deposition survey	External source
Soil chemistry					
$S_{org\ layer}$		tree species	pH-CaCl		temperature
$[Pb]_{org\ layer}$	altitude	tree species			climatic region
Soil solution					
$[SO_4]_{topsoil}$		tree species		$SO_{4,throughfall}$	
				precipitation	
$[NO_3]_{topsoil}$		tree species		$NH_{4,throughfall}$	
				precipitation	
Foliar condition					
$[N]_{foliar}$		tree species			climatic region
$[N]_{foliar,\ P.\ abies}$	altitude	stand age	$C/N_{organic\ layer}$	$N_{deposition}$	
$[N]_{foliar,\ P.\ sylvestris}$				$N_{throughfall}$	
$[N]_{foliar,\ conifers}$			$C/N_{organic\ layer}$		

5 General methodological aspects

5.1 Level II data and data processing

5.1.1 Database

The Level II database used for this study was supplied by PCC of ICP Forests on a CD, which is dated 10. September 2003. It is supposed to be the latest version compiled by FIMCI. The data arrived as 178 MB in 76 single tables, which were exported from a database management system (Table 11). The entity relationship model (ERM) therefore was lost and had to be reconstructed.

Aditionally, DAR-Q information on the surveys crown condition, foliar condition, soil condition, soil solution chemistry, atmospheric deposition, forest growth, meteorology and ground vegetation was supplied (one MS Access database per survey).

Table 11: Tables of the Level II database

Export date	File size (Byte)	File name
06.08.2003 06:38	2.226	AIR_QUALITY_ACTIVE_SAMPLERS.ASC
06.08.2003 06:38	164	AIR_QUALITY_COMPOUND_DEF.ASC
06.08.2003 06:38	193.467	AIR_QUALITY_MEASUREMENTS.ASC
06.08.2003 06:38	11.066	AIR_QUALITY_PASSIVE_SAMPLERS.ASC
06.08.2003 06:38	614	AIR_QUALITY_VARIABLES_DEF.ASC
04.08.2003 10:46	1.025	ALTITUDE_DEF.ASC
04.08.2003 10:46	440	CLIMATE_ZONE_DEF.ASC
04.08.2003 10:46	919	COUNTRY_DEF.ASC
04.08.2003 10:46	246.249	CROWN_INVENTORY.ASC
04.08.2003 10:46	4.581.926	CROWN_TREE.ASC
04.08.2003 10:46	14.333	DEPOSITION_INFO.ASC
04.08.2003 10:46	675.700	DEPOSITION_INVENTORY.ASC
04.08.2003 10:46	750.366	DEPOSITION_MEASUREMENTS_AIR.ASC
04.08.2003 10:47	7.943.079	DEPOSITION_MEASUREMENTS_MAN.ASC
04.08.2003 10:47	2.593.493	DEPOSITION_MEASUREMENTS_OPT.ASC
04.08.2003 10:48	9.045.712	DEPOSITION_PERIOD.ASC
04.08.2003 10:46	1.255	DEP_ANALYSIS_DEF.ASC
04.08.2003 10:46	201	DEP_SAMPLE_DEF.ASC
04.08.2003 10:48	218	DISCOLOURATION_DEF.ASC
04.08.2003 10:48	131	EXPOSURE_DEF.ASC
04.08.2003 10:48	479	FOLIAR_ANALYSIS_DEF.ASC
04.08.2003 10:48	437.463	FOLIAR_ANALYSIS_MAN.ASC
04.08.2003 10:48	204.129	FOLIAR_ANALYSIS_OPT.ASC
04.08.2003 10:48	124.812	FOLIAR_INVENTORY.ASC

04.08.2003	10:48	50.266	GENERAL_PLOT.ASC
04.08.2003	10:48	5.918.543	GROUND_VEG_ASSESSMENT.ASC
04.08.2003	10:48	419.784	GROUND_VEG_INVENTORY.ASC
04.08.2003	10:48	162	GROUND_VEG_LAYER_DEF.ASC
04.08.2003	10:48	34.263	GROUND_VEG_LOCAL_SPECIES_DEF.ASC
04.08.2003	10:48	813.960	GROUND_VEG_SPECIES_DEF.ASC
04.08.2003	10:48	1.559	HORIZON_DEF.ASC
04.08.2003	10:48	137	HUMUS_DEF.ASC
06.08.2003	06:53	587.525	INCREMENT_ANALYSIS.ASC
04.08.2003	10:48	37.385	INCREMENT_EVALUATED.ASC
06.08.2003	06:54	99.956	INCREMENT_INVENTORY.ASC
06.08.2003	06:54	8.179	increment_inventory_poland.asc
06.08.2003	06:52	7.798.420	INCREMENT_PERIODIC.ASC
06.08.2003	06:52	1.914.671	increment_periodic_poland.asc
04.08.2003	10:49	175	MEAN_AGE_DEF.ASC
04.08.2003	10:49	718.399	MET_MEASUREMENTS_INVENTORY.ASC
04.08.2003	14:18	78.392.446	MET_MEASUREMENTS_MAN.ASC
04.08.2003	10:56	44.107.162	MET_MEASUREMENTS_OPT.ASC
04.08.2003	11:00	618	MET_VARIABLE_DEF.ASC
04.08.2003	11:00	377	MET_YEARS.ASC
04.08.2003	11:00	182	ORIENTATION_DEF.ASC
06.08.2003	06:38	228	OZONE_INJURY_ASSESSMENT.ASC
06.08.2003	06:38	502	OZONE_INJURY_LESS_GVMS.ASC
06.08.2003	06:38	394	OZONE_MAIN_TREE_SPECIES.ASC
04.08.2003	11:00	7.938	PARENT_MATERIAL.ASC
04.08.2003	11:00	3.621	PARENT_MATERIAL_DEF.ASC
04.08.2003	11:00	51.052	PLOT_VOLUMES.ASC
04.08.2003	11:00	2.203	SOIL_ANALYSIS_DEF.ASC
04.08.2003	11:00	181	SOIL_ANALYSIS_SAMPLE_DEF.ASC
04.08.2003	11:00	4.687	SOIL_DEF.ASC
04.08.2003	11:00	373.276	SOIL_HORIZON_ANALYSIS_MAN.ASC
04.08.2003	11:00	311.762	SOIL_HORIZON_ANALYSIS_OPT.ASC
04.08.2003	11:00	418	SOIL_HORIZON_SAMPLE_DEF.ASC
04.08.2003	11:00	36.267	SOIL_HORIZON_SAMPLE_MAN.ASC
04.08.2003	11:00	37.581	SOIL_HORIZON_SAMPLE_OPT.ASC
04.08.2003	11:00	11.184	SOIL_INFO.ASC
04.08.2003	11:00	45.631	SOIL_INVENTORY.ASC
04.08.2003	11:00	4.470.097	SOIL_SOLUTION_ANALYSIS_MAN.ASC
04.08.2003	11:01	3.958.789	SOIL_SOLUTION_ANALYSIS_OPT.ASC
04.08.2003	11:01	904.825	SOIL_SOLUTION_INVENTORY.ASC
04.08.2003	11:01	5.722.515	SOIL_SOLUTION_PERIOD.ASC
04.08.2003	11:01	42.901	SOIL_TEXTURE.ASC

04.08.2003	11:01	3.672	SPECIES_DEF.ASC
04.08.2003	11:01	814	SSO_ANALYSIS_DEF.ASC
04.08.2003	11:01	166	SSO_SAMPLE_DEF.ASC
04.08.2003	11:01	279	TEXTURE_DEF.ASC
04.08.2003	11:02	9.060.079	TREE_ASSESSMENT_MANDATORY.ASC
04.08.2003	11:03	4.250.135	TREE_ASSESSMENT_OPTIONAL.ASC
04.08.2003	11:03	6.065	VIEW_SPECIES_GROUP_DEF.ASC
04.08.2003	11:03	109	WATER_DEF.ASC
04.08.2003	11:03	174	YIELD_ABS_DEF.ASC
04.08.2003	11:03	95	YIELD_REL_DEF.ASC

Each table consisted of a header with field names and formats (number/string/date), export date, and the subsequent data part: one line per entity, field values delimited with comma. As an illustration, here the first lines of the table "SOIL_HORIZON_ ANALYSIS_MAN.ASC" are presented:

```
!
! YEAR Number
! COUNTRY_C Number
! PLOT_NR Number
! HORIZON_C String
! SOIL_HORIZON_SAMPLE_C Number
! ANALYSIS_DATE Date
! PH_CACL2 Number
! C_ORG Number
! N Number
! P Number
! K Number
! CA Number
! MG Number
! ORG_LAY Number
! CACO3 Number
! AC_EXC Number
! BCE Number
! ACE Number
! CEC Number
! BASE_SAT Number
! OTHER_OBS String
!
! 4-8-2003
!
1990,3,39,'M12',1,'12-3-1990',,23,1.3,,,,,,,0.1,4,4.2,3,
1990,3,58,'O',1,'23-4-1990',,244,10,400,530,1300,310,7,,,,,,
1990,3,58,'M01',1,'23-4-1990',,7,0.4,,,,,,,0.1,1.3,1.4,7,
```

5.1.2 Data processing

For each relationship to be investigated (Table 1) the relevant information - available within Level II (Table 10) - was assembled as a MS Access database by importing the respective tables (s. Table 11). The import was carried out by a VisualBasic program, which had to written. Table and field (attribute) names were preserved.

As far as it was possible, primary keys were defined. This was generally possible for tables containing descriptive information on coded variables (i.e. tables labelled by appendix "_DEF"), e.g. SCECIES_DEF and COUNTRY_DEF where the fields SPECIES_C and COUNTRY_C are the primary keys. These master tables provide 1:n relationships with detail tables, which were defined when appropriate, e.g. SPECIES_DEF:SPECIES_C <- 1:n <- GENERAL_PLOT:SPECIES_C. In order to detect coding errors in the detail tables, the master-detail relationships were defined as "right join".

However, with the exception of this master-detail coding structure that was established to reduce redundancy, no primary keys could be detected. Tables of different surveys generally can be linked only by super keys, keys that are a combination of several attributes. In the simplest case the super key constitutes of country code and plot number. But frequently, additional variables are required, e.g. reference year or ecosystem compartment. For instance, the super key essential to relate the mandatory and optional part of the soil condition survey - tables SOIL_HORIZON_ANALYSIS_MAN and SOIL_HORIZON_ANALYSIS _OPT- must indicate country, plot, soil horizon, and a temporal reference. Since four 'independent' variables are included, there is quite a big chance for data processing errors to occur. With respect to analytical statistics, these may generate incorrect input or bias the sample or, unnecessarily, reduce number of observations Here only some possibilities:

- Plots may have been measured twice or more, but should be included only once in regression analysis.
- Mandatory and optional measurements on a plot were not conducted in the same year.
- Horizon labelling may be different in mandatory and optional measurements.

In order to eliminate such data processing errors, when defining super keys each candidate key was checked for irregularities, e.g. by assessing occurrences of single plots or by linking the respective tables "right join" and "left join".

Finally, an input table, which contained all relevant data for the subsequent statistical and geograpgical analyses was generated by querying. In order to reduce the chance of data communication errors, this input table was accessed by both, the statistics program and the GIS via ODBC SQL connection.

5.2 Level I data and data processing

The Level I database used for this study was supplied by PCC of ICP Forests on a CD, which is dated 11. March 2003. The data on plot characteristics, foliar survey and soil survey arrived as 6.4 MB in 6 spreadsheets of MS Excel format.

Data were processed in MS Access and accessed via ODBC SQL connection by the statistics program and the GIS.

5.3 Data of external source

In several regression analyses of DE VRIES et al. considered here, predictor variables of external source were included. Besides temperature and climatic region, which turned out to be explanatory variables in three of the models (Table 10), precipitation was a candidate variable in the regression model of sulphur pool in the organic layer.

5.3.1 Temperature and precipitation (long term average)

The plot related values for temperature and precipitation DE VRIES et al. (2000) used in regression analyses were derived from interpolation of 30-year averaged modelled data. The underlying dataset was published by LEEMANS & CRAMER (1991) as grids of average monthly values for the period 1931 – 1960 with a 30-minute resolution in latitude and longitude, and global terrestrial coverage[1].

Here, instead of the LEEMANS & CRAMER (1991), the dataset developed/modelled by NEW et al. (1999, 2002) was used[2]. The NEW et al. dataset also comprises gridded data of mean monthly climate with global terrestrial coverage, but the spatial resolution is higher (10 minutes in latitude and longitude) and the temporal association is more up to date (period 1961 -1990).

From the monthly values of the NEW et al. dataset, annual averages (temperature) and annual sums (precipitation) were calculated, which represent long term average recent climate. Finally, the meteorological variables were assinged to the plots by nearest neighbour method (not interpolation).

5.3.2 Climatic region

Climatic regions were introduced in the Level I monitoring programme with the survey of 1995 (UN/ECE & EC, 1996). The climatic region was assigned to Level II plots according to nearest neighbour Level I plot.

5.3.3 Deposition

Estimations of EDACS for Level I plots were supplied by the PCC, Hamburg, and assigned to Level II plots by geographical nearest neighbour method. Estimations of EMEP-deposition for the centre points of the EMEP 150 km x 150 km grid – supplied by PCC - were spline interpolated (local spline with a tension setting based on the 12 nearest points) to a 0.5° geographical grid, and assigned to Level I and Level II plots.

5.4 Data evaluation

5.4.1 Statistical data evaluation

Statistical data evaluation was carried out with the software package R[3]. For **regression analysis** (Table 1), the function *lm* "Linear models" was used. In case model selection was required, the function *step* was applied, which features forward, backward and combined forward/backward selection based on Akaike's 'An Information Criterion' (AIC).

However, as it is known that several environmental variables within the Level II dataset are correlated (cf. DE VRIES et al. 2000) regression analysis was generally accompanied by a tree based approach. Rather than seek an explicit global linear model for prediction or interpretation, tree based models seek to bifurcate the data, recursively, at critical points of the determining variables in order to partition the data ultimately into groups that are as

[1] cf. http://www.ngdc.noaa.gov/seg/eco/cdroms/gedii_a/datasets/a03/lc.htm

[2] CRU CL 2.0: http://www.cru.uea.ac.uk/cru/data/hrg.htm

[3] www.r-project.org

homogeneous as possible within, and as heterogeneous as possible between. For this **recursive partitioning** the function *rpart* was applied. Models were specified in the ordinary linear model form. The results - regression trees - often lead to insights that other data analysis methods, especially regression analysis, tend not to yield.

5.4.2 Spatial data evaluation

In addition to statistical methods, data, i.e. the identical sample of Level II plots as used in statistical evaluation, was spatially assessed with a GIS. The program applied was ArcView from ESRI.

Generally explanatory and response variables were plotted on a country map of Europe, either with symbol size proportional to value in case of numeric variables, or with different symbols in case of qualitative variables. In the first phase it was only determined visually whether spatial clusters or spatial trends were apparent, which both can bias statistical data evaluation.

Spatial range of definition

The spatial range of definition of a Level II plot sample was determined by a so-called point-to-polygon procedure. Such a procedure creates a geographic region (polygon) representing the connection of the outermost points from a cluster of points. The program applied was *points to polygons*[4], an extension to ArcView.

In case the plot locations showed a spatial clustering, several regions were determined. In the statistical evaluation, these regions were introduced as additional qualitative variable (cf. 3.2.3).

In case plots were assessed as spatial outliers, i.e. single plots far distant from plot clusters, the plots were dropped from further evaluation. This assessment was supported by measured distance to nearest cluster, and the shape of Theissen polygons (small angled at point under consideration).

[4] www.sacnasp.org.za/usergroups/arcview/pts2poly(1).avx

6 Results

6.1 Sulphur pool in the organic layer (Model 1)

Sulphur, mainly in the form of sulphate, was the most dominant soil acidifying component in the period from industrialisation in the 19th century until the end of the 20th century, when nitrogen components became dominant. Sulphur content (pool) in forest soils may therefore by an indicator for the degree of historical and actual sulphur input into forest ecosystems.

DE VRIES et al. (2000: Chapter "Soil condition", p. 107ff) examined the relationship between sulphur pool in the organic layer and environmental factors with means of multiple regression analysis – without interaction - by using the so-called select procedure. This procedure combines forward selection, starting with a model including one predictor variable, and backward elimination, starting with a model including all predictor variables. The 'best' model was found as combination of a high degree of explanation (variance accounted for) by a low number of predictor variables [p. 31].

In total, eight predictor variables were allowed by DE VRIES et al., six originating from the surveys "Stand and site characteristics" (soil type cluster, tree species, tree height/age, altitude), "Deposition" (sulphur flux in throughfall) and "Soil chemistry" (pH_{CaCl} in organic layer), and two meteorological variables [p. 117]. The meteorological variables, precipitation and temperature, were derived from interpolation of 30-year averaged modelled data. The dataset used, was published by LEEMANS & CRAMER (1991) as grids of average monthly values for the period 1931 – 1960 with a 30-minute resolution in latitude and longitude, and global terrestrial coverage[5].

The relationship determined is:

$$S_{org\ layer} = f(-\text{ tree species}, +\text{ temperature}, -\ pH_{CaCl});\ N = 68;\ R^2_{adj.} = 0.72.$$

Regression parameters were not published [p. 125]. DE VRIES et al. mention the chance that the relationship is influenced by several extreme plots [p.126].

The number of plots (sample number) supporting the relationship is low compared to other element pools considered in the same study, e.g. N = 190 for nitrogen; N = 243 for phosphors. The reason for the low number is (i) that measurement of sulphur concentration in the organic layer is not mandatory, and (ii) that atmospheric deposition is not measured at all plots, although mandatory. However, since atmospheric deposition is not significant for any element pool considered in the study (N, P, S, K, Ca, Mg, BC_{exch}), there is a good chance to increase sample number by dropping deposition as predictor variable.

6.1.1 Compilation of relevant data

Element pools in single organic layers are defined as product of the element content per unit of solid material and the amount of solid material that layer. Element pool of the total organic layer is calculated as sum over the organic layers distinguished per plot (e.g. O, O_2, O_3).

Sulphur concentration (mg kg^{-1}) is an optional and the amount of organic layer (kg m^{-2}) a mandatory parameter within Level II. Hence, to compute sulphur pool the tables SOIL_HORIZON_ANALYSIS_MAN and SOIL_HORIZON_ANALYSIS _OPT must be related first. Table 12 gives an overview on the steps applied.

[5] cf. http://www.ngdc.noaa.gov/seg/eco/cdroms/gedii_a/datasets/a03/lc.htm

Table 12: Procedure applied to retrieve coherent data sets on sulphur pool in the organic layer, and number of cases.

Step	Description	Parameter table	
		mandatory	optional
1	Number of organic layers in database; all years	896	604
2	- as before, but additionally with values available for S concentration and amount of solid material, respectively	566	417
3	- as before, but additionally periodic measurement repeatments excluded; i.e. only one date datum per organic layer	542	275
4	- as before, but total organic layer; i.e. only one datum per plot	508	274
5	Mandatory and optional parameter tables from step 4 related with keys country code and plot number	-> 117 <-	
6	- subset of step 5 with organic layers number or coding not identical in mandatory and optional parameter tables. Irregularities could be corrected for 6 plots via the original data reported to FIMCI, which was requested and kindly supplied from the contributing state	9	
7	- as step 5, but 3 plots of step 6 were removed because irregularities could not be clarified	114	

On several plots the sulphur concentration is measured but not the amount of organic layer, and vice versa. Both parameters are available for 114 plots. For some plots, mainly the ones from The Netherlands, several data related to different survey years are available. In this case always the most recent datum is used.

From the 114 plots, two were sorted out because predictor variables were not measured and one was eliminated as an outlier.

Hence, 111 plots could be passed for further evaluation. Compared to the "old" dataset of DE VRIES et al. (2000) this is an increase of about 50%. The year with the largest number of cases is 1995 (N = 63), followed by 1996 (N = 17) and 1991 (N = 12). Sampling years included range from 1991 to the year 2000. The geographical distribution of the plot sample is depicted in Figure 1.

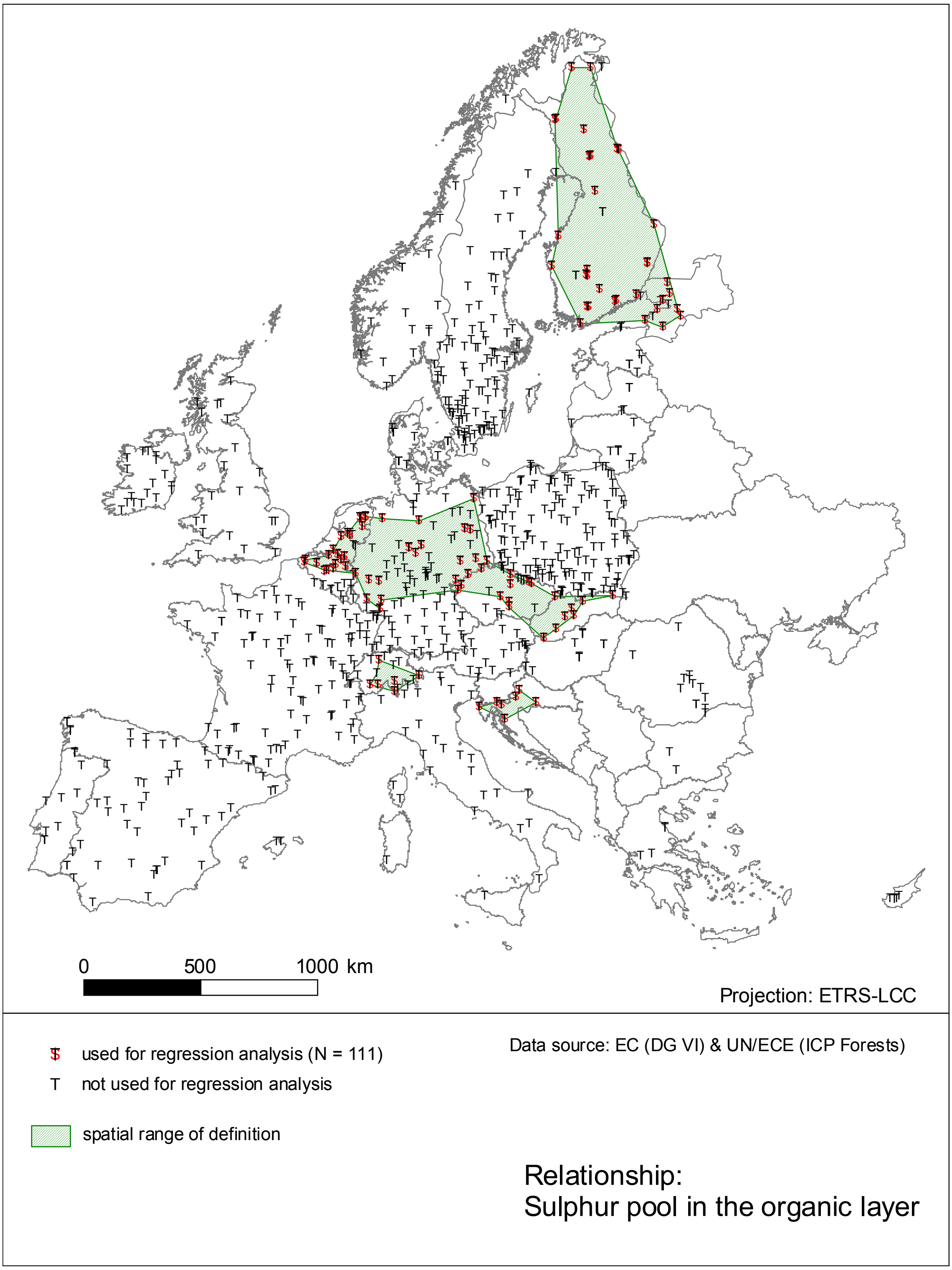


Figure 1: Geographical distribution of the plots used in statistical analysis, and spatial range of definition.

The "regression" plots exhibit a distinct spatial clustering, so that a spatial range of definition with four regions had to be distinguished.

The ranges of the response variable and the quantitative predictor variables are presented in Table 13. Compared to the percentiles reported by DE VRIES et al. (2000, Table 8.8) only small deviances can be observed. The minimum and maximum values describe the statistical range of definition. Because of skewness altitude, precipitation and sulphur pool in the organic layer were log-transformed (natural logarithm).

For the distribution of the qualitative variable tree species see Table 14, Table 15 and Figure 2.

Table 13: Range of sulphur pool in the organic layer, and ranges of the quantitative predictor variables used in statistical analysis

Variable	Unit	No. plots	Min	5%	50%	95%	Max	Transf.
S	kg ha-1	111	1.3	9.4	71.8	266.8	316.0	ln
Tree Age*	yr	96**	30	50	70	130	130	
Altitude*	m	111	25	25	175	1100	1875	ln
Temperature	°C	111	-2.4	-1.0	7.6	10.0	13.6	
Precipitation	mm yr-1	111	433	513	743	1280	1688	ln
pH-CaCl	-	111	2.5	2.8	3.2	5.4	6.6	

* value determined as mean of class range (e.g. 30 yr for age class 20 – 40 yr and 75 m for altitude class 50 – 100 m)
** additional 15 uneven aged stands

Table 14: Distribution of tree species and assignment of species to the species groups used in statistical analysis

Species group	Pine	Spruce	Other conifers	Oak	Beech	Other broadleaves
Abies alba			3			
Carpinus betulus						1
Fagus sylvatica					15	
Fraxinus excelsior						1
Picea abies		36				
Pinus mugo			1			
Pinus nigra			2			
Pinus sylvestris	35					
Pseudotsuga menziesii			4			
Quercus cerris						2
Quercus petraea				2		
Quercus pubescens				1		
Quercus robur				8		
Sum	35	36	10	11	15	4

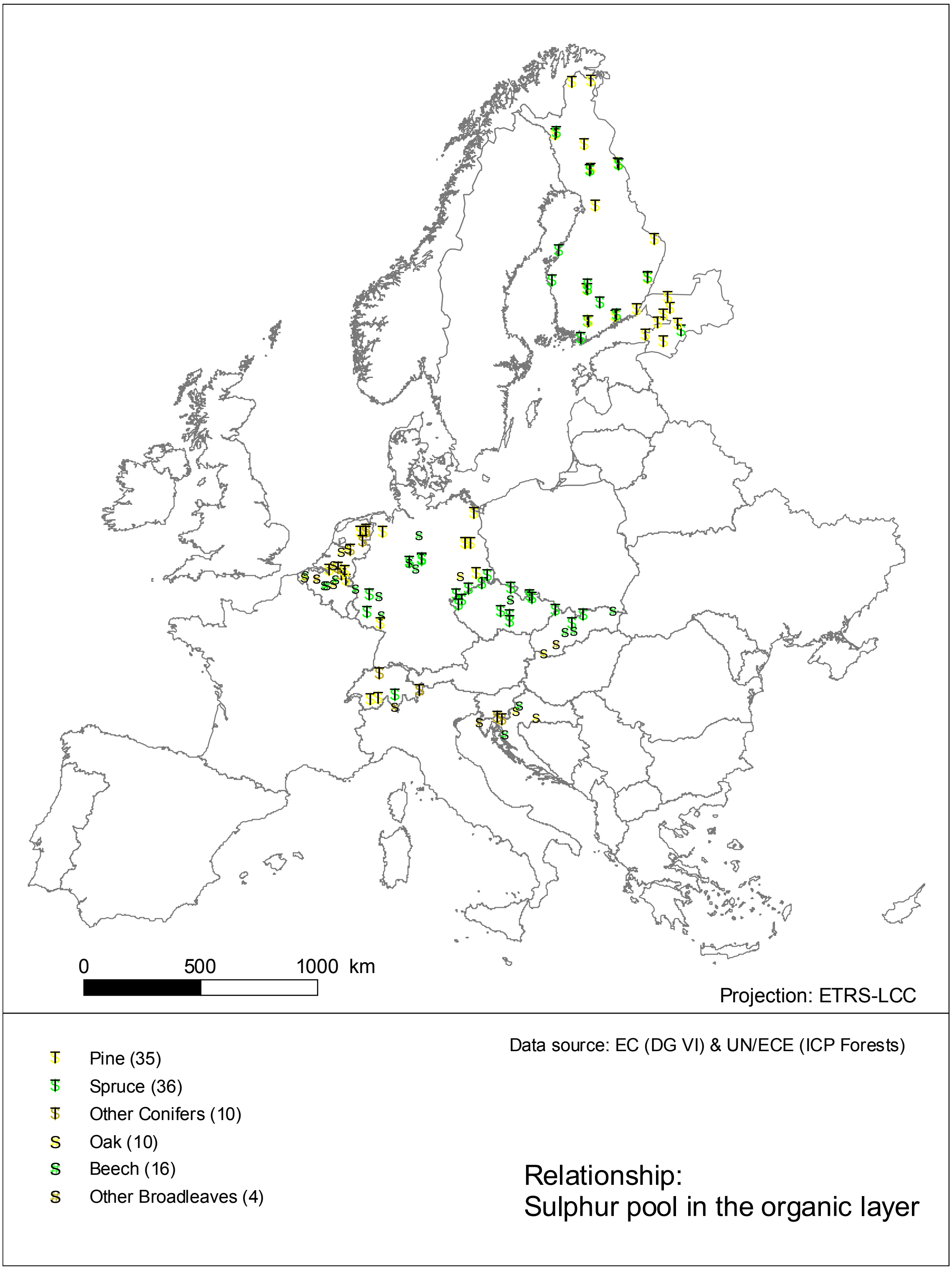


Figure 2: Geographical distribution tree species groups used in statistical analysis

Table 15: Distribution of soil types and assignment of soil types to the soil clusters used in statistical analysis

Soil type cluster	**Podzols and Arenosols**	**Cambisols and Luvisols**	**Remaining non-calcareous soils**	**Calcareous soils**
Calcaric Fluvisols				2
Eutric Gleysols			2	
Dystric Leptosols			1	
Haplic Arenosols	2			
Cambic Arenosols	4			
Gleyic Arenosols	3			
Eutric Cambisols		3		
Dystric Cambisols		19		
Chromic Cambisols		2		
Ferralic Cambisols		1		
Gleyic Cambisols		5		
Haplic Calcisols				2
Calcaric Phaeozems				2
Gleyic Luvisols		2		
Dystric Planosols			2	
Eutric Podzoluvisols			1	
Dystric Podzoluvisols			5	
Haplic Podzols	18			
Cambic Podzols	10			
Ferric Podzols	13			
Carbic Podzols	3			
Gleyic Podzols	5			
Haplic Alisols			2	
Fimic Anthrosols			2	
Sum	58	32	15	6

6.1.2 Analytical statistics

Since the plot sample used here differs from one DE VRIES et al. (2000) employed to describe the relationship – in terms of size and actuality – the original approach of the research proposal had to be modified. The regression model on sulphur pool in the organic layer will not simply be recalculated on the dataset or stratum reported, with the predictor variables and the methods reported, but will be re-established on the actual dataset following the approach reported, in order to determine: global significance, partial significance, partial contribution to explained variance, and model parameters.

Regression analysis

For regression analysis an ordinary linear model was applied, which - as a full model - included soil type cluster, tree species group, tree age, altitude, precipitation, temperature, and pH_{CaCl} as predictor variables (cf. chapter 6.1.1). A forward selection/backward elimination approach was used for model selection (cf. chapter 5.4.1).

Deposition of sulphur was not included, because deposition turned out to insignificant for all the element pools considered by DE VRIES et al. (2000). In order to account for the plots with uneven aged tree stands, tree age was replaced by the interaction of tree age and 'even aged' (as qualitative variable).

Table 16: Summary of the (full) regression model explaining sulphur pool in the organic layer (log-transformed) with estimates for significant variables. Sum of squares from ANOVA. (N = 111, adj.-r^2 = 0.662)

	Estimate	Std. error	t value	Signif.	DF	Sum of squares
(Intercept)	5.980	0.378	15.825	***		
pH-CaCl	-0.825	0.093	-8.851	***	1	78.26
Temperature	0.116	0.023	5.155	***	1	5.21
Tree species group				***	5	13.56
Spruce	0.222	0.162	1.369			
Other conifers	-0.066	0.262	-0.250			
Oak	-0.827	0.280	-2.949	**		
Beech	-0.740	0.254	-2.908	**		
Other broadleaves	-1.547	0.395	-3.922	***		
Tree age				*	2	3.64
Tree age:even age	0.0071	0.0026	2.692	**		
Tree age:uneven age	0.335	0.288	1.164			
Model				***	9	100.67
Residuals		0.6693			101	45.24
Total						145.91

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

The results of the full model (Table 16) confirm the findings of DE VRIES et al. (2000) in that: (i) soil type cluster, altitude and precipitation show no effect on sulphur pool, (ii) pool size is larger in situations with higher acidity (low pH), (iii) pool size increases with higher temperature, and (iv) tree species influence the pool size. The highest sulphur pool is found for spruce, followed by pine (estimate = 0) and other conifers. Plots with broad leaved species show a distinctively lower pool, presumably because their litter much faster is decomposed.

The largest contribution to the variation accounted for is found for pH, followed by tree species. Temperature explains only a small part of the variation.

While the direction of effect for pH and tree species is in accordance with expectations, the increase of pool size with higher temperatures is remarkable. As decomposition rate generally increases with temperature in humid climates, some other effect might be covered by temperature.

Additionally, on plots with of even aged stands, a positive effect of tree age on pool size can be found. As the effect of tree age is quite week, the result of a model with predictor variables restricted to pH, temperature and tree species is presented as Table 17. Compared to the full model, in the restricted model only the significance of beech had decreased slightly.

Table 17: Summary of the restricted regression model explaining sulphur pool in the organic layer with estimates for significant variables. Sum of squares from ANOVA. (N = 111, adj.-r^2 = 0.642)

	Estimate	Std. error	t value	Signif.	DF	Sum of squares
(Intercept)	6.440	0.351	18.334	***		
pH-CaCl	-0.828	0.093	-8.951	***	1	78.26
Temperature	0.119	0.0228	5.234	***	1	5.21
Tree species group				***	5	13.56
'Pine'						
'Spruce'	0.306	0.164	1.871	.		
Other conifers	-0.178	0.260	-0.686			
'Oak'	-0.814	0.288	-2.828	**		
'Beech'	-0.561	0.253	-2.220	*		
Other broadleaves	-1.572	0.398	-3.950	***		
Model				***	7	97.03
Residuals		0. 6889			103	48.88
Total						145.91

Signif. codes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Recursive partitioning

Recursive partitioning is used as a complement to regression analysis (cf. chapter 5.4.1) in order to clarify data structures or to simplify the relationship under consideration.

In recursive partitioning all seven predictor variables of the full model were included in ordinary linear model form. The only difference to regression analysis is that the tree age component 'uneven age' could not be treated as interaction. Consequently tree age of uneven aged stands was treated as missing value and additionally 'even aged' was introduced as a qualitative variable.

Branching of the regression tree was stopped by a 0.05 limit criterion for explanation increase, this means that the overall Rsquare must have had increased by – in minimum - 0.05 at each step.

Table 18: Summary of recursive partitioning analysis explaining sulphur pool in the organic layer (log-transformed). Decrease of relative error indicates model quality. Relative error is measured as quotient of residual and total sum of squares, i.e. 1 - R-Square.

Step	Complexity parameter	No. of splits	Residual sum of squares	Relative error	Std. error
1	0.445	0	145.91	1.000	
2	0.120	1		0.555	
3	0.055	2		0.434	
4	0.050	5	39.44	0.270	0.613

The result of recursive partitioning is quite striking, as only 6 groups had to be distinguished in order to account for 73.0% of the variation in sulphur pool size. Additionally, the standard error achieved is smaller than the one achieved for regression analysis (cf. Table 16 and Table 18).

In accordance to regression analysis, pH was found to be the most important explanatory variable in terms of variation accounted for: with pH as criterion, the first two splits already explain 56.6% of the variation (cf. Table 18 and Table 19).

The pH limits established were 4.22 and 2.975, which distinguish the very acidic, the acidic, and the remaining organic layers. The estimated sulphur pool for these groups are 5.075 log(kg ha^{-1}) for very acidic, 4.157 log(kg ha^{-1}) for acidic, and 2.444 log(kg ha^{-1}) for remaining organic layers (Table 19).

For the very acidic organic layers and the remaining organic layers no further distinction was made, as within group variation was already small (terminal node).

Only the plots with a pH between 2.975 and 4.22 were subdivided. The first split criterion applied for this group was temperature (limit 3.117 °C), which distinguished plots with very cold climate (i.e. plots of Finland) and other climate. For the very cold plots (with a pH between 2.975 and 4.22), which are a very homogeneous group, no further distinction was made. Estimated sulphur pool for this group is 3.558 log(kg ha^{-1}) (Table 19, Figure 3).

The remaining plots, i.e. with acidic organic layer and not very cold climate, were, again, split by the pH criterion (limit: 3.35) in a more and less acidic group. The more acidic group is a terminal node with an estimated sulphur pool of 4.754 log(kg ha^{-1}).

The remaining plots, i.e. with a pH in organic layer between 3.35 and 4.22 and not very cold climate, were split by precipitation (limit: 6.533 log(mm yr^{-1}) = 687 mm yr^{-1}) in a more and less moist group. Here it is remarkable, that the group with higher precipitation shows a smaller sulphur pool than the group with lower precipitation (Table 19, Figure 3).

The geographical distribution of the groups distinguished by recursive partitioning is presented as Figure 4. Only one group shows a distinct clustering, the very cold climate plots (with a pH between 2.975 and 4.22).

Hence, the main finding of recursive partitioning analysis is that, besides the dominant effect of pH, the effect of temperature as determined by regression analysis is an artefact of spatial allocation of plots.

Table 19: Branching of recursive partitioning analysis explaining sulphur pool in the organic layer (log-transformed). Node and split criterion describe the grouping. Groups are characterised by number of plots, deviance within group, estimated value of sulphur pool in organic layer (log(kg ha^{-1})), and whether group is terminal node.

Node	**Split criterion**	**No. of plots**	**Deviance (Sum of squares)**	**Estimate**	**Terminal node**
1)	All plots	111	145.910	4.128	
..2)	pH-CaCl >= 4.22	19	10.642	2.444	yes
..3)	pH-CaCl < 4.22	92	70.273	4.476	
.. 6)	pH-CaCl >= 2.975	60	44.107	4.157	
12)	T < 3.117	14	2.265	3.558	yes
13)	T >= 3.117	46	35.284	4.339	
26)	pH-CaCl >= 3.35	24	17.454	3.959	
52)	Precipitation >= 6.533	12	4.224	3.311	yes
53)	Precipitation < 6.533	12	3.136	4.608	yes
27)	pH-CaCl < 3.35	22	10.581	4.754	yes
….7)	pH-CaCl < 2.975	32	8.589	5.075	yes

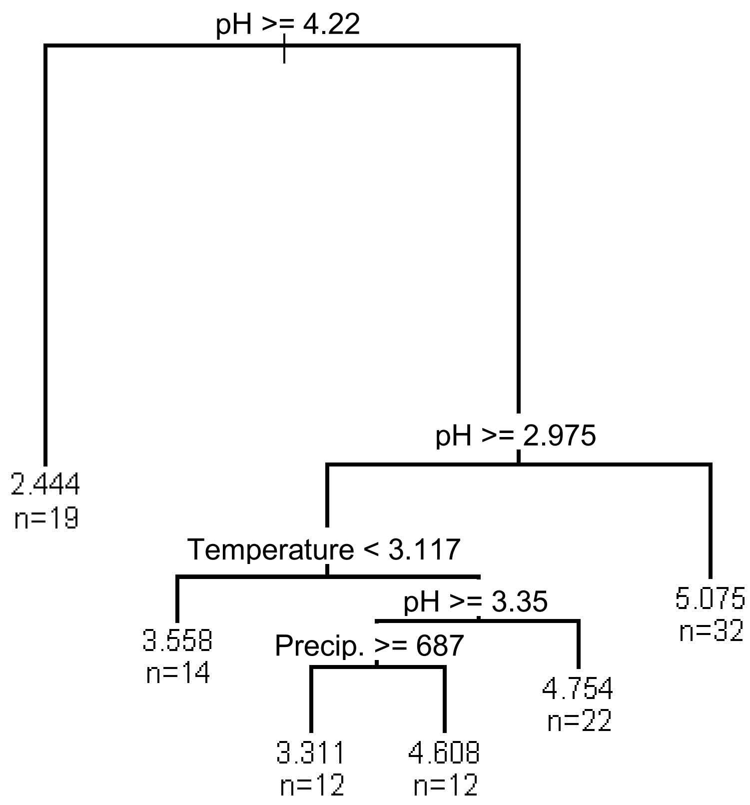


Figure 3: Dendrogram of recursive partitioning analysis with branching criteria and, for terminal nodes, estimated value of sulphur pool in organic layer (log(kg ha^{-1})) and number of plots. Branching criteria split to the left.

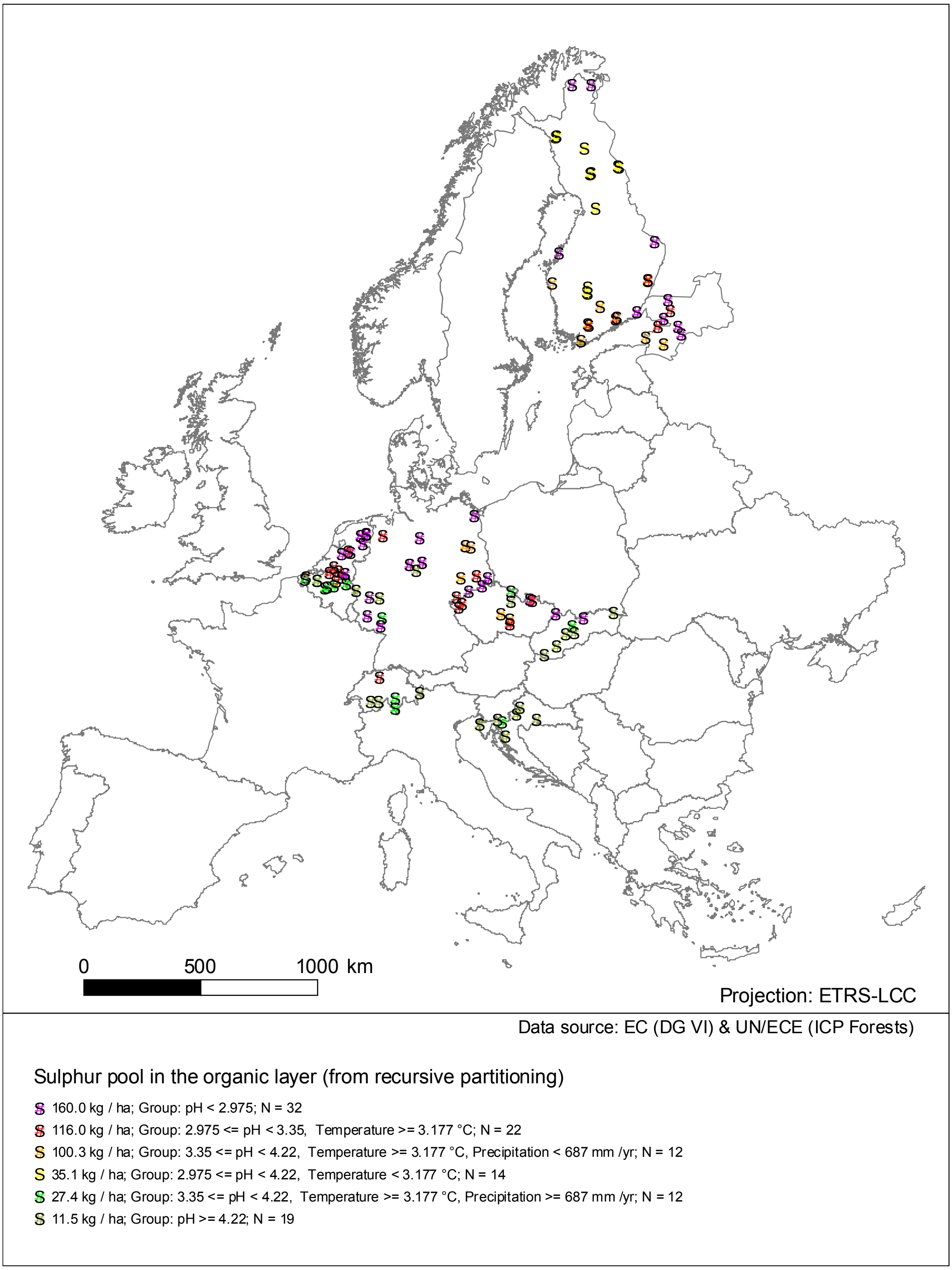


Figure 4: Geographical distribution of the plot groups distinguished by recursive partitioning analysis with estimates for sulphur pool, group characterisation, and number of plots. Because of plots closely located to each other marker overlay occurs.

6.1.3 Transfer to Level I

In general, the findings from regression analysis and recursive partitioning analysis support each other. Both revealed the pH of the organic layer as the main environmental factor explaining the variation of sulphur pool in organic layer and also detected the effect of temperature.

However, in detail the results are different. Tree species contributed significantly to explanation in regression analysis, but was not distinctive in recursive partitioning. The same is true for precipitation, but vice versa. The most obvious explanation for this discrepancy is that predictor variables are correlated: not only altitude, precipitation and temperature, as mentioned by DE VRIES et al. (2000), but also climate and tree species (cf. Figure 2), which is common sense in forestry and geobotany. This presumption of correlation clear ranks the results of recursive partitioning over the results regression analysis, as tree species occurrence is a causal function of climate, and hence, should be substituted by the more basic variables.

Target Level I plots for function transfer

With GIS point-in-polygon analysis 796 Level I plots - out of the 4904 Level I plots listed in the soil survey table - were found to be located within the spatial range of definition (Figure 1). The meteorological variables temperature and precipitation were assigned to these plots by nearest neighbour method (cf. Chapter 5.3.1).

787 out of the 796 plots were listed in the mandatory data table.

For 729 out of the 787 plots an organic layer not saturated with water was found (soil horizon code 'O').

For 724 out of the 729 plots data for pH (pH_{CaCl}) was available.

Finally, for 712 out of the 724 plots the values of pH_{CaCl}, temperature and precipitation matched the functional range of definition (Table 13).

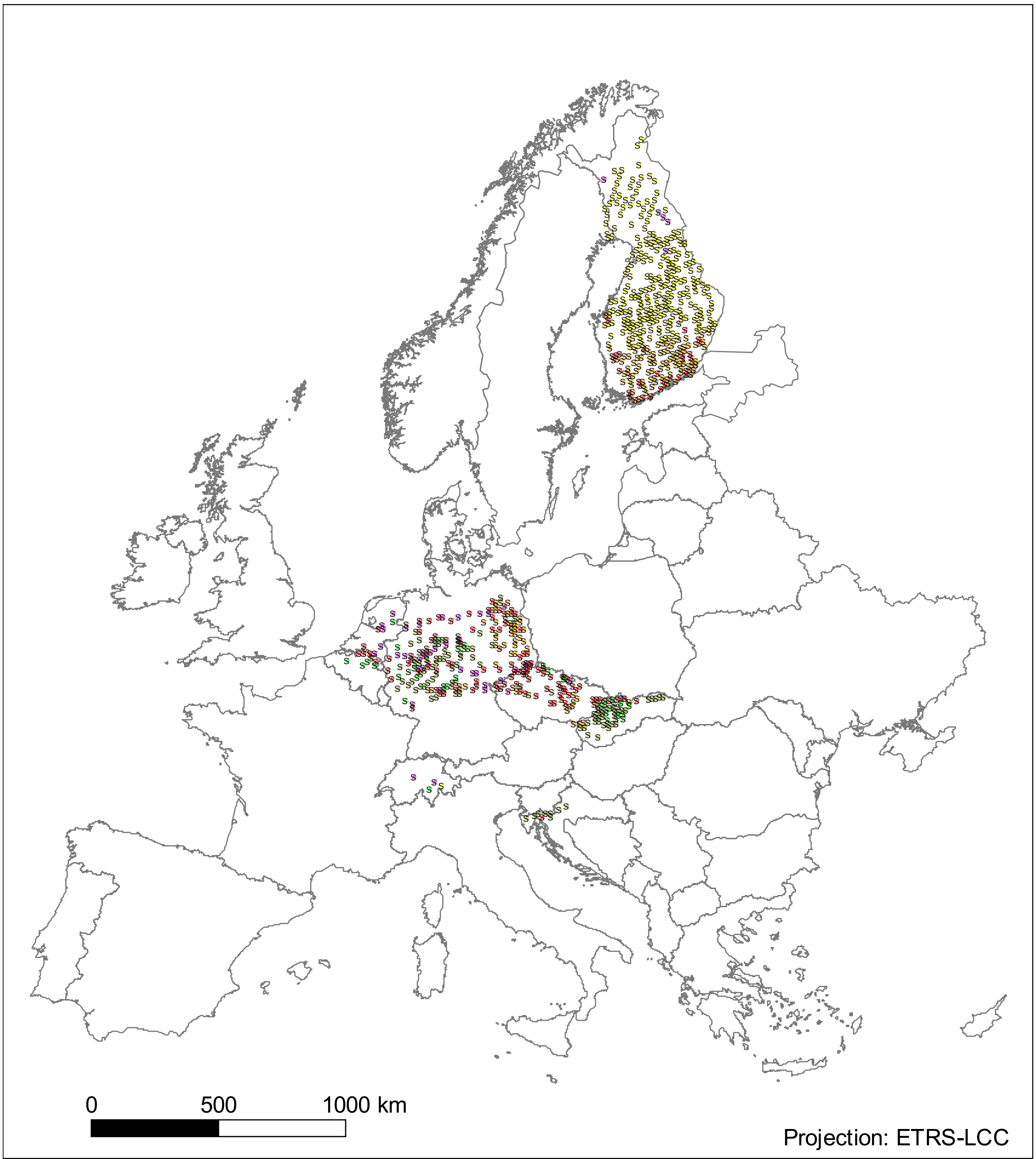
Sulphur pool in the organic layer of Level I plots

The result of the function transfer of the recursive partitioning model (Table 19) for the 712 target Level I plots is presented as (Figure 5).

The map exhibits a high degree of homogeneity for Scandinavia, and a high variability for Western and Central Europe, which resembles the variability of large scale geological structures, i.e. the variability of parent material which again contributes to variability of soil pH. Regions known for their of high historical S-deposition, i.e. Eastern Germany, Czech Republic, and northern border of Slovak Republic, were - in accordance to expectations - characterised by a high sulphur pool.

For the southern part of Finland a high and for the central part of Slovak Republic a low sulphur pool was estimated.

A comparison between the Level II and Level I results shows distinct differences with higher shares of Level II plots in extreme high and low sulphur pool groups determined from the recursive partitioning model (Figure 6). Also the means differ distinctly. For Level II the mean is 89 kg S ha^{-1}, whereas for the Level I plots it is 66 kg S ha^{-1}. These differences show the added value of up-scaling results as the higher number of Level I plots give more precise results with regards to area representativity.



Data source: EC (DG VI) & UN/ECE (ICP Forests)

Sulphur pool in the organic layer for Level I plots (from function transfer)

- S 160.0 kg / ha; Group: pH < 2.975; N = 42
- S 116.0 kg / ha; Group: 2.975 <= pH < 3.35, Temperature >= 3.177 °C; N = 141
- S 100.3 kg / ha; Group: 3.35 <= pH < 4.22, Temperature >= 3.177 °C, Precipitation < 687 mm /yr; N = 127
- S 35.1 kg / ha; Group: 2.975 <= pH < 4.22, Temperature < 3.177 °C; N = 251
- S 27.4 kg / ha; Group: 3.35 <= pH < 4.22, Temperature >= 3.177 °C, Precipitation >= 687 mm /yr; N = 40
- S 11.5 kg / ha; Group: pH >= 4.22; N = 111

Figure 5: Result of function transfer from Level II to Level I for sulphur pool in the organic layer. Relationship used: recursive partitioning model (cf. Table 19). Estimates for sulphur pool and grouping of plots as specified for Level II plots (cf. Figure 4) (N = number of plots).

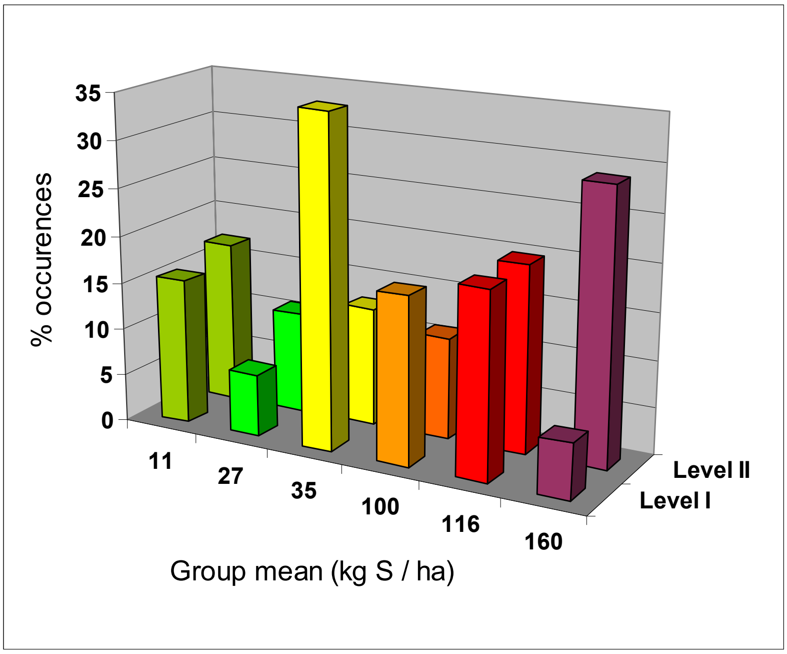


Figure 6: Distribution of Level I and Level II plots according to groups of the recursive partitioning model.

6.2 Lead concentration in the organic layer (Model 2)

DE VRIES et al. (1998: Chapter 6.1, p. 105ff) examined the relationships between soil and foliage condition parameters on the one hand and stand and site characteristics on the other hand. The soil condition parameters considered were macro nutrient (N, P, Ca, Mg, K) and heavy metal concentrations (Pb, Cd, Cu, Zn) in the organic layer. Tree species, soil type, climatic region, and altitude were used as explanatory variables.

The relationship between lead concentration in the organic layer (mg kg^{-1}) and stand and site characteristics was determined as [p. 108]:

$[Pb]_{org\ layer}$ = f (tree species***, climatic region***, altitude**); N = 122; $R^2_{adj.} = 0.53$.

*** = highly significant; $p < 0.001$

** = significant; $0.001 < p < 0.05$

Regression parameters were not published.

6.2.1 Compilation of relevant data

Lead concentration in the organic layer is an optional parameter within Level II. In case several organic layers were recorded for a plot (a number up to 3 was found), the lead concentration was calculated via the lead pool of total organic layer. In order to calculate pool size, the parameter 'amount of organic layer' was used, which is mandatory within level II.

For some plots, mainly the ones from The Netherlands, several datums related to different survey years are available - up to 3 sampling years were found. In this case always the most recent datum was used. However, it turned out that the most recent year was 1995 always. Table 20 gives an overview on the steps applied.

Table 20: Procedure applied to retrieve consistent data sets on lead concentration in the organic layer, and number of cases.

Step	Description	Parameter table	
		mandatory	optional
1	Number of organic layers in database; all years	896	610
2	Number of plots with organic layers; all years	858	603
3	- as before, but: (i) with values for Pb when only 1 organic layer per plot or (ii) with values for Pb and amount of organic layer when more than 1 organic layer per plot; all years	854	204
4	Mandatory and optional parameter tables related with keys country code, plot number, organic layer code and sampling year; all years	-> 173 <-	
5	Number of plots with Pb concentration of total organic layer; all years (i.e. 7 plots showed 2 organic layers)	166	
6	- subset of step 5, but repeated measurements excluded; only the most recent date was used (i.e. 11 plots showed 3 sampling datums)	144	
7	as 6, but without 3 outlayers with very high [Pb] and 3 isolated plots	138	

Predictor variables and lead concentration in the organic layer are available for 144 plots. Tree species, stand age, and altitude were taken from the survey "Stand and site characteristics". Climatic region was determined from closest Level I plot (cf. chapter 5.3.2). To limit the degrees of freedom within the model, as soil type the respective parent material classes, and as tree species the respective tree clusters from DE VRIES et al. (1998) were used.

From the 144 plots 3 were sorted out as outliers, because of very high lead concentrations. The outlieres are located in central Germany and may by effected by local emmitents.

From the remaining 141 plots the 3 plots located in Portugal were assessed to be spatial outliers, because of their isolated location and small number.

Hence, 138 plots could be passed for further evaluation. Compared to the original dataset of DE VRIES et al. (1998) this is an increase of 13%. The sampling year with the highest number of cases is 1995 (80 plots), followed by 1996 (15) and 1991 (14). The geographical distribution of the plot sample is depicted in Figure 7. The plots exhibit a distinct spatial clustering, so that a spatial range of definition with two regions has been delineated (Finland including Leningrad region and Estonia, and Western and Central Europe).

The ranges of the response variable and the quantitative predictor variables are presented in Table 21. The minimum and maximum values describe the statistical range of definition. Because of skewness lead concentration and altitude were log-transformed (natural logarithm).

For the distribution of the qualitative variables climatic region, soil type and tree species see Table 22, Table 23 and Table 24, respectively.

Table 21: Range of lead concentration in the organic layer, and ranges of the quantitative predictor variables used in statistical analysis (No. of plots: 138)

Variable	**Unit**	**Minima, percentiles, and maxima**							**Transf.**
		Min	**5%**	**25%**	**50%**	**75%**	**95%**	**Max**	
[Pb]	mg kg^{-1}	7.0	15.0	29.75	69.0	107.5	217.8	322.0	ln
Altitude*	m	25	25	75	200	575	1182.5	1875	ln
Tree Age*/**	yr	30	50	50	70	110	130	130	

* value determined as mean of class range (e.g. 30 yr for age class 20 – 40 yr and 75 m for altitude class 50 – 100 m)
** for uneven aged stands an age of 110 years was used

Table 22: Distribution of climatic regions used in statistical analysis

Climatic region	**No. plots**
Atlantic (North)	29
Sub-Atlantic	41
Boreal	35
Boreal (Temperate)	7
Continental	3
Mountainous (South)	23

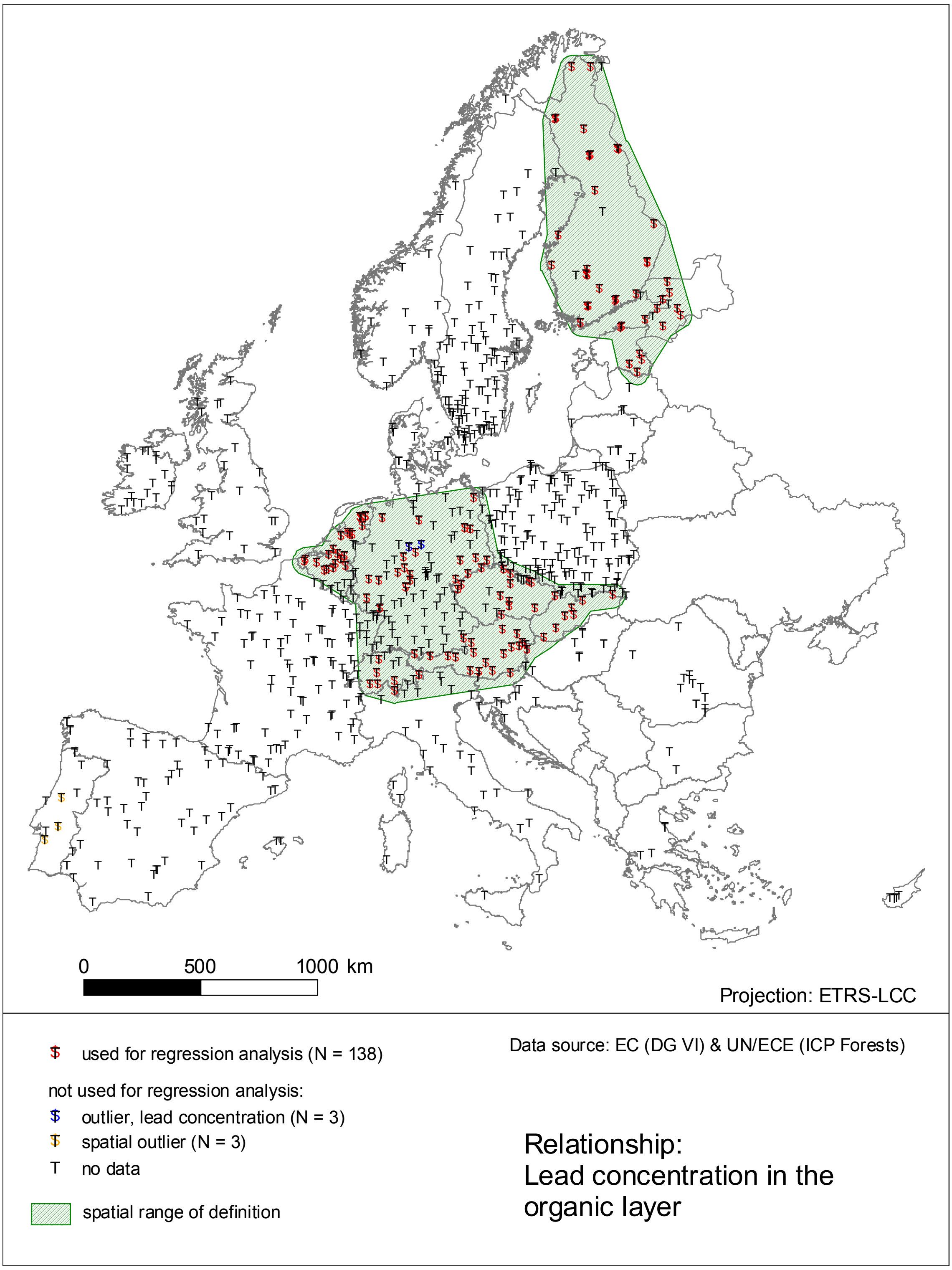


Figure 7: Geographical distribution of the plots used in the statistical analyses, and spatial range of definition.

Table 23: Distribution of soil types and assignment of soil types to the soil clusters used in the statistical analysis

Soil type cluster	Podzols and Arenosols	Cambisols and Luvisols	Remaining non-calc. soils	Calcareous soils
Calcaric Fluvisols				2
Eutric Gleysols			3	
Dystric Gleysols			1	
Dystric Leptosols			2	
Rendzic Leptosols				2
Haplic Arenosols	4			
Cambic Arenosols	5			
Ferralic Arenosols	1			
Gleyic Arenosols	3			
Eutric Cambisols		7		
Dystric Cambisols		23		
Chromic Cambisols		1		
Gleyic Cambisols		5		
Haplic Calcisols				2
Calcaric Phaeozems				2
Stagnic Luvisols		1		
Gleyic Luvisols		2		
Dystric Planosols			2	
Eutric Podzoluvisols			1	
Dystric Podzoluvisols			5	
Haplic Podzols	23			
Cambic Podzols	12			
Ferric Podzols	14			
Carbic Podzols	3			
Gleyic Podzols	6			
Haplic Alisols			2	
Stagnic Alisols			1	
Fimic Anthrosols			3	
Sum	71	39	20	8

Table 24: Distribution of tree species and assignment of species to species groups and conifer/broadleaf type used in the statistical analysis

Species group	Pine	Spruce	Other conifers	Oak	Beech	Other broadleaves
Abies alba			1			
Carpinus betulus						1
Fagus sylvatica					20	
Fraxinus excelsior						1
Larix decidua			1			
Picea abies		49				
Pinus mugo			1			
Pinus nigra			2			
Pinus sylvestris	43					
Pseudotsuga menziesii			5			
Quercus cerris						2
Quercus petraea				4		
Quercus robur				8		
Sum	43	49	10	12	20	4
Conifers / Broadleaves		102			36	

6.2.2 Analytical statistics

Regression analysis

The results from a re-sampled full model - with tree species, soil type, climatic region, and altitude as predictor variables - partly confirm the findings of DE VRIES et al. (1998). In terms of sum of squares (and hence partial R^2) the most important predictors are climatic region (30.0%) and tree species cluster (20.6%). Soil type (parent material) remains to be not significant. Also the variance accounted for is about comparable. The model explains after adjustment 46.4% of the variation of the lead concentration in the organic layer, which is c. 6.5% less than the original model of DE VRIES et all. (1998). However, deviant from the 'original' model altitude is not among the significant predictors.

Additionally, with respect to the tree species groups, it turned out that the parameter differences within conifers and broadleaves are small, while deviating substantially between conifers and broadleaves.

In order to determine the model parameters and to test further predictor variables, a regression analysis with mixed forward-backward selection strategy was performed. The additional predictor variables included were: regions of spatial range (s. Figure 7), stand age, and tree type as conifers/broadleaves. The results of the selection approach (s. Table 25) coincide with the findings of the re-sampled full model in terms of predictors selected. None of the additional predictor variables were found to contribute significant to lead concentration.

With respect to climatic region, lowest concentrations were found for Boreal and Boreal Temperate regions and highest for Atlantic (North) and Continental regions. Plots dominated by conifers show substantially higher lead concentrations than broadleaved stands. However, there may be an interaction between climatic region and tree type, since conifers dominate the Boreal region.

With respect to soil type, lowest concentrations were found in calcareous soils. However, the predictor soil type is not significant at the 5% level.

Table 25: Summary of linear regression model explaining lead concentration (log-transformed) in the organic layer with mixed forward/backward selection of predictors (only predictors significant at the 5% level are given). Sum of squares from ANOVA. (N = 138, adj.-r^2 = 0.463).

	Estimate	**Std. error**	**t value**	**Signif.**	**DF**	**Sum of squares**
(Intercept)	4.117	0.134	30.664	***		
Climatic region				***	5	28.45
boreal	-1.654	0.164	-10.089	***		
boreal (temperate)	-0.736	0.263	-2.793	**		
continental	-0.325	0.370	-0.877			
mountainous (South)	-0.515	0.173	-2.981	**		
sub-atlantic	-0.444	0.148	-3.002	**		
Tree type				***	1	17.72
Conifers	0.904	0.131	6.906	***		
Model				***	6	46.17
Residuals		0.6096			131	48.67
Total						94.84

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

Results of a a covariance model with soil type and interaction of tree type and climatic region as predictor variables confirm the assumption, that tree type and climatic region are not independent variables (Table 26). The interaction term of tree type and climatic region contributes more to partial explanation of lead concentration than the simple additive approach. Soil type is found to be significant in this model (contributing c. 3%), so that the explanation of the whole model is higher compared to the model without interaction terms.

Lowest lead concentrations are found, in the order mentioned, for conifers in boreal climate, broadleaves in sub-atlantic climate, broadleaves in mountainous (south) climate, and conifers in boreal temperate climate, which all deviate significantly from the mean.

However, since tree species are not equally represented within the climatic regions (cf. Table 27), the model shows singularities. Only within atlantic (North) and sub-atlantic climate conifers and broadleaves are represented approximately equal. For boreal climates only conifers are recorded.

Table 26: Summary of a covariance model explaining lead concentration (log-transformed) in the organic layer with intercation of tree type and climatic region. Sum of squares from ANOVA (N = 138, adj.-r^2 = 0.521).

	Estimate	Std. error	t value	Signif.	DF	Sum of squares
(Intercept)	4.819	0.143	33.699	***		
Tree type x Climatic region				***	9	50.12
Broadleaves, atlantic (North)	-0.375	0.210	-1.782	.		
(Broadleaves, continental)	(-1.448)	(0.609)	(-2.379)	(*)		
Broadleaves, mountainous (South)	-0.924	0.288	-3.214	**		
Broadleaves, sub-atlantic	-1.364	0.193	-7.072	***		
Conifers, atlantic (North)	-0.087	0.198	-0.442			
Conifers, boreal	-1.449	0.169	-8.560	***		
Conifers, boreal temperate	-0.580	0.263	-2.204	*		
(Conifers, continental)	(0.102)	(0.429)	(0.238)			
Conifers, mountainous (South)	-0.272	0.189	-1.437			
Conifers, sub-atlantic	0.000					
Soil type				*	3	3.27
Cambisols and Luvisols	-0.062	0.144	-0.432			
Remaining non-calc. soils	0.094	0.183	0.518			
Calcareous soils	-0.414	0.246	-1.683	.		
Model				***	12	53.39
Residuals		0.5759			125	41.45
Total						94.84

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05, . p < 0.01, (): only one case

Table 27: Cross tabulation of climatic region and tree type with number of plots.

Climatic region	Broadleaves	Conifers
atlantic (North)	13	16
sub-atlantic	17	24
boreal		35
boreal (temperate)		7
continental	1	2
mountainous (South)	5	18

The results of the covariance model support the hypothesis that the variation in lead concentration in the organic layer is an effect of airborne lead deposition, since plots dominated by conifers show higher values - generally (Table 25) as well as within single climatic regions (Table 26) - and, since plots within climates of lowest emmitent densities show lowest values (boreal climates).

Recursive partitioning

Recursive partitioning is used as a complement to regression analysis (cf. chapter 5.4.1) in order to clarify data structures or to simplify the relationship under consideration.

In recursive partitioning all six predictor variables of the mixed forward/backward selection regression model (cf. Table 25) were included. Branching of the regression tree was stopped by a 0.05 limit criterion for explanation increase, this means that the overall R^2 must have had increased by – in minimum - 0.05 at each step.

Table 28: Summary of recursive partitioning analysis explaining lead concentration in the organic layer (log-transformed). Decrease of relative error indicates model quality. Relative error is measured as quotient of residual and total sum of squares, i.e. 1 - R^2.

Step	Complexity parameter	No. of splits	Residual sum of squares	Relative error	Std. error
1	0.268	0	94.84	1.000	
2	0.162	1		0.732	
3	0.089	2		0.570	
4	0.050	3	45.65	0.481	0.581

In accordance to the regression analyses (without and with interaction), recursive partitioning found climatic region and tree species to be the most important explanatory variables in terms of variation accounted for. Additionally, model R^2 (c. 51%) and standard error (0,581) are compareable to regression analysis.

With climatic region – boreal vs. non boreal - as criterion, the first split explains 28.8% of the variation in lead concentration, and with tree species as criterion – conifers vs. broadleaves - the second split additionally explains another 16.2%. (cf. Table 28 and Table 29). The estimated lead concentrations for these groups are 3.366 log(mg kg $^{-1}$) for (conifers in) boreal climate, 4.636 log(mg kg $^{-1}$) for conifers in non-boreal climate, and 3.826 log(mg kg $^{-1}$) for remaining plots dominated by broadleaves (Table 29).

Table 29: Branching of recursive partitioning analysis explaining lead concentration in the organic layer (log-transformed). Node and split criterion describe the grouping. Groups are characterised by number of plots, deviance within group, estimated value of lead concentration in organic layer (log(mg kg $^{-1}$)), and whether group is terminal node.

Node	Split criterion	No. of plots	Deviance (Sum of squares)	Estimate	Terminal node
1)	All plots	138	94.841	4.103	
2)	Climatic region: boreal	35	12.843	3.366	*
3)	Climatic region: not boreal	103	56.568	4.353	
6)	Tree type: broadleaves	36	19.498	3.826	
12)	Climatic region: sub-atlantic, mountainous (South), continental	23	9.228	3.463	*
13)	Climatic region: atlantic (North)	13	1.861	4.469	*
7)	Tree type: conifers	67	21.714	4.636	*

The group of broadleaves was subdivided with climatic region – atlantic (North) - as criterion again. For broadleaves in atlantic (North) climate lead concentrations of 4.469 log(mg kg^{-1}) were estimated; for remaining plots dominated by broadleaves in other climates a value of 3.463 log(mg kg^{-1}) was determined, which is nearly as low as the value for conifers in boreal climate.

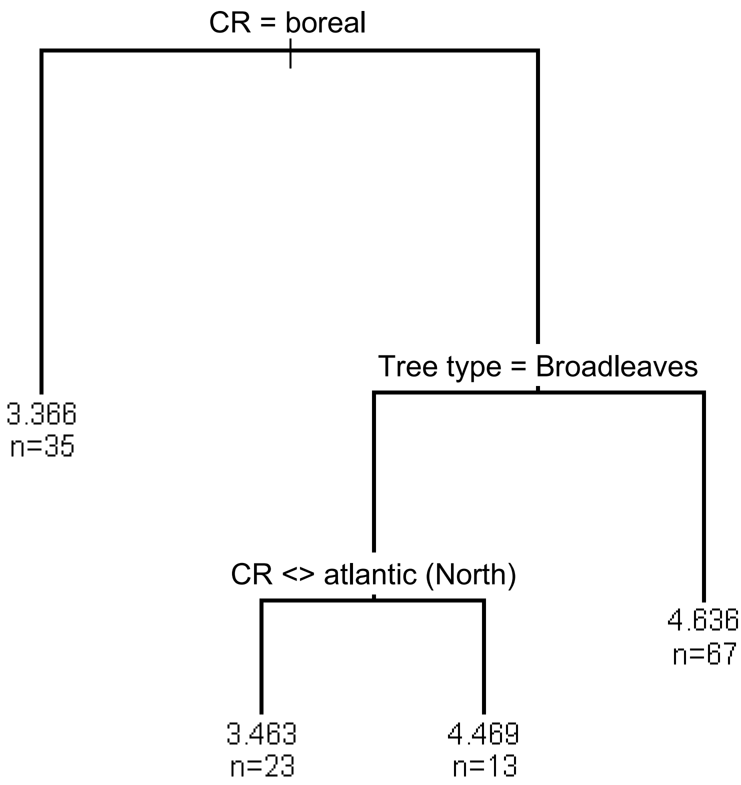


Figure 8: Dendrogram of recursive partitioning analysis with branching criteria and, for terminal nodes, estimated value of lead concentration in organic layer (log(mg kg^{-1})) and number of plots. Branching criteria split to the left. ('CR' = Climatic region)

6.2.3 Transfer to Level I

The findings from regression analysis and recursive partitioning analysis support each other. Both revealed climatic region and tree type as the main factors explaining the variation of the lead concentration in organic layer. However, with respect to model quality and model simplicity, the result from recursive partitioning is superior to the results of the regression approaches: (i) compared to simple linear regression (Table 25) the degree of explanation is higher and the standard error lower, compared to a covariance model with interaction of tree type and climatic region (Table 26) insignificant interaction terms and, hence, over parameterisation are avoided.

Target Level I plots for function transfer

With GIS point-in-polygon analysis 1650 Level I plots - out of the 5961 Level I plots listed in the crown condition survey table of the year 2001 - were found to be located within the spatial range of definition (cf. Figure 7).

For 1448 out of the 1650 plots an assignment to the tree type group 'conifer' or 'broadleaves' could be conducted. The remaining 202 plots were classified as 'mixed', since neither conifers nor broadleaves exceeded 75% of the number of individual trees assessed in the crown condition survey.

Finally, for 1425 out of the 1448 plots the climatic region declaration was within the range of definition. The remaining 23 plots are characterised as 'mediterranean (lower)', these are located in the vicinity of Lake Konstanz.

Lead concentration in the organic layer of Level I plots

The result of the function transfer of the recursive partitioning model (Table 29) for the 1425 target Level I plots is presented as (Figure 9).

The map exhibits a high degree of homogeneity for Scandinavia, and a distinct variability for Western and Central Europe, which resembles tree type (conifers versus broadleaves) and geographical location (atlantic North versus other West and Central european climates).

As the relationship has an overview characteristic only, no in depth considerations are appropriate.

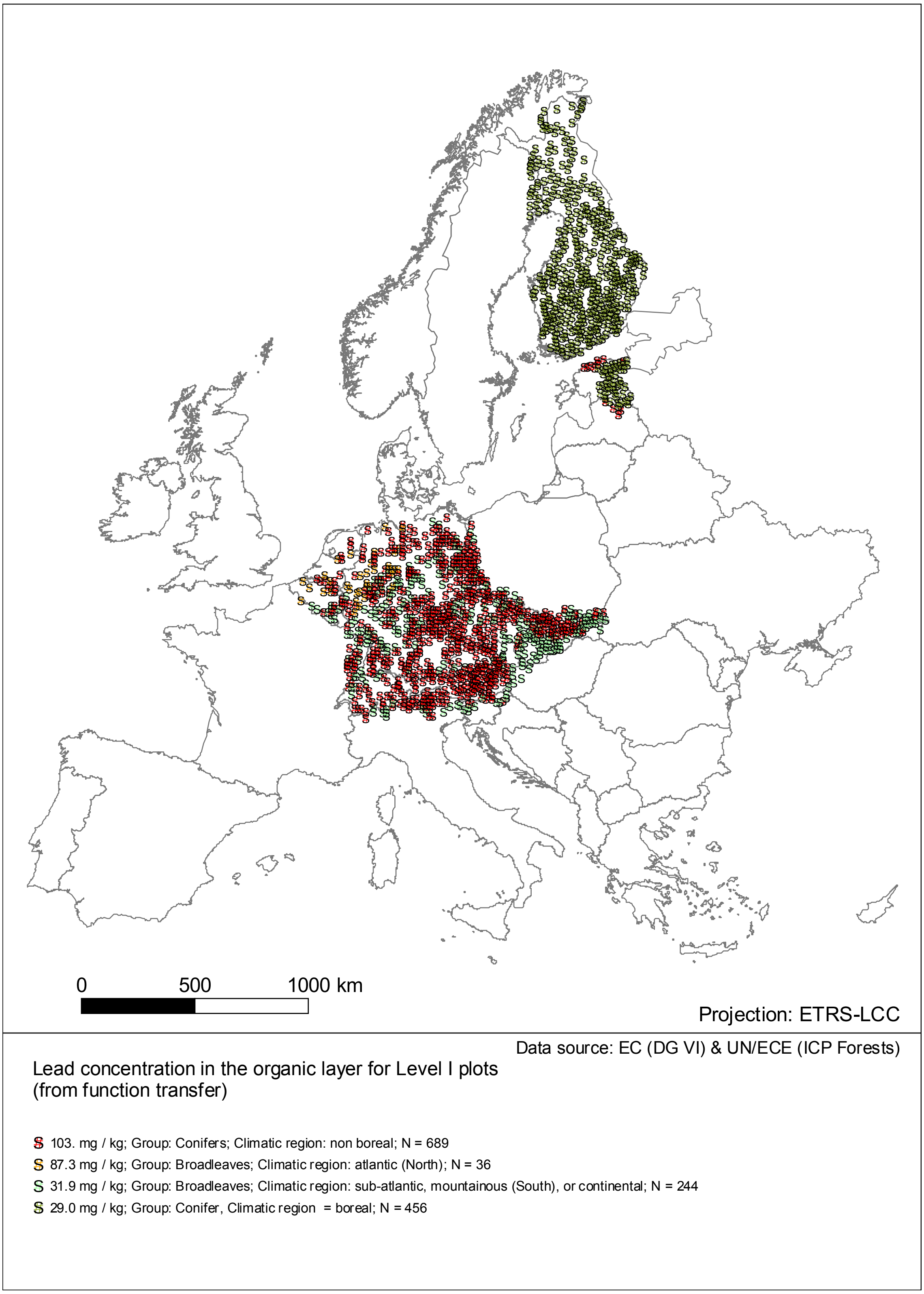


Figure 9: Result of function transfer from Level II to Level I for lead concentration in the organic layer. Relationship used: recursive partitioning model (cf. Table 29); N = number of plots.

6.3 Sulphate concentration in the soil solution of the topsoil (Model 3)

DE VRIES et al. (2000: Chapter "Soil solution chemistry", p. 131ff.) examined the relationships between soil solution chemistry, stand and site characteristics and atmospheric deposition. The soil solution ions considered were macro nutrients (S, N, Ca, Mg, K), pH and aluminium in the top- (0 cm – 40 cm) and subsoil (40 cm – 80 cm). The explanatory variables were soil type, tree species, throughfall deposition, precipitation, precipitation excess and, whenever relevant, C/N ratio, base saturation and/or pH. Since nothing more specific is mentioned (stepwise, etc.), the statistical approach applied should have been an ordinary linear regression with a full model.

The relationship explaining sulphate concentration in soil solution of the topsoil (mg l^{-1}) for the year 1997 was determined as [p. 145]:

$$[SO_4]_{topsoil} = f(-\text{ tree species}, + SO_{4,throughfall}, -\text{ precipitation}) ; N = 99; R^2_{adj.} = 0.63,$$

with all 3 explanatory variables being highly significant. Regression parameters were not published. Additionally, it is not clear whether the tabulated degree of explanation is related to the full model or to the significant variables only and whether 'topsoil' consists of mineral layers only or of mineral and organic layers.

6.3.1 Compilation of relevant data

For re-calculation of the full model soil type, tree species, sulphate throughfall deposition and precipitation were used as explanatory variables. Precipitation excess was dropped, because evapotranspiration is not available within Level II and turned out to be not significant for all response variables examined by DE VRIES et al. (2000).

Sulphate concentration in soil solution is a mandatory parameter of the soil solution chemistry survey and both sulphate deposition and precipitation[6] are mandatory within the deposition survey. Soil type and tree species are mandatory properties of stand and site characteristics survey.

Wet throughfall deposition has been collected on a total of 536 plots during more or less extended periods between 1990 and 2001. Due to the distinct seasonal variation of precipitation as well as sulphate within throughfall deposition, only those plots were used for which throughfall deposition was sampled at least for 244 days within each single year. For each valid year the respective fluxes were projected to the whole year by the ratio 365/number of sampling days.

Soil solution has been collected on a total of 254 plots during more or less extended periods between 1990 and 2001. Annual means of sulphate concentration were calculated with two approaches: (i) following the approach of DE VRIES et al. (2000) as simple annual average concentrations and (ii) as annual average weighted with individual sampling period duration. It turned out that both approaches retrieved very similar results, probably because sampling periods are mostly constant for the single plot. Here, however, the weighting with individual sampling period duration was used.

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[6] Following DE VRIES et al. (2000) precipitation was taken from the deposition survey.

Soil solution may be collected in different sampling depths and/or with different sampling devices within single plots and within Lavel II. Concerning the sampling devices, here only the methods 'tension lysimeter' and 'zero tension lysimeter' were considered. Concerning the aggregation of sampling depths of soil solution - in order to calculate plot means – equal significance of the single measurement was assumed. Thus, plot means were calculated as annual average of single observations within evaluation depth - here 0 cm - 40 cm - weighted with individual sampling period duration, as long as total accumulated sampling duration exceeded 122 days for each single year.

Table 30 gives an overview on the steps applied to derive the sample.

Table 30: Procedure applied to retrieve coherent data sets for sulphate concentration in soil solution of the topsoil (0 cm - 40 cm) and predictor variables including number of cases.

Step	Description	Survey	
		Soil solution chemistry	Deposition
1	Number of plots with annual mean values for sulphate concentration; all years*	822	
2	Number of plots with annual sulphate and precipitation throughfall deposition; all years*		1814
3	**Soil solution and deposition survey data related for plots; all years**	**-> 762 <-**	
4	- subset of step 3, but only measurements of the years 1996 – 2001	709	
5	- subset of step 4, but outliers eliminated; years 1996 – 2001	692	

* according to the criteria mentioned in the text

To limit the degrees of freedom within the model, as soil type the respective parent material classes and as tree species the respective tree species groups from DE VRIES et al. (1998) were used.

Distribution properties of the quantitative variables for the years 1996 to 2001 are summarized in Table 33. Because of skewness sulphate in soil solution, sulphate deposition and precipitation were log-transformed (natural logarithm).

Table 31: Distribution of soil types (soil clusters) used in statistical analysis

Year	Podzols and Arenosols	Cambisols and Luvisols	Remaining non-calc. soils	Calcareous soils
1996	31	32	14	1
1997	40	41	14	1
1998	55	52	19	1
1999	52	57	22	2
2000	57	51	20	2
2001	56	51	20	1

Table 31 and Table 32 summarize the expression of the qualitative variables soil type and tree species, respectively. The geographical distribution of the plots including number of sampling years is depicted in Figure 10.

Table 32: Distribution of tree species (tree species groups) used in statistical analysis

Year	'Pine'	'Spruce'	Other conifers	'Oak'	'Beech'	Other broadleaves
1996	11	34	6	11	15	1
1997	15	45	6	14	16	
1998	24	52	7	16	27	1
1999	24	50	8	18	31	2
2000	28	47	9	16	28	2
2001	28	47	10	14	26	3

Table 33: Range of sulphate concentration in soil solution of the topsoil, and ranges of the quantitative predictor variables used in statistical analysis.

Variable	Unit	No. of plots	Minima, percentiles, and maxima							Transf.
Year			Min	5%	25%	50%	75%	95%	Max	
[SO_4] Topsoil										
1996	mg S l^{-1}	78	0.207	0.579	1.465	3.125	6.002	14.77	21.55	ln+1*
1997	mg S l^{-1}	96	0.246	0.564	1.415	2.373	4.191	9.459	16.57	ln+1
1998	mg S l^{-1}	127	0.154	0.606	1.245	2.270	4.583	9.505	17.24	ln+1
1999	mg S l^{-1}	133	0.193	0.563	1.219	1.981	4.034	8.424	18.62	ln+1
2000	mg S l^{-1}	130	0.160	0.401	1.021	1.802	3.469	5.542	8.973	ln+1
2001	mg S l^{-1}	128	0.182	0.496	1.042	2.009	3.685	6.938	11.00	ln+1
SO_4 – Throughfall										
1996	kg S ha^{-1}	78	1.261	2.485	6.989	10.40	16.46	34.59	56.88	ln+1
1997	kg S ha^{-1}	96	0.993	2.977	5.573	7.980	13.69	25.98	47.47	ln+1
1998	kg S ha^{-1}	127	0.452	1.852	4.306	8.267	14.54	26.30	38.14	ln+1
1999	kg S ha^{-1}	133	0.832	1.928	4.615	7.513	11.58	23.05	47.15	ln+1
2000	kg S ha^{-1}	130	1.063	2.269	4.610	6.661	10.16	22.13	30.75	ln+1
2001	kg S ha^{-1}	128	0.576	1.806	4.069	6.552	8.428	21.21	30.70	ln+1
Precipitation										
1996	mm	78	310.1	405.0	499.9	607.1	742.9	1116.9	1520.1	ln
1997	mm	96	282.4	393.0	507.5	669.5	825.4	1266.3	1680.6	ln
1998	mm	127	324.3	452.9	585.2	743.1	968.3	1411.1	1749.5	ln
1999	mm	133	349.3	404.3	548.5	710.8	936.3	1444.7	2141.3	ln
2000	mm	130	342.0	443.6	566.5	780.1	1010.9	1637.9	2441.7	ln
2001	mm	128	313.8	431.8	561.0	743.9	992.5	1378.0	1756.7	ln

* as values <1 occur, the transformation used was ln(x + 1).

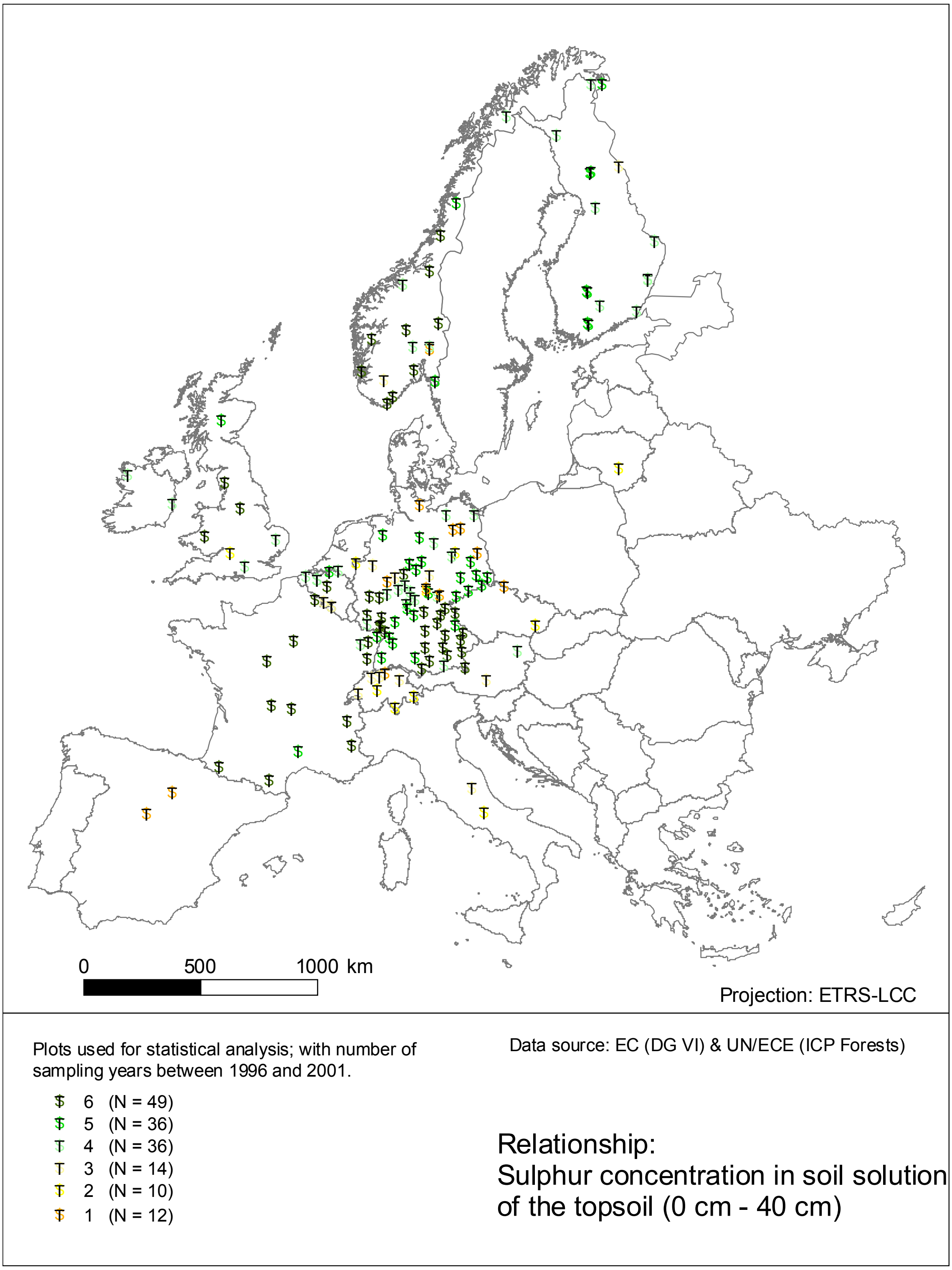

Figure 10: Geographical distribution of the plots used in analytical statistics.

6.3.2 Analytical statistics

The results from the re-sampled full model - with tree species, soil type, sulphate throughfall deposition, and precipitation as predictor variables - confirm the findings of DE VRIES et al. (2000) for the year 1997, in that sulphate deposition and precipitation are highly significant predictors (s. Table 34). For the year 1997 the model explains after adjustment 65% of the variation of the sulphate concentration in soil solution of the topsoil, which is about the value DE VRIES et all. (2000) found. However, deviant from the 'original' model tree species is not among the significant predictors.

The predictor structure is very similar for all sampling years considered. From 1996 to 2001, constantly, sulphate deposition and precipitation were found to be the predictors with the largest impact. Tree species and soil type turned out to be significant only for single years; tree species in 1998 and soil type in 1997 and 1999. However, the degree of explanation of the full model decreased substantially during the period investigated, from c. 71% in 1996 to c. 51% in 2000 and 2001.

Table 34: Overview on significance of predictor variables of the full regression model explaining sulphate concentration in soil solution of the topsoil (0 cm – 40 cm) for the years 1996 – 2001.

Predictor variable	1996	1997	1998	1999	2000	2001
Soil type		*		*		
Tree species			*			
SO_4 – Throughfall	***	***	***	***	***	***
Precipitation	***	***	***	***	***	***
N	78	96	127	133	130	128
$R^2_{adj.}$	71.1	65.0	63.8	55.8	50.8	51.4

Signif. codes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Table 35: Summary of the restricted regression model explaining sulphate concentration in the soil solution of the topsoil (0 cm – 40 cm) for the years 1996 – 2001. Parameters for predictor variables with standard errors (in brackets) and partial explanation of variation (from ANOVA).

Predictor variable	1996	1997	1998	1999	2000	2001
(Intercept)	5.669 (0.858)	6.354 (0.688)	7.551 (0.673)	5.182 (0.583)	4.937 (0.506)	5.394 (0.610)
SO4 – Throughfall	0.845 (0.064) 52.7%	0.681 (0.063) 28.0%	0.690 (0.054) 24.3%	0.624 (0.059) 24.7%	0.620 (0.062) 17.2%	0.618 (0.064) 19.4%
Precipitation	-0.974 (0.136) 19.2%	-1.017 (0.111) 34.2%	-1.171 (0.108) 36.8%	-0.802 (0.092) 27.6%	-0.769 (0.082) 30.6%	-0.828 (0.098) 29.3%
N	87	96	127	133	130	133
$R^2_{adj.}$	71.1	61.5	60.4	51.6	49.8	47.8

In order to assess the change in the impact structure of the highly significant predictor variables on sulphate concentration during time, the regression parameters were calculated with a model including only sulphate deposition and precipitation as predictors (s. Table 35).

The restricted model shows the same trend for the degree of explanation as the full model, a continual decrease of r^2 from 1996 to 2001. This decrease in overall explanation however is not equally distributed to the predictors, but is accompanied by drastic changes in the impact structure; while the partial explanation - in terms of sum of squares - of precipitation remains at about 30% of the total variation for the whole period, the partial explanation of sulphate deposition decreases from over 40% in 1996 to c. 20% in 2000 and 2001. Hence, the decrease in overall explanation can be attributed to the loosening of the relationship between sulphate deposition and soil solution sulphate. The results also indicate a decrease of the effect of sulphate deposition, since the regression parameter tends to show lower values in later years.

To eliminate the effect of changing samples between the years, the restricted model was applied to those plots only, which were measured during the whole period (N = 49, s. Figure 10). The results for this continuous sample not only confirm the findings, but show the time trend observed in a pronounced manner.

Table 36: Means for sulphate concentration (mg SO_4-S l^{-1}) in the soil solution of the topsoil (0 cm – 40 cm), sulphate throughfall deposition (kg SO_4-S ha^{-1} yr^{-1}) and sulphate throughfall deposition concentration (mg SO_4-S l^{-1}) for the years 1996 – 2001, only for plots measured during the whole period (N = 49)

Variable	1996	1997	1998	1999	2000	2001
[SO_4] Topsoil	3.43	2.97	2.85	2.55	2.29	2.28
SO4 – Throughfall	11.36	9.67	9.09	8.63	8.53	7.27
[SO4] - Throughfall	1.76	1.35	1.06	0.98	0.92	0.82

Table 37: Summary of the restricted regression model explaining sulphate concentration in the soil solution of the topsoil (0 cm – 40 cm) for the years 1996 – 2001, only for plots measured during the whole period. Parameters for predictor variables with standard error (in brackets) and partial explanation of variation (from Anova).

Predictor variable	1996	1997	1998	1999	2000	2001
(Intercept)	4.914 (0.940)	6.124 (0.933)	5.957 (1.085)	6.034 (1.130)	4.981 (1.064)	5.020 (1.306)
SO4 - Throughfall	0.765 (0.088) 43.8%	0.734 (0.089) 30.7%	0.650 (0.098) 23.4%	0.567 (0.109) 13.8%	0.605 (0.122) 13.1%	0.582 (0.127) 15.4%
Precipitation	-0.831 (0.146) 23.2%	-0.994 (0.149) 34.0%	-0.916 (0.173) 28.9%	-0.905 (0.179) 30.8%	-0.765 (0.172) 26.1%	-0.756 (0.127) 19.0%
N	49	49	49	49	49	49
$R^2_{adj.}$	65.6	63.2	50.3	42.1	36.6	31.6

The general trends over the years are: that firstly, the *average* sulphate concentration in the topsoil decreases with decreasing *average* sulphate deposition (Table 36), and that secondly, the impact of sulphate deposition on sulphate concentration in soil solution decreases in qualitative and quantitative terms (Table 37). Qualitative reduction of sulphur deposition impact describes the fact that the degree of explanation of inter-plot variability (i.e. overall and partial r^2) decreases from 1996 to 2001. The quantitative reduction of sulphur deposition impact indicates that the response of soil solution sulphate concentration on sulphate deposition is continuously weaker for later years (i.e. smaller parameter slopes).

The findings support the hypothesis that forest ecosystems recover from the high historical levels of sulphur deposition and increasingly re-gain the capability to control sulphur flow and ecosystem sulphur cycle.

Model simplification

Sulphate deposition rate and precipitation rate, as an additive term introduced by DE VRIES et al. (2000), can be replaced by the mean annual sulphate concentration in deposition. Such a bivariate concentration versus concentration approach is commonly used to investigate the relationships of ions with a low degree of ecosystem interaction along a water flow pathway.

The simple linear regression between mean sulphate concentration in throughfall deposition and mean sulphate concentration in soil solution of the topsoil (0 cm – 40 cm) (s. Table 38 and Figure 11) is fully equivalent to the more complicated model - with deposition rate and precipitation - in terms of variation accounted for. Thus, it also confirms the finding of the qualitative decrease of sulphate deposition impact for the period 1996 to 2001. However, on the concentration basis is no indication for a quantitative reduction of sulphur deposition impact; as the regression parameter slope remains almost constant.

Table 38: Summary of linear regression between mean sulphate concentrations in (i) throughfall deposition (mg S l^{-1}) and in (ii) soil solution of the topsoil (0 cm – 40 cm, (mg S l^{-1}) for the years 1996 – 2001, only for plots measured during the whole period. Parameters for predictor variables with standard error (in brackets).

Predictor variable	1996	1997	1998	1999	2000	2001
(Intercept)	0.213 (0.134)	0.201 (0.135)	0.371 (0.146) *	0.359 (0.158) *	0.322 (0.162)	0.393 (0.161) *
SO_4 – mean throughfall conc.	1.182 (0.132) ***	1.286 (0.157) ***	1.216 (0.196) ***	1.140 (0.227) ***	1.192 (0.243) ***	1.174 (0.262) ***
N	49	49	49	49	49	49
$R^2_{adj.}$ (%)	62.2	58.0	43.7	33.6	33.5	28.4

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

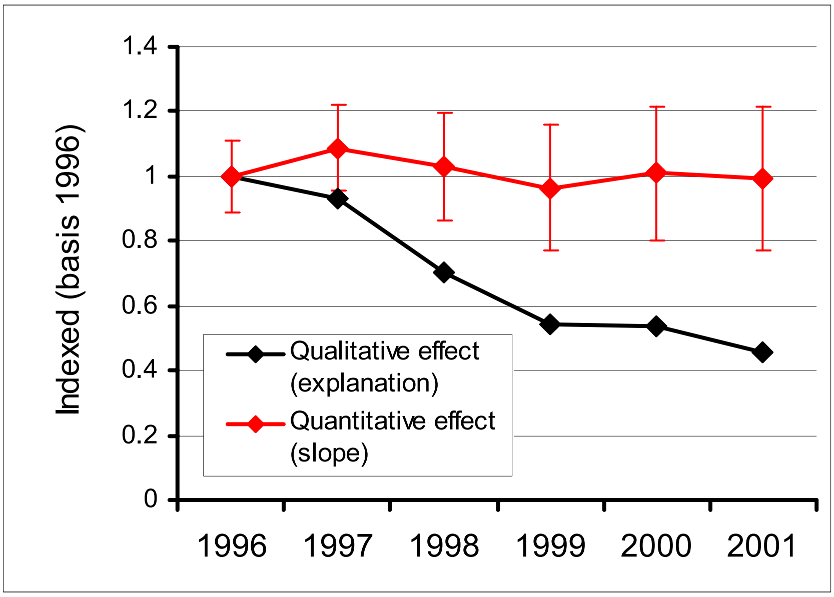

Figure 11: Time trend of degree of explanation and slope (with standard error) of the linear regression between mean sulphate concentrations in throughfall deposition and in soil solution of the topsoil for the years 1996 – 2001. (For non-indexed values see Table 38)

As reliable data on deposition rates with a European wide coverage are not available, no attempt to transfer the relationship to Level I was made. Neither EMEP nor EDACS SO_4 deposition estimates have been proven as a sufficiently qualified source in this respect.

6.4 Nitrate concentration in the soil solution of the topsoil (Model 4)

DE VRIES et al. (2000: Chapter "Soil solution chemistry", p. 131ff.) examined the relationships between soil solution chemistry, stand and site characteristics and atmospheric deposition. The soil solution ions considered were nitrate, ammonium and total nitrogen, other macro nutrients (S, Ca, Mg, K), pH and aluminium in the top- (0 cm – 40 cm) and subsoil (40 cm – 80 cm). The explanatory variables were soil type, tree species, throughfall deposition, nitrate concentration in the soil solution of the topsoil precipitation, precipitation excess and, whenever relevant, C/N ratio, base saturation and/or pH. Since nothing more specific is mentioned (stepwise, etc.), the statistical approach applied should have been a linear regression with a full model.

The relationship explaining nitrate concentration in soil solution of the topsoil (mg l^{-1}) for the year 1997 was determined as [p. 145]:

$$[NO_3]_{topsoil} = f\,(\text{ tree species}, + NH_{4,throughfall}, - \text{precipitation}); N = 90; R^2_{adj.} = 57\%,$$

with all 3 explanatory variables being highly significant. Regression parameters were not published. Additionally, it is not clear whether the tabulated degree of explanation is related to the full model or to the significant variables only and whether 'topsoil' consists of mineral layers only or of mineral and organic layers.

6.4.1 Compilation of relevant data

For re-calculation of the full model soil type, tree species, nitrate deposition, ammonium deposition, total nitrogen deposition and precipitation were used as explanatory variables. Precipitation excess and C/N ratio were dropped, because they turned out to be not significant for all response variables examined by DE VRIES et al. (2000).

Nitrate concentration in soil solution is a mandatory parameter of the soil solution chemistry survey and deposition of nitrate, ammonium and total N as well as precipitation[7] are mandatory within the deposition survey. Soil type and tree species are mandatory properties of stand and site characteristics survey.

Wet throughfall deposition has been collected on a total of 536 plots during more or less extended periods between 1990 and 2001. Due to the distinct seasonal variation of precipitation as well as nitrogen compounds within throughfall deposition, only those plots were used for which throughfall deposition was sampled at least for 244 days within each single year and, additionally, for which throughfall water fluxes were available[8] for at least 80% of the sampling periods. For each valid year the respective fluxes were projected to the whole year by the ratio 365/number of sampling days.

Soil solution has been collected on a total of 254 plots during more or less extended periods between 1990 and 2001. Annual means of nitrate concentration were calculated with two approaches: (i) following the approach of DE VRIES et al. (2000) as simple annual average concentrations and (ii) as annual average weighted with individual sampling period duration. It turned out that both approaches retrieved very similar results, probably because sampling

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7 Following DE VRIES et al. (2000) precipitation was taken from the deposition survey.

8 available means: values of 0 or greater 0 but not 'no data'

periods are mostly constant for the single plot. Here, however, the weighting with individual sampling period duration was used.

Soil solution may be collected in different sampling depths and/or with different sampling devices within single plots and within Level II. Concerning the sampling devices, here only the methods 'tension lysimeter' and 'zero tension lysimeter' were considered. Concerning the aggregation of sampling depths of soil solution - in order to calculate plot means – equal significance of the single measurement was assumed. Thus, plot means were calculated as annual average of single observations within evaluation depth - here 0 cm - 40 cm - weighted with individual sampling period duration, as long as total accumulated sampling duration exceeded 122 days for each single year. ‘Layer type’ was not considered. Soil solution N concentration values embrace therefore measurements from the humus layer and the upper mineral soil layer.

Table 39 gives an overview on the steps applied to derive the sample.

Table 39: Procedure applied to retrieve coherent data sets for nitrate concentration in soil solution of the topsoil (0 cm - 40 cm) and predictor variables including number of cases.

Step	**Description**	**Survey**	
		Soil solution chemistry	**Deposition**
1	Number of plots with annual mean values for nitrate concentration; all years*	656	
2	Number of plots with annual NO_3, NH_4, N_{total} and precipitation throughfall deposition; all years*		1201
3	**Soil solution and deposition survey data related for plots; all years**	**-> 524 <-**	
4	- subset of step 3, but only measurements of the years 1996 – 2001	524	
5	- subset of step 4, but outliers eliminated; years 1996 – 2001	523	

* according to the criteria mentioned in the text

To limit the degrees of freedom within the model, as soil type the respective parent material classes and as tree species the respective tree species groups from DE VRIES et al. (1998) or conifers vs. broadleaves were used.

Table 40 and Table 32 summarize the expression of the qualitative variables soil type and tree species, respectively. The geographical distribution of the plots including number of sampling years is depicted in Figure 12.

With reference to the findings of Chapter 6.3 "Sulphate concentration" also the mean annual concentrations of the nitrogen compounds NO_3, NH_4 and N_{total} in throughfall deposition were computed for use in analytical statistics.

Distribution properties of the quantitative variables for the years 1996 to 2001 are summarized in Table 42. Because of skewness nitrate soil solution concentration, deposition concentrations, deposition rates and precipitation were log-transformed (natural logarithm).

Table 40: Distribution of soil types (soil clusters) used in statistical analysis

Year	Podzols and Arenosols	Cambisols and Luvisols	Remaining non-calc. soils	Calcareous soils
1996	11	18	7	1
1997	25	34	11	1
1998	38	46	15	1
1999	37	48	16	2
2000	38	45	17	2
2001	47	45	16	2

Table 41: Distribution of tree species (tree species groups) used in statistical analysis

Year	'Pine'	'Spruce'	Other conifers	'Oak'	'Beech'	Other broadleaves
1996	7	11	1	5	13	
1997	13	27	3	11	17	
1998	20	35	5	13	26	1
1999	21	31	6	12	31	2
2000	21	31	8	13	27	2
2001	26	38	6	12	26	2

Table 42: Range of nitrate concentration in soil solution of the topsoil, and ranges of the quantitative predictor variables used in the statistical analysis.

Variable	Unit	No. of plots	Minima, percentiles, and maxima							Transf.
Year			Min	5%	25%	50%	75%	95%	Max	
[NO$_3$] Topsoil										
1996	mg N l^{-1}	37	0.108	0.113	1.059	2.417	4.495	16.279	24.53	ln+1*
1997	mg N l^{-1}	71	0.024	0.046	0.383	1.628	3.268	8.905	20.67	ln+1
1998	mg N l^{-1}	100	0.016	0.021	0.176	0.833	2.401	9.129	19.85	ln+1
1999	mg N l^{-1}	103	0.025	0.046	0.173	0.959	2.742	9.917	14.20	ln+1
2000	mg N l^{-1}	102	0.025	0.040	0.194	0.829	1.881	5.435	11.88	ln+1
2001	mg N l^{-1}	110	0.013	0.024	0.131	0.560	1.919	7.120	15.01	ln+1
NO$_3$ – Throughfall										
1996	kg N ha^{-1}	37	0.110	3.938	6.234	7.275	9.444	13.67	14.44	ln+1
1997	kg N ha^{-1}	71	0.525	0.962	4.949	6.970	9.360	15.94	17.64	ln+1
1998	kg N ha^{-1}	100	0.373	0.766	3.957	6.868	10.33	14.81	22.28	ln+1
1999	kg N ha^{-1}	103	0.432	0.927	5.107	7.632	10.28	14.11	16.08	ln+1
2000	kg N ha^{-1}	102	0.325	0.832	3.807	6.731	9.232	12.86	18.52	ln+1
2001	kg N ha^{-1}	110	0.344	0.613	4.058	6.202	9.130	14.02	17.70	ln+1
NH$_4$ – Throughfall										
1996	kg N ha^{-1}	37	0.320	3.800	7.260	8.540	11.79	20.30	26.92	ln+1
1997	kg N ha^{-1}	71	0.094	0.571	5.128	7.710	10.93	18.32	21.68	ln+1
1998	kg N ha^{-1}	100	0.212	0.507	3.646	7.175	9.692	19.74	36.84	ln+1
1999	kg N ha^{-1}	103	0.173	0.621	4.676	7.743	10.78	16.97	30.59	ln+1
2000	kg N ha^{-1}	102	0.128	0.612	4.160	7.143	9.523	18.15	26.27	ln+1
2001	kg N ha^{-1}	110	0.106	0.264	3.027	6.073	8.246	13.16	20.93	ln+1
N$_{total}$ – Throughfall										
1996	kg N ha^{-1}	37	1.803	14.17	18.04	21.36	23.96	36.11	54.63	ln+1
1997	kg N ha^{-1}	71	1.158	2.980	13.96	18.81	25.29	38.53	63.05	ln+1
1998	kg N ha^{-1}	100	0.862	2.489	10.59	18.34	25.65	38.32	55.40	ln+1
1999	kg N ha^{-1}	103	0.938	2.576	13.41	19.37	23.68	33.10	45.25	ln+1
2000	kg N ha^{-1}	102	0.723	2.301	11.79	18.56	22.60	36.63	43.30	ln+1
2001	kg N ha^{-1}	110	0.803	1.887	9.686	15.96	20.09	31.35	38.49	ln+1
[NO$_3$] – Throughfall										
1996	mg N l^{-1}	37	0.016	0.396	0.960	1.325	1.577	2.378	3.507	ln+1
1997	mg N l^{-1}	71	0.111	0.191	0.779	1.173	1.586	2.223	3.223	ln+1
1998	mg N l^{-1}	100	0.086	0.163	0.505	0.907	1.229	1.791	2.864	ln+1
1999	mg N l^{-1}	103	0.054	0.168	0.625	1.015	1.393	1.949	3.046	ln+1
2000	mg N l^{-1}	102	0.045	0.141	0.501	0.886	1.215	1.746	2.235	ln+1
2001	mg N l^{-1}	110	0.081	0.125	0.424	0.799	1.166	1.935	2.682	ln+1

Table 4: cont.

Variable	Unit	No. of plots	Minima, percentiles, and maxima							Transf.
Year			Min	5%	25%	50%	75%	95%	Max	
[NH_4] – Throughfall										
1996	mg N l^{-1}	37	0.048	0.368	1.176	1.666	2.140	3.703	4.131	ln+1
1997	mg N l^{-1}	71	0.018	0.121	0.739	1.237	1.810	2.901	4.271	ln+1
1998	mg N l^{-1}	100	0.043	0.097	0.573	0.896	1.384	2.588	4.827	ln+1
1999	mg N l^{-1}	103	0.040	0.097	0.544	1.051	1.451	2.914	4.848	ln+1
2000	mg N l^{-1}	102	0.028	0.108	0.425	0.946	1.382	2.225	3.497	ln+1
2001	mg N l^{-1}	110	0.026	0.063	0.354	0.775	1.043	1.922	3.319	ln+1
[N_{total}] – Throughfall										
1996	kg N ha^{-1}	37	0.272	1.319	3.183	3.744	4.527	6.693	7.928	ln+1
1997	kg N ha^{-1}	71	0.278	0.578	1.985	3.062	4.274	6.231	11.58	ln+1
1998	kg N ha^{-1}	100	0.238	0.395	1.719	2.361	3.216	4.795	7.596	ln+1
1999	kg N ha^{-1}	103	0.220	0.529	1.578	2.519	3.497	5.494	7.171	ln+1
2000	kg N ha^{-1}	102	0.165	0.455	1.165	2.515	3.146	4.704	5.524	ln+1
2001	kg N ha^{-1}	110	0.194	0.380	1.107	1.958	2.549	4.345	6.244	ln+1
Precipitation										
1996	mm	78	412	419	498	588	652	1024	1520	ln
1997	mm	96	386	405	493	641	740	947	1681	ln
1998	mm	127	329	454	567	694	901	1212	1626	ln
1999	mm	133	255	398	531	691	890	1413	2141	ln
2000	mm	130	329	438	568	759	960	1639	2442	ln
2001	mm	128	314	425	553	701	939	1378	1757	ln

* as values <1 occur, the transformation used was ln(x + 1).

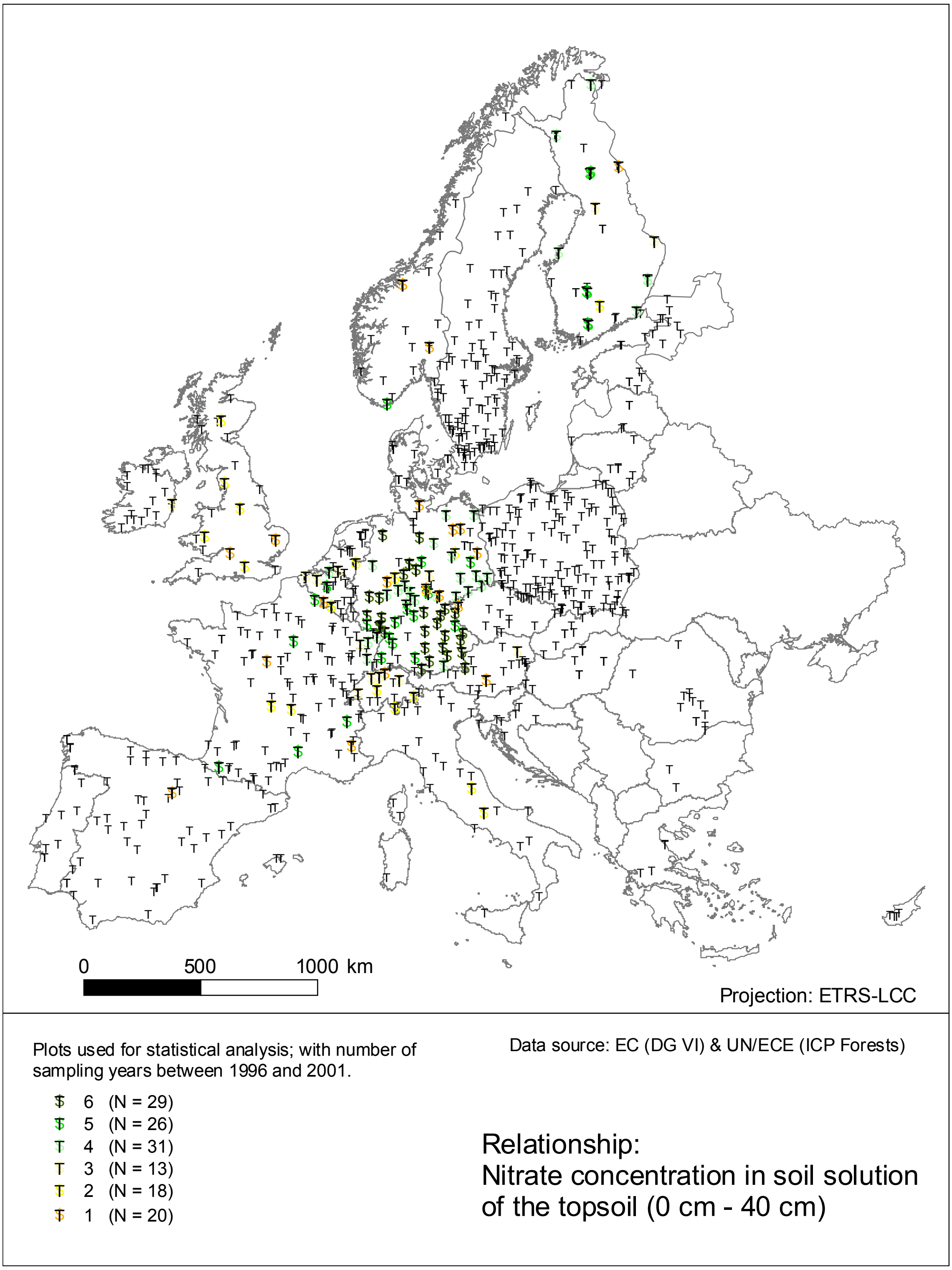

Figure 12: Geographical distribution of the plots used in analytical statistics (small, not coloured symbols: other Level II plots).

6.4.2 Analytical statistics

For regression analyses ordinary linear models were applied. Since several predictor variables should be tested simultaneously, a forward selection/backward elimination approach was used for model selection (cf. Chapter 5.4.1).

The result from the re-sampled model - with tree species, soil type, throughfall deposition of nitrogen compounds (NO_3, NH_4 and N_{total}), and precipitation as predictor variables - confirms the finding of DE VRIES et al. (2000) for the year 1997 with respect to the predictor structure (Table 26). In accordance with DE VRIES et al. (2000) NH_4 deposition, precipitation and tree species were determined to contribute significantly to explanation of the nitrate concentration in the soil solution of the topsoil. Soil type, nitrate deposition and total nitrogen deposition could not enter the model. Additionally, the direction of effect is the same for NH_4 deposition and precipitation; soil solution concentration increases with higher deposition and decreases with higher precipitation. Concerning the predictor tree species, the dichotomy conifers vs. broadleaves entered the model (and not the 6 tree species groups). Plots dominated by conifers show a lower nitrate concentration in the soil solution than plots dominated by broadleaves, as indicated by the negative parameter for conifers.

However, the overall degree of explanation differs considerably between the original work and the re-sampled model, while DE VRIES et al. (2000) found an $R^2_{adj.}$ of 58% we can confirm 32%. The reason for that discrepancy may be a differing sample, since also the number of plots is different (90 plots vs. 71 plots).

We tried to re-construct the data set originally used, by modifying the criteria of data compilation, especially by reducing the limit of minimum annual sampling duration for deposition and soil solution measurements (244 and 122 days, respectively, see Chapter 6.4.1). With a minimum annual sampling duration of c. 120 days for deposition and c. 50 days for soil solution measurements a number of plots comparable to the original work could be achieved (89 plots). The regression analysis with this sample showed a higher degree of explanation than it was found for the sample defined more strictly, but it also showed a changed predictor structure. As a consequence the more strict data compilation setting described in Chapter 6.4.1 was kept.

Table 43: Summary of the re-sampled regression model explaining nitrate concentration in the soil solution of the topsoil (0 cm – 40 cm) for the year 1997. Variable selection by a forward selection/backward elimination approach. Sum of squares from ANOVA. (N = 71, adj.-r^2 = 0.32)

	Estimate	**Std. error**	**t value**	**Signif.**	**DF**	**Sum of squares**
(Intercept)	3.713	1.540	2.411	*		
NH_4 Throughfall	0.563	0.107	5.277	***	1	9.266
Precipitation	-0.573	0.243	-2.355	*	1	2.242
Tree species				*	1	1.807
Broadleaves	0					
Conifers	-0.327	0.148	-2.209	*		
Model				***	3	13.315
Residuals		0.608			67	24.805
Total						38.120

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

For further analyses of all the observation years available - from 1996 to 2001 – the annual average concentrations of nitrogen compounds (NO_3, NH_4 and N_{total}) in throughfall deposition were introduced as additional predictor variables.

Table 44 gives an overview on the results of regression analyses with variable selection by a forward selection/backward elimination approach. The findings can be summarized as follows:

1. The predictor structure is similar for all sampling years considered.
2. Mean throughfall deposition concentrations of nitrogen compounds were found to be highly significant for all sampling years considered.
3. Mean throughfall deposition concentrations of nitrogen compounds show the highest partial explanation among the significant predictors.
4. In no case throughfall deposition rates of nitrogen compounds entered the models; throughfall rates were consistently replaced by throughfall concentrations
5. The incorporation of throughfall deposition concentrations of nitrogen compounds into the models also 'eliminated' the effect of throughfall precipitation rate.
6. Among the nitrogen compounds of throughfall deposition, NH_4 concentration was found to be the most effective compound within four years and total N within two years. In no case nitrate concentration contributed significantly to the explanation of nitrate concentration in soil solution.
7. Tree species contributed to explanation within four years. Always the dichotomy conifers vs. broadleaves was selected.
8. Plots dominated by conifers show lower mean nitrate concentrations in the soil solution than plots dominated by broadleaves.
9. There may be a trend towards loosening of the relationship, since the models of the first three years (1996 - 1998) show a higher overall explanation than the models of the last three years.

Table 44: Overview on significance of predictor variables of the regression model explaining nitrate concentration in the soil solution of the topsoil (0 cm – 40 cm) for the years 1996 – 2001. Variable selection by a forward selection/backward elimination approach.

Predictor variable	1996	1997	1998	1999	2000	2001
Soil type						
Tree species	o	*	*	*		*
Throughfall rate						
NO_3						
NH_4						
N_{tot}						
Mean throughfall conc.						
$[NO_3]$	o					o
$[NH_4]$	***	***	***			***
$[N_{tot}]$				***	***	
Precipitation						
N	37	71	100	103	102	110
$R^2_{adj.}$	41.3	37.1	46.0	31.8	28.0	16.1

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

o: marks a predictor variable which is not significant, but entered the model based on Akaike's information criterion (AIC)

In order to distinguish the effect of tree species and deposition, the regression model was applied to those plots only, which are dominated by conifers (s. Table 45). With respect to the effect of nitrogen compounds of throughfall deposition the analysis fully confirms the findings of the combined coniferous and broadleaves sample – points 1 to 6 mentioned above. However, the effect of tree species, i.e. pine, spruce and other conifers (cf. Table 32), disappears. Thus, it can be concluded that the tree species effect is indeed an effect of the conifer vs. broadleaves dichotomy.

Additionally the overall degree of explanation is increased for all years considered, compared to the combined conifer and broadleaves sample. This means that most of the variation explained for the combined conifer and broadleaves sample can be attributed to the subsample of conifers, while for plots dominated by broadleaves only a weak dependency of soil solution nitrate on deposition of nitrogen compounds is detectable. This finding was confirmed by regression analysis of the subsample of plots dominated by broadleaves (not depicted).

Table 45: Overview on significance of predictor variables of the regression model explaining nitrate concentration in soil solution of the topsoil (0 cm – 40 cm) for the years 1996 – 2001. Only plots dominated by conifers. Variable selection by a forward selection/backward elimination approach.

Predictor variable	1996	1997	1998	1999	2000	2001
Soil type						
Tree species						
Throughfall rate						
NO_3						
NH_4						
N_{tot}						
Mean throughfall conc.						
$[NO_3]$				o		
$[NH_4]$	**	***	***			***
$[N_{tot}]$	o			***	***	
Precipitation						
N	16	43	60	58	60	70
$R^2_{adj.}$	47.4	47.8	55.7	40.4	40.0	20.8

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

o: marks a predictor variable which is not significant, but entered the model based on Akaike's information criterion (AIC)

In order to eliminate the effect of changing samples between the years, the regression model was applied to those plots only, which are dominated by conifers and were measured during the whole period 1997 to 2001 (N = 32, s. Figure 13). (The condition of an available measurement in the year 1996 was excluded, because it would have resulted in a drastic reduction of the sample size.)

The results for this continuous conifer sample (Table 46), again, confirm the findings of the dominant effect of NH_4 and/or total N concentration in throughfall deposition on the nitrate concentration in the soil solution. However, the continuous conifer sample gives no indication for a loosening of the relationship with time, since the degree of explanation remains comparatively stable.

A closer analysis of the variable selection steps of the applied stepwise regression approach, retrieved that the predictors NH_4 deposition concentration and total N deposition concentration are more or less equivalent, with NH_4 deposition concentration being slightly superior when the effect within all years under consideration is summarised.

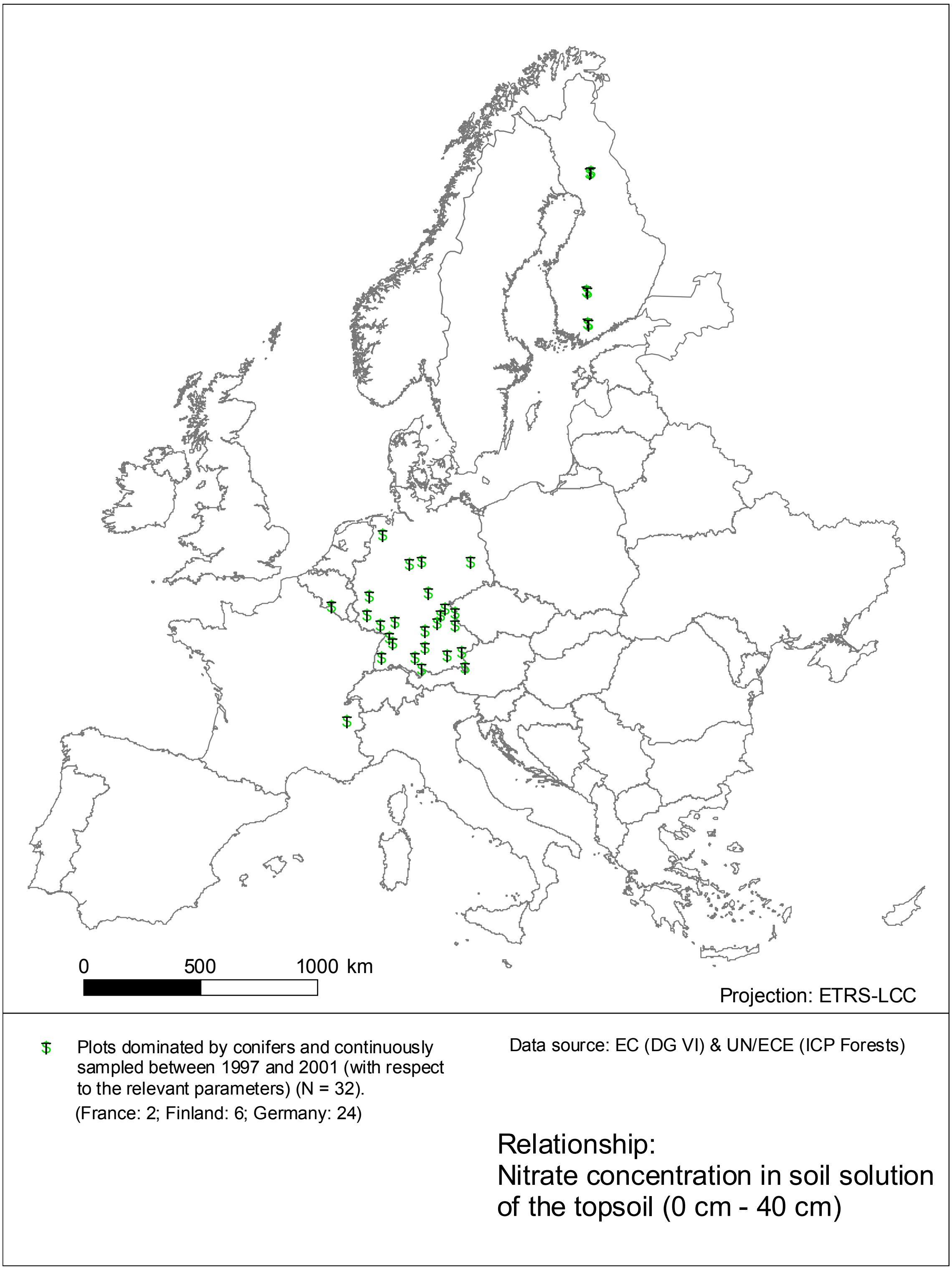

Figure 13: Geographical distribution of plots dominated by conifers and, additionally, sampled continuously within the period 1997 to 2001.

Table 46: Overview on significance of predictor variables of the regression model explaining nitrate concentration in soil solution of the topsoil (0 cm – 40 cm) for the years 1997 – 2001. Only plots dominated by conifers and measured during the whole period. Variable selection by a forward selection/backward elimination approach.

Predictor variable	**1997**	**1998**	**1999**	**2000**	**2001**
Soil type					
Tree species					
Throughfall rate					
NO_3			o		
NH_4					
N_{tot}					
Mean throughfall conc.					
$[NO_3]$					
$[NH_4]$		***		***	***
$[N_{tot}]$	***		***		
Precipitation					
N	32	32	32	32	32
$R^2_{adj.}$	50.7	46.4	53.1	51.7	42.4

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

o: marks a predictor variable which is not significant, but entered the model based on Akaike's information criterion (AIC)

Model simplification

Based on the findings presented, a simple linear regression between mean annual nitrate concentration in the soil solution of the topsoil and mean annual ammonium concentration in throughfall deposition was performed for the years 1997 – 2001 (Table 47). Elimination of total N concentration in throughfall deposition from the regression model did only slightly reduce the degree of model explanation for the years concerned (1997 and 1999).

With respect to the parameter estimates and to the variance accounted for, no distinct trend with time can be detected, i.e. neither quality nor quantity of the deposition effect did change.

Thus, a continuing effect of the deposition of nitrogen compounds – especially ammonium – on nitrate concentration in the soil solution for plots dominated by conifers has to be supposed.

Since deposition rate and deposition concentration of nitrogen compounds decreased during the observation period (Table 48), as it was found for sulphur accordingly, this non-reaction distinguishes the ecosystem impact of nitrogen from the one of sulphur (cf. Chapter 6.3).

Table 47: Summary of linear regression between mean annual nitrate concentration in soil solution of the topsoil (0 cm – 40 cm, (mg N l^{-1}) and mean annual ammonium concentration in throughfall deposition (mg N l^{-1}) for the years 1997 – 2001. Only for plots dominated by conifers and measured during the whole period. Parameters for predictor variables with standard errors (in brackets).

Predictor variable	1997	1998	1999	2000	2001
(Intercept)	-0.005 (0.166)	-0.058 (0.167)	-0.107 (0.164)	-0.039 (0.146)	0.010 (0.151)
NH_4 – mean throughfall conc.	1.068 (0.194) ***	1.290 (0.245) ***	1.301 (0.225) ***	1.230 (0.210) ***	1.190 (0.242) ***
N	32	32	32	32	32
$R^2_{adj.}$ (%)	48.5	46.4	51.1	51.7	42.4

Signif. codes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

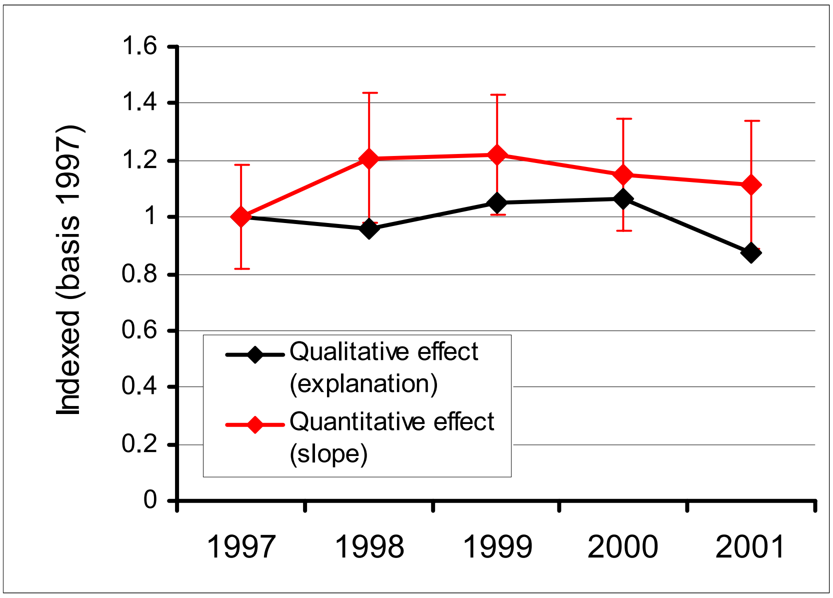

Figure 14: Time trend of degree of explanation and slope (with standard error) of the linear regression between mean annual nitrate concentration in soil solution of the topsoil and mean annual ammonium concentration in throughfall deposition for the years 1997 – 2001. (For non-indexed values see Table 47)

Table 48: Means for nitrate concentration in the soil solution of the topsoil (0 cm – 40 cm) and means for nitrogen compounds in throughfall deposition for the years 1997 – 2001. Only for plots dominated by conifers and measured during the whole period. (N = 32)

Variable	Unit	1997	1998	1999	2000	2001
[NO_3] Topsoil	mg N l^{-1}	1.8	1.6	1.73	1.45	1.43
Throughfall rate						
NO_3	kg N ha^{-1}	7.85	7.99	7.69	7.53	6.90
NH_4	kg N ha^{-1}	8.28	7.79	7.76	7.29	6.62
N_{tot}	kg N ha^{-1}	20.01	19.54	18.82	17.93	16.78
Mean throughfall conc.						
[NO_3]	mg N l^{-1}	1.18	0.93	0.97	0.93	0.78
[NH_4]	mg N l^{-1}	1.29	0.91	1.02	0.93	0.78
[N_{tot}]	mg N l^{-1}	3.08	2.28	2.42	2.25	1.94

As reliable data on deposition rates with a European wide coverage are not available, no attempt to transfer the relationship to Level I was made. Neither EMEP nor EDACS nitrogen compounds deposition estimates have been proven as a sufficiently qualified source in this respect.

6.5 Nitrogen concentration in the foliage and general stand and site factors (Model 5)

Foliar element concentrations have frequently been used to indicate nutrient deficiencies or imbalances (e.g. REEMTSMA 1986, HÜTTL 1991, LINDER 1995) and may determine different aspects of tree performance like stem increment or crown condition (e.g. ROBERTS et al. 1989). As foliage element contents are not only dependent on tree internal element allocation, but may also respond to external impacts due to the direct exposure towards particulate and gaseous aerosols as well as to precipitation (e.g. RAUTIO et al. 1998). Both underline the importance of respective investigations within both levels of the forest monitoring programme (STEFAN et al. 1997).

This motivated DE VRIES et al. (1998: 108 ff., 2000: 85 ff.) to study the different relationships between foliar element concentration and major environmental factors repeatedly. In the study published 1998 they investigated the basic statistical relationship between the contents of major nutrients and stand and site factors in order i) to prove its relevance in other cause-effect studies and ii) to gain insight in their statistical contribution in accord with other key parameters from different ecological domains.

For the foliar nitrogen concentration (mg N kg^{-1} of dry matter) DE VRIES et al. (1998) found an adjusted coefficient of determination of 79%, which was the highest among all relationships determined between foliar concentrations of major nutrients and stand/site factors (25 – 79%). On the predictor side of the model the following stand/site characteristics have been included: tree species (from potentially 11 tree species clusters [p. 18] 10 were used [p. 54]), soil type (from potentially 10 soil clusters including 1 class of 'unknown' assignment [p. 24] 9 were used [p. 54]), climatic region (from potentially 6 clusters [p. 22, geographically in accordance with UN/ECE & EC 1996] 5 were used [p. 54]), as well as altitude, and stand age.

The relationship between foliar N concentration and stand/site characteristics was found as [p. 109]:

$[N]_{foliar}$ = f (tree species, climatic region); n = 423; $R^2_{adj} = 0.79$.

Detailed model parameters were not published.

6.5.1 Compilation of Data

The parameters used in the original model (DE VRIES et al. 1998: 109) were re-sampled from the current database according to Table 49. Information from general plot information, the foliar condition survey and the soil survey had to be matched. Due to the optional exclusion of cases with unknown or unusual tree species two slightly differing final samples with 719 respectively 714 cases have been constituted. For foliar nitrogen contents, plot related mean values are calculated for plots with respective determinations in several years. The assignment of each plot to the respective climatic zone was performed by a nearest neighbour algorithm within a GIS system.

As Table 49 shows, 719 respectively 714 of the Level II plots could be kept within the analysis, which is distinctively more than in the original model of DE VRIES et al. (1998) with only 423 plots. This increase in number of cases accounts substantially on the general increase of Level II plots from 1998 to 2003 and a higher availability of data sets for single plots achieved during that period.

Table 49: Procedure applied to retrieve coherent data sets for nitrogen concentration in foliage inclusive number of valid cases

Step	Description	N of plots (cases)
1	General plot information	822
2	Foliar Condition Survey; all years	767
3a	- as before, but with at least one valid N determination	764
3b	- as 2, but with at least one valid N determination and tree species, which could be assigned to one of the ecological groups	752
4	Soil Inventory, exclusion of repetitions, than most recent entry taken	738
5a	intersection of step 3a and 4	719
5b	intersection of step 3b and 4	714

Figure 15 displays the geographic distribution of the valid Level II plots. They cover more or less all parts of Europe inclusive the Canary Islands. As the model includes climatic zone used elsewhere within the forest monitoring programme (e.g. DE VRIES et all. 1998, LORENZ et al. 2001), there is no need for an a-priori delineation of a model area, even if the density of Level II plots varies between different parts of Europe.

The response variable, the average foliar nitrogen concentration measured at Level II sites is the only true numeric variable within this model. Its variation is considerable large (Table 50). However, the model includes a broad spectrum of ecologically different tree species from quite different habitats and climatic regions (Table 51). While the distribution of the age classes is comparatively equal, altitude is skewed to the lowland sites. Deviant from the original model instead of the eleven soil class from DE VRIES et al. (1998: 24) the four parent material classes according to DE VRIES et al. (1997: 63 f.) were used, to avoid the large amount of 'unknown' cases in the original model (29% within the total data set used by DE VRIES et al. (1998: 24).

*Table 50: Univariate characteristics (extremes, percentiles) of the response variable; *: in 20 year's classes, class means are given, uneven aged stands were set to an age of 110 y, **: altitude in 50 m intervals: class means are given, ***: soil type as parent material classes according to DE VRIES et al. (1997).*

Variable	Unit	Minima, percentiles, and maxima							Transf.
		Min	5%	25%	50%	75%	95%	Max	
$[N]_{foliar}$	mg g^{-1}	7.78	10.99	13.41	15.46	21.87	26.69	34.89	
Stand age *	y	10	30	50	70	90	130	130	
Altitude **	m a.s.l.	25	25	125	225	575	1175	2025	
Soil type ***	qual.								

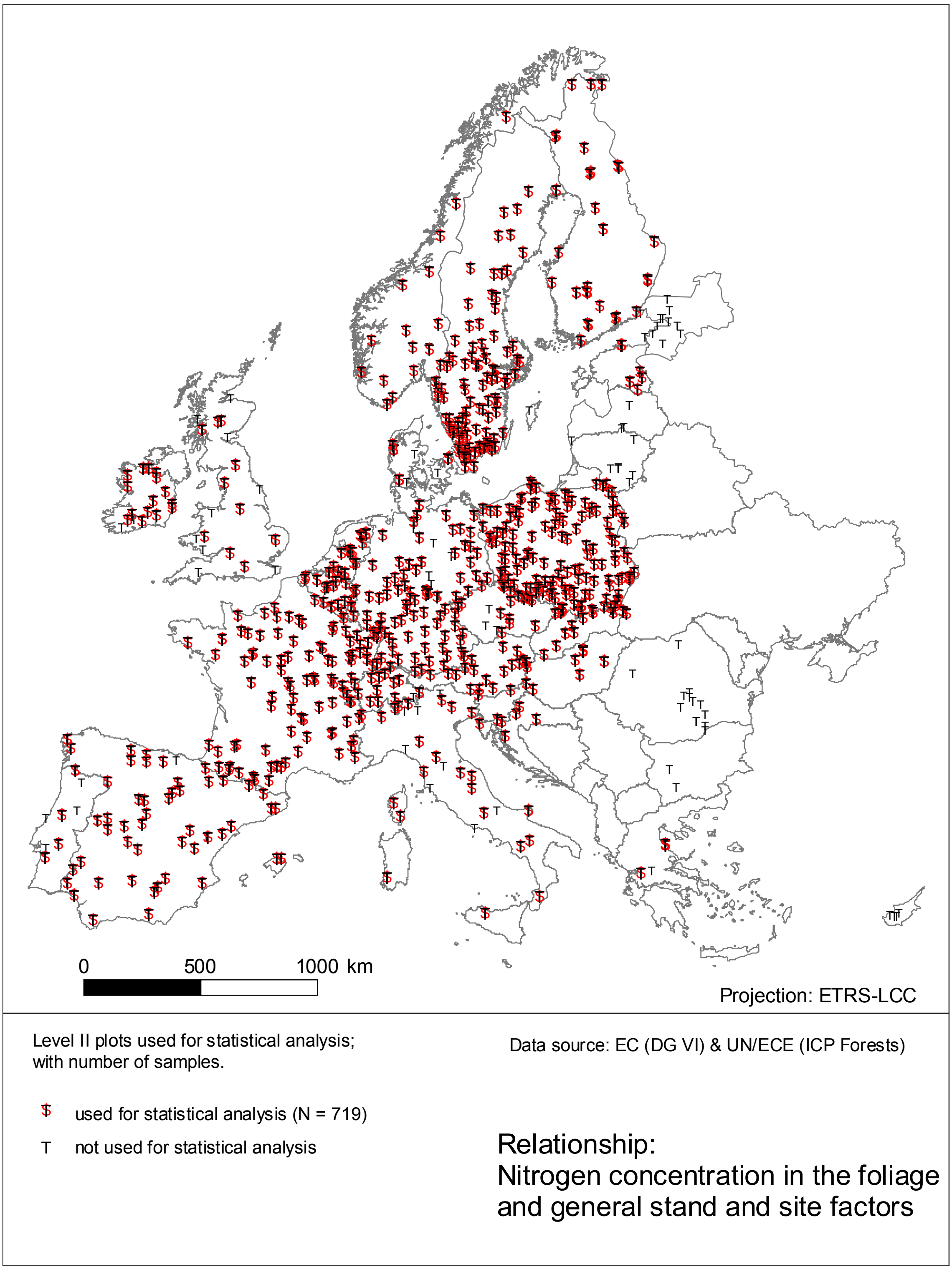

Figure 15: Geographic distribution of valid Level II plots used within the re-sampled Model 5. (3 Plots located at Canary Islands are not displayed)

Table 51: List of species with given foliar N concentrations; means, standard deviation (std) and number (n) of cases referring to year-wise observations, not to plot-related means.

Species	species clusters of DE VRIES et al. (1998)	ecological species group	mean foliar N	std	n of cases
Alnus glutinosa	remaining broadleaves	deciduous broadleaves	21.87	6.52	3
Carpinus betulus	beech	deciduous broadleaves	23.18	1.79	7
Castanea sativa	beech	deciduous broadleaves	22.47	0.37	2
Eucalyptus spec.	remaining broadleaves	not assigned broadleaves	12.98	2.33	12
Fagus moesiaca	beech	deciduous broadleaves	22.27	0.83	4
Fagus sylvestris	beech	deciduous broadleaves	24.83	2.87	477
Fraxinus angustifolia	remaining broadleaves	deciduous broadleaves	23.11	3.91	8
Fraxinus excelsior	remaining broadleaves	deciduous broadleaves	23.36	6.11	8
Populus canescens	remaining broadleaves	deciduous broadleaves	25.31		1
Quercus cerris	oak other	deciduous broadleaves	24.27	3.53	23
Quercus faginea	oak other	deciduous broadleaves	19.13	2.25	10
Quercus frainetto	oak other	deciduous broadleaves	19.80	1.70	4
Quercus ilex	oak evergreen	evergreen broadleaves	14.49	1.65	72
Quercus petraea	European oak	deciduous broadleaves	24.89	3.00	236
Quercus pubescens	oak other	deciduous broadleaves	16.01	2.97	8
Quercus pyrenaica	oak other	deciduous broadleaves	22.33	2.39	17
Quercus robur	European oak	deciduous broadleaves	25.81	3.34	220
Quercus rotundifolia	oak evergreen	evergreen broadleaves	12.01	0.44	4
Quercus suber	oak evergreen	evergreen broadleaves	15.53	3.11	20
Erica arborea	remaining broadleaves	evergreen broadleaves	12.80	1.33	5
Ceratonia siliqua	remaining broadleaves	not assigned broadleaves	24.80	2.26	2
other broadleaves	remaining broadleaves	not assigned broadleaves	13.75	3.11	9
Abies alba	fir	firs	13.63	1.34	118
Juniperus oxycedrus	remaining conifers	not assigned conifers	9.97	1.00	4
Juniperus thurifera	remaining conifers	not assigned conifers	11.60	0.87	4
Larix deciduas	high elevation conifers	larches	22.85	2.94	10
Picea abies	spruce	spruces	13.67	1.91	684
Picea sitchensis	spruce	spruces	15.06	1.74	50
Pinus canariensis	warm temperate pines	other pines	10.09	1.60	5
Pinus cembra	high elevation conifers	other pines	16.56	0.85	3
Pinus contorta	high elevation conifers	other pines	14.67	2.99	17
Pinus halepensis	warm temperate pines	other pines	11.20	1.55	16
Pinus nigra	warm temperate pines	other pines	13.13	3.48	37
Pinus pinaster	warm temperate pines	other pines	10.25	3.17	65
Pinus pinea	warm temperate pines	other pines	9.63	0.84	12
Pinus radiata	warm temperate pines	other pines	13.77	0.46	4
Pinus sylvestris	Scots pine	Scots pine	15.51	2.74	645
Pinus uncinata	high elevation conifers	other pines	11.27	0.63	6
Pseudotsuga menziesii	fir	Douglas fir	18.16	2.78	101
other conifers	remaining conifers	not assigned conifers	12.11	1.94	8

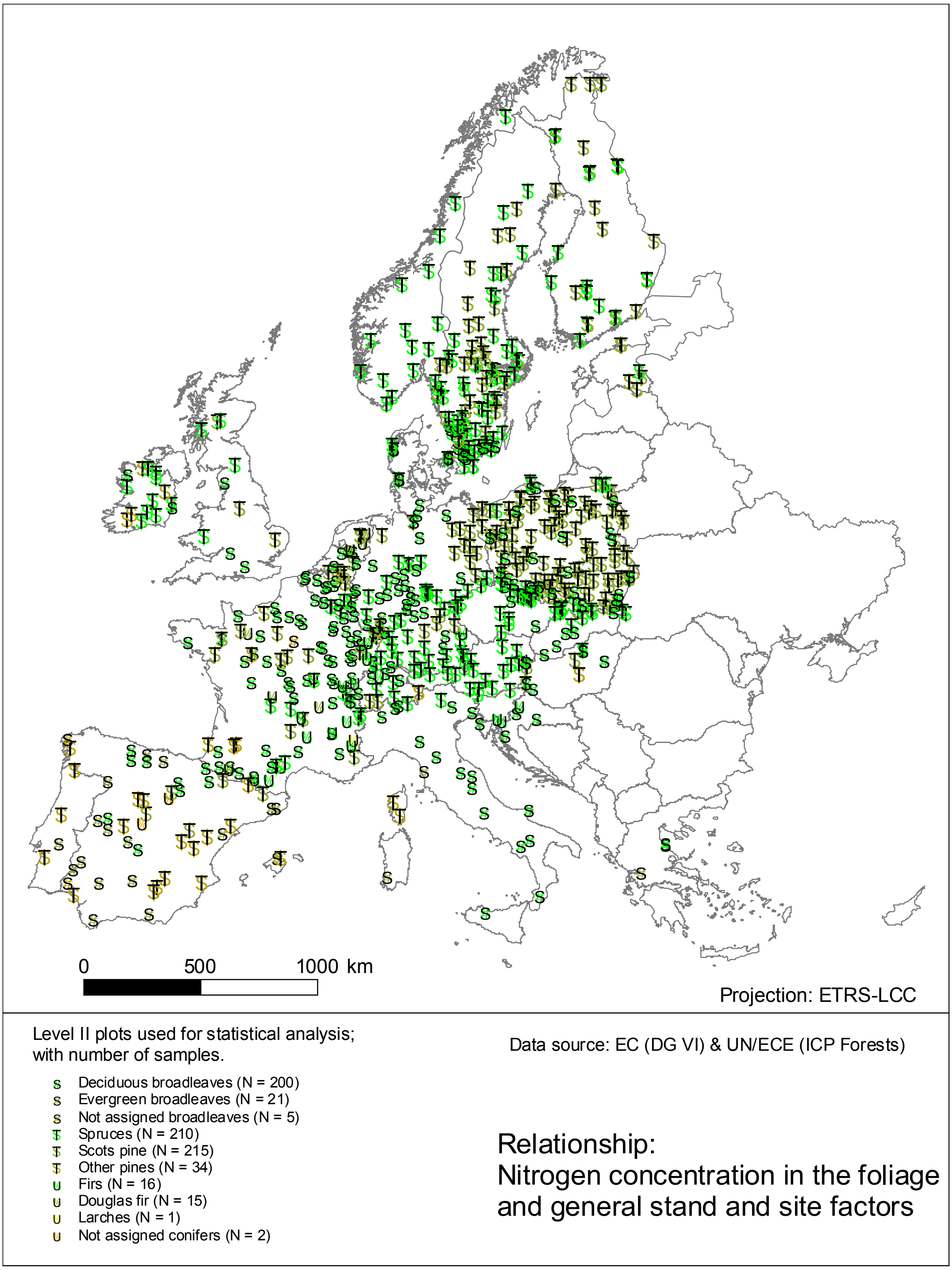

Figure 16: Geographic distribution of the "ecological species groups" used within the re-sampled Model 5. (3 Plots located at Canary Islands are not displayed)

Foliar N concentrations were measured at a total of 21 distinguished broadleaved species and 17 distinguished conifer species (Table 51) in addition to some cases with unknown broadleaved or conifer species. It is common knowledge that each tree species behaves ecologically as an entity. However, the number of cases in many species is rather small and with respect to eco-physiological traits species can be summarised based on similarities between species in evolutionary and/or eco-physiological terms. DE VRIES et all. (1998: 141) established “associated tree clusters”, which are also included in Table 51. However, this classification reveals some inconsistencies (e.g. *Carpinus betulus* is classified along with *Fagus sylvatica* as “beech”, while *Quercus pubescens* and *Q. petraea* are in different clusters in spite of frequent hybrids in south-eastern Europe). Therefore a more ecological and phyllogenetically sound classification was invented, titled as “ecological species groups” in Table 51 and Figure 16.

Focusing nitrogen assimilation, all deciduous broadleaved tree species behave comparatively similar. They all reveal high foliar N concentrations (see Table 51) and have therefore been summarised in one category only (“deciduous broadleaves”). All evergreen broadleaved species display distinctively lower foliar N concentrations. They constitute the second species group of broadleaves (“evergreen broadleaves”). The coniferous tree species are less homogeneous with regard to foliar N concentrations. The categories have only slightly changes against the old clusters. Unknown species (“other broadleaves”, “other conifers”) have been dropped within the recent clustering. Plots with *Ceratonia seliqua* - an evergreen species which behaves obviously different than the other evergreen broadleaves - and *Eucalyptus spec.* as well as both *Juniperus* species have also been left out.

6.5.2 Re-sampling the original relationship

While DE VRIES et al. (1998) refer only to tree species cluster, in this approach also an analysis with single tree species was performed. With all species included in a respective covariance model a total of more than 86% (R^2_{adj}) could be explained (Table 52). The overwhelming amount of variance (83%) is explained by the species-specific N allocation behaviour. Climatic region explains another 3.6% while age is still significant, but with less than a half percent almost negligible. Species and climatic region were also significant predictors within the original model of DE VRIES et al. (1998), but age was not.

Table 52: ANOVA results from a covariance model with separate species, climatic region, stand age, altitude, and parent material class as predictors and foliar nitrogen contents as response variables; n = , R^2 = 0.874, R^2_{adj} = 0.865, Res. std. err. = 1.923.

	Df	Sum Sq	Mean Sq	F value	Signif.
Species (separate)	32	16338.9	510.6	138.1287	***
Climatic region	9	697.2	77.5	20.9555	***
Stand age	1	79.6	79.6	21.5211	***
Altitude	1	0.4	0.4	0.0990	
Parent material class	4	19.9	5.0	1.3447	
Model	47	17136.0		98.63	***
Residuals	671	2480.3	3.7		
Total	718	19616.3			

Signif. code: `***' 0.001

If the species clusters given in DE VRIES et al. (1998: 141 f.) are used instead of the distinct species, the model still explains an amount of 83% of the variance of the foliar nitrogen concentration (Table 53). This is an increase of c. 4% against the original model and demonstrates that many species can be grouped with respect to their nitrogen allocation behaviour. A *further* obvious difference against the model with single species is the reduced predictive power of age. In this case the well-known reduction of foliar nitrogen in older trees might be less *pronounced* due to aggregation of species.

Table 53: ANOVA results from a covariance model with species clusters taken from DE VRIES et al. (1998), climatic region, stand age, altitude and parent material class (PC) as predictors and foliar nitrogen as response variable; n = 719, R^2 = 0.832, R^2_{adj} = 0.825, Res. Std. err. = 2.184.

	Df	Sum Sq	Mean Sq	F value	Signif.
FIMCI species classes	10	15415.2	1541.5	323.2379	***
Climatic region	9	849.5	94.4	19.7934	***
Age	1	35.6	35.6	7.4685	**
Altitude	1	0.7	0.7	0.1368	
Parent material class	4	10.3	2.6	0.5413	
Model	25	16303.6		136.8	***
Residuals	693	3304.9	4.8		
Total	718	19608.5			

Signif. code: `***' 0.001, `**' 0.01

Table 54: ANOVA results from a covariance model with ecological species clusters, climatic region, stand age, altitude and parent material class as predictors and foliar N concentration as response variable; n = 714, R2 = 0.853, R2adj = 0.849, Res. std. err. = 2.034.

	Df	Sum Sq	Mean Sq	F value	Signif.
Ecolog. species class	7	15696.5	2242.4	542.1003	***
Climatic region	9	858.9	95.4	23.0722	***
Age	1	45.9	45.9	11.0971	***
Altitude	1	2.1	2.1	0.5187	
Parent Material class	4	22.5	5.6	1.3585	
Model	22	16625.9		182.7	***
Residuals	691	2858.3	4.1		
Total	713	19484.2			

Signif. code: `***' 0.001

The model with a more ecological grouping of species is given in Table 54. In this case the full results are given, as the model reveals an increase of predictive power with an even reduced number of categories of tree species. This model explains almost 85% of the variance of the foliar N concentration. Besides ecological species class and climatic region stand age has a significant negative influence onto foliar N concentration, which is well-known from more detailed studies. Altitude and parent material class did not gain any significant influence. As the spatial distribution of tree species is to a great extent determined by substrate and altitude both factor may have almost no additional chance becoming a significant predictor within such an overview model.

For up-scaling purposes the last model has been transformed to a restricted covariance model (Table 55) with the significant predictors only. The results are therefore given in more detail than for the other models.

Table 55: Results of a restricted covariance model with ecological tree species groups, climatic regions and stand age as predictor variables and foliar N concentration as response variable; n = 714, R^2 = 0.852, R^2_{adj} = 0.848; degrees of freedom (DF), sum of squares (SSQ) and significance of F values (Sig F) from ANOVA.

	Estimate	**Std. Error**	**t value**	**Sig t**	**DF**	**SSQ**	***Sig F***
(Intercept)	26.277267	0.317455	82.775	***			
Ecolog. species group					7	15696.5	***
Broadl. evergreens	-8.566418	0.580754	-14.751	***			
conif. Douglas	-7.261039	0.562867	-12.900	***			
conif. firs	-9.917130	0.527553	-18.798	***			
conif. larches	-3.902830	1.453129	-2.686	**			
conif. Scots pine	-8.992213	0.235976	-38.106	***			
conif. other. pines	-12.654830	0.415237	-30.476	***			
conif. spruces	-10.420806	0.226642	-45.979	***			
Climatic region					9	858.9	***
Atlantic South	-0.525567	0.416631	-1.261				
Boreal	-3.617232	0.336273	-10.757	***			
Boreal temp.	-2.433801	0.353572	-6.883	***			
Continental	0.899846	0.602538	1.493				
Mountain S.	-0.742985	0.309280	-2.402	*			
Mountain N.	-2.633110	0.666873	-3.948	***			
Medit. higher	-2.502597	0.485437	-5.155	***			
Medit. Lower	-2.553809	0.461590	-5.533	***			
Sub-Atlantic	-0.908201	0.245014	-3.707	***			
Age	-0.010630	0.003193	-3.329	***	1	45.9	***
Model					17	16601.3	***
Residuals		2.035			696	2882.9	
Total					*713*	*19484.2*	

signif. codes: 0 `***' 0.001 `**' 0.01

6.5.3 Recursive Partitioning

The results of recursive partitioning revealed in each variant a three-step model. In the first step always a sorting of species into two groups is performed. This step alone accounts for 77.4% of the total *variance* if single species are used, for 73.7% if FIMCI classes are taken and 76.5% if *ecological* groups are introduced. This result reveals the ecological clustering of species superior against the FIMCI tree species clusters. In a second step the species group with the lower foliar N concentrations is partitioned in all tree models by climatic regions (Figure 17).

Table 56: Comparison of the results of three recursive partitioning models with single species, species classes according to DE VRIES et al. (1998) and to ecological species groups according to Table 51.

Step	Complexity parameter	No. of splits	Relative error	Xerror	Xstd
Model with single tree species; total explained variance: 83.5%					
1	0.774	0	1.000	1.003	0.045
2	0.041	1	0.226	0.252	0.018
3	0.020	2	0.184	0.218	0.018
Model with FIMCI-classification of tree species; total explained variance: 80.0 %					
1	0.737	0	1.000	1.003	0.045
2	0.043	1	0.263	0.288	0.024
3	0.020	2	0.220	0.244	0.024
Model with ecological clusters of tree species; total explained variance: 83.0 %					
1	0.765	0	1.000	1.005	0.045
2	0.045	1	0.235	0.239	0.016
3	0.020	2	0.191	0.197	0.014

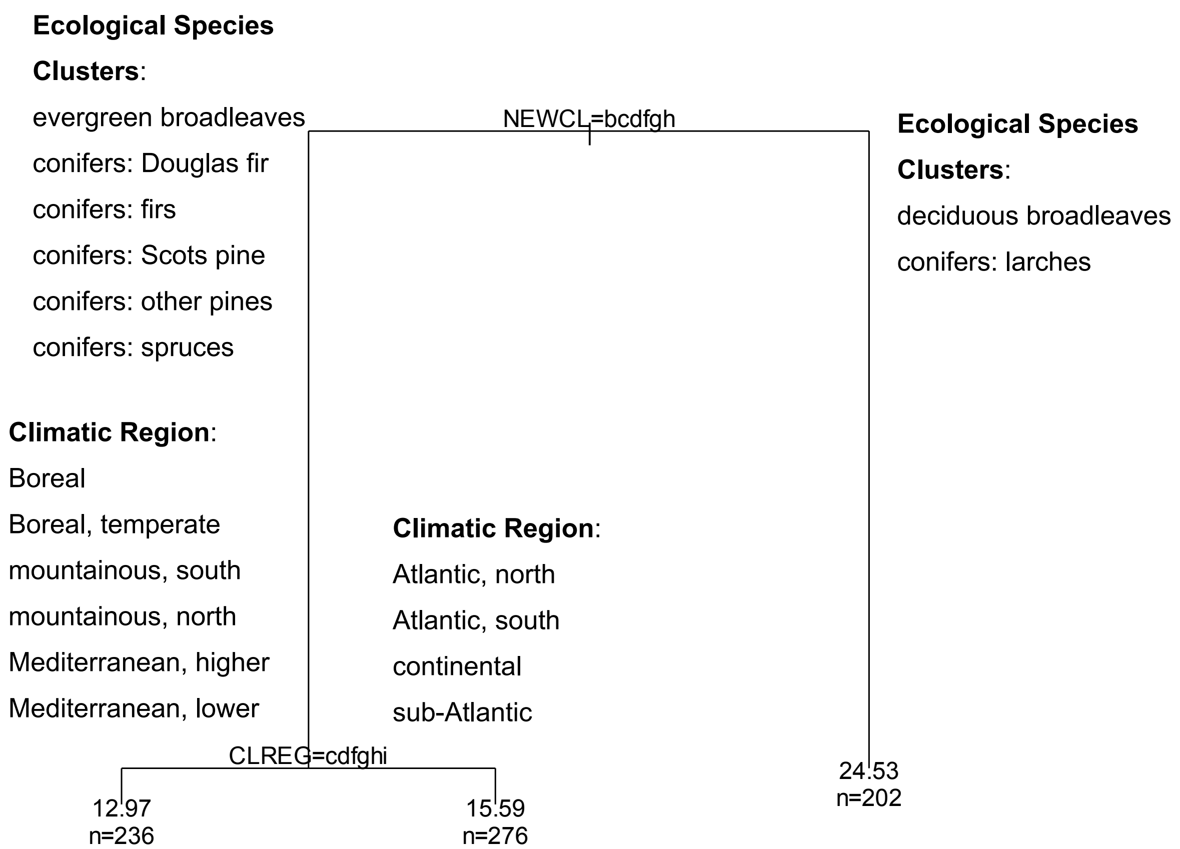

Figure 17: Cluster diagramm from recursive partitioning, version with ecological tree species groups (NEWCL) and climatic reagions (CLREG) as crucial categories (split criteria); at the final nots cluster means of N foliar concentration an number (n) of cases are given.

6.5.4 Transfer to Level I

Model Structure

The structure of the covariance model shown in Table 55 is transferred to the Level I data. A total of 1054 plot could be used from all over Europe. The up-scaling results are summarized in Table 57. The strong relationship found at Level II between foliar N concentration and ecological species groups is largely corroborated by the transferred model with the Level I data, even if a certain reduction of the predictive power from 80.6% to 64.0% can be stated. Climatic region has an increased influence of 7.9% in the Level I model against 4.4% in the Level II model. Age does not significantly contribute to the model in Level I and the respective regression coefficient ("estimate" in Table 57) has – against expectation - even become positive.

Table 57: Structure of the covariance model from Table 55 transferred to data from the Level I programme with ecological tree species groups, climatic regions and stand age as predictor variables and foliar N concentration as response variable; R^2 = 0.719, R^2_{adj} = 0.715*; degrees of freedom (DF), sum of squares (SSQ) and significance of F values (Sig F) from ANOVA.*

	Estimate	**Std. Error**	**t value**	**Sig t**	**DF**	**SSQ**	***Sig F***
(Intercept)	25.579845	0.357497	71.553	***			
Ecolog. Species group					7	17481.3	***
Broadl. evergr	-8.246260	0.378146	-21.807	***			
Conif. Douglas fir	-6.728367	2.733291	-2.462	*			
Conif. firs	-9.231687	0.591918	-15.596	***			
Conif. larches	2.779702	1.050770	2.645	**			
Conif. Scots pine	-8.290736	0.271016	-30.591	***			
Conif. other pine	-10.287229	0.324393	-31.712	***			
Conif. spruces	-9.219954	0.248749	-37.065	***			
Climatic region					9	2152.3	***
Atlantic South	-1.908223	0.543621	-3.510	***			
Boreal	-4.900345	0.579335	-8.459	***			
Boreal temp.	-5.571675	0.954297	-5.839	***			
Continental	-6.715189	0.513345	-13.081	***			
Mountain S.	-3.481242	0.316512	-10.999	***			
Mountain N.	-6.068140	1.396462	-4.345	***			
Medit. higher	-3.688663	0.390001	-9.458	***			
Medit. Lower	-3.323892	0.413562	-8.037	***			
Sub-Atlantic	-1.790415	0.317507	-5.639	***			
Age	0.001631	0.002542	0.642		1	3.0	
Model					17	19636.6	***
Residuals		2.721			1036	7665.0	
Total					*1053*	*27301.6*	

signif. codes: 0 `***' 0.001 `**' 0.01 `*' 0.05

The relative order of the species groups within both model (Table 57 compared with Table 55) are obviously constant with highest values for deciduous broadleaved species (intercepts) and the also deciduous larches and low values for all evergreen species especially pines and spruces. These results call for a species-specific treatment of foliar nitrogen concentrations and foliar element concentrations in general (cf. Capt. 6.6 and Capt. 6.7), even if species clusters may also suffice certain limited requirements in overview models.

With regard to climatic regions the most obvious difference is found for plots within the continental climatic region. While for Level II plots the respective values vary around the intercept minus the species specific discounts, for Level I plots the N concentrations within this zone vary at a level generally 6.74 mg g^{-1} lower. This effect is the most obvious one, even if there are some other deviations too.

Parallel to the covariance model a recursive partitioning model has been performed with the Level I data too. Again, in a first split, which explains with alone 61.2% a huge amount of the variance of foliar nitrogen, the deciduous species (broadleaves and larches) are separated from the evergreen species (respective broadleaves and conifers). The next two steps divide both branches explaining an additional 3.6% in case of the right branch and 3.2% in the left branch (see Table 58 and Figure 18). In both cases - regardless of species class - one twig represents all cases form the sub-Atlantic, the northern Atlantic and the southern Atlantic zone, while the other represents the remaining climatic zones. In the main, both Atlantic zones together with the sub-Atlantic zone embrace more or less all regions with high N immission loads.

Table 58: Summary of results of recursive partitioning analysis with Level I data with N foliar concentration as response variable and all variables from Table 57 as predictors.

Step	Complexity parameter	No. of split	Relative error	Std. error	Split criteria
1	0.612203	0	1.00000	1.00099	ecological species group
2	0.035905	1	0.38780	0.38884	climatic region
3	0.031580	2	0.35189	0.35380	climatic region
4	0.020000	3	0.32031	0.32747	

The most substantial difference against the respective Level II model (Figure 17) refers to the deviant behaviour of the continental climatic zone. This zone has changed from the cluster with high foliar N concentrations in Level II to cluster with low foliar N concentrations in Level I. This result indicates that climatic zones may rather accidentally coincide with the factor governing foliar N contents like high N deposition loads.

It can be seen as promising hint that even at this rather crude level of information foliar N concentration may respond to different levels of N deposition. The results call for more detailed and than species specific models. Models elaborated under the next tow up-scaling approaches (Model 6 and 7), refer to single species and cover a broad variety of environmental factors.

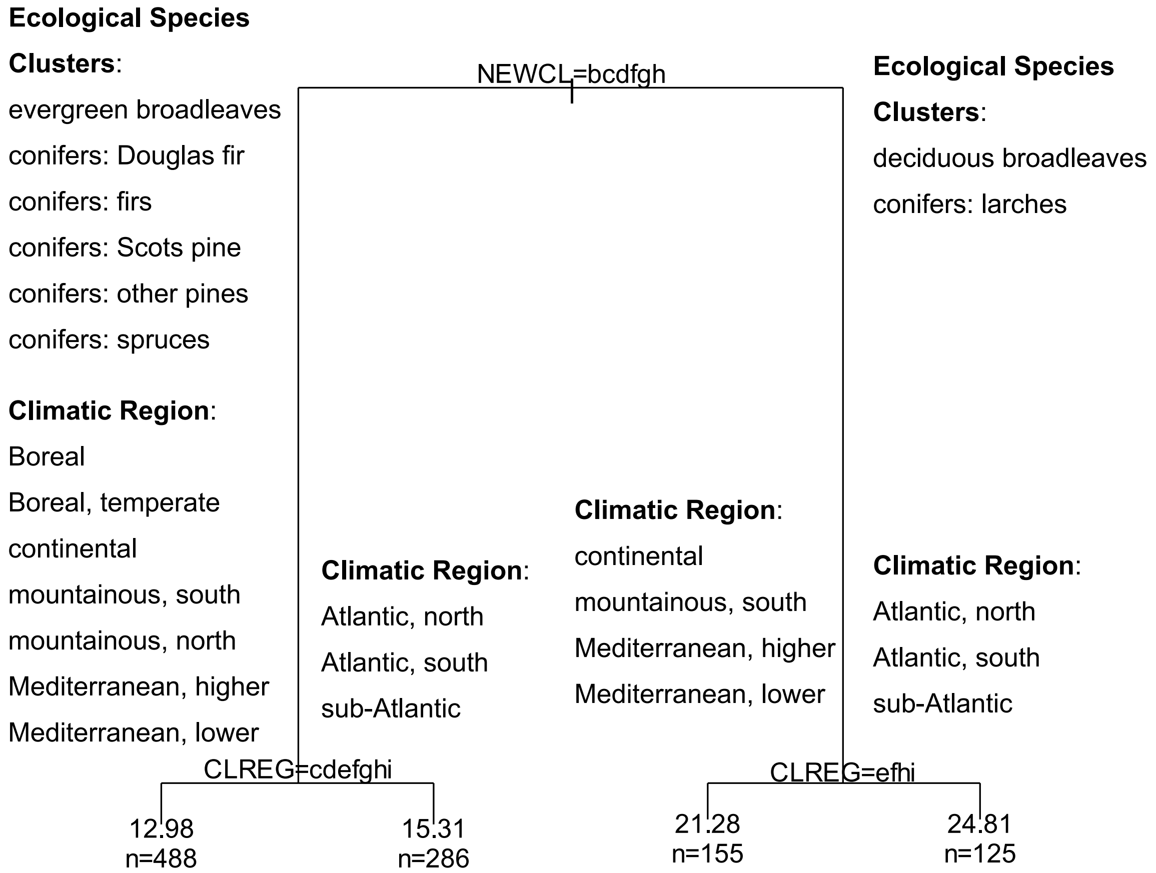

Figure 18: Cluster diagramm from recursive partitioning analysis of Level I data, version with groups of ecological tree species (NEWCL) and climatic region (CLREG) as crucial categories (split criteria); at the final nots cluster means and number (n) of cases are given.

Function transfer

Since for a considerable number of Level I plots needle or leaf contents of nitrogen have been sampled, for Model 5 the predictions from function transfer can be directly compared with measurements, in order to assess the predictive capacity of the approach.

The covariance model shown in Table 55 is transferred to Level I. A total of 1054 plot could be used from all over Europe. 96 of these plots are located in Bulgaria, which is not covered by the Level II plots used for statistical analysis (cf. Figure 15). Linear regression between function transferred estimates and measured nitrogen concentration in foliage of Level I plots yielded a degree of explanation (R^2) of 61.7%. In case the plots from Bulgaria were excluded a degree of explanation of 71.3% was determined.

The geographical distribution of the residuals of estimated and measured nitrogen concentration is depicted as Figure 19. For plots located in Scandinavia and the majority of plots located in Western Europe, Central Europe and Spain, the deviance between estimate and measurement is within a range of ±2 mg N g-1. Extreme outliers are rare. A clustering of outliers can be found only for Bulgaria.

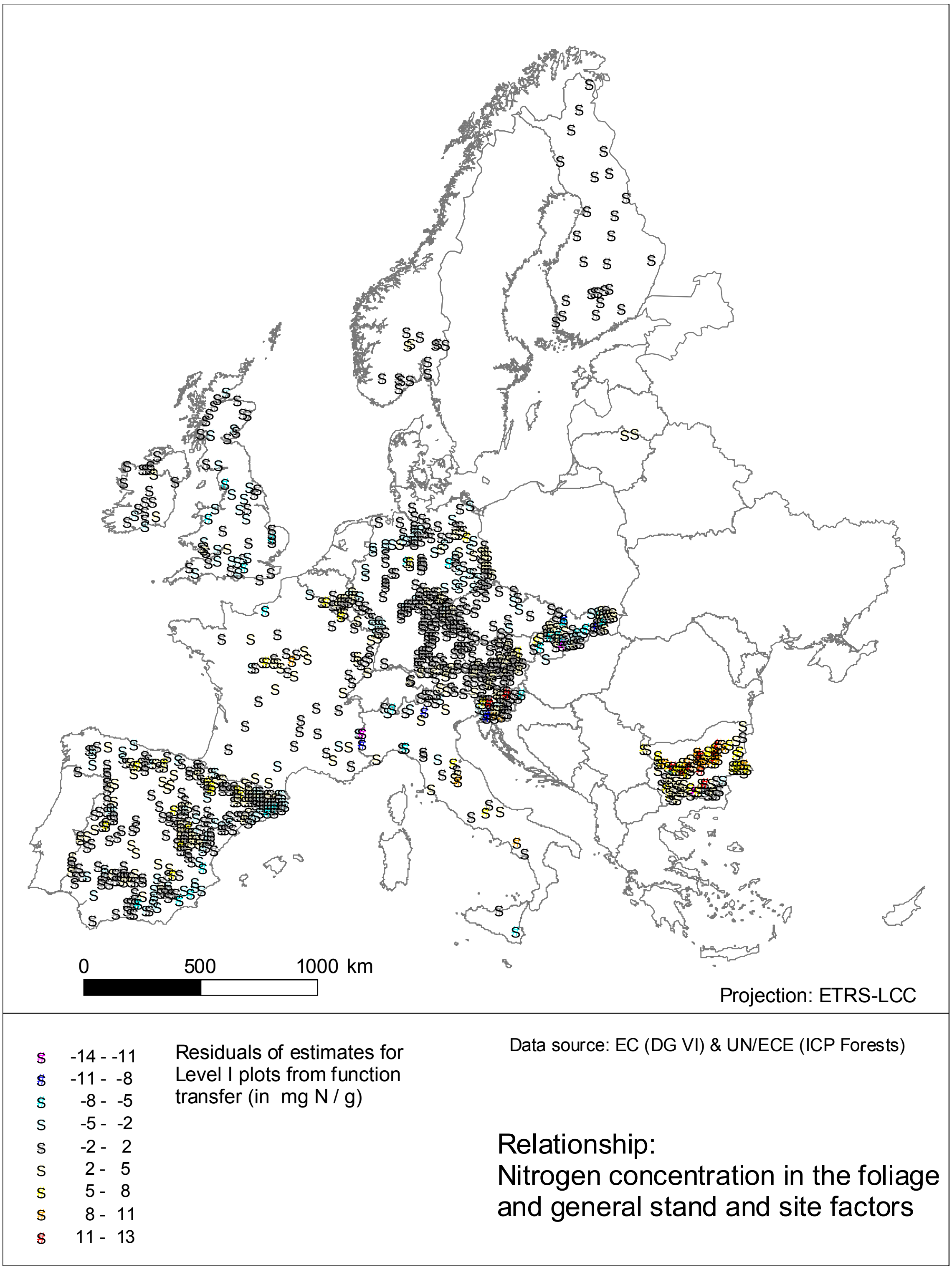

Figure 19: Geographical distribution of residuals of function transferred estimates and measured nitrogen concentration in the foliage of Level I plots.

6.6 Foliar nitrogen concentration of *Picea abies* explained by environmental and stand factors (Model 6)

Foliar concentrations of macro-nutrients like nitrogen have been used as indicators of tree nutrition for a long time (e.g. REEMTSMA 1986, HÜTTL 1991, LINDER 1995). Model 5 (Capt. 6.5) revealed species as the most important determinant for foliar nitrogen content. It is logically consistent with this finding to develop in-depth models on a species-specific basis as DE VRIES et al. (2000: 98 ff.) has done in the context of a larger evaluation on foliar condition of European tree species (DE VRIES et al. 2000: 85 ff.).

As foliar concentrations of chemical elements are influenced by available element budgets within the soil as well as by atmospheric deposition and leaching processes both ecosystem compartments together with various marginal conditions must be taken into consideration. The model developed by DE VRIES et al. (2000: Tab. 7.10 and 7.11) covers the following ecological domains: site and stand characteristics, meteorological conditions, deposition and different soil related key factors.

For Norway spruce (*Picea abies*) two variants have been carried out: one with log-transformed foliar element concentrations and one with the original data. Both reveal in Norway spruce almost the same results:

$lg[N]_{foliar,\ Picea\ abies} = f(+N_{depo}, -C/N_{org}, +altitude, -stand\ age)$; $R^2_{adj} = 59\%$, n = 91

$[N]_{foliar,\ Picea\ abies} = f(+N_{depo}, -C/N_{org}, +altitude, -stand\ age)$; $R^2_{adj} = 58\%$, n = 91

Detailed model parameters have not been published.

6.6.1 Compilation of Data

The parameters used in the original model (DE VRIES et al. 2000: 100) were re-sampled from the current database. The foliar condition survey includes a total of 767 plots (Table 59). From these 209 plots with Norway spruce as the main tree species were selected, with at least one value for foliar nitrogen. If more than one sample was taken during the years, the plot related means were calculated and used further on.

Wet throughfall deposition has been collected on a total of 536 plots during more or less extended periods between 1990 and 2001. Due to the distinct seasonal variation of precipitation and N compounds within the throughfall deposition, only those plots were used when throughfall was sampled at least for 122 days within each year. For each valid year the respective fluxes were projected to the whole year by the ratio 365/(number of sampling days). As an additional criterion the annual amount of the total throughfall N deposition has to be greater than 75% of the sum of the annual fluxes of NO_3-N and NH_4-N. If data cover more than one year, again mean values were used. After these selections, a total of 314 cases (plots) remained.

Temperature and precipitation values were taken from interpolated 30-year averaged model data (source: Chapter 5.3.1). The soil related parameters were derived from the "Soil Chemistry" survey and adequately prepared. To limit the degrees of freedom within the model, for soil type the respective parent material classes from DE VRIES et al. (1997) were used. Altitude and stand age are taken from the survey "Stand and site characteristics".

After merging all data sets and the exclusion of one plot, a total of 94 plots (Table 59) could be included in the following evaluations. This is only 3 cases more than the original approach (n = 91) has contained. Table 60 gives the boundaries of the model with respect to all included parameters. Most parameters reveal no distinct deviation from normal distribution.

Only in throughfall N and in precipitation slight improvements could be achieved by ln-transformation.

Table 59: Procedure applied to retrieve coherent data for modelling nitrogen concentration in foliage of Norway spruce inclusive number of valid cases

Step	Description	No. of plots (cases)
1	Foliar Condition Survey; all years	767
2	- as before, but with dominant Norway spruce and at least one N determination	209
3	Deposition Survey; all years	536
4	- as before, but throughfall measurements for more than 122 days per (at least) one year	314
5	Soil Chemistry Survey, organic layer, at least one valid value for C and N; if values for more than one year are available, means were calculated	610
6	Soil Chemistry Survey, upper mineral layer (0 – 5 cm or 0- 10 cm depth), at least one valid value for C, N, pH, and an entry for soil type; if values for more than one year are available, means for C, N and pH were calculated	722
7	Altitude and stand age from “General Plot” information	822
8	Precipitation and temperature from external source	822
9	Intersection of step 2, 4, 5, 6, 7, and 8	95
10	Exclusion of one outlayer from step 9	94

*Table 60: Univariate characteristics (extremes, percentiles) of the response and predictor variables used in Model 6; *: three occurring soil type (parent material) classes according to* DE VRIES *et al. (1997), **: Altitude in 50 m classes: here class means are given, ***: stand age in 20 year’s classes, class means are given, uneven aged stands were set to an age of 110 y.*

Variable	Unit	Minima, percentiles, and maxima							Transf.
		Min	5%	25%	50%	75%	95%	Max	
$[N]_{Foliar,\ P.\ abies}$	mg g^{-1}	9.36	10.08	12.17	13.30	14.64	15.79	16.79	
$N_{tot,throughfall}$	kg ha^{-1} y^{-1}	1.22	2.41	6.35	15.40	22.80	34.91	46.31	ln
Temperature	°C	-2.4	-0.4	4.0	6.3	7.6	8.6	9.2	
Precipitation	mm	451	566	713	869	1066	1548	2295	ln
N_{org}	g kg^{-1}	1.30	6.50	12.28	14.16	16.79	21.38	27.30	
C/N_{org}		12.16	18.14	23.25	26.08	30.17	37.08	47.21	
N_{min}	g kg^{-1}	0.40	0.67	1.60	2.90	5.23	9.54	19.80	
C/N_{min}		9.15	13.89	17.79	21.49	25.44	31.65	43.29	
pH_{min}		2.6	2.8	3.0	3.2	3.5	4.7	7.1	
Soil type *	qual.								
Altitude **	m	25	25	275	575	825	1225	1775	
Stand age ***	y	30	50	70	90	110	130	130	

Figure 20 displays the geographic distribution and as an overlay the spatial range of the model based on these data. The plots cover parts of central Europe and the whole of Scandinavia. Two geographical groups have been delineated. The statement of DE VRIES et al. (2000: 99) that all plots are evenly distributed over the whole of Europe can by no means be corroborated for this specific model.

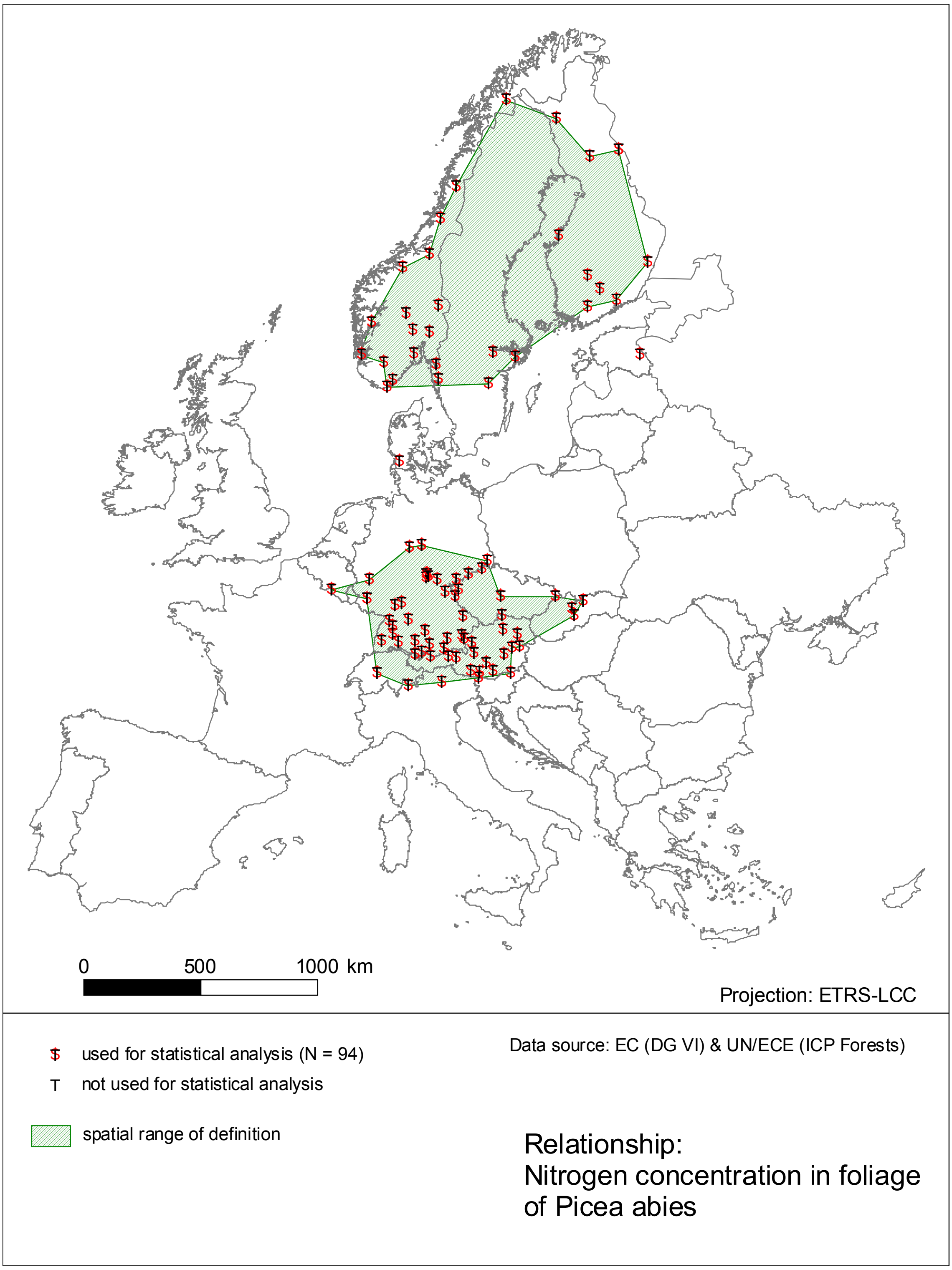

Figure 20: Geographic distribution of the valid Level II plots used for regression analysis and area determining the spatial (geographic) range of the model definition.

6.6.2 Re-sampling the original Model by Covariance and Regression Models

The results from the re-sampled full model are given in Table 61. It partly confirms results of DE VRIES et al. (2000). The most important predictor in terms of sum of squares (and hence partial R^2) is throughfall deposition of total nitrogen. Also the C/N ratio of the organic layer (C/N_{org}) and stand age as significant predictors correspond with the model of DE VRIES et al. (2000). Altitude is, deviant from the "original" model, not among the significant predictors. Instead, N concentration in the upper mineral layer and parent material (class 4 = calcareous soils) become significant predictors. The model explains after adjustment 55.7% of the variation of the foliar nitrogen in Norway spruce, which is c. 3% less than the original model of DE VRIES et al. (2000).

The result of the re-sampled model reveal throughfall N deposition as a by far the dominant predictor explaining more than 44% of the variance of the foliar nitrogen concentration. Each of the other four significant predictors contributes only 5% and less to the total model.

Table 61: *Full re-sampled covariance model according to the original model of de Vries et al. (2000: Table 7.11) explaining foliar N concentration of Norway spruce; degrees of freedom (DF), sum of squares (SSQ) and significance of F values (Sig F) from ANOVA; n = 94, R^2 = 0.614, R^2_{adj} = 0.557*

	Estimate	**Std. Error**	**t value**	**Sig t**	**DF**	**SSQ**	***Sig F***
Intercept	11.86692	3.04785	3.894	***			
$\ln(N_{tot,throughfall})$	0.85216	0.26526	3.213	**	1	119.446	***
Temperature	0.06417	0.07591	0.845		1	0.530	
ln(Precipitation)	-0.03043	0.41720	-0.073		1	0.067	
N_{org}	-0.05129	0.03058	-1.677		1	0.164	
C/N_{org}	-0.05767	0.02654	-2.173	*	1	11.834	**
N_{min}	0.09908	0.04172	2.375	*	1	8.728	*
C/N_{min}	0.01138	0.02377	0.479		1	0.148	
pH_{min}	0.57870	0.32516	1.780		1	0.409	
Parent material					2	14.351	**
PM type 2	-0.63963	0.41447	-1.543				
PM type 4	-3.10347	1.20480	-2.576	*			
Altitude	0.02255	0.02033	1.109		1	0.003	
Stand age	-0.01425	0.004992	-2.855	**	1	10.527	**
Model					12	166.207	***
Residual		1.136			81	104.596	
Total					*93*	*270.803*	

signif. codes: `***' 0.001 `**' 0.01 `*' 0.05

In order to achieve the most stabile predictor configuration regression models with different predictor selection options were performed. Forward selection and a mixed forward-backward selection strategy resulted in a model with three significant predictors only (Table 62). In this model stand age explains an additional 6.3% of the variance of the N concentration of spruce needles (cf. RAITIO 1999). The contribution of total N concentration in the upper mineral soil is only 3.1%.

Table 62: Filtered re-sampled linear regression model explaining foliar N concentration of Norway spruce with forward and mixed forward/backward selection of predictors (only predictors significant at the 5% level are included; degrees of freedom (DF), sum of squares (SSQ) and significance for F values (Sig F) from ANOVA; n = 94, R^2 = 0.536, R^2_{adj} = 0.521.

	Estimate	Std. Error	t value	Sig t	DF	SSQ	*Sig F*
Intercept	11.647867	0.541096	21.526	***			
$\ln(N_{tot,throughfall})$	1.096519	0.140357	7.812	***	1	119.446	***
Stand age	-0.016233	0.004444	-3.653	***	1	17.367	***
N_{min}	0.089067	0.036311	2.453	*	1	8.396	*
Model					3	145.209	***
Residual		1.181			90	125.594	
Total					*93*	*270.803*	

signif. codes: `***' 0.001 `*' 0.05

The regression model resulting from the backward selection is more similar to the reconstructed full model (Table 63). Besides throughfall N some predictors with very small contributions could be selected. Stand age, the most important of these parameters explains mere 4.7%. The analysis of variance and the t-test resulted even in different significance scores indicating a generally unstable predictor structure for this model.

Table 63: Filtered re-sampled linear regression model explaining foliar N concentration of Norway spruce with backward selection of predictors;; degrees of freedom (DF), sum of squares (SSQ) and significance for F values (Sig F) from ANOVA; n = 94, R^2 = 0.574, R^2_{adj} = 0.545.

	Estimate	Std. Error	t value	Sig t	DF	SSQ	*Sig F*
Intercept	13.305272	1.035270	12.852	***			
$\ln(N_{tot,throughfall})$	0.893666	0.175711	5.086	***	1	119.446	***
C/N_{org}	-0.049826	0.025564	-1.949	.	1	10.984	**
Stand age	-0.013763	0.004476	-3.075	**	1	12.841	**
N_{min}	0.096312	0.036528	2.637	**	1	6.840	*
Parent material					2	5.370	
PM type 2	-0.140471	0.353042	-0.398				
PM type 4	-1.394652	0.699385	-1.994	*			
Model					6	155.481	***
Residual		1.151			87	115.323	
Total					*93*	*270.804*	

signif. codes: `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1

6.6.3 Recursive Partitioning

The results from recursive partitioning reflect the unbalanced predictor structure already seen during the different approaches of the covariance respective multiple regression models (Table 61, Table 62, Table 63). After a distinct group formation caused by total throughfall N no further significant increase could be detected. Even if the absolute R^2 value increases, the respective error term does not (Figure 21).

Moreover, neither the inclusion of the two geographic regions (see Figure 20) nor country code as additional categorical variables did result in a more distinct predictor structure.

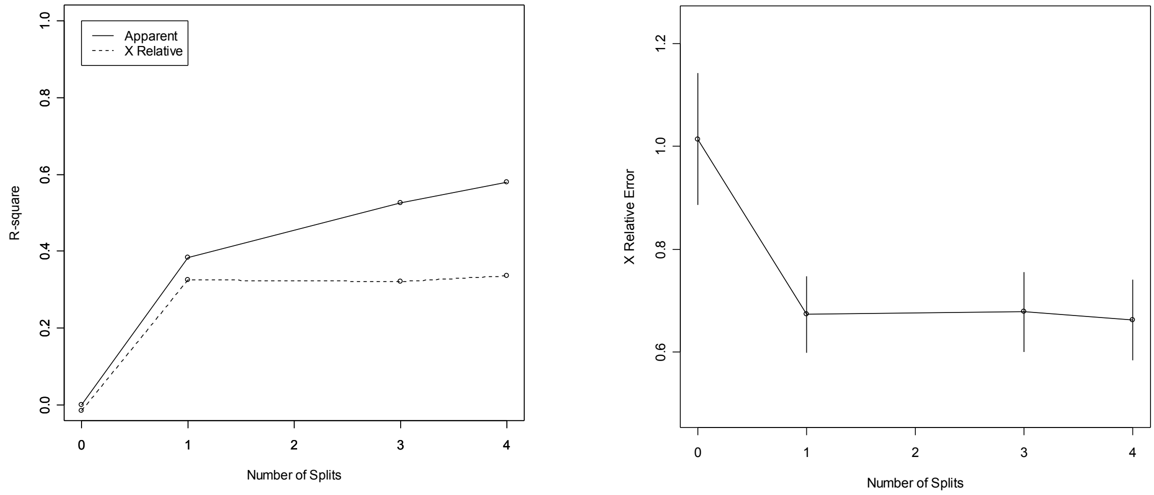

Figure 21: Results of a recursive partitioning approach with N_{fol} as response variable and total N bulk deposition, N content of the mineral layer, age, parent material, C/N ratio in the organic layer, pH in the mineral layer, nitrogen in the organic layer and region (Scandinavia and central Europe) as predictors; control variable = 0.03.

6.6.4 Substitute Model: Bulk instead of Throughfall as Response Variable

For a considerable number of Level I plots needle or leaf contents of nutrients especially nitrogen have been sampled (STEFAN et al. 1997). However, it is much more difficult and very time-consuming to measure N deposition at Level I plots. If a respective up-scaling approach could result in reliable estimates of N deposition for Level I plots, we would attain a powerful means to get an independent estimate for N deposition and verify the respective down-scaling efforts from the EMEP grid (with the EDACS model, cf. DE VRIES et al. 2002). As bulk deposition is in comparison to throughfall deposition less influenced by the trees stand itself, it may reflect more closely the recent deposition processes, even if dry deposition is not covered by this fraction.

Throughfall deposition is therefore substituted by bulk deposition in two steps. First, within a correlative approach the relationship between throughfall and bulk deposition is investigated. In a second step, bulk deposition substitutes throughfall deposition within the re-sampled models.

If information on bulk deposition is processed in the same way as throughfall deposition (cf. Table 59), a total of 77 valid cases are finally obtained. For the comparison of bulk and throughfall deposition 72 plots are available. The resulting, slightly logarithmic relationship reveals a highly significant coefficient of determination of R^2 = 0.8333. Even if some inhomogeneities are recognisable within the scatter plot (Figure 22) the relationships seems to be viable enough to proceed with this approach.

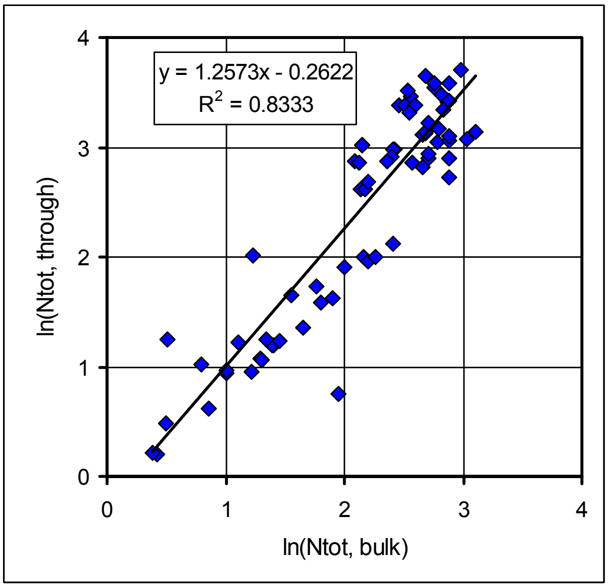

Figure 22: Scatter plot between natural logarithm of total N in throughfall deposition and the natural logarithm of total N in bulk deposition of 72 Level II plots stocked by Norway spruce (cf. DE VRIES et al. 2001: 164)

Table 64 informs about the univariate properties of the involved parameters. Obviously there are only marginal differences of median values or ranges of the parameters between the re-sampled throughfall model and the substituted bulk model.

Based on these far-reaching conformities between measured bulk and throughfall deposition a substitute linear regression model was carried out with foliar nitrogen concentration of spruce needles as dependent variable and the natural logarithm of total nitrogen bulk deposition and all further variables from the original model as predictors. Forward, backward and both-sided selection was performed. Results from the forward selection model, which are identical with those from the both-sided selection routine, are summarized by Table 65. The adjusted R^2 is with 58% even slightly better than for the re-sampled model with throughfall (Table 63). Again, deposition explains with almost 44% the greatest portion of the variance of the foliar nitrogen contents of spruce needles.

An approach with recursive partitioning resulted again in an instable predictor structure and was not followed further on.

*Table 64: Univariate characteristics (extremes, percentiles) of the response variable and the predictor variables used in substitute Model; *: three occurring soil type (parent material) classes according to de Vries et all. (1997), **: Altitude calculation with 50 m classes: here class means are given, ***: stand age in 20 year's classes, class means are given, uneven aged stands were set to an age of 110 y.*

Variable	Unit	Minima, percentiles, and maxima							Transf.
		Min	5%	25%	50%	75%	95%	Max	
$[N]_{Foliar,\ P.\ abies}$	mg g^{-1}	9.36	9.83	12.05	12.96	14.70	15.90	16.79	
$N_{tot,bulk}$	kg ha^{-1} y^{-1}	1.47	2.10	4.71	8.97	14.92	18.10	22.36	ln
Temperature	°C	-2.4	-0.7	3.4	6.3	7.6	8.4	9.2	
Precipitation	mm	451	561	675	811	958	1457	2295	ln
N_{org}	g kg^{-1}	1.30	5.40	11.90	14.00	16.77	21.50	27.30	
C/N_{org}		12.16	18.60	23.08	26.15	30.07	38.61	47.21	
N_{min}	g kg^{-1}	0.40	0.60	1.30	2.30	4.90	9.48	19.80	
C/N_{min}		12.00	15.28	17.83	21.43	25.71	32.52	43.29	
pH_{min}		2.6	2.8	3.0	3.2	3.5	3.7	5.1	
Soil type *	qual.								
Altitude **	m	25	25	175	525	675	1125	1775	
Stand age ***	y	30	50	70	70	110	130	130	

Table 65: Substituted linear regression model explaining foliar N concentration of Norway spruce with bulk deposition and other predictors from the original model (forward selection of predictors, only predictors significant at the 5% level are included);, DF, SSQ and Sig F from ANOVA; n = 77, R^2 = 0.600, R^2_{adj} = 0.577.

	Estimate	Std. Error	t value	Sig t	DF	SSQ	*Sig F*
Intercept	13.932852	1.149916	12.116	***			
$ln(N_{tot,bulk})$	1.084415	0.250599	4.327	***	1	111.563	***
C/N_{org}	-0.073428	0.028118	-2.611	*	1	22.120	***
Stand age	-0.016637	0.005553	-2.996	**	1	11.896	**
N_{min}	0.093193	0.039554	2.356	*	1	7.900	*
Model					4	153.479	***
Residual		1.193			72	102.458	
Total					*76*	*255.937*	

signif. codes: 0 \`***' 0.001 \`**' 0.01 \`*' 0.05

6.6.5 Converted Models: N Bulk Deposition as Response Variable

According to Table 65 the relationship between foliar N, basic soil parameters, deposition and stand variables can be expressed by the following formula (1):

$N_{fol} = 13.9329 + 1.0844 \ln(N_{tot,bulk,y}) – 0.0734 C/N_{org} – 0.0166 age + 0.0932 N_{min}$ (1).

As an estimation of nitrogen within the bulk deposition is of great interest for Level I plots a respectively converted model was calculated with $\ln(N_{tot,bulk,y})$ as the dependent variable and the other parameters including foliar nitrogen contents of spruce as predictors accordingly:

$\ln(N_{tot,bulk,y}) = \alpha + ß_1 N_{fol} + ß_2 C/N_{org} + ß_3 age + ß_4 N_{min} + \varepsilon$ (2).

Table 66 gives the respective results. With an adjusted R^2 of 0.53 the coefficient of determination is in almost the same order than the respective parameter in model of Table 65 (R^2_{adj} = 0.58). However, N_{min} did not become a significant predictor of N bulk deposition within this converted model.

Table 66: Reversed linear regression model for Norway spruce plots with annual N bulk deposition as dependent variable and all significant predictors from the substituted model given in Table 65, later referred also as 'ecological' model; degrees of freedom (DF), sum of squares (SSQ) and significance for F values (Sig F) from ANOVA; n = 77; R^2 = 0.548, R^2_{adj} = 0.529

	Estimate	**Std. Error**	**t value**	**Sig t**	**DF**	**SSQ**	***Sig F***
Intercept	0.134252	0.824487	0.163				
N_{fol}	0.193838	0.041467	4.675	***	1	17.3552	***
C/N_{org}	-0.039728	0.011311	-3.512	***	1	2.8351	**
Age	0.005976	0.002327	2.567	*	1	1.6253	*
Model					3	21.8156	***
Residual		0.4965			73	17.9989	
Total					*76*	*39.8145*	

signif. codes: `***' 0.001 `**' 0.01 `*' 0.05

Besides this model with the same parameter structure as the substitute model (Table 65), a further model can be calculated with bulk deposition of total nitrogen as dependent variable and all parameter from the original model (Table 61) as predictors. Such a converted original model does not necessarily imply any causation (e.g. bulk deposition is never influenced by foliar element contents), but may foster the prediction of an impact factor for forests, which can hardly be measured on larger scales. Appling a forward selection this approach resulted in the model structure given in Table 67. Backward and both-sided selection gave the same model coefficients; only in the case of backward selection, F statistics are slightly different.

Table 67: Reversed linear regression model for Norway spruce plots with annual N bulk deposition as dependent variable and all remaining variables from the original model as predictors (only significant predictors are included, later referred also as 'climatic' model; degrees of freedom (DF), sum of squares (SSQ) and significance for F values (Sig F) from ANOVA; n = 77, R^2 = 0.778, R^2_{adj} = 0.766.

	Estimate	Std. Error	t value	Sig t	DF	SSQ	*Sig F*
Intercept	-2.022490	0.947648	-2.134	*			
Temperature	0.154274	0.017474	8.829	***	1	27.2711	***
Altitude	0.018499	0.006259	2.955	**	1	2.1524	***
N_{fol}	0.076038	0.028327	2.684	**	1	0.8949	**
ln(Precipitation)	0.316075	0.136571	2.314	*	1	0.6575	*
Model					4	30.9759	***
Residual		0.3502			72	8.8386	
Total					*76*	*39.8145*	

signif. codes: `***' 0.001 `**' 0.01 `*' 0.05

This model reveals an overwhelming coincidence between bulk deposition and temperature the latter explaining alone 68.5% of the variance of N bulk deposition at plots stocked by Norway spruce. This is surely a result of the specific geographical distribution of the respective Level II plots within Europe (cf. Figure 20), with plots located in the warmer central part having higher N deposition loads and plots in the colder Scandinavia with lower N deposition. Similar coincidences might be responsible for the roles of altitude and precipitation. Only a small influence of the foliar N concentration slightly accounts for the role of nitrogen within ecosystems.

Both models will be applied to Level I data, because their predictor structures differ considerably. While in model displayed in Table 67 predominate predictors like mean air temperature vary on a large geographic scale, the predictors of model given in Table 66 reflect much more the status of individual ecosystems resembling the proceeding of bio-indication.

6.6.6 Transfer to Level I

The GIS point-in-polygon procedure revealed a total of 3,111 Level I plots within the geographic limits determined by all spatially coherent and therefore valid Level II plots (compare Figure 20). From a total of 405 Level I plots stocked with Norway spruce and having foliar nitrogen concentration between 9 and 17 mg g^{-1} (derived from the range given by Table 64) only 246 plots could be finally selected. Braking down the total of 3,781 plots for which a C/N ratio of the organic layer between 10 and 50 (according to Table 64) could be determined to the geographic limits, 1,371 plots will be left. Selecting all plots with the information necessary to transfer the model given in Table 66 (the 'ecological' model), only 141 plots constitute the final set. As the meteorological data for Level I plots are derived from an external data base which covers entire Europe (cf. Chapter 5.3.1), no respective restrictions are attached to it. Nevertheless, only a total of 154 plots are available to transfer the respective 'climatic' substitute model represented by Table 67.

Table 68: Univariate statistical properties of N_{tot} bulk deposition calculated according to both up-scaling models and total N deposition from EMEP (interpolated) and EDACS model (de Vries et al. 2002); v_r: coefficient of variation, shaded part: R^2 /: coefficient of determination between the estimates from different models/sources.

	Predicted bulk total N deposition [kg ha^{-1} y^{-1}] by the reversed ('climatic') Model (Table 6-8, n = 141)	Predicted bulk total N deposition [kg ha^{-1} y^{-1}] by the substitute ('ecological') model (Table 6-7, n = 154)	Interpolated total N deposition [kg ha^{-1} y^{-1}] from the EMEP model (n = 146)	Total N deposition [kg ha^{-1} y^{-1}] from the EDACS model (n = 146)
Min – Max	1.59 – 19.81	1.83 – 15.63	2.14 – 25.04	0.52 – 30.09
Mean ± Stw	8.89 ± 3.511	10.68 ± 3.390	15,97 ± 5.597	13.51 ± 7.194
v_r	0.40	0.32	0.35	0.53
R^2 /N_{total} EDACS	0.348	0.345	0.476	1.000
R^2 /N_{total} EMEP	0.697	0.186	1.000	
R^2 /ecol. Model	0.290	1.000		
R^2 /clim. Model	1.000			

The estimates for bulk deposition from the more 'climatic' and the more 'ecological' models differ slightly. The results of the reversed model with the ecosystem oriented predictor structure reveal a wider range of N bulk deposition, but a lower mean value (Table 68). The model with the more climatic predictor structure reveals a higher mean value, however, the range is narrower. The spatial distribution of the N bulk deposition values is considerable different: while the 'ecological' model shows a high degree of spatial small scale variation, the 'climatic' model reveals a largely monotonous spatial process. This result reflects again the different predictor structures with predominating ecosystem-oriented parameters varying on a scale of stands or regions and predominating climatic factors varying on a large geographical scale (compare Figure 25).

Total interpolated N deposition (method: spline-interpolated tension surface from EMEP grid centre points, sum of NO_x-N and NH_y-N) from the existing deposition estimates from the large-scale EMEP grid as well as results from the EDACS model are referenced to the respective Level I sample are also documented in Table 68. As to expect, the mean values are c. 50% higher than bulk deposition, because dry deposition is included in modelled total deposition, but not in measured bulk deposition. The variation of EMEP deposition is distinctively lower than estimates calculated by the more complex EDACS model, which is derived from EMEP under the additional consideration of stand related parameters.

The general features of the models are revealed by a correlation study performed between the plot-specific estimates from the four different models (Table 68 shady part; for the ease of comparison with regression models R^2-values are given instead of r-values). Most obvious is the high correlation between interpolated EMEP estimates and the outcomes from the 'climatic' model (R^2 almost 0.70), which may largely depend on the geographic distribution of the sample (cold and less polluted Scandinavia against warmer and more polluted central Europe). At the same time, EMEP estimates reveal the lowest correlation with the results from the 'ecological' model, corroborating the deviant outcomes of this model based on its different predictor structure. EDACS estimates take with respect to up-scaling models developed here an intermediated position. Interestingly, EMEP and EDACS estimates are better correlated than the predictions from the two up-scaling models. It would be an ambitious but rewarding task to investigate which of the estimates comes closest to the real but actually unknown N deposition at the Level I sites.

Table 69: *Regression model for Norway spruce plots with the logarithm of the annual (1996) total N deposition interpolated from EMEP grid as dependent variable and predictor structure transferred from the 'climatic' substitute model (Table 67); degrees of freedom (DF), sum of squares (SSQ) and significance for F values (Sig F) from ANOVA; n = 146, R^2 = 0.874, R^2_{adj} = 0.871.*

	Estimate	Std. Error	t value	Sig t	DF	SSQ	*Sig F*
Intercept	-0.346920	0.611577	-0.567				
Temperature	0.196180	0.009596	20.44	***	1	25.9079	***
ln(Precipitation)	0.133004	0.089963	1.478		1	6.9752	***
N_{fol}	0.032446	0.015107	2.148	*	1	0.4448	***
Altitude	0.036359	0.003339	10.89	***	1	4.5875	***
Model					4	37.9154	***
Residual		0.1967			141	5.4540	
Total					*145*	*43.3694*	

signif. codes: `***' 0.001 `**' 0.01 `*' 0.05

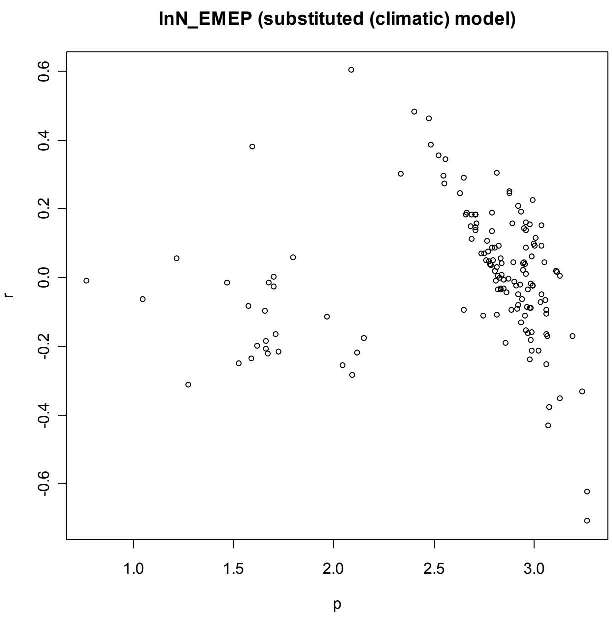

Figure 23: Residuals (r) against predicted values (p) from the transferred 'climatic' model documented in Table 69.

If the structures from the 'climatic' and 'ecological' models are transferred to Level I and total N bulk deposition are substituted by the interpolated plot-specific total N deposition from the EMEP or estimates from the EDACS model, we receive in total four models. The results of the two EMEP models are given in Table 69 and Table 70. The relationship for the climatically determined model (Table 69) is with an R^2_{adj} of 0.87 distinctively tighter than for the original model in Table 67 (R^2_{adj} = 0.77). We can conclude that EMEP estimates refer closely to the climatic gradient from Scandinavia to central Europe. However, the residual structure is obviously twofold with high predicted values from central Europe and low values from Scandinavia (Figure 23). The residuals from central Europe are slightly skewed with positive scores at lower and negative scores at higher predicted values.

Table 70: Regression model for Norway spruce plots with the logarithm of the annual (1996) total N deposition after EMEP as dependent variable and 'ecological' predictors transferred from the reversed model (Table 66); degrees of freedom (DF), sum of squares (SSQ) and significance for F values (Sig F) from ANOVA; n = 141, R^2 = 0.425, R^2_{adj} = 0.412.

	Estimate	**Std. Error**	**t value**	**Sig t**	**DF**	**SSQ**	***Sig F***
Intercept	2.4174016	0.5537039	4.366	***			
N_{fol}	0.1143786	0.0302024	3.787	***	1	11.2699	***
C/N_{org}	-0.046254	0.0083037	-5.570	***	1	5.1332	***
Age	-0.000448	0.0010795	-0.415		1	0.0280	
Model					3	16.4311	***
Residual		0.4028			137	22.2293	
Total					*140*	*38.6604*	

signif. codes: `***' 0.001 `**' 0.01 `*' 0.05

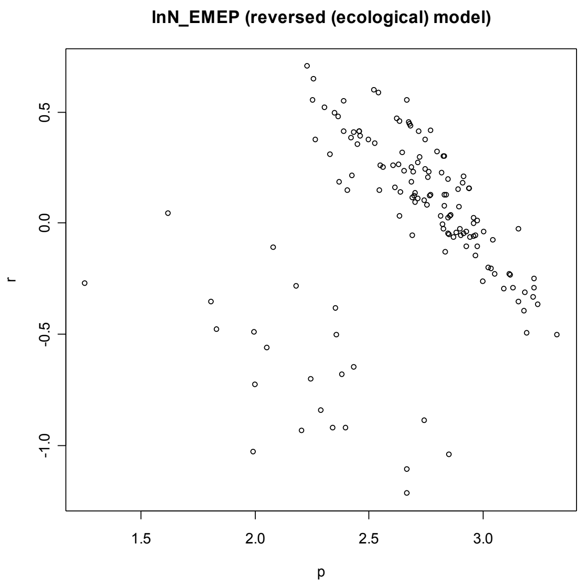

Figure 24: Residuals (r) against predicted values (p) from the 'ecological' model documented in Table 70.

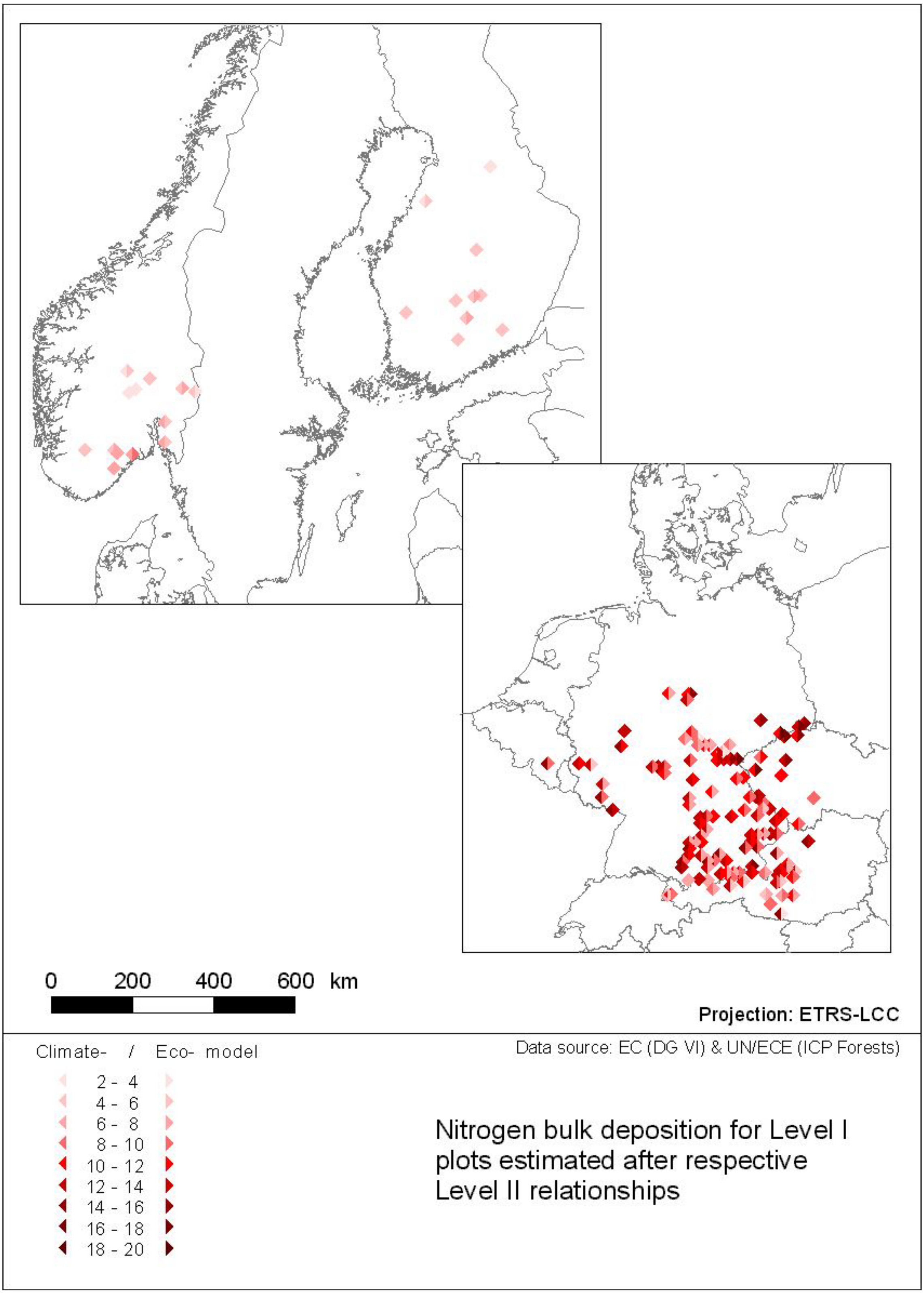

Figure 25: Map of predicted N bulk deposition of 141 Level I plots stocked by Norway spruce and laying within the statistically and geographically determined limits. The predictions of the "climatic" model are calculated according to the estimates given in Table 67, the predictions of the "ecological" model are calculated according to the estimates given in Table 66.

For the more ecosystem-oriented predictor structure of the reversed model generally a weaker relationship with EMEP N deposition estimates results. Age does in this case not account statistically for the variation of total EMEP N deposition. Again a twofold residual structure of the scatter diagram appears (Figure 24). Additionally the residuals from both geographic regions (but especially from central Europe) are skewed with positive scores at the lower and negative scores at the higher end of the predicted values. This indicates a bias in either the up-scaled model or within the EMEP model (or in both). It is beyond the scope of this project to explore this relationship in more detail, as a thorough analysis of the EMEP predictions would become necessary.

The respective models with the EDACS estimates are with an R^2_{adj} = 0.67 and R^2_{adj} = 0.37 in both cases distinctively weaker. The scatter diagrams with residuals against predicted values are respectively organised than Figure 23 and Figure 24, but the respective structures are fussier in both cases.

Mapping the predicted values of both models finalises this up-scaling approach, proceeding from the relationship between N concentration of needles in Norway spruce and its significant predictors. Figure 25 shows the estimated total nitrogen deposition within the bulk precipitation estimated for 141 Level I plots by the relationship found for 77 statistically and geographically comparable Level II plots (the ‘ecological’ model according to Table 66). Obvious is the fine scaled within structure of the N bulk deposition estimates. This result is in contrast to the map produced from the model documented in Table 67 with a predominant climatic predictor structure. This map reflects a continuous variation of N bulk deposition in parallel to the continuously varying climatologic factors mainly temperature.

6.7 Foliar N concentration of *Pinus sylvestris* and N throughfall concentration (Model 7)

The overview model in Chapter 6.5 showed, that tree species is generally an important predictor of foliar nitrogen concentration. The Chapter 6.6 gave a convincing example for a species-specific multivariate covariance approach to model foliar N concentration in dependence from different ecological domains. Conversions of the found relationships may even open up opportunities to model deposition as statistically dependent variable based on this up-scaling approach.

This model with Scots pine (*Pinus sylvestris*) is a bivariate but non-linear model. The original model in DE VRIES et al. (2000: 100) is not explicitely formulated but the relationship is graphically displayed [100: Figure 7.7 A]. The following dependency can be stated:

$[N]_{\text{foliar, Pinus sylvestris}} = f(+[N]_{\text{depo, throughfall}})$

The coefficient of determination is given with 60%, but neither a note about an adjustment is given nor any further model parameters are published.

6.7.1 Data preparation

Wet throughfall deposition has been collected on a total of 536 plots during more or less extended periods between 1990 and 2001. Due to the distinct seasonal variation of precipitation as well as N compounds within throughfall deposition, only those plots were used when throughfall deposition was sampled at least for 122 days within each single year. For each valid year the respective fluxes were projected to the whole year by the ratio 365/(number of sampling days). As an additional criterion the annual amount of the total throughfall N deposition has to be greater than 75% of the sum of the annual fluxes of NO_3-N and NH_4-N. After these selections, a total of 314 cases (plots) remain (Table 71).

Table 71: Procedure applied to retrieve coherent models for nitrogen concentration in foliage of Scots pine inclusive number of valid cases

Step	Description	No. of plots (cases) Parameter table
1	Foliar Condition Survey; all years	767
2	- as before, but with dominant Scots pine and at least one N determination	221
3	Deposition Surveys on Pine plots; all years	1370
4.1	- as before, but throughfall measurements for more than 122 days per (at least) one year	314
5.1	Intersection of step 2 and 4.1	57
4.2	- as 3, but bulk measurements for more than 122 days per (at least) one year	237
5.2	Intersection of step 2 and 4.2	48

The foliar condition survey includes a total of 767 plots where at least one, but up to 14 surveys have been conducted. From these 221 plots with Scotch pine as the main tree species were left, with a respectively attributed mean value for foliar nitrogen.

The intersection between pine plots with foliar N values and those with N throughfall deposition data amounts 57 plots. These plots became the basis of the following nonlinear regression analysis. This might be an increase of 14% against the original approach with probably 49 cases. The univariate properties of the relevant parameters, which denote the application limits of the model, are given in Table 72.

Table 72: Univariate characteristics (extremes, percentiles) of the response and predictor variable(s) used in Model 7, supplemented by nitrogen fractions as some additional potential predictors.

Variable	Unit	Minima, percentiles, and maxima							Transf.
		Min	5%	25%	50%	75%	95%	Max	
$[N]_{Foliar,\ P.\ sylv.}$	mg g^{-1}	9.160	10.473	12.390	15.741	17.755	20.848	22.921	-
$N_{tot,throughfall}$	kg ha^{-1} y^{-1}	0.763	1.359	3.388	12.014	17.272	40.756	53.680	-
NH_4-$N_{throughfall}$	kg ha^{-1} y^{-1}	0.098	0.354	1.148	4.425	8.888	31.884	45.847	-
NO_3-$N_{trhroughfall}$	kg ha^{-1} y^{-1}	0.271	0.453	1.616	4.426	6.704	12.099	17.185	-

6.7.2 Re-sampling the original model

The original model elaborated by DE VRIES et al. (2000: 100) was a 2nd order polynomial. The respective model with the up-dated Level II data revealed the following equation:

$$[N]_{fol} = -0.00588\ N_{tot,throughfall,y}^{2} + 0.463009\ N_{tot,throughfall,y} + 10.959395 \qquad (7.1).$$

This relationship is in terms of R^2 (R^2_{adj} = 0.74) even tighter than the original model (R^2 = 0.60), however, a distinct vertex appeared within the range of the occurring throughfall deposition values at $N_{depo,tot,y}$ = 39.37 kg ha^{-1} y^{-1} with a respective foliar N value of $[N]_{FOL}$ = 20.07 mg g^{-1}.

Since decreasing foliar N contents at N deposition values beyond 39.37 kg ha^{-1} y^{-1} clearly contradict theoretical assumptions, an asymptotic regression model (7.2, see Table 73 and Figure 27, “SSasymp” in “R”; cf. BATES & WATTS 1988) was fitted in order to describe the relationship adequately:

$$[N]_{fol} = Asym + (R0 - Asym) * \exp(-\exp(lrc) * N_{tot,throughfall,y}) \qquad (7.2).$$

The Level II plots which could be used for this nonlinear regression model show a distinct spatial concentration in the middle of Europe and a well-distributed coverage in Finland (Figure 26). Minor occurrences exist in Austria/Hungary. One plot in southern Norway will be ignored within the up-scaling procedure, due to its spatial isolation. Probably, the model might be applicable within a broader geographical frame, however, the later selection of Level I plots will follow a rather conservative strategy.

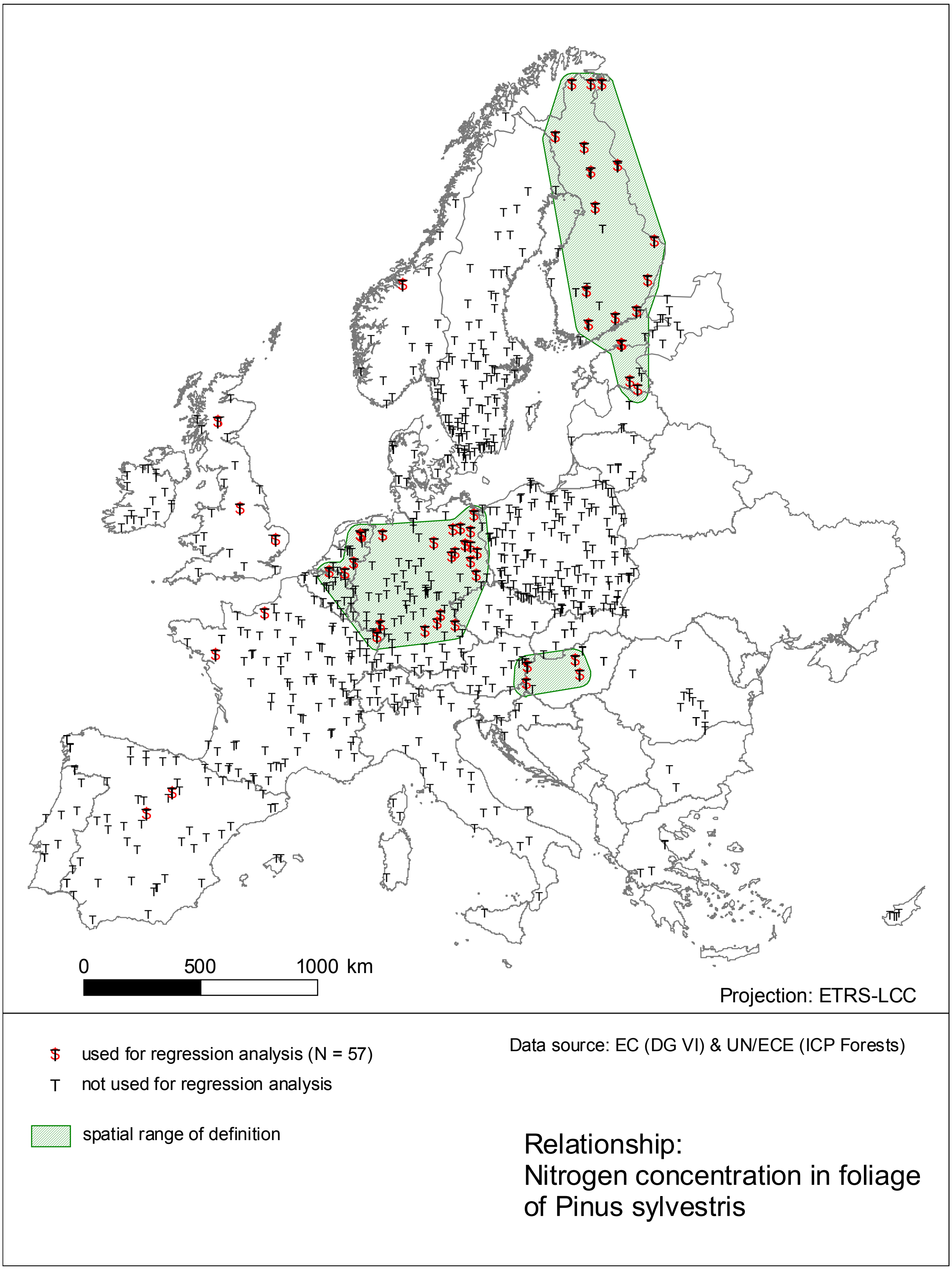

Figure 26: Geographical distribution of valid Level II plots in comparison to all Level II plots in Europe and spatial range for transfer of Model 7 from Level II to Level I (hatched area).

Table 73: Summary of the parameters of the fitted asymptotic regression model (Formula 7.2), n = 57, Res. std. err. = 1.687 on 54 DF.

	Estimate	Std. Error	t value	Sig t
Asym	20.981043	1.2028	17.44	***
R0	10.714633	0.5856	18.30	***
lrc	-2.872129	0.2688	-10.69	***
Correlation of parameter estimates:		Asym	R0	
	R0	0.4210		
	lrc	-0.9088	-0.6538	

Signif. code: `***' 0.001

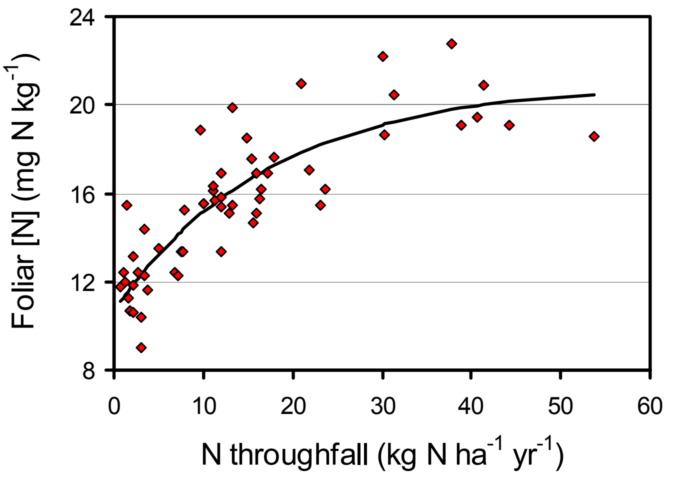

Figure 27: N concentration of the recent set of pine needles ($[N]_{FOL}$) plotted against total N in throughfall ($N_{depo,tot,y}$) corresponding to Figure 7.7 A in DE VRIES et al. (2000); the graph of the fitted modified asymptotic regression (exponential saturation) graph according to formula (7.2) is included.

6.7.3 Model with bulk instead of throughfall deposition (Substitute Model)

Additionally an alternative approach with bulk instead of throughfall deposition was performed. This model could be based on a total of 48 cases (Table 71). Table 74 shows the ranges of the involved parameters. The lower limit of the foliar concentration of nitrogen is slightly narrower than in the model with throughfall deposition as predicting variable (Table 73).

Table 74: Univariate characteristics (extremes, percentiles) of the response and predictor variable(s) used in Model 7 with throughfall substituted by bulk deposition.

Variable	Unit	Minima, percentiles, and maxima							Transf.
		Min	5%	25%	50%	75%	95%	Max	
$[N]_{Foliar,\ P.\ sylv.}$	mg g^{-1}	8.906	9.829	11.788	13.161	14.651	15.716	16.338	-
$N_{tot,bulk,y}$	kg ha^{-1} y^{-1}	1.217	2.128	6.464	16.369	23.060	35.856	48.546	-

Regressing foliar N concentration against bulk deposition, it becomes obvious that no asymptotic behaviour could be detected. Therefore a simple linear regression performs sufficiently well. The results of this linear regression model are given in Table 75.

Table 75: Substituted regression model explaining foliar N concentration of the recent needle set of Scots pine by N bulk deposition; n = 48, R^2 = 0.653, R^2_{adj} = 0.645

	Estimate	Std. Error	t value	Sig t	DF	SSQ	*Sig F*
Intercept	11.07955	0.50444	21.964	***			
$N_{tot,bulk,y}$	0.47243	0.05083	9.294	***	1	315.511	***
Model					1	315.511	***
Residual		1.911			46	168.011	
Total					*47*	*483.522*	

signif. code: `***' 0.001

6.7.4 Reversed Models within Level II

The prediction of nitrogen deposition at forest sites might be of greater practical relevance than the prediction of foliar nitrogen contents from N deposition. Therefore a reversed model is developed, which predicts - as a kind of bioindication - nitrogen throughfall deposition and nitrogen bulk deposition from the N concentration of the recent set of pine needles. This model does not imitate any cause-effect mechanism, but uses foliar N concentration as a passive bioindicator for N deposition.

To predict total N throughfall deposition from foliar contents the following nonlinear regression model could be very successfully fitted (Table 76, Figure 28):

$$N_{depo,throughfall,y} = 9.123E\text{-}5 * (N_{fol})^{4.2355}.$$

An adjusted R-squared value of 0.81 is even better than for the original model. This model reveals the recent needle sets of Scots pine, an oligotraphent tree species, as more sensitive towards nitrogen deposition than needles of the eutraphent Norway spruce (Model 6).

Table 76: Revered regression model explaining N throughfall deposition by N foliar concentration (recent needle set) in the Scots pine; n = 58, R^2 = 0.811, R^2_{adj} = 0.8074.

	Estimate	Std. Error	t value	Sig t	DF	SSQ	*Sig F*
$(N_{fol})^{4.2355}$	9.123e-05	5.891e-06	15.49	***	1	16599.4	***
Model					1	16599.4	***
Residual		8.318			56	3875.0	
Total					*57*	*20474.4*	

signif. code: `***' 0.001

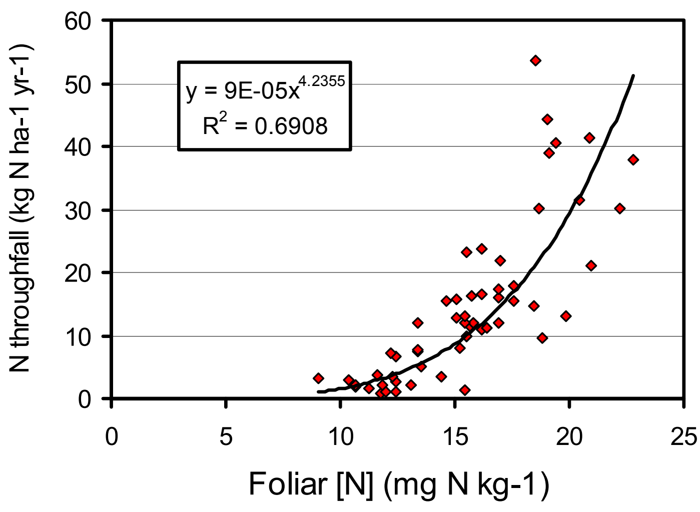

Figure 28: Relationship between N throughfall deposition and foliar N concentration of the recent needle set of Scotch pine at hand of Level II plots with available data sets.

The linear model, where N bulk deposition substitutes throughfall deposition, was reversed as well (Table 77). This model reveals a weaker relationship than the throughfall model, however, captivates due to its simpler structure.

Table 77: Revered regression model explaining N bulk deposition by N foliar concentration in Scots pine; n = 48, R^2 = 0.653, R^2_{adj} = 0.645.

	Estimate	Std Error	t value	Sig t	DF	SSQ	*Sig F*
Intercept	-12.4162	2.2792	-5.448	***			
N_{fol}	1.3812	0.1486	9.294	***	1	922.44	***
Model					1	922.44	***
Residual		3.268			46	491.20	
Total					*47*	*1413.64*	

signif. code: `***' 0.001

6.7.5 Transfer of the re-sampled relationship from Level II to Level I

The area for the transfer of the model-specific relationships is defined by the spatial distribution of the relevant Level II plots and is given by Figure 26. The area covers three more or less isolated parts of Europe.

At Level I we do have foliar nitrogen concentrations within the limits given by Table 74 (9 – 23 mg g^{-1} was chosen) for 237 plots which are stocked by Scotch pine. However, measurements of deposition are not available at Level I. Therefore, models are of great interest predicting N deposition. Up to now, N deposition values have been derived from the large-scale EMEP grid by spatial interpolation. Additionally N deposition rates regarding wet and dry deposition at plot level are available from the EDACS model for all Level I plots regarding stand specific peculiarities (DE VRIES et al. 1998). Estimates from both models can be used to test the relationships developed at hand of Level II for extensive monitoring sites (Level I).

The close relationship found for Level II sites between N foliar deposition of recent pine needles and total N throughfall deposition respective N bulk deposition (substituted model) could only be weakly corroborated using foliar N concentration of Level I plots and the total N deposition (sum of oxidised and reduced nitrogen) derived from the large-scale EMEP model by interpolation (Table 78, Figure 29). N input estimates for the year 1996 are used, which were gained due to interpolation. The distinctively reduced relationship between foliar N concentration of the recent needle set and deposition estimates may largely be attributed to short-comings of the spatial interpolation from the 150 km by 150 km EMEP grid to the level of individual Level I plots. The results from the given up-scaling exercise indicate that respective procedures can substantially contribute to a better understanding of deposition processes at plot level and thus effectively supplement a large-scaled model like EMEP.

Table 78: Transferred regression model explaining N foliar concentration in Scots pine by total N deposition (NOx-N + NHy-N) from the EMEP-Model; n = 110, R^2 = 0.336, R^2_{adj} = 0.329.

	Estimate	**Std. Error**	**t value**	**Sig t**	**DF**	**SSQ**	***Sig F***
Intercept	11.01929	0.64607	17.056	***			
N_{fol}	0.27384	0.03708	7.385	***	1	226.59	***
Model					1	226.59	***
Residual		2.038			108	448.72	
Total					*109*	*675.31*	

signif. code: `***' 0.001

If plot-specific nitrogen deposition values from the EDACS model also for the year 1996 are used, the relationship between foliar N concentration of pine needles and N total deposition becomes even weaker, even if the relationship is still significant. The EDACS model is designed to account for plot-specific (small scale) variation of N deposition, but does obviously neither suit to the relationship between foliar N concentration and N throughfall deposition nor to those between foliar N concentration and N bulk deposition from this up-scaling approach. EDACS primarily considers tree species and stand age at individual sites (plots). The results of this up-scaling approach suggests a modified derivation process for plot-specific N deposition values, especially on the background that interpolated EMEP estimates show a closer relationship to foliar N concentration of pine needles than plot-specific EDACS estimates.

Table 79: Transferred regression model explaining N foliar concentration in Scots pine by total N deposition (NOx-N + NHy-N) from the EDACS-Model; n = 110, R^2 = 0.124, R^2_{adj} = 0.116.

	Estimate	**Std. Error**	**t value**	**Sig t**	**DF**	**SSQ**	***Sig F***
Intercept	13.69166	0.52909	25.878	***			
N_{fol}	0.11648	0.02976	3.914	***	1	83.89	***
Model					1	83.89	***
Residual		2.34			108	591.41	
Total					*109*	*675.3*	

signif. code: `***' 0.001

Figure 29 illustrates the incoherent geographic distribution of the two main model areas. The EMEP estimates are clearly grouped Scandinavian cluster with low N deposition estimates and a central European cluster with N deposition estimates almost entirely higher than 15 kg ha^{-1} y^{-1}. Here, within a comparatively narrow window of interpolated EMEP values around 17 kg ha^{-1} y^{-1}, foliar N values vary over the whole range, indicating total independence for this sector. This can be taken as a distinct hint that EMEP values, even when spatially interpolated, may over medium-scaled distances hardly reflect small-scale variations of N deposition.

The fact that plot-specific estimates calculated by the EDACS model are even less correlated with foliar N concentration than EMEP estimates needs a thorough investigation, which cannot be performed within the frame of this up-scaling study.

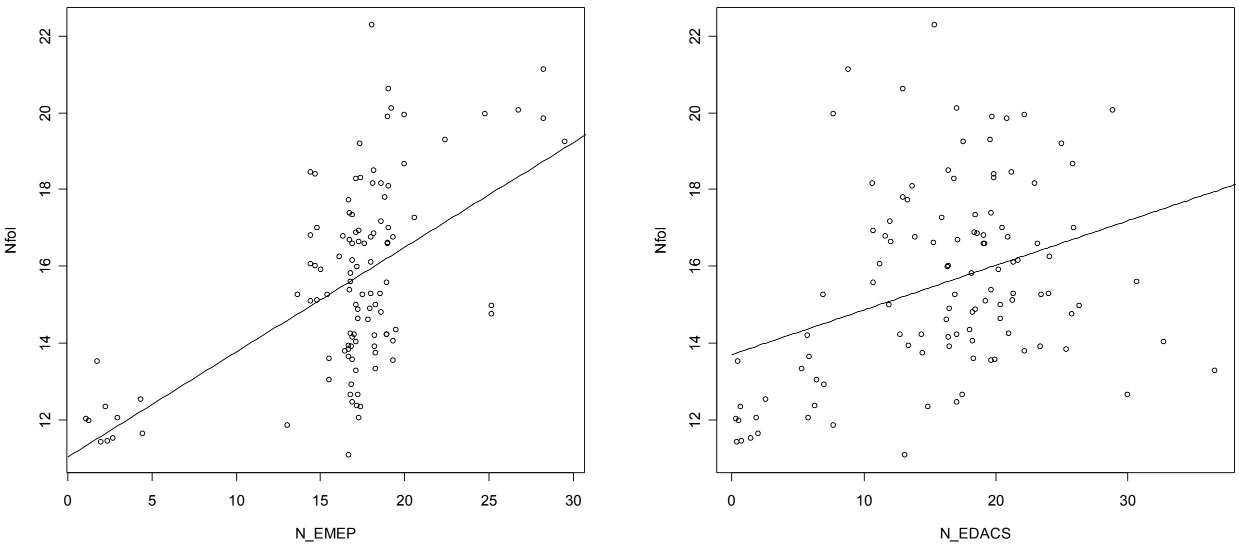

*Figure 29: Scatterplots of foliar N concentration of pine needles (*Pinus sylvestris*) against interpolated or modelled total N deposition from the EMEP respectively EDACS model inclusive regression lines from the models given in Table 78 respectively Table 79.*

6.7.6 Plot related N deposition estimates for Level I plots

The relationships documented above as 'reversed Models' could be used to calculate estimates for N bulk and N throughfall deposition for individual Level I plots. The result for the N total bulk and total N throughfall estimates is given in Figure 30. This statistical/mathematical procedure can be confessed in terms of applied bioindication: The amount of the N concentration of an ecosystem compartment – here the N concentration of the recent needle set of Scots pine trees – is used to predict the amount of an environmental impact. After a thorough investigation of a more general applicability in geographical and substantial terms, this model might be very useful within the context of estimating N deposition for larger areas. At the moment it can already be confessed as an independent means to check and verify plot-specific EDACS estimates for N deposition within the current model boundaries.

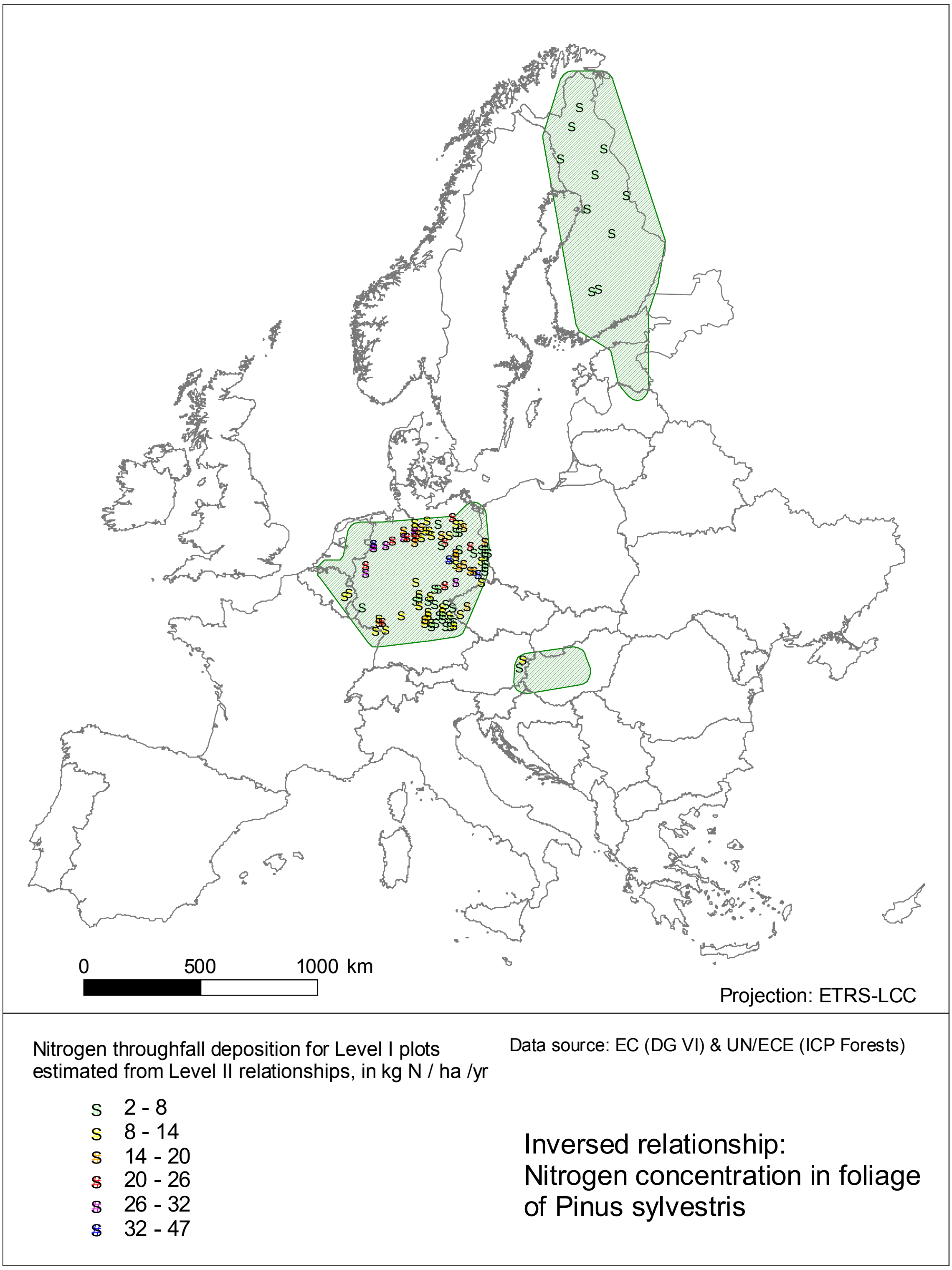

Figure 30: Calculated total N throughfall deposition according to the relationships found for Level II plots stocked with Scots pine (reversed models) and applied for Level I plots within the same geographic area and stocked by Scots pine as well.

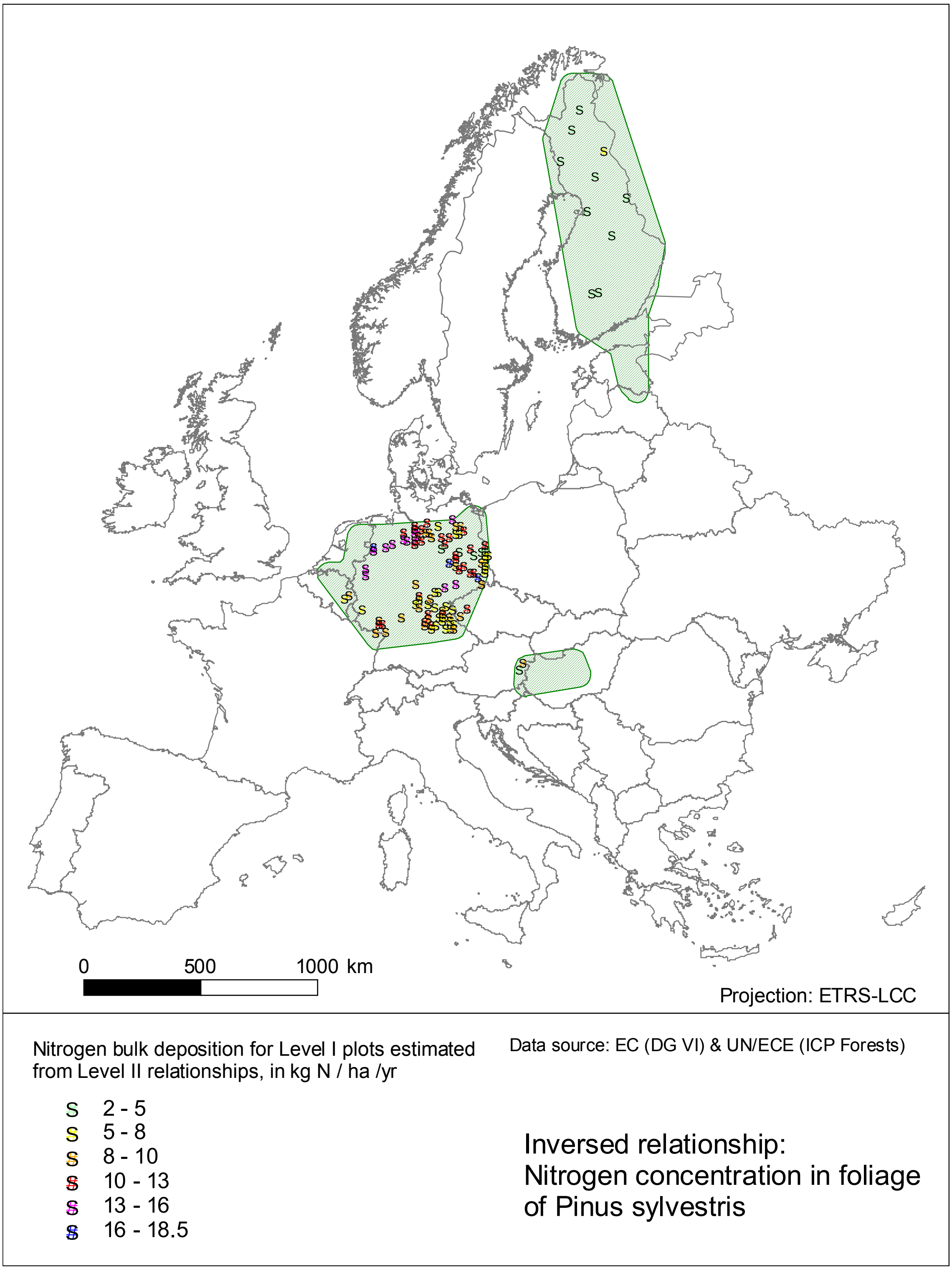

Figure 31: Calculated total N bulk deposition according to the relationships found for Level II plots stocked with Scots pine (reversed models) and applied for Level I plots within the same geographic area and stocked by Scots pine as well.

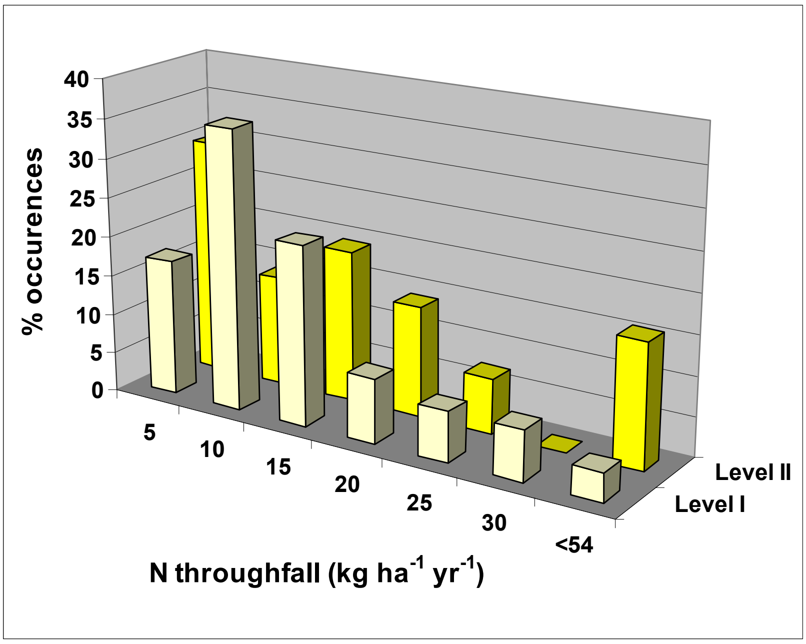

Figure 32: Distribution of calculated total N throughfall deposition for Level I and Level II plots stocked with Scots pine.

A comparison between the Level II and Level I results shows distinct differences with higher shares of Level II plots in extreme high and low nitrogen deposition ranges (Figure 32), while Level I plots exibit a left steep normal distribution. This difference shows the added value of up-scaling results as the higher number of Level I plots gives more precise results with regards to area representativity.

6.8 Nitrogen concentration in the foliage of conifers (Model 8)

DE VRIES et al. (2001: Chapter "Annex 6", p. 166ff) examined the intercorrelations between (i) C/N ratio of the organic layer, (ii) throughfall N deposition, (iii) foliage N concentration, and (iv) soil nitrate concentration. Significant linear bivariate relationships were found between throughfall N deposition, C/N ratio in the organic layer, and foliage N concentration, for plots dominated by conifers, which may illustrate the effect of elevated N deposition on soils and trees and the relation between soil and tree N status.

The relationship between C/N ratio in the organic layer and foliage N concentration for conifers (mg g^{-1}) was determined as [p. 167]:

$$[N]_{foliar,\ conifers} = 21.2 - 0.21\ C/N_{organic\ layer};\ R^2_{adj.} = 16\%.$$

The sample number was not published.

Table 80: Procedure applied to retrieve coherent data sets for nitrogen concentration in foliage of conifers and predictor variable including number of cases.

Step	Description	Survey	
		Soil cond.	Foliar
1	Number of organic layers in database; all years	896	
2	Number of plots with organic layers; all years	858	
3	- as before, but: (i) with values for C and N when only 1 organic layer per plot or (ii) with values for C, N and amount of organic layer when more than 1 organic layer per plot; all years	**853**	
4	Plots with foliar N concentration for conifers; all years, all species		**1789**
5	**Soil and foliar survey data related for plots; all years, all species. Sampling year of foliar survey equal or later than sampling year of soil survey.** The resulting difference between sampling of soil and foliage is at maximum 5 years.	**-> 625 <-**	
6	- subset of step 5, but repeated measurements excluded; only the youngest date was used	490	
7	- subset of step 5, but only the year 1995 for foliar survey.	184	
8	- subset of step 5, but identical sampling year of soil and foliar surveys; all years	231	
9	- subset of step 8, but repeated measurements excluded; only the youngest date was used	215	
10	- subset of step 8, but only year 1995	141	

6.8.1 Compilation of relevant data

Foliar N concentration is a mandatory parameter of the foliar survey and both C and N concentration in the organic layer are mandatory parameters of the soil condition survey. For the single plot foliar and soil condition surveys are not necessarily conducted in the same year, as well as several surveys dates, up to 3 for soil condition surveys, may be available. This possibility of differing sampling years made it feasible to use two approaches to combine the surveys on the plot base: (i) identical sampling year and (ii) with respect to foliage survey date, closest previous soil condition survey. The second approach supplies a larger number of cases. Additionally, for both approaches a subset with 1995 - the year with the largest number of cases - as reference year was determined (i.e. foliar survey in 1995).

In case several organic layers were recorded for a plot, the C/N ratio was calculated via the C and N pools of total organic layer.

Table 80 gives an overview on the steps applied.

Foliar N and C/N ratio of the organic layer are available for 215 plots with the same reference year. The reference year with the highest number of cases is 1995 (141 plots).

The number of cases can be increased when the foliar survey may be dated up to 5 years after the soil condition survey (N = 490). The year with the largest number of cases with respect to foliage survey is 1995 (N = 184), followed by 2001 (N = 134) and 1997 (N = 74).

6.8.2 Analytical statistics

The relationship between foliar N concentration of conifers and C/N ratio of the organic layer was evaluated for the 6 data sets compiled (s. Table 80) with means of simple linear regression. The result (s. Table 81) confirms the finding of DE VRIES et al. (2001) in that the relationship is significant and that foliar N concentration tends to decrease with increasing C/N ratio. Also the relatively small degree of explanation when conifer species are evaluated together can be confirmed.

Table 81: Summary of simple linear regressions between foliar N concentration of conifers and C/N ratio of the organic layer for the data sets compiled (cf. Table 80).

Data set of:	Data set description	Intercept	Slope (C/N ratio)	$R^2_{adj.}$	N
Step 5	Maximally 5 years difference between sampling of soil and foliage	15.70 (***)	-0.037 (**)	1.4 (**)	625
Step 6	Subset of step 5, but only *youngest date* per plot; i.e. without repeated measurements	15.77 (***)	-0.04 (**)	1.8 (**)	490
Step 7	Subset of step 5, but only the year *1995* for foliar survey	17.50 (***)	-0.134 (***)	11.5 (***)	184
Step 8	Subset of step 5, but *identical sampling year* of soil and foliar surveys for the single plot	18.64 (***)	-0.140 (***)	11.8 (***)	231
Step 9	Subset of step 8, but only *youngest date* per plot; i.e. without repeated measurements	18.00 (***)	-0.126 (***)	10.6 (***)	215
Step 10	Subset of step 8, but only year *1995*	17.7 (***)	-0.141 (***)	16.4 (***)	141

Signif. codes: *** p < 0.001, ** p < 0.01, * p < 0.05

From the differences of the results of the six data sets compiled it can be concluded, that the relationship is closer when foliage and soil are sampled within the same year for the single plot, and, further, when plots of the same sampling year are evaluated.

However, further in-depth evaluations were conducted, because:

- an overall relationship for all conifers does not make much sense, since foliar N concentration is largely dependent on tree species (cf. Model 5, Chapter 6.5)

- a bivariate relationship is not sufficient for predicting foliar N, since several variables contribute significantly to its explanation (cf. Model 6, Chapter 6.6)

- C/N ratio is not the best predictor variable for a bivariate relationship, since N deposition explains the variability of foliar N in a much higher degree (cf. Models 6 and 7, Chapters 6.6 and 6.7)

- only with a single species setting a substantial degree of explanation was found; e.g. for Norway spruce (sample of step 10: N = 70, adj. $r^2 = 0.43$) and for Scotch pine (sample of step 10: N = 46, adj. $r^2 = 0.33$). However, with Models 6 and 7 relevant relationships for these species are already presented.

7 Summary

The results of this pilot project "up-scaling of results from Level II to Level I" are promising. From the eight models selected by a comprehensive screening procedure (cf. Chapter 4.1), which, among others, demands that interdependencies of all surveys conducted on Level II are represented,

- one relationship could be transferred to the European scale entirely (Model 5) and, additionally, could be validated,
- three relationships could be transferred to the European scale with restrictions due to current data availability (Model 1, Model 2 and Model 7),,
- three relationships could not be transferred (Model 3, Model 4 and Model 6), because the main explaining variable, the deposition rate, is not available in sufficient quality for the single plot from modelling approaches, and
- one relationship was not transferred (Model 8), because it was already be explained more specifically by other relationships (Model 6 and Model7).

What we conclude is that 'function transfer' from Level II to Level I:

- (i) can explain the variability forest ecosystem parameters by up to 71% (Model 5).
- (ii) can contribute to a quantitative assessment of the distribution of forest ecosystem parameters on a European scale (Model 1 and Model 7).
- (iii) may contribute to estimation of forest ecosystem parameters, which otherwise are hardly accessible on a large scale, by bioindication (Model 6 and Model 7).

Screening

From 1998 onwards Technical Reports of FIMCI have been concentrating on thematic evaluations. The major hypotheses comprise of natural stress, direct air pollution impacts, soil acidification, and soil eutrophication. Regression models are kept to be the most powerful means. Response parameters and predictors were selected according to theoretical considerations. These reports were systematically screened for significant relationships of special interest for up-scaling according to environmental sectors: (1) Foliar element concentrations, (2) chemical soil conditions (solid phase), (3) soil solution chemistry, and (4) deposition regime. Eight relationships were selected. With respect to data availability for up-scaling, the models can be grouped in the ones dependent and independent of deposition, as deposition is generally not measured at Level I.

The selected relationships focus on the elements sulphur and nitrogen, which both are known for their impact on forest ecosystems. Sulphur, as the dominant air pollution component of the last century, is represented in two relationships. Nitrogen, the currently dominant air pollution component, is represented in five relationships. One additional relationship spotlights the heavy metal lead.

Relationships

Sulphur was the most dominant air pollution component from early industrialisation until the end of the 20th century. The relationships selected portray the sulphur status of forest ecosystems in terms of pool size of the organic layer (Model 1) and soil solution concentration in the topsoil (Model 3).

Model 1 is concerned with the sulphur pool size of the organic layer. In the original approach of FIMCI with 68 plots, the S pool in the organic layer was related to eight environmental factors (soil type cluster, tree species, tree age, altitude, S flux in throughfall, pH_{CaCl} in organic layer, precipitation and temperature). Three of them revealed to be statistically significant: tree species, temperature, and pH_{CaCl} with a coefficient of determination ($R^2_{adj.}$) of 72%.

For the re-sampled model 111 plots could be used, mainly because of the more recent database. The ranges of the variables deviate only marginally in comparison to the original approach. Due to a distinct spatial clustering a spatial range of definition with four separate areas were distinguished. With a slightly adjusted model including seven environmental factors the original findings could be confirmed with a coefficient of determination of 66%. The largest contribution to the variation accounted for is found for pH, followed by tree species and temperature.

Recursive partitioning with seven predictors revealed a striking result. Only 6 groups distinguished, account for 73% of the variation in S pool size with a smaller standard error than the regression analysis. Here, the very cold climate plots form a distinct spatial cluster. Hence, the added value of recursive partitioning is that, besides the dominant effect of pH, the effect of temperature, determined by regression analysis, is an artefact of the spatial allocation of plots. An explanation for this finding is that predictors are correlated: not only altitude, precipitation and temperature, but also climate and tree species.

With a GIS analysis 712 Level I plots were found to be located within the spatial range of the definition and matched all additional conditions. The result of the function transfer of the recursive partitioning model exhibits a high degree of homogeneity for Scandinavia, and a high variability for Western and Central Europe. Regions known for their high historical S deposition, like eastern Germany, Czech Republic, and northern border of Slovak Republic, were - in accordance to expectations - characterised by high sulphur pools.

A comparison between the Level II and Level I recursive partitioning results show distinct differences with higher shares of Level II plots in extreme high and low sulphur pool groups. Also the means differ distinctly. For Level II the mean is 89 kg S ha^{-1}, whereas for the Level I plots it is 66 kg S ha^{-1}. These differences indicate the added value of up-scaling, as the area representative Level I plots give more representative results with regard to the European scale.

The results of the models on sulphate and nitrogen soil solution concentration in the topsoil – **Model 3** and **Model 4** – do have much in common. In both cases the original model focussed on the effect of the deposition rate of the respective element ions, sulphate and nitrogen compounds. Additionally an inverse effect of precipitation rate was found.

The re-sampled models confirmed the original findings. However, both models could be simplified by replacing the additive term of deposition rate and precipitation rate by the mean annual deposition concentration. An analysis of consecutive single years up to 2001 revealed remarkable differences in the forest ecosystem dependency on sulphur and nitrogen deposition. For sulphur, the qualitative effect of sulphate deposition concentration on soil solution sulphate decreased with the decrease of sulphate deposition rate in that periode. In the year 1996 the relationship could explain as much as 62% of the variation of sulphate concentration in the soil solution. The degree of explanation constantly decreased, and finally reached a value as low as 28% in the year 2001. This finding supports the hypothesis that forest ecosystems recover from the high historical levels of sulphur deposition and increasingly re-gain the capability to control sulphur flow and ecosystem sulphur cycle.

For nitrogen no comparable trend could be detected. Nitrate concentration in soil solution of plots dominated by conifers shows a time invariant dependency on nitrogen deposition with a stable degree of explanation of c. 45% to 50%. Thus, it has to be assumed that forest ecosystems are – still – controlled by nitrogen deposition. This dependency facilitates the assessments on foliar nitrogen status.

Foliar nutrient concentrations have frequently been used to determine the respective status of forest trees. As foliar element concentrations respond to atmospheric impacts as well, its usefulness within an environmental monitoring programme is evident and will be demonstrated by the following three (four) models, which focus on **nitrogen**.

Model 5 is concerned with the foliar nitrogen concentration in response to tree species, climatic regions, soil type, and general site factors. The original model depicted tree species class and climatic region as highly significant predictors on the base of 423 plots (R^2_{adj} = 0.79). This could be corroborated on the base of a re-sampled European-wide Level II data set (n = 719) with an R^2_{adj} of 0.83, however with stand age as an additional significant predictor. If the concerned tree species are more ecologically grouped, this relationship could even be enhanced. A recursive partitioning analysis confirms the strong influence of species (or species groups) with deciduous broadleaves and larches on one side and evergreen conifers and broadleaves on the other side. The evergreens are further partitioned by climatic region.

The transfer of the multiple regression (covariance) model to Level I data at hand of foliar element concentration data of 1054 plots results in a relationship almost as tight (R^2_{adj} = 0.71) as for the Level II data, however, stand age has ceased its significant contribution. The application of the recursive partitioning model corroborates the results from Level II data, only that both the evergreens and the deciduous species are further split by region into clusters with higher N foliar concentrations in both Atlantic regions and the sub-Atlantic region and those with lower values in the remaining parts of Europe.

These results clearly assign tree species respectively ecologically defined tree species groups as a main determinant of foliar N concentration, calling for models specific for species or at least species groups.

Model 6 consequently applies to Norway spruce only. It includes different soil related key factors, site and stand characteristics, deposition and meteorological conditions as predictors and needle N concentration as response variable. The original model explained 59% of the variation of foliar N in *Picea abies* at the basis of 91 Level II plots with total N throughfall deposition, the C/N ratio of the organic layer, altitude, and stand age as significant predictors.

The re-sampled model, based on 94 Level II plots from parts of central Europe and Scandinavia, is with an R^2_{adj} of 56% slightly less efficient. Among the significant predictors throughfall N deposition explains more than 44%. Each of the remaining predictors, C/N ratio of the organic layer, stand age, parent material class and nitrogen concentration within the mineral soil contribute 5% and less to the full model. Variants with different selection routines and a recursive partitioning approach reveal the latter as more or less unstable predictors. If throughfall N deposition is substituted by total N bulk deposition the remaining predictor structure keeps almost constant. Within a reversed model, total N bulk deposition becomes the statistically dependent variable foliar N concentration, the C/N ratio of the organic layer and stand age are the significant predicting factors. A parallel approach revealed mean air temperature besides altitude, foliar N concentration and precipitation as significant predictors.

From a total of 3,111 Level I plots within the geographic range defined by the Level II model plots, only 146 respectively 141 remain in two valid samples. Estimates for deposition and the meteorological situation not sampled at Level I were derived from respective large-scale models (e.g. EMEP, EDACS). A transferred model with predominant climatic predictors is able to explain after adjustment 87% of the variance of interpolated EMEP deposition, a model with more ecological predictors yet 41%. The first approach largely reflects the climatic contrast between a part of central Europe and Scandinavia, which is distinctively paralleled by a deposition gradient. Even the second approach largely reflects environmental differences between both geographic units.

Both reversed Level II models can be used to predict the annual N deposition rates at Level I plots making use of parameters largely surveyed within Level I. Especially from the model with foliar N concentration, C/N ratio of the organic layer and stand age as predictors, esteems of N bulk deposition for individual Level I plots can be obtained, which can in turn be used to enter a validation process of plot-specific EDACS estimates.

Model 7 investigates the relationship between foliar nitrogen concentration of Scots pine needles and N throughfall deposition, which was originally set up as a second degree polynomial regression with a coefficient of determination of 60%. In a re-sampled model for a total of 57 plots a non-linear relationship was successfully fitted, however, a modified asymptotic regression model reconciled best practical requirements and theoretical considerations. In a reversed approach the relationship between both parameters is best reproduced by an exponential regression term revealing an R^2_{adj} of 0.81. If throughfall deposition is substituted by bulk deposition, a linear model with an $R^2_{adj} = 0.65$ turned out to be the optimal solution, which can of course also be formulated as a reversed model with the same goodness of fit.

As in Model 6, the transfer of these relationships to data from the large scale Level I monitoring makes it necessary to substitute throughfall or bulk deposition as it is not measured there. The invention of modelled total N deposition estimates from the EMEP or EDACS models is obvious. Using those esteems, the resulting models reveal disappointing weak relationships with R^2_{adj}-values between 0.34 for EMEP estimates and 0.12 for plot-specific EDACS estimates.

The models formulated at Level II can in its reversed form be used to calculate esteems for N bulk or N throughfall deposition rates at Level I plots stocked by Scots pine. Respective maps reveal areas with spatially structured deposition estimates and deliver a base for in-depth evaluations on differentiated nitrogen deposition processes.

Model 2 investigates the relationship between lead concentration of the organic layer and stand and site characteristics. The original model explained 53% of its variance by tree species, climatic region and altitude at hand of 122 plots. With 138 plots this relationship could be largely corroborated, however without altitude as a significant predictor. A recursive partitionjng approach revealed a similar result, but with the Boreal region against all non-Boreal regions on the other site as the main split. In a second split conifers were separated from broadleaves.

Transferred to Level I plots the approach exhibits its overview characteristic and no further more detailed investigation were conducted.

Deposition

Deposition is a crucial term in up-scaling, since it contributes to four of the models selected, but is not measured at Level I. In case no 'secure' estimate of deposition is available, the logical deduction is that deposition terms have to be dropped or replaced.

However, two European scale model driven estimates for total deposition are available, the EMEP and the EDACS approach. In order to deduce a European wide transfer function for estimation of Level I deposition from EMEP and EDACS, the both were correlated with the measured Level II throughfall deposition.

Both European scale deposition estimates do not explain the measured Level II throughfall deposition adequately for sulphur, NOy and NHx compounds, as already mentioned for EDACS by De Vries et al. (2001). However, direct comparison revealed, that EDACS, which claims the higher spatial resolution, does not exceed interpolated EMEP in terms of variability accounted for, and residual distribution.

Both deposition estimates do have in common that Level II sample means are only appropriate for plots dominated by coniferous trees. Additionally, for both, but pronounced for EDACS, a spatial clustering of residuals was detected.

Probably, model estimations could be enhanced when additional plot specific information would become available, for instance tree height.

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