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Institute for World Forestry

Integrative Studies on Forest Ecosystem Conditions

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1 Introduction

Under the UNECE Convention on Long-range Transboundary Air Pollution the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) is operated under the Lead of Germany with a participation of 39 countries. The Programme Co-ordinating Centre (PCC) of the ICP Forests is hosted by the Federal Research Centre for Forestry and Forest Products in Germany. The present report pursues the objective of ICP Forests “to compile information on forest ecosystem processes”.

Soon after the first publications on forest decline in central Europe by the end of the seventies, direct and indirect impacts of air pollution were made responsible for poor crown condition of forest trees or even for their dying back (e.g. ULRICH et al. 1979, SCHÜTT 1982). In contrast to classical smoke damage on forest trees, no simple relations in the sense of KOCH's postulate between single environmental agents like mean SO_2 air concentration and the occurrence of symptoms like leaf or needle loss were found. A number of rather complex pathways of cause-effect relations were outlined to explain defoliation or discoloration of leaves and needles (e.g. SCHÖPFER & HRADETZKY 1984).
As simple empirical approaches failed in finding one or some conclusive chains of effects to explain the observed phenomena, on one hand local ecosystem-oriented in-depth studies (e.g.: MATZNER 1989, SCHULZE et al. 1989, CORNELIUS et al. 1997, BREDEMEIER et al. 1999) with a variety of specific questions (e.g. KRATZ et al. 1997) were started. On the other hand the collection and evaluation of epidemiological data over large areas was advocated (e.g. KNABE 1983). The last approach resulted in a series of nation-wide monitoring activities and led to the European-wide monitoring programme of the UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE (UN/ECE) in co-operation with the EUROPEAN COMMISSION (LORENZ 1993).
A systematic and representative sample of now c. 5600 permanent monitoring (so-called Level I) plots has been installed (FISCHER et al. 2000). Within this programme tree crown condition is collected annually, in part since 1986. The plots cover large areas of western and central Europe. Additionally, data concerning the solid phase of soils were sampled (VANMECHELEN et al. 1997) and element concentration within leaves or needles were determined for many Level I plots (STEFAN et al. 1997). Along with these data, basic biological data (stand age, occurrence of insects or fungi) are available. Moreover, external interpolated or simulated data describing the meteorological situation and the deposition of air pollutants at the monitoring sites (VAN LEEUWEN et al. 2000) give an appropriate basis for integrated evaluations.
According to the idea of a joint action of predisposing, accompanying and decisive factors (MANION 1981), statistical models should consider all relevant spheres of ecological stress. Multivariate statistical methods provide appropriate tools to encircle parameters, which stand for processes of direct or indirect influences on tree crown condition (DE VRIES et al. 2000a, see SEIDLING 2000 for an overview). Different from process-based modelling, statistical models do not imitate those processes, but they may depict relevant indicators. In that sense multivariate statistics help to generate hypotheses about relations between tree condition and the natural and anthropogenic environmental factors and explore the respective probabilities.

In that sense a study with multivariate methods on two comparatively homogeneous, but transnational pilot areas has been started. Both areas include regions with high inputs of air pollutants, either high immissions of nitrogen compounds or high deposition rates of total acidity. Variation of soils and other natural factors were minimised by adequate delineation.

The presented workreport is the unmodified version of the Integrative Studies Report 2001.

Dr. Walter Seidling was scientist at the Institute for World Forestry from 1998 until 2001

2 Objectives

With the concept of a joint action of predisposing, accompanying and decisive factors causing the decline of forest trees (MANION 1981), besides hierarchical aspects, the idea of a complex dependency of tree condition from natural and anthropogenic factors was outlined. This entails that the differentiation between effects caused by natural factors on one side and man-made causes on the other has become a crucial objective (MANION 1988). Since anthropogenic factors interact in different ways with natural preconditions of stands and sites, especially with soil factors, it is recommended to interpret results on the background of possible anthropogenous changes of this compartment.
Crown condition of forest trees in terms of defoliation and also discoloration is a rather complex and unspecific indicators of individual tree condition. Moreover methodological problems associated with their accurate estimations in the field (e.g. INNES 1988, STRAND 1996, DOBBERTIN et al. 1997, FERRETTI 1997) makes it in general a comparatively weak indicator. Plot-wise and also medium-term temporal aggregation of defoliation and/or discoloration values should give an overall estimation of the average status of tree crown condition at a site.
It is well known that some factors out of the hypothetical predictor complex (Chapt. 3.3) like climatic drought or activities of insects are capable to cause defoliation. However, a number of intricate temporal pattern and feed-back mechanisms of the involved trees and other components of the respective forest ecosystem (e.g. re-sprouting after insect attacks, see e.g. FISCHER 1999) blur out dose-effect or even simple cause-effect relationships. We have to accept that weak correlations may indicate even crucial mechanisms due to weaknesses of the effect parameter on one side and real (on the level of ecosystems) as well as statistical interrelations on the other side. The ability of living organisms like trees to buffer different types of environmental pulses by different physiological and morphological reactions is universal. Results of statistical calculation have therefore to undergo a critical evaluation within the context of the general knowledge on effects of air pollutants on forest trees (e.g. LANDMANN 1995) along with effects by the climatic, biotic and soil related stresses. This quite ambitious task is surely a step-wise process and may need approximations on several spatial, temporal and methodological levels.

Multiple statistics are among the adequate means to cope with those types of relationships. Various stress factors and even its interactions can be related to the spatial variation of the effect variables (defoliation, discoloration). Some similar approaches on different spatial scales already exist (cf. SEIDLING 2000), giving a basis for comparisons.

3 Data and Methods

3.1 The Pilot Areas

The study investigates statistical relations between crown condition and environmental factors within two transnational pilot areas (Fig. 3.1.1). Their delineation is based on the idea that the variation of geological and other natural factors should be kept as small as possible. In that sense plots from calcareous parent materials should not be treated together with those from siliceous sands. Along with more homogeneous natural preconditions, genotypes and also phenotypes of the tree species should vary to a lesser extent. The number of possible causes of (and hypotheses on) defoliation (and discoloration) should easier be focused on anthropogeneous influences. The general concept based on larger, but nevertheless comparatively homogenous pilot areas is in a way reductionistic: While limiting the variation of natural factors, defoliation caused by direct and indirect effects of air pollutants should become more pronounced. In this respect pilot area 1 represents an area with regionally very high inputs of nitrogen, contrasting to the poor sandy soils, which originally dominated large parts of these lowlands. Pilot area 2 covers one of the most SO_2 polluted regions in northern Bohemia, but contains also regions with low impact. Both pilot areas include regions from three different states, which guarantees a certain representativity within the European context. The pilot areas can be characterised as follows:

Pilot area 1 covers an area c. 500 km long and c. 150 km broad. This transect includes all Level 1 plots from Flanders, The Netherlands and the north-western German lowlands (parts of North-Rhine-Westphalia, Lower Saxony, Schleswig-Holstein, and Saxony-Anhalt, see Fig. 3.1.1). It is part of the pleistocene lowlands of northern central Europe. Podzols and related soil types derived from sandy substrates predominate within the area. A climatic gradient exists, with predominant oceanic features (mild and humid) in the north-western and sub-continental climate (generally dryer, warmer in the summer, colder in the winter) in the south-eastern part. The pilot area 1 contains a total of 53 Level I plots. 34 of them are stocked with at least 1 specimen of Scots pine (*Pinus sylvestris*) and 16 by at least 1 specimen of one or both of the common oak species (*Quercus robur*, *Q. petraea*). The remaining plots are stocked by less common tree species and have not been considered in the statistical analysis.

Pilot area 2 has a west-east extension of c. 520 km and a north-south extension of c. 240 km. It is composed of the southern hilly and mountainous part of Saxony (Germany), the northern parts of Bohemia and Moravia (Czech Republic), and the hilly and mountainous part of south-western Silesia (Poland, see Fig. 3.1.1). The transect includes the so called 'Black Triangle', named after the high air pollution figures reached especially in the 70ties and 80ties. Fig. 3.1.2 gives a rough impression of the overall orographic situation with the distinct west-easterly oriented chain of the Ore and the Sudety Mountains. Parent material of the soils are predominantly acidic cristallin rocks from which mainly dystric cambilsols have developed. The region is climatically differentiated in a moister part on the northern fringe of the mountains and a more continental southern part (Bohemian basin). The number of plots are in total 487, but many of them have been sampled only once between 1990 and 1998. Results of the soil survey are available for a total of 97 plots and foliar data of 44 plots. The focus species in this area are *Picea abies* (70 plots with soil data) and *Pinus sylvestris* (25 plots with soil data). Because soil data for oak only from 2 plots are available, no evaluations are possible. Other poorly represented tree species have not been considered.

Fig. 3.1.1: Plots of both pilot areas within the pan-European context

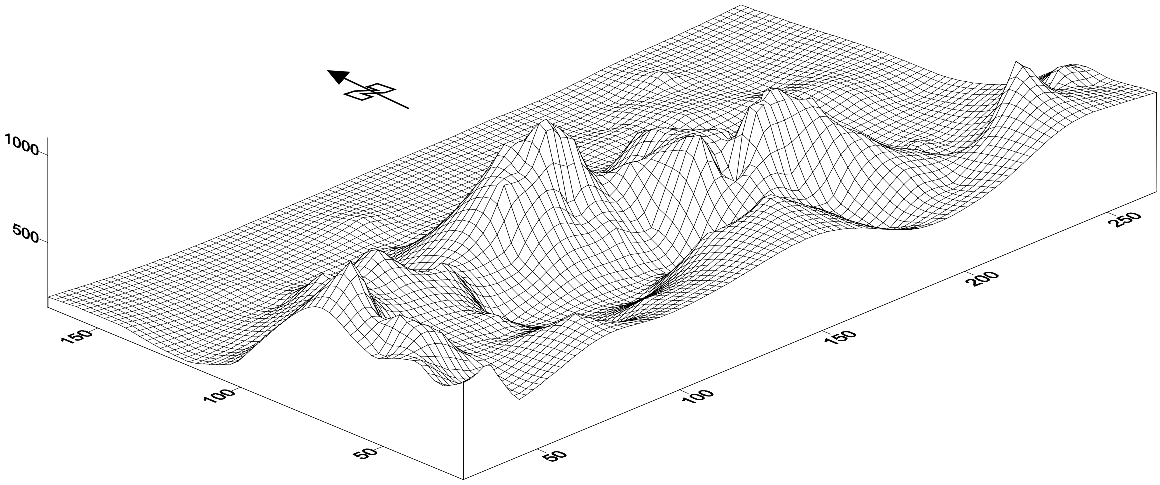

Fig. 3.1.2: Pilot area 2: Interpolated altitude over plot position, giving an impression about the orographic situation of pilot area 2. the chain of the sudety mountains is streching from west to east (Krušné hory/Erzgebirge [Ore Mts.], Děčínská vrchovina/Elbsandsteingebirge, Lužické hory/Lausitzer Bergland, Jizerské hory/Gŏry Jzerskie, Krkonoše/Karkonosze [Giant Mts.); the deep valley in the foreground signifies the river Ohře. Projection is based on Lambert azimuthal, 1 x/y-units equal c. 2 km, z-units in m a.s.l., max. altitude: 1050 m a.s.l.

3.2 Response Variables

The core variable within the annual monitoring of crown condition is defoliation. Since 1989 this has been a visual estimate of the missing leaf or needle mass with an accuracy of 5% in comparison to a species-specific local or regional standard with the optimal mass of leaves or needles (the so-called reference tree) (UN/ECE 1998). This measure is individually assessed from each of the normally 20 to 24 trees per sample plot, which do not necessarily belong to one species. All specimen belonging to a focal tree species (*Pinus sylvestris* and *Quercus robur et petraea* in pilot area 1, *Picea abies* and *Pinus sylvestris* in pilot area 2) have been averaged plot-wise, because almost all predictors refer to the plot level and not to individual trees. No weighting according to the number of specimen per plot was performed in order to avoid bias from monocultures. Instead, the number of focal specimen per plot was used as a predictor variable. Besides defoliation, discoloration is estimated by a five class scale (UN/ECE 1998). In order to obtain a plot related indicator, the discoloration ranks were for each species also levelled plot-wise. Table 3.2.1 gives the descriptive statistics of crown condition data including percentiles for both pilot areas, calculated as plot related means over time (XMDEFOL, XMDISCO).
Besides plot-wise means of defoliation from 1989 to 1998 in pilot area 1 resp. 1990 to 1998 in pilot area 2 plot, means for single years (MDEFOL, MDISCO) are also used. Plot-wise mean slopes (MSLODEF) have been calculated as linear trends over the whole time span for which information was available for each plot. Plots with less than 6 observations in time were excluded from further calculations. One outlayer plot (maximum for *Pinus sylvestris* in pilot area 2) has been omitted in respective subsequent calculations.

Tab. 3.2.1: Basic statistics of crown condition parameters.

Variable	Definition and unit	N	Mini-mum	25th pctl	Mean	50th pctl	75th pctl	Maxi-mum	SD	CV	transform.
Pilot Area 1, *Pinus sylvestris*											
XMDEFOL	mean defoliation 1989-1998 [%]	34	4.30	9.39	13.84	13.61	18.36	27.75	5.69	0.41	logit: ltXMDEF
MSLODEF	mean slope of defoliation 1989-1998 [%]	34	-5.62	0.00	0.09	0.18	0.68	2.28	1.42	-	-
XMDISCO	mean discoloration 1989-1998 [%]	34	0.00	0.01	0.11	0.07	0.17	0.59	0.13	1.18	logit: ltXMDISC
Pilot Area 1, *Quercus robur et petraea*											
XMDEFOL	mean defoliation 1989 - 1998 [%]	16	9.50	13.51	17.32	15.23	21.46	28.25	5.92	0.34	logit: ltXMDEF
XMSLODEF	mean slope of defoliation 1989 - 1998 [%]	16	-0.60	-0.16	0.74	0.66	1.22	3.52	1.08	-	-
XMDISCO	discoloration means [%]	16	0.00	0.01	0.14	0.11	0.22	0.54	0.16	1.14	logit: ltXMDISC
Pilot Area 2, *Picea abies*											
XMDEFOL	mean defoliation 1989-1998 [%]	73	8.67	27.76	30.70	30.65	35.03	45.00	6.88	0.22	logit: ltXMDEF
MSLODEF	mean slope of defoliation 1990-1998 [%]	73	-4.48	-0.93	0.61	0.65	2.13	5.90	2.13	-	-
XMDISCO	mean discoloration 1990-1998 [%]	72	0.00	0.00	0.02	0.00	0.00	0.33	0.06	3.00	logit: ltXMDISC
Pilot Area 2, *Pinus sylvestris*											
XMDEFOL	mean defoliation 1990-1998 [%]	32	0.00	17.25	25.43	27.71	33.61	50.00	11.83	0.47	logit: ltXMDEF
XMSLODEF	mean slope of defoliation 1990-1998 [%]	32	-2.62	-0.64	1.00	0.40	1.80	15.00	3.10	-	-
XMDISCO	mean discoloration 1990-1998 [%]	31	0.00	0.00	0.06	0.00	0.08	0.39	0.10	1.67	logit: ltXMDISC

logit transformation: ltX = ln(X / (1 - X)), if the argument could become 0 then 0.01 was added.

The results show distinct differences of the mean defoliation between both pilot areas. For *Pinus sylvestris* e.g. it is almost twice as high in pilot area 2 as in pilot area 1, but values broadly overlap as extremes and percentiles show. *Picea abies* in pilot area 2 possesses with 30.7% the highest mean defoliation value at all, while defoliation of *Quercus robur et petraea* within pilot area 1 is only slightly higher than that of *Pinus sylvestris*.

Also discoloration of the needles of Scots pine differs distinctively between both pilot areas, but values in pilot area 1 are higher than in pilot area 2. As percentiles show, discoloration values of pilot area 2 are heavily skewed. Their usage as effect parameter is therefore limited.

Besides the absolute values of defoliation, tree-related slopes of defoliation over time were computed and levelled plot-wise in order to get estimates about the worsening respective improvement of defoliation estimates over time. This parameter should be less influenced by country specific peculiarities. The same is true for differences between two particular times (e.g. KLAP et al. 1997), but slopes give a levelled mean-term estimate about the general trend of crown condition at a certain point. However, different from absolute values, this parameter is less sensitive towards the level of defoliation.

3.3 Predictor Variables

Since the effect variable defoliation is rather unspecific, its variation according to natural site esp. soil and regional climatic conditions (e.g. ELLENBERG 1995) should already be adequately considered during the field survey, while actual or chronic deficiencies of foliar mass from other causes are intended to be estimated. According to the idea of a joint action of predisposing, accompanying and decisive factors on forest trees (MANION 1981), it was aspired to include the relevant predictive parameter from each complex of ecological factors as predictor (Fig. 3.3.1). The subsequent application of multiple statistics is seen as a chance to separate the different causes of foliage loss, observed with an overall increase of its intensity over the last 15 years on the European level (FISCHER et al. 2000).

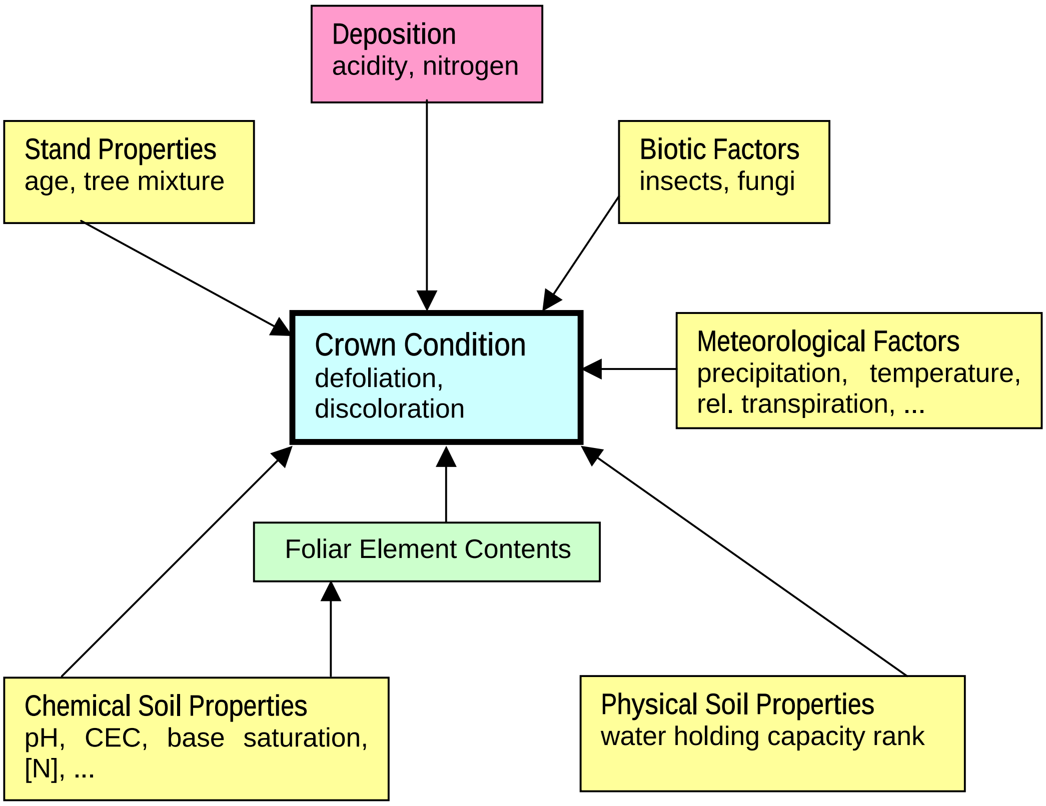

Fig. 3.3.1: Simplified scheme on ecological dependencies of crown condition of forest trees from different ecological domains. Interactions between single factors of the different domains exist, but are not depicted.

Apart from crown condition, the Level I data base provides information on chemical soil properties, foliar element contents, stand age classes and qualitative estimates of the occurrences of insects or fungi (other so-called 'easily identifiable damages' like 'game and grazing', 'abiotic agents', 'direct action of man', 'fire', 'known regional pollution', 'other causes' have not been used, due to lack of relevance or incomplete assessments). To cover medium- and short-term influences from weather condition, especially from climatic droughts, respective parameters or indices have been used. Water holding capacity was derived from the FAO soil type. Direct and indirect influences of forest condition by air pollutants are a main theme within the activities of ICP Forests. Since air concentrations or deposition of pollutants are measured at Level II sites, only modelled estimates for Level I plots exist.

3.3.1 Parameters on Stand Properties

The crown condition of individual trees in any forest stand is influenced by their spatial position and the stand history (e.g. LANDMANN 1993). The selection of predominant, dominant or co-dominant trees without significant mechanical damages

(UN/ECE 1998) as sample trees should minimise those effects. Stand age class (20 years intervals, AGE) is recorded along with the surveys. Stand or tree age might have effects on crown condition due to several mechanisms. In how far general age-dependent physiological or allometric functions determine crown condition, or weather age-dependent artefacts connected with the visual estimation of the tree crown condition evoke this relation, is not entirely clear. JALKANEN et al. (1998: Fig. 3a) found for Scots pine in Finland an age dependent decline of needle density, but not for the number of needle sets. Moreover, direct and indirect influences from local thinning regimes on age-dependent processes are possible. Since age has empirically often been found to be a significant predictor of crown condition (e.g. RIEK & WOLFF 1999, KLAP et al. 2000, SEIDLING 2000), it has to be viewed at least as an accompanying factor and should be included in any approach to explain crown condition.

Tab. 3.3.1.1: Stand properties and estimates on the activity of biotic agents.

Variable	Definition and unit	N	Minimum	25th pctl	Mean	50th pctl	75th pctl	Maximum	SD	CV	subsequent transformations
Pilot Area 1, *Pinus sylvestris*											
AGE	stand age class (ranks of 20 year's intervals)	34	1	3	3.71	4	4	7	1.55	0.42	exponential*1: exAGE
PFOCUS	mean proportion of Scots pine trees per plot	34	0.33	0.83	0.87	1	1	1	0.21	0.24	logit: ltPFOCUS
XMFUNGI	mean shares of trees per plot with damage by fungi	34	0	0	0.05	0.02	0.08	0.38	0.08	1.60	logit: ltFUNGI
XMINSECT	mean shares of trees per plot with damage by insects	34	0	0.04	0.11	0.10	0.16	0.37	0.10	0.91	logit: ltINSECT
Pilot Area 1, *Quercus robur et petraea*											
AGE (8 = 6)	stand age class (ranks of 20 year's intervals)	16	3	3	4.50	4	6	7	1.51	0.33	exponential*2: exAGE
PFOCUS	mean proportion of oak trees per plot	16	0.04	0.14	0.56	0.53	1	1	0.41	0.73	logit: ltPFOCUS
XMFUNGI	mean shares of trees per plot with damage by fungi	16	0	0	0.08	0.01	0.10	0.32	0.11	1.38	logit: ltFUNGI
XMINSECT	mean shares of trees per plot with damage by insects	16	0.07	0.25	0.46	0.50	0.69	0.78	0.25	0.54	logit: ltINSECT
Pilot Area 2, *Picea abies*											
AGE	stand age class (ranks of 20 year's intervals)	66	1	4	4,94	5	6	7	1.04	0.21	exponential*3: exAGE
PFOCUS	mean proportion of Norway spruce trees per plot	72	0.21	1	0.97	1	1	1	0.12	0.12	
XMFUNGI	mean shares of trees per plot with damage by fungi	73	0	0	0.001	0	0	0.05	0.007	7.00	
XMINSECT	mean shares of trees per plot with damage by insects	73	0	0	0.01	0	0	0.18	0.03	3.00	
Pilot Area 2, *Pinus sylvestris*											
AGE	stand age class (ranks of 20 year's intervals)	19	1	2	3.05	3	4	5	1.39	0.46	exponential*4: exAGE
PFOCUS	mean proportion of Scots pine trees per plot	31	0.04	0.60	0.78	1	1	1	0.37	0.47	logit: ltPFOCUS
XMFUNGI	mean shares of trees per plot with damage by fungi	32	0	0	0.003	0	0	0.04	0.009	3.00	
XMINSECT	mean shares of trees per plot with damage by insects	32	0	0	0.02	0	0.005	0.23	0.05	2.50	

*1: $exAGE = 16.736 \cdot (1-e^{(-0.657 \cdot age)})$, *2: $exAGE = 24.858 \cdot (1-e^{(-0.525 \cdot age)})$, *3: $exAGE = 46.290 \cdot (1-e^{(-0161 \cdot age)})$, *4: $exAGE = 17.215 \cdot (1-e^{(-0.702 \cdot age)})$, logit transformation: $ltX = \ln(X / (1 - X))$, 0.01 was added, if the argument could become 0.

As Tab. 3.3.1.1 shows, age class (AGE) is not always an ideal variable in statistical terms. Its distribution can be skewed (*Picea abies* within pilot area 2) or does not cover the full range (*Quercus* in pilot area 1, *Pinus sylvestris* in pilot area 2). For *Pinus sylvestris* in pilot area 1 a negative exponential regression curve could be successfully fitted between country corrected defoliation values (country correction was done by adjusting the country specific cumulative frequency distributions towards the German curve, which was taken as a standard) and age class. Since this non-linear relationship corresponds well with results from other studies, this kind of transformation is used in subsequent regression models. For all other species similar non-linear regressions were found (see Tab. 3.3.1.1). This type of relation does not only hold true for annual plot-wise estimates, but also for means over the whole observation time. In this case the 95% confidence intervals are broader than shown in Fig. 3.3.1.1. In additional runs of regression analysis also non-transformed age classes were used.

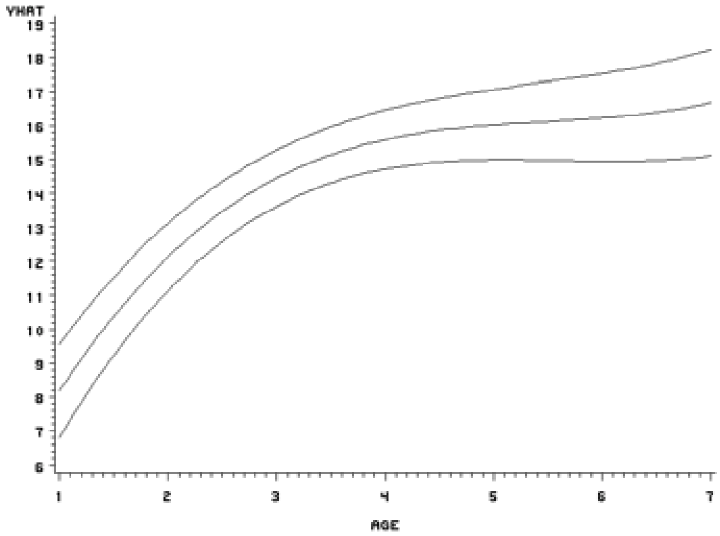

Fig. 3.3.1.1: Non-linear regression between country corrected defoliation values [%] from 1989 to 1998 (YHAT = predicted values of country corrected defoliation with 95% confidence intervals) and age class (AGE) of *Pinus sylvestris* within pilot area 1, each year is taken as an independent estimate (n = 343).

$YHAT = 16.736 \cdot (1-e^{(-0.657 \cdot AGE)})$.

A differentiation between pedunculate and sessile oak (*Quercus robur*, *Q. petraea*) as recommended by e.g. MATHER et al. (1995) was not be applied, because *Q. petraea* is present at two plots only. In order to avoid any further reduction of the already low number of oak plots, both species were treated as one species.

Another rather complex, but crude parameter referring to tree stand properties is the proportion of the respective focal tree species among all sample trees at plot level (PFOCUS). This parameter may cover different aspects of forest trees growing in mixtures. There could be ameliorating (broad-leaved species) or degrading (conifers) effects on humus resp. soil properties. Also mass affects due to an easier spread of infestations by insects and fungi within monocultures might be covered by this parameter. Moreover, interference between tree specimen of different species on the base of adverse (allelopathic) effects and different species-specific traits of spatial exploitation features above and below ground are possible. Significant effects of this parameter have to be interpreted with caution, but may provide hints on general effect of monocultures on crown condition. The percentage of the focal tree per plot (PFOCUS) is comparatively well distributed in *Quercus robur et petraea* within pilot area 1 and with some restriction also in *Pinus sylvestris* within both pilot areas. For *Picea abies* within pilot area 2 the univariate distribution is severely skewed and will not be used in any case.

3.3.1 Parameters on Biotic Factors

Biotic agents undoubtedly influence the amount of foliage of trees. Temporal patterns within and between years can however be quite complex, often additionally triggered by specific weather conditions. It is in general more probable to detect significant effects on defoliation within yearly based evaluations, but long-term effects cannot be excluded, especially for fungal infections. Also delayed effects are highly probable, but confounding with meteorological condition has additionally be taken into account. The percentages of trees per plot noted as infested by either of the two groups have been calculated and were taken as a rough plot-related estimate of their average activities. This rather arbitrary procedure is justified because many biotic agents occur more or less aggregated within forests. Thus it is probable that the detection of phytophageous insects or phytopathogeneous fungi on trees of a sample might be proportional to the general occurrence of those agents at a plot within a certain year. Within time-dependent approaches, annual plot related means have been taken, in all other cases means over time were used.
As Tab. 3.3.1.1 shows, both parameters on needle or leaf loss caused by biotic agents do in most cases not vary continuously. Especially fungi on pine and spruce within pilot area 2 were observed at one plot only (the maximum value). Almost the same is true for the observation of insects within pilot area 2. Both parameters were therefore not used within multiple regression models. Within pilot area 1 both parameters behave more consistently, but were logit-transformed for subsequent calculations.

3.3.3 Parameters on Soil Properties

Soil mediated causes of defoliation processes are subject of the classical hypotheses developed to explain poor tree crown conditions. High concentrations of dissolved Al along with Mg deficiency and nutrient imbalances caused by high N inputs have been suggested to cause nutritional disturbances in trees and to provoke premature leaf or needle loss (ULRICH 1986, VEERHOFF et al. 1996, AUGUSTIN & BÜTTNER 1997). Indirect effects of malnutrition or an unbalanced nutrition like a reduced frost resistance or weaker defence mechanisms against insect or fungal attacks, have also been discussed (e.g. VUORINEN & KURKELA 2000).
Data concerning chemical properties of the soil solid phase were sampled once on most Level I plots and were compiled by the FSCC (VANMECHELEN et al. 1997). The data within the German parts of both pilot areas date mainly from 1990 to 1992 (on some plots without an entry of date, probably as early as 1987). In Flanders soil inventory was done in 1993, in The Netherlands and the Czech Republic in 1995 and in Poland in 1996.
As Tab. 3.3.3.1 shows, not all parameters are available for each plot. Within the Polish part of pilot area 2, only for 5 from a total of 94 Level I plots soil data are available. For Flanders no optional data for the organic layer are available and for the mineral soil even the mandatory data are not complete in parts of the considered areas. This must be seen as a serious drawback for any kind of multivariate data analysis, as gaps sum up and reduce the number of cases to a greater extent than they would do in bivariate approaches. Therefore all variables missing at too many plots (e.g. optional parameters for the organic layer) have been omitted within the multivariate analyses.

Tab. 3.3.3.1: Chemical soil parameters available in the data base for pilot area 1 and 2.

Pilot Area 1			Pilot Area 2		
Flanders	The Netherlands	Germany	Czech Rep.	Germany	Poland
organic layer, mandatory according to ICP Forests Manual					
pH	**pH**	**pH**	**pH**	**pH**	**(pH)**
C_{org}	**C_{org}**	**C_{org}**	**C_{org}**	**C_{org}**	**(C_{org})**
N	**N**	**N**	**N**	**N**	**(N)**
P	**P**	**P**	**P**	**P**	**(P)**
K	**K**	**K**	**K**	**K**	**(K)**
Ca	**Ca**	**Ca**	**Ca**	**Ca**	**(Ca)**
Mg	**Mg**	**Mg**	**Mg**	**Mg**	**(Mg)**
Orglay	**Orglay**	**Orglay**	**Orglay**	**Orglay**	•
organic layer, optional according to ICP Forests Manual					
•	Na	(Na)	Na	(Na)	(Na)
•	Al	Al	Al	Al	(Al)
•	Fe	Fe	Fe	Fe	(Fe)
•	Cr	(Cr)	Cr	(Cr)	•
•	Ni	(Ni)	Ni	(Ni)	•
•	Mn	Mn	Mn	Mn	(Mn)
•	Zn	Zn	Zn	Zn	(Zn)
•	Cu	Cu	Cu	Cu	(Cu)
•	•	Pb	Pb	Pb	(Pb)
•	•	Cd	Cd	Cd	•
•	•	•	ACEXC	•	(ACEXC)
•	BCE	•	BCE	•	(BCE)
•	ACE	•	ACE	•	(ACE)
•	CEC	•	CEC	•	(CEC)
•	BASESAT	•	BASESAT	•	(BASESAT)
mineral layers, mandatory according to ICP Forests Manual					
pH	**pH**	**pH**	**pH**	**pH**	**(pH)**
Corg	**Corg**	**Corg**	**Corg**	**Corg**	**(Corg)**
N	**N**	**N**	**N**	**N**	**(N)**
•	P	P	P	P	(P)
•	K	•	K	•	(K)
•	Ca	•	Ca	•	(Ca)
•	Mg	•	Mg	•	(Mg)
mineral layers, optional according to ICP Forests Manual					
Na	Na	(Na)	Na	(Na)	(Na)
Al	Al	(Al)	Al	(Al)	(Al)
Fe	Fe	(Fe)	Fe	(Fe)	(Fe)
•	Cr	(Cr)	•	(Cr)	•
•	Ni	(Ni)	•	(Ni)	•
•	Mn	(Mn)	Mn	(Mn)	(Mn)
•	Zn	(Zn)	Zn	(Zn)	(Zn)
•	Cu	(Cu)	Cu	(Cu)	(Cu)
•	•	(Pb)	Pb	(Pb)	(Pb)
•	•	(Cd)	Cd	(Cd)	•
ACEXC	•	•	ACEXC	•	(ACEXC)
BCE	**BCE**	**BCE**	**BCE**	**BCE**	**(BCE)**
•	ACE	ACE	ACE	ACE	(ACE)
CEC	**CEC**	**CEC**	**CEC**	**CEC**	**(CEC)**
BASESAT	**BASESAT**	**BASESAT**	**BASESAT**	**BASESAT**	**(BASESAT)**
general, mandatory according to ICP Forests Manual					
Soil Type	Soil Type	Soil Type	Soil Type	Soil Type	•

(): for a fraction of the plots available, • : not available, solid signs indicate introduction to multiple statistics.

Tab. 3.3.3.2: Basic univariate statistics for soil parameters of plots within pilot area 1.

Variable	Definition [unit]	N	Minimum	25th pctl	50th pctl	Mean	75th pctl	Maximum	SD	CV
WATERAV#	water availability class [rank: 1 - 5]	52	1	1	2.9	2.52	3.5	5	1.40	0.56
ORGLAY*	depth of organic layer [cm]	52	0.4	4.35	8.4	9.64	11.95	57.8	8.96	0.93
PH_0*	pH_{CACl2} or pH_{KCl} (organic layer)	51	2.6	2.9	3.1	3.35	3.7	6.8	0.77	0.23
PH_01+*	pH_{CACl2} or pH_{KCl} (surface layer)	52	2.6	3	3.23	3.26	3.4	5.45	0.46	0.14
PH_13*	pH_{CACl2} or pH_{KCl} (subsurface layer)	52	3	3.4	3.7	3.70	3.9	5.6	0.45	0.12
CORG_0	organic C [g kg^{-1}] (organic layer)	52	169	335.5	373	375.83	414	521	72.86	0.19
CORG_01+	organic C [g kg^{-1}] (surface layer)	52	3.5	16.25	27.5	31.48	43.25	83	19.54	0.62
CORG_13	organic C [g kg^{-1}] (subsurface layer)	52	1	9	14.5	15.62	22	48	9.27	0.59
N_0	N [g kg^{-1}] (organic layer)	52	6.7	13.75	15.35	15.42	17.15	28	3.42	0.22
N_01+*	N [g kg^{-1}] (surface layer)	52	0.25	0.6	1.18	1.37	1.6	4.6	0.99	0.72
N_13*	N [g kg^{-1}] (subsurface layer)	51	0	0.4	0.6	0.7	0.8	2.6	0.53	0.76
P_0*	P [mg kg^{-1}] (organic layer)	52	331	541.5	620	673.06	727	1413	215.24	0.32
{P_01+*}	P [mg kg^{-1}] (surface layer)	37	25	57.5	77.5	124.27	153	775	134.29	1.08
{P_13*}	P [mg kg^{-1}] (subsurface layer)	37	24	61	92	123.05	143	432	99.46	0.81
K_0*	K [mg kg^{-1}] (organic layer)	52	361	616	765	1241	1010	5989	1252	1.01
CA_0*	Ca [mg kg^{-1}] (organic layer)	52	1024	1762.5	3300.5	5002	5514	22730	5087	1.02
MG_0*	Mg [mg kg^{-1}] (organic layer)	52	276	387	588.5	928.77	965.5	3777	909.78	0.98
BASE_01+*	base saturation [%]	52	3	12,75	19.25	25.69	27	97.5	21.68	0.84
BASE_13*	base saturation [%]	52	4	7	10.5	18.71	19.5	97	22.79	1.22
BCE_01+*	basic exchangeable cations [mol_c kg^{-1}]	52	0.1	0.3	0.58	1.42	1.13	15.15	2.87	2.02
BCE_13*	basic exchangeable cations [mol_c kg^{-1}]	51	0	0.15	0.2	1.14	0.4	23.6	3.67	3.22
CEC_01+*	cation exchange capacity [mol_c kg^{-1}]	52	1.1	2.03	2.9	3.76	5.15	16.75	2.86	0.76
CEC_13*	cation exchange capacity [mol_c kg^{-1}]	52	0.6	1.4	2.35	3.10	3.45	24.9	3.58	1.15
{AL_0*}	Al [mg kg^{-1}] (organic layer)	41	1241	2550	3207	25634	4910	290000	63257	2.47
{FE_0*}	Fe [mg kg^{-1}] (organic layer)	41	1152	2690	3283	4415	4209	19780	3506	0.79
{MN_0*}	Mn [mg kg^{-1}] (organic layer)	40	7	60.5	140	2141	441	31771	6144	2.87
{ZN_0*}	Zn [mg kg^{-1}] (organic layer)	41	9	54	72	86.37	101	277	51.44	0.60
{CU_0*}	Cu [mg kg^{-1}] (organic layer)	41	1	12	17	20.78	24	82	15.12	0.73

#: derived from soil type, *: ln-transformed for subsequent calculations; suffix 0: organic layer, suffix 01: mineral surface layer, +: for Flanders and Germany arithmetic mean between horizon 05 and 51 has been used, suffix 13: mineral subsurface layer (= 12 + 23); {}: not used within multiple approaches because of too many missing values.

Also the depths soil samples were taken, vary between countries. In The Netherlands, the Czech Rep. and Poland the upper mineral soil was sampled in 0 - 10 cm depth, while in Germany and Flanders samples were taken in depths of 0 - 5 cm and in 5 - 10 cm. For the last two countries, means of both depths were used within all statistics. At the German plots the lower mineral soil layer was sampled in 10 to 30 cm depth instead of 10 to 20 cm. For this systematic divergence of the soil sampling routine no specific correction could be applied.
Physical soil conditions are essential for the soil water household, which is an important factor for tree condition. It can be supposed that a very high and a low water availability can - together with climatic conditions - influence the amount of foliage. Because the indication of relative access of water according to the average stand condition is defined ambiguously, a ranking of the potential water availability has been done by experts on a scale from 1 to 5 on the basis of the FAO soil types (Annex).

Tab. 3.3.3.3: Basic univariate statistics of chemical soil parameters and derived water availability class of plots within pilot area 2. Definitions and units see Tab. 3.3.3.2.

Variable	N	Minimum	25th pctl	Mean	50th pctl	75th pctl	Maximum	SD	CV
WATERAV#	92	1	1.5	2.78	3	4	5	1.17	0.42
ORGLAY	92	1.9	6.05	8.67	8.45	10.9	18.6	3.41	0.39
PH	97	2.5	3.1	3.25	3.2	3.4	4.6	0.33	0.10
PH01	97	2.5	3.2	3.31	3.3	3.5	4	0.27	0.08
PH13	97	2.8	3.5	3.69	3.7	3.9	4.3	0.30	0.08
CORG	97	166	271	323.95	315	374	475	75.12	0.23
CORG01	97	1	13	28.41	23	38	116	21.69	0.76
CORG13	97	0	5	11.97	10	16	62	10.23	0.85
N	97	6.7	12	14.84	14	7.4	24.7	4.01	0.27
N01*	97	0	0.6	1.55	1.3	2.1	7.6	1.29	0.83
N13*	97	0	0.3	0.74	0.6	1	4.4	0.65	0.88
P	97	1.25	656	759.07	891	983	1739	425.02	0.56
K	97	4.01	529	816.57	786	986	3230	632.87	0.78
CA	96	1.6	1421	2599	2603	3530	13927	2096	0.81
MG*	97	0.83	377	866.20	614	962	5432	912.71	1.05
BASE01*	97	3	10	18.30	14	24	61	12.30	0.67
BASE13*	97	2	7	17.99	11	22	86	17.44	0.97
BCE01*	97	0.2	0.6	1.42	1	1.6	10.9	1.53	1.08
BCE13*	97	0.1	0.3	1.21	0.6	0.9	17.9	2.58	2.13
CEC01	97	1.4	4.5	8.14	8.7	11.1	19.5	4.08	0.50
CEC13	97	0.6	3.4	6.09	5.8	7.9	20.7	3.89	0.64
AL*	97	1309	4295	7014.31	5721	9208	19815	4312.14	0.61
FE*	97	1564	7117	11866.1	10702	14770	35155	6751.90	0.57
MN*	92	41	189.5	474.43	362.5	644	1542	375.54	0.83
ZN*	97	10	48	68.08	58	76	300	38.61	0.57
CU*	97	0	19	28.35	26	37	89	15.11	0.53
{PB*}	97	0	84	142.03	115	173	944	121.13	0.85
{PB*$}	92	14	88.5	149.75	118	175.5	944	119.62	0.80
{NA}	76	15	66.5	104.80	86	106	465	88.08	0.84

#: derived from soil type, *: ln-transformed in subsequent calculations, suffix 05: mineral surface layer, suffix 13: mineral subsurface layer, parameters without suffix refer to the organic layer; $: not plausible values omitted, {}: not used within multiple approaches because of too many missing values.

3.3.4 Parameters on Foliar Element Concentrations

Foliar element composition has been considered to be a good indicator for the nutritional status of trees. Its suitability as a predictor of crown condition is however limited, because the element concentrations of the foliage is not only dependent on soil related nutrient availabilities, but also subject to direct dry deposition of gas and dust particles as well as leaching processes. It is partly influenced by annual weather conditions and even biological agents. These complex relations deny simple approaches and support the treatment of foliar element concentrations as effect variables (e.g. HENDRIKS et al. 1997b).

Chemical concentrations of current year's needles and leaves were in most cases measured once, but not on all Level I plots. Data were compiled at the FFCC (STEFAN et al. 1997, see Tab. 3.3.4.1). In Germany foliage was sampled in 1989, 1990 1992 and 1995, on some plots even twice. In the Czech Republic the survey was conducted in 1995. In conifers only the needle set of the current year was sampled on a sufficient number of plots; older needles have deviant element contents, but were not available in sufficient high number. A problem related to foliar element contents is given by a significant dependency on the annual weather conditions (see WEHRMANN 1958). According to STEFAN & GABLER (1998) especially the dry and hot summer of 1992 reduced the N, P, K, and Mg contents of spruce needles distinctively.

Tab. 3.3.4.1: Chemical element contents for pilot area 1 and 2 available in the data base.

Pilot Area 1			Pilot Area 2		
Flanders	Netherlands	Germany	Czech Rep.	Germany	Poland
•	•	(N)	(N)	N	•
•	•	(S)	(S)	S	•
•	•	(P)	(P)	P	•
•	•	(Ca)	(Ca)	Ca	•
•	•	(Mg)	(Mg)	Mg	•
•	•	(K)	(K)	K	•
•	•	(Na)	(Na)	Na	•
•	•	(Zn)	(Zn)	Zn	•
•	•	(Al)	•	Al	•
•	•	(Fe)	(Fe)	Fe	•
•	•	(Mn)	(Mn)	Mn	•
•	•	(Cu)	(Cu)	Cu	•
•	•	(Pb)	•	Pb	•
•	•	(n-age)	(n-age)	n-age	•
•	•	•	(n-mass)	•	•

(): data for a fraction of the plots available; • : no data available.

Tab. 3.3.4.2: Basic statistics of element contents (dry weight) of current year's needles of Scots pine within pilot area 1.

Variable	unit	N	Min.	25 pctl	50 pctl	Mean	75 pctl	Max.	SD	CV	Eu mean*	NL mean**
N	mg g^{-1}	24	15.19	16.61	18.10	18.10	19.75	21.12	1.82	0.10	13.89	18.5
S	mg g^{-1}	25	1.08	1.19	1.27	1.34	1.44	1.97	0.22	0.16	1.07	1.20
P	mg g^{-1}	25	1.06	1.40	1.48	1.49	1.63	1.98	0.23	0.15	1.48	1.32
K	mg g^{-1}	22	4.47	5.09	5.29	5.42	5.84	6.79	0.58	0.11	6.65	6.1
Ca	mg g^{-1}	25	1.65	2.23	2.66	2.67	3.14	3.73	0.61	0.23	4.86	1.8
Mg	mg g^{-1}	25	0.57	0.66	0.78	0.83	0.91	1.35	0.22	0.27	1.23	0.72
Na	mg kg^{-1}	23	63	100	144	213.70	245	970	197.47	0.92		160
Zn	mg kg^{-1}	25	34	41	46	47.6	50	69	9.66	0.20		47
Fe	mg kg^{-1}	25	58	75	104	126.84	140	550	99.91	0.79		66
Mn	mg kg^{-1}	25	86	143	250	332.32	415	1170	266.29	0.80		234
Cu	mg kg^{-1}	23	1.93	3.61	4.12	4.52	4.81	11.9	1.97	0.44		3.7
Al	mg kg^{-1}	22	139	179	243	229.68	268	338	56.31	0.25		204
Pb	mg kg^{-1}	19	1.2			2.86		7.1	1.76	0.62		

*: European mean according to STEFAN et al. (1997: Tab. 3-3), **: mean of The Netherlands according to HENDRIKS et al. (1997b: annex 1).

Chemical composition of needles and leaves strongly depend on tree species. Therefore separate tables are given for each considered species. Within pilot area 1 only data for the current year's needle sets of *Pinus sylvestris* are available in sufficient numbers to be taken into consideration. However, neither Flanders nor The Netherlands have delivered data on the foliar chemical composition (Tab. 3.3.4.1). The number of cases is therefore considerably reduced compared to the soil data.

Tab. 3.3.4.2 gives the basic statistics of chemical foliar contents within pilot area 1. In comparison to soil data, the relative variation within each parameter is much smaller. Coefficients mostly vary between 10 and 20% for the main nutritional elements. Only Ca, Mg, and especially Na show higher coefficients. Frequency distributions of the parameters often resemble normal distributions. Only for Na, Fe, and Mn outlayers raise the means distinctively above the 50th percentile.
In comparison to the European mean given by STEFAN et al. (1997), on the majority of plots within pilot area 1 nitrogen is well above the European average, but still lower than in The Netherlands (HENDRIKS et al. 1997b). The same holds true for sulphur, while Ca and Mg show distinctively lower means than in Europe and in The Netherlands.

Tab. 3.3.4.3: Basic statistics of element contents (dry weight) of current year needles of Norway spruce (*Picea abies*) within pilot area 2 and means for comparable areas.

Variable	n	Min.	25th pctl	50th pctl	Mean	75th pctl	Max.	SD	CV	EU mean[1]	NL mean[2]	RL-PF mean[3]	A 50 pctl[4]
N	29	12.93	14.78	15.36	15.67	16.8	19.15	1.53	0.10	13.89	17.1	14.9	
S #	27	0.75	0.94	1.11	1.25	1.51	2.41	0.42	0.34	1.07	1.1	1.02	
P	29	1.27	1.43	1.55	1.60	1.8	2.18	0.22	0.14	1.48	1.27	1.3	
K	28	4.25	5.42	6.06	6.08	6.95	7.99	1.01	0.17	6.65	5.8	5.45	
Ca #	29	2.29	3.31	4.17	4.41	5.45	7.59	1.49	0.34	4.86	2.5	4.24	
Mg #	29	0.57	0.78	0.89	0.95	1.14	1.51	0.26	0.27	1.23	0.79	0.81	
Na	29	0	20	24	26.72	31	46	10.71	0.40		120	33.2	
Zn #	29	19	24	27	28.59	31	41	5.83	0.20		24	37.3	34
Fe #	29	27	55	67	81.38	84	242	47.83	0.59		62	86	38.7
Mn	29	162	606	1253	1268.45	1664	3108	777.82	0.61		304	203	481
Cu	27	2.13	2.57	2.77	2.75	2.93	3.47	0.30	0.11		2.8	2.92	
Al	5	103	118	124	136.4	161	176	30.75	0.23		114	102.4	
NG	24	2.23	3.57	3.82	3.83	4.87	5.11	0.70	0.18				

units see Tab. 3.3.4.2, NG: dry mass of 1000 needles [g], [1]: European mean according to STEFAN et al. (1997: Tab. 3-3), [2]: mean of The Netherlands according to HENDRIKS et al. (1997b: Annex 1), [3]: mean Rheinland-Pfalz (Germany) according to BLOCK et al. (1996: Annex 2, Tab. 2.1b), [4]: median Austria 1993 according FÜRST 1996. #: in order to adjust to normal distributions natural logarithms are used in subsequent calculations.

Tab. 3.3.4.4: Basic statistics of element contents (dry weight) of current year needles of Scots pine (*Pinus sylvestris*) within pilot area 2.

Variable	N	Min.	25th pctl	50th pctl	Mean	75th pctl	Max.	SD	CV	EU mean[1]	NL mean[2]
N	15	12.71	14.06	15.82	15.97	17.16	20.61	2.35	0.15	13.89	18.5
S	15	0.90	1.58	1.68	1.81	2.11	3.25	0.61	0.34	1.07	1.20
P	16	1.25	1.32	1.39	1.47	1.68	1.72	0.18	0.12	1.48	1.32
K	16	4.01	5.03	5.44	5.61	6.36	6.88	0.83	0.15	6.65	6.1
Ca	15	1.60	2.17	2.74	2.76	3.20	4.18	0.74	0.27	4.86	1.8
Mg	16	0.83	0.94	1.03	1.06	1.18	1.36	0.16	0.15	1.23	0.72
Na	16	0	24	38	78.5	47	400	112.20	1.43		160
Zn	16	33	38.5	45.5	46.63	55	67	10.58	0.23		47
Fe	16	0	86	170.5	193.75	251	560	147.82	0.76		66
Mn	16	165	245.5	534.5	632.69	817.5	1900	456.59	0.72		234
Cu	14	2.95	3.3	4.05	8.83	5.6	30.4	10.00	1.13		3.7
Pb	11	0.5			2.01		3.2	0.80	0.40		
Al	7	377	377	429	456.29	526	600	84.65	0.19		204

Units see Tab. 3.3.4.2, [1]: European mean according to STEFAN et al. (1997: Tab. 3-3), [2]: mean of The Netherlands according to HENDRIKS et al. (1997b: Annex 1).

Within pilot area 2 for 29 *Picea abies* plots (Tab. 3.3.4.3) and 18 *Pinus sylvestris* plots (Tab. 3.3.4.4) data of the chemical foliar contents are available. The values of Norway spruce differ for certain parameters from the European mean or from the reference values from The Netherlands respective Rheinland-Pfalz in Germany. Most obvious is a distinctively lower Na concentration within pilot area 2 compared to The Netherlands, which is certainly based on the area's greater distance from the sea. The very high concentrations of manganese may reflect geogeneous peculiarities, since other heavy metals are not obviously higher than in the compared areas. The elevated sulphur concentration in spruce needles within pilot area 2 can be taken as an indication of a high atmospheric SO_2 burden in great parts of that region (see Fig. 3.3.6.2). The N concentration is also higher than the European average, but lower as the Dutch mean, which is in line with the general expectations of the large-scale EMEP model (e.g. TUOVINEN et al. 1994). The supply of the spruce needles with phosphorous in pilot area 2 is higher in comparison to the other two areas mentioned, while the supply with Ca and Mg is on the average almost as low as in The Netherlands.

The average foliar nitrogen, calcium and magnesium contents of Scots pine within pilot area 2 (Tab. 3.3.4.4) is, like in Norway spruce, intermediate in comparison to the European and the Dutch average, while the sulphur values are distinctively higher than in the compared areas. This clearly reflects the large scale pattern of the EMEP model with high SO_2 impacts in great parts of the so-called 'Black Triangle'. The Al contents of the pine needles is more than double as high as in The Netherlands, but shows a low coefficient of variation. Again, Na as well as Cu, Fe, and Mn reveal high coefficients of variation. Most metal concentrations are also higher than the values from The Netherlands.

3.3.5 Meteorological Parameters

Climatic factors cannot be considered as stress factors for forest trees per se, but can influence the current amount of foliage considerably. In that sense climatic differences in space may coincide with different numbers of needle sets: e.g. JALKANEN et al. 1995 present a close exponential relationship between thermal sum and mean annual needle retention for Scots pine in Finland. It is not clear whether this is due to genetic differentiations, or due to actual physiological reactions, or both. It can be supposed that trees have adjusted to that, not only in phyto-geographical terms (e.g. distribution of tree species according to climatic zones), but also on levels of intraspecific variation, as expressed by race and provenance. Regional adaptations to average weather conditions may even be expressed by genetically or ontogenetically (individual adaptations covered by phenotypic plasticity) fixed crown condition features. Anyhow, regional reference trees should consider fixed crown features, but this might have not always been properly executed. Therefore, due to the inclusion of medium-term weather condition some amount of the explained variance might cover some of the respective adaptations of forest trees.

Temporal variation of meteorological factors like droughts and periods of strong frosts respective late frosts may influence crown condition. If "normal" physiological measures, e.g. the closure of stomata in the case of droughts, is not sufficient, leaf or needle loss might be one additional mechanism of trees to adjust to current periods of insufficient water supply. Especially exceedances over (e.g. for summer heat) or below (e.g. winter frost, mean precipitation) an average range can denote physiological stress. Periods with a combination of high temperature and low precipitation primarily during the vegetation period can be identified as phases of drought stress. Drought stress in that sense might influence the temporal variation of crown condition. The same is true for strong winter or late frosts. Both can strongly influence the physiological and morphological status of forest trees, especially at the edge of their phytogeographical or ecological range (e.g. at high altitudes). Because of autocorrelative effects over one and even more years due to species-specific features like storage and allocation pattern of organic carbon compounds or the evolution of needle of leaf primordia, respective effects on tree crown condition might be even more complicated. Distinct dependencies of crown condition on meteorological features can hardly be evaluated by 10 years time series, but might be relevant for the analysis of spatial variation of single year's crown condition.

Tab. 3.3.5.1: Basic statistics of meteorological parameters of both pilot areas; #: natural logarithms used in subsequent calculations.

		Pilot Area 1				Pilot Area 2			
Variable	Definition [unit]	N	Min.	Mean	Max.	N	Min.	Mean	Max.
XTEMPR	mean annual temperature [°C]	53	8.6	9.4	10.6	214	6.1	8.1	9.2
XWINTER	mean winter index [°C days]	53	8.7	38.5	72.6	214	71.1	138.3	242.8
XLFROST	mean late frost index [°C]	53	0.2	2.3	4.0	214	2.4	3.3	5.4
MALFROST	maximum of late frost index [°C]	53	1.4	4.9	8.6	214	4.2	6.6	28.9
XHEAT #	mean heat index [°C days]	53	0.3	2.4	6.6	214	0.4	5.7	10.8
XPRECI	mean annual precipitation [mm]	53	578	781	857	214	457	613	820
XRELTR #	relative transpiration [%]	53	0.52	0.88	0.99	214	0.63	0.82	0.99

Meteorological data were not measured at Level I plots. Therefore values of respective parameters have been interpolated and partly simulated by ALTERRA GREEN WORLD RESEARCH (for detailed information see HENDRIKS et al. 1997a, VAN LEEUWEN et al. 2000) based on data from nearby weather stations and were made available for the Level I monitoring plots within pilot area 1 and 2 on a yearly basis. These parameters and indices (Tab. 3.3.5.1) cover tree relevant features of weather condition. Temperature stress is expressed by

- winter index: sum of daily mean temperature below 0 °C from 1st of October to 1st of April (degree days below 0 °C),
- late frost index: lowest temperature below 0 °C in a period starting 15 days before growing season and 30th of June,
- heat index: sum of differences between daily maximum temperature during growing season and 35 °C (degree days above 35 °C).

Drought stress is indirectly covered by

- precipitation (mm) and
- relative transpiration expresses the ratio between actual and potential transpiration [%] and was calculated according to a model with regard to meteorological conditions, stand parameters and soil condition (The calculation is documented in detail in HENDRIKS et al. (1997), see also VAN LEEUWEN et al. 2000).

For regional considerations, means over the years 1985 to 1996 were used (Tab. 3.3.5.1). For the late frost index also the maximum was used as an extra parameter. Annual mean temperature and precipitation cannot be considered as stress factors, but in regional approaches both parameters may stand for general climatic traits with great value of morphological and physiological adaptations of forest trees.
A severe limitation of the plot-related meteorological data is caused by its interpolated nature. Especially in mountainous regions like in pilot area 2 local deviations from the regional climatic regime due to great small- and medium-scale differences in altitude, exposition, or other local geomorphological features might be enormous.

3.3.6 Air Pollution Parameters

Higher concentrations of different air pollutants are known to cause direct damages to needles and leaves of trees. Among them, sulphur dioxide is the most wide-spread. Very high concentrations of SO_2 are partly found in pilot area 2 (Fig. 2.3.6.1). It is known to cause classical smoke damage. However, also lower concentrations may cause membrane damages within needle tissue and subsequently higher leaching rates. Besides direct impacts on the foliage of trees, deposition of sulphur and even more pronounced nitrogen compounds may alter ecosystems properties, especially the soil status. SO_2, NO_x and NH_y inputs have predominantly acidifying effects on soils, while all nitrogen compounds act additionally as eutrophicative agents within ecosystems.

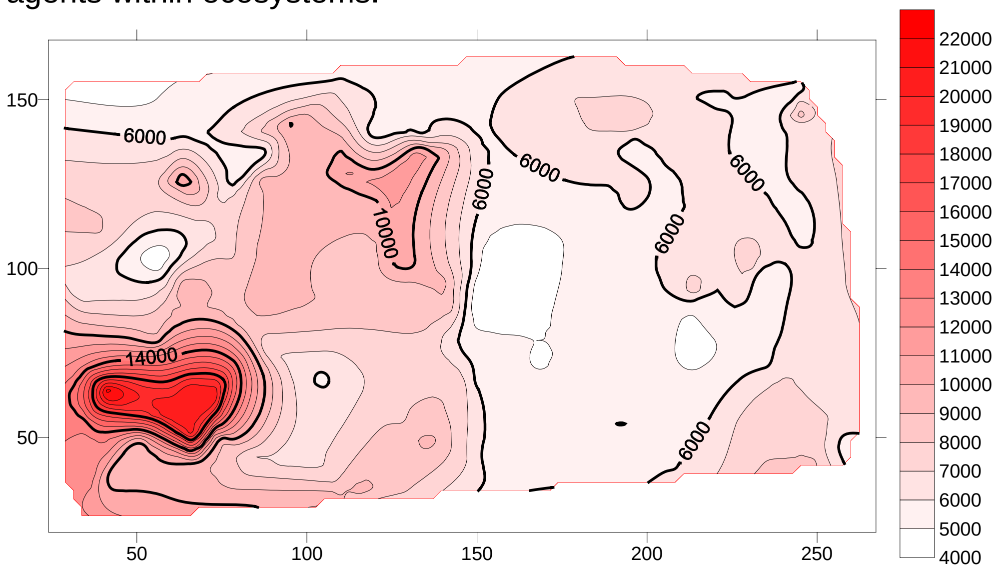

Fig. 3.3.6.1: Spatially interpolated (natural neighbour) distribution of modelled potential acid deposition [mol_C ha^{-1} a^{-1}] within pilot area 2, 1 x/y-unit equals c. 2 km; data source: Alterra.

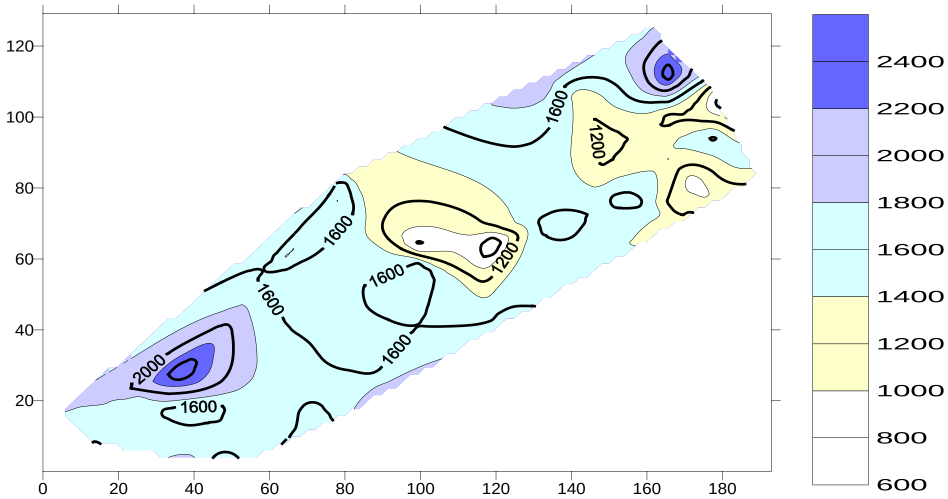

Fig. 3.3.6.2: Spatially interpolated (natural neighbour) distribution of modelled nitrogen deposition [mol_C ha^{-1} a^{-1}] within pilot area 1, 1 x/y-unit equals c. 2 km; data source: Alterra.

Neither concentrations nor deposition rates of air pollutants are measured at Level I plots. On the base of the EMEP model on large-scale concentration and deposition of acidifying compounds in Europe (TUOVINEN at al. 1994) in combination with the EDACS model and further information like estimates of wet deposition, for each Level I plot site-specific estimates of deposition fluxes for acidity have been modelled by ALTERRA, GREEN WORLD RESEARCH (for detailed information see VAN LEEUWEN et al. 1997, VAN LEEUWEN et al. 2000). The same has been done for nitrogen inputs. Data have been provided as annual means from 1985 to 1996. For annual approaches yearly values are used to cover possible acute damages especially in highly polluted parts of pilot area 2 (Fig. 2.3.6.1), but in calculations with long-term means (1989 resp. 1990 to 1998) deposition means averaged over time are taken as an adequate measure for accumulated mean-term impacts. However, the accumulated errors from different sources of uncertainty amount 90 - 140% (van LEEUWEN et al. 2000). Therefore results from regression models have to be interpreted carefully.
As Tab. 3.3.6.1 shows, pilot area 2 has distinctively higher deposition rates of total acidity than pilot area 1. Especially the occurrence of extremely high values up to an 11 years average of 23,034 mol_C ha^{-1} a^{-1} (equivalent to 368.5 kg S $ha^{-1}a^{-1}$) in the valley of the river Ohře (comp. Fig. 3.3.6.1) raises the overall average considerably. The median of the simulated potential acid deposition rates at Level I plots within the whole of Europe was around 2000 mol_C $ha^{-1}a^{-1}$ (equiv. to 32 kg S $ha^{-1}a^{-1}$) in 1986, and around 1000 mol_C $ha^{-1}a^{-1}$ (equiv. to 16 kg S $ha^{-1}a^{-1}$) from 1993 onwards (VAN LEEUWEN et al. 1997). In order to obtain estimates for the long-term effects of potential acidity at the concerned forest ecosystems, natural buffer capacities (which are low in both pilot areas) and deposition of base cations have to be counterbalanced. Base cation input can regionally reach high values e.g. in parts of pilot area 2 (1000 - 1500 mol_C $ha^{-1}a^{-1}$ according to VAN LEEUWEN et al. 1997).

Tab. 3.3.6.1: Basic statistics of air pollution parameters of both pilot areas.

		Pilot Area 1				Pilot Area 2			
Variable	Definition [unit]	N	Min.	Mean	Max.	N	Min.	Mean	Max.
D_NITRO	nitrogen deposition [mol_C $ha^{-1}a^{-1}$]	53	455	1540	2630	214	349	1109	2903
D_ACID	acidity deposition [mol_C $ha^{-1}a^{-1}$]	53	1701	4148	7230	214	3839	7602	23034

Pilot area 1 has a distinctively lower deposition rate of potential acidity than pilot area 2, but is with a mean of 4148 mol_C $ha^{-1}a^{-1}$ also above the European average. Nitrogen deposition is on average higher in pilot area 1 than in pilot area 2, but some plots within pilot area 2 also receive considerable amounts of nitrogen. The median at the European level was between 500 and 1000 mol_C $ha^{-1}a^{-1}$ around 1986. Since 1991 the median is even below 500 mol_C $ha^{-1}a^{-1}$ (VAN LEEUWEN et al. 1997: Fig. 4.2.2.2-2). In general, pilot area 1 is characterised by strong gradients of nitrogen deposition, whereas pilot area 2 has parts with extraordinary high deposition rates of total acidity.
In both pilot areas, nitrogen deposition and deposition of potential acidity are strongly correlated with each other ($R^2_{adj\ (D\_NITRO\ \surd\ D\_ACID)}$ = 0.91 in pilot area 1 and $R^2_{adj\ (D\_NITRO\ \surd\ D\_ACID)}$ = 0.69 in pilot area 2). In order to keep degrees of freedom within multiple regression approaches small, within pilot area 1 only the deposition of total nitrogen is used.

3.4. Methodological Approaches

3.4.1 Bivariate Statistics

Bivariate statistics give an overview on basic relations between two sets of parameters. Especially in the case of a strong influence of a single predictor on an effect variable, bivariate analyses in combination with a graphic representation of the relation prior to multiple approaches can clarify what type of regression, linear or non-linear, is appropriate. Such considerations - beside univariate measures - facilitate decisions concerning data transformation. The results of bivariate statistics are not documented in detail, but prominent examples are given (e.g. Fig. 2.3.1.1).

3.4.2 Principal Factor Analysis

Factor analysis is mainly used to transform sets of more or less correlated original variables into sets with a limited number of uncorrelated but unobservable latent variables, loosing as little information as possible. These latent variables are the so-called principal factors and each of them represents - at least partly - more than one of the observed variables (SAS INSTITUTE Inc. 1990, for a general introduction see e.g. MULAIK 1972). The factor patterns in terms of linear relations to the original variables to the principal factors are usually estimated as standardised regression coefficients (loadings) and serve as a basis for the substantial interpretations of the factors.

Since the common factors are uncorrelated, they may as ideal predictors within subsequent multiple regression models. Moreover, in connection with multiple regression analysis the reduced number of predictors is advantageous, because the number of cases is mostly limited, which calls for a restriction of the number of independent variables.

Since the aim of the study is the exploration of dependencies between tree crown condition and environmental factors respectively anthropogeneous impacts, factors which are interpretable in ecological terms have been preferred. Therefore soil and meteorological variables have been analysed separately.

Runs of factor analysis became unstable in terms of the KAISER's measure of sampling adequacy (over-all MSA) if too many predictors were introduced. This index is based on the relation between the bivariate correlations and the partial bivariate correlations. The overall measure should not fall below 50% (SAS INSTITUTE Inc. 1991) and single parameters with very low values should not be included into the principal factor model.

Factor analyses are also used for indirect ordination of sites (monitoring plots, e.g. WHITTAKER 1967). Since this task is of minor relevance in this study and in order to achieve a better interpretability of the axes (factors) in ecological terms, some loss of explained variance on the first axis could be afforded. Therefore as an optimisation strategy after the initial extraction of factors, the orthogonal varimax rotation technique was additionally applied (SAS INSTITUTE Inc. 1990).

3.4.3 Multiple Linear Regression

Multiple linear regression focuses on the statistical dependencies of one effect variable (dependent variable) from more than one predictor (independent) variables. In this study linear models are used not only for reasons of its simplicity, but also for their consistent theory and comparatively distinct possibilities of interpretation (c.f. BECHER 1999). In addition, it is unknown whether other types of relations are ecologi-

cally adequate and any assertions of prognostic models in the present explorative stage of statistic modelling are not indicated.
Since full models often deliver unclear results and the order of predictors would underlie subjective decisions, different model selection methods have been applied. Mainly forward selection has been used (SAS INSTITUTE INC. 1990), but in order to get an overview on alternative models, also a selection technique was used, sorting all possible models according to their decreasing degree of explained variance.
Generally in all empirical statistical models, attention must be paid to the fact that any statistical correlation cannot simply be taken as a true cause-effect relation. This is especially true for ecosystems with their multitude of partly non-linear cause-effect relations, delay effects and feed-back functions. Each statistical relation found, has to be checked for plausibility, respective coherence with other findings. If e.g. high amounts of insect damage is negatively correlated with defoliation, no general conclusion can be drawn that leaf-eating insects enhance crown density, even if overcompensational growth of foliage can be observed in some cases (SEIDLING et al. 1996). Especially biotic factors can lead to complex reaction of trees as e.g. FISCHER (1999) has shown.
Within multiple regression models the number of predictors should not exceed one quarter of the number of cases (e.g. BORTZ 1993). This is a considerable obstacle for stratifications of the available data sets from both pilot areas, because stratification is always connected with a reduction of the number of cases.
Prior to introduction into multiple regression most parameters have been log- or logit-transformed in order to achieve optimal relationships either in statistical or in functional terms (see. tables in chapter 3.2 u. 3.3). Age class (AGE) for Scots pine was transformed by a negative exponential function according to functional considerations.
Since country effects have already been detected in other transnational studies (KLAP et al. 1997, 2000), country dummy variables were introduced. Because defoliation values among the three states within pilot area 1 show a very distinct ranking (see Fig. 4.1.1), only one respectively ranked dummy variable was used, in order to keep the number of variables as low as possible. For pilot area 2 two neutral dummy variables were introduced if data from the three states were jointly evaluated.

4 Results

4.1 Prominent Bivariate Relations

4.1.1 Correlations with and among Effect Variables

Systematic deviations of the effect variable defoliation among different countries, due to methodological differences during the field surveys and other differences, have already been reported (LANDMANN & BOUHOT-DELDUC 1995, KLAP et al. 1997, KLAP et al. 2000). This holds also true for both delineated pilot areas used in this study. Figure 4.1.1 gives an example on systematic differences of defoliation values between Flanders, The Netherlands, and north-western Germany. Obviously no spatial trend exists, since the most westerly Flanders shows the highest defoliation values, The Netherlands the lowest, and Germany - most easterly situated - has medium values. Within pilot area 1 this relationship is stable over the whole time of observation. In subsequent regression models a ranked dummy variable has been introduced to consider these effects and neutralise them within subsequent steps of analyses. In calculations with mean discoloration as dependent variable, two neutral dummies have been used.

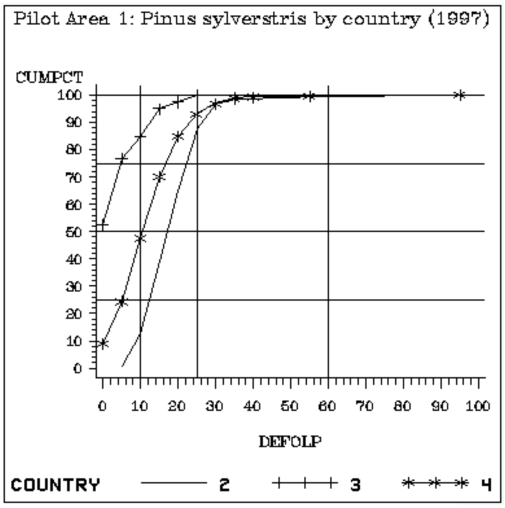

Fig. 4.1.1: Cumulative frequency distribution of defoliation values from 1997 of all *Pinus sylvestris* trees within pilot area 1 stratified according to country; DEFOLP: defoliation (%), CUMPCT: cumulative percentage, country 2: Flanders, 3: Netherlands, 4: Germany; vertical lines denote traditional damage classes (ANONYMUS 1998).

Within pilot area 2, the German plots generally reveal lower defoliation values for Scots pine and Norway spruce, compared to the Polish and Czech plots. However, this relationship is not stable over time and moreover partly influenced by the age structure of the stands. Therefore always two dummy variables have been used within multivariate regression analyses.

As already mentioned in chapter 3.3.1 defoliation and age show a distinct non-linear relationship as demonstrated by Fig. 3.3.1.1. In order to optimise subsequent multiple regression models, age was transformed according to the formulas given in table 3.3.1.1. Since age effects become only obvious if country effects are neutralised, in this case a before-hand country correction was applied. Due to the lack of independent correction factors (e.g. outcomes from intercalibration courses; estimations made by DOBBERTIN et al. (1997) cannot be used for this purpose), an adjustment of the defoliation data was done by polynomials resp. smoothed empirical lists derived from accumulated frequency distributions of long-term means (1989 to 1997 in pilot area 1 resp. 1990 to 1997 in pilot area 2). This procedure is based on the assumption that the average means within each of the countries is equal but varies within each country for similar reasons. This procedure seems to be sufficient in order to achieve a good and reasonable fit for the influence of age on defoliation. This transformation was only used to optimise the relationship between age and defoliation. Alternatively non-transformed or log-transformed age classes were used in subsequent multiple regression models, but results were often worse in terms of explained variance.

4.1.2 Bivariate Statistical Relations of Foliar Contents

As shown in chapter 3.3.4 data on foliar element contents are only available from monitoring plots within Germany and the Czech Republic. This results in a low number of cases with foliar data and hinders an adequate introduction within multiple regression models. In order to give an overview on the relations among the element concentrations and their relationships towards soil data, bivariate relations have been investigated. Within pilot area 1 only data from Germany are available, therefore no country bias has to be considered.

Tab. 4.1.2.1: Matrix of bivariate correlation coefficients (PEARSON, x 100) between foliar element concentrations of *Pinus sylvestris* for pilot area 1.

S	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	Al	
23	14	06	-03	-01	21	-15	-06	46*	-43*	-19	N
	00	09	26	53**	48*	79***	81***	65***	39	-09	S
		39	08	55**	-44*	-31	-29	-14	-32	28	P
			-08	20	-37	-14	-29	25	-37	17	K
				20	-07	19	12	19	33	-37	Ca
					-02	36	34	12	20	20	Mg
						31	49*	40	06	-12	Na
							94***	31	65***	-27	Fe
								33	64**	-18	Cu
									-10	-28	Zn
										-12	Mn

n of cases 22 - 25, levels of significance: ***: p <= 0.001, **: p <= 0.01, *: p <= 0.05.

Table 4.1.2.1 shows distinct correlation patterns of the element concentrations (= contents) of pine needles within pilot area 1. Sulphur is strongly positively correlated with heavy metals (Fe, Cu, Zn) and those heavy metals with the exception of Zn are positively correlated with each other. A principal factor analysis (results not shown) revealed these elements to contribute to the 1st factor (= axis), where 53% of the total variation is concentrated. This suggests a more or less common deposition process of the mentioned metals. Phosphorous and magnesium are also positively correlated. Both contribute to the 2nd axis of the principal factor analysis (31% of the total variance). All the other elements show minor or no correlations among each other. Even nitrogen, in deposition or air concentration data often found positively correlated with sulphur (e.g. DE VRIES et al. 2000c), exhibits only two comparatively unclear relations with zinc and manganese.
Most of the foliar element contents exhibit more or less distinct geographical patterns. Nitrogen for example (Fig. 4.1.2.1) has low values only in needles from monitoring plots situated in the eastern part of the area. According to Figure 3.2.6.2 lower deposition rates of N compounds predominate here.

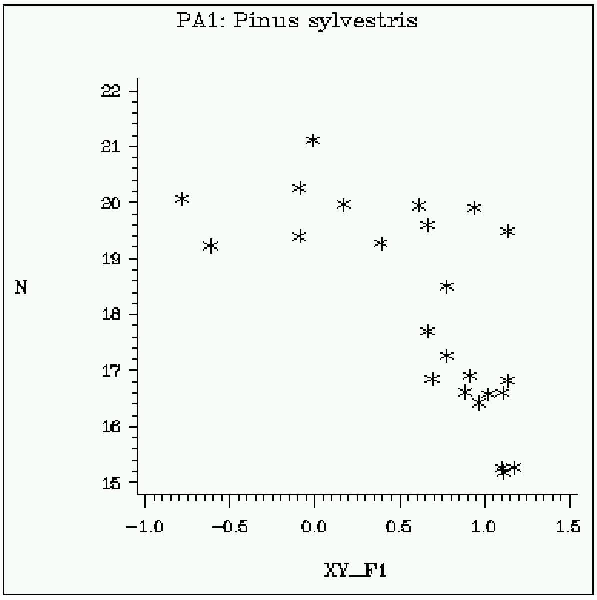

Fig. 4.1.2.1: N contents [mg g^{-1}] of Scots pine needles against PCA scores of a geographic gradient (XY_F1): westerly situated: low values, easterly situated: high values.

This tendency could, however, not be confirmed by bivariate correlations between deposition estimates and concentrations of foliar element concentrations. According to table 4.1.2.2 only the concentration of Ca is weakly correlated to deposition of nitrogen and acidity. The often observed coupling of acid deposition and deposition of basic substances might be a possible explanation, but the general weakness of modelled deposition data based on the large-scale patterns of the EMEP programme for single monitoring plots may also cause weak correlations.
The low concentration of phosphorous in pine needles coinciding with high deposition of acidity is however quite interesting. It gives at least some supports to the finding of a deficient P nutrition in conifers at high acidity (and nitrogen) deposition levels (e.g. MOHREN et al. 1986).

Tab. 4.1.2.2: Matrix of bivariate correlation coefficients (PEARSON, x 100) between foliar element concentrations of *Pinus sylvestris* and deposition for total nitrogen and acidity and geographic factors within pilot area 1.

foliar:	N	S	P	K	Ca	Mg	Na	Zn	Fe	Mn	Cu	Al
Nitrogen	14	25	-39	-17	42*	-21	36	44*	41*	24	13	-31
Acidity	-07	13	-48*	-29	46*	-20	30	30	39	43*	17	-28
F_WE	-68***	-46*	-07	-24	-17	02	-23	-59**	-13	24	-19	34
F_NS	-29	23	-19	-00	09	00	-11	11	44*	45*	46*	20

n of cases: 25 - 22; F_WE: geographic PCA factor westerly situated (low values) < easterly situated (high values), F_NS: geographic PCA factor northerly situated (low values) < southerly situated (high values); level of significance: ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$.

The correlation coefficients between foliar element concentrations and geographical factors derived from plot position according to LAMBERT's projection indicate geographical patterns below the resolution of 150 x 150 km, possibly due to large farms situated close to one of those forest fragments, typically occurring within pilot area 1. Higher N concentration in the western parts of the German part of pilot area 1 was

also found by Riek & Wolff (1999) and is in agreement with results of calculations concerning N immissions by UBA (1994).
Concentrations of single elements within leaves or needles are usually taken as indicators for the respective nutritional status of trees. Level I data collected at the monitoring sites give the opportunity to investigate these relationships. Table 4.1.2.3 shows that only Ca and the heavy metals Zn, Fe, and Mn within the foliage are positively and significantly correlated with the respective element concentration in the solid phase of the soil. However, Becher (1999) and others have found that the element composition of the soil solution shows narrower relations to the foliar composition than the element concentrations of solid phase, but the finding also underlines selective uptake and translocation processes of the trees.

Tab. 4.1.2.3: Matrix of bivariate correlation coefficients (Pearson, x 100) between foliar chemical concentrations of *Pinus sylvestris* (columns) and soil parameter (rows) within pilot area 1.

	N	S	P	K	Ca	Mg	Na	Zn	Fe	Mn	Cu	Al
WATERAV	23	36	-31	-06	29	-17	45*	19	35	19	27	-45*
lnORGLAY	-18	-40	-05	26	09	-14	-14	-08	-35	-15	-54*	-40
lnPH_0	02	05	07	-11	31	10	-26	-29	09	56**	21	19
lnPH_01	06	02	29	03	-09	31	-12	-37	05	12	13	29
lnPH_13	-30	-11	-55**	-32	-09	-15	19	-06	11	45*	20	03
lnBASE_01	24	32	23	16	16	41*	24	11	01	11	-02	-06
lnBASE_13	09	08	-25	-12	-12	-14	52*	06	-04	03	-18	-11
lnBCE_01	33	28	-02	14	09	02	26	38	01	00	04	-21
lnBCE_13	17	-23	20	32	10	-25	-12	-08	-27	-27	-38	-25
lnCEC_01	26	16	-22	07	02	-28	16	44*	05	-06	09	-29
lnCEC_13	-03	-21	34	45*	17	-06	-53**	03	-15	-28	-18	-17
CORG_0	-00	-18	-30	-07	-11	-26	14	27	-19	-26	-17	-03
CORG_01	37	40*	-12	16	16	-15	11	67***	21	-11	28	-40
CORG_13	-15	-29	28	46*	-06	-20	-46*	01	-20	-38	-27	-04
N_0	15	01	-25	-02	-01	-26	14	31	-05	-05	-02	01
lnN_01	35	38	-13	10	18	-13	17	65***	16	-09	21	-40
lnN_13	10	-01	00	15	12	-05	-12	27	05	-30	-00	-38
lnP	20	19	-01	-14	01	-11	00	29	07	09	17	11
lnK	-07	59**	-24	-10	01	33	10	18	76***	70***	76***	13
lnCa	-06	-16	18	-10	55**	07	-46*	-24	-18	37	-12	-03
lnMg	-04	-06	06	-11	51*	23	-36	-12	-04	43*	-02	03
lnZn	51*	54**	09	28	18	01	18	73***	20	-15	28	-32
lnFe	34	57**	-27	07	22	-05	09	63**	49*	31	56**	-35
lnMn	18	48*	-02	09	56**	-08	-22	36	68***	49*	65**	-36
lnCu	38	14	-04	11	12	-30	00	57**	-11	-23	-00	-25
lnAl	28	51*	-14	13	35	-07	-05	57**	45*	22	49*	-42

n of cases: 22 - 25, abbreviations see Tab. 3.3.3.2, level of significance: ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$; corresponding elements within soil organic layer and within foliage are encircled.

A combined multivariate treatment of foliar data along with soil and other plot related data is not appropriate due to the small overlap of data and the resulting reduction of cases. Therefore a matrix of bivariate correlation coefficients between crown condition and foliar element concentrations is given in Table 4.1.2.4. From this evaluation it can be concluded that high plot related mean defoliation values correspond significantly with low needle concentrations of phosphorous and potassium on one side and high sodium and manganese concentrations on the other side. Especially the co-occurrence of low foliar P concentration and high medium-term mean defoliation is a certain support of P deficiency as a consequence of high N inputs in Scots pine (MOHREN et al. 1986, HENDRIKS et al. 1997b).

Tab. 4.1.2.4: Matrix of bivariate correlation coefficients (PEARSON, x 100) between chemical foliar contents of *Pinus sylvestris* (columns) and crown resp. stand related parameters (rows) within pilot area 1.

	N	lnS	P	lnK	Ca	lnMg	lnNa	lnZn	lnFe	lnMn	lnCu	Al
ltXMDEF	-22	05	-56**	-45*	25	-14	48*	04	11	43*	18	-23
MSLODEF	06	-64***	-05	03	01	-66***	-13	-10	-54**	-20	-57**	-08
ltXMDISCO	26	41*	-12	-09	52**	30	43*	24	05	10	25	-33
AGE	09	22	-45*	-33	46*	-26	43	36	32	37	25	-38

n of cases: 25 - 22; XMDEFOL: mean defoliation 1989 - 1998, MSLODEF: mean slope of defolation 1989 - 1998, XMDISCO: mean discoloration 1989 - 1998, AGE: age class; level of significance: ***: p ≤ 0.001, **: p ≤ 0.01, *: p ≤ 0.05.

Tab. 4.1.2.6: Matrix of bivariate correlation coefficients (PEARSON, x 100) between foliar element concentrations (*Picea abies*) for pilot area 2.

	lnS	P	K	lnCa	lnMg	Na	lnZn	lnFe	Mn	Cu	NG
N	50**	-32	24	30	17	-31	-00	23	08	07	04
lnS		-23	21	42*	-15	21	33	11	23	31	25
P			17	-07	46*	25	10	-36	-44*	-07	20
K				05	-06	-20	21	41*	-14	-02	28
lnCa					47**	11	33	-07	41*	-00	51*
lnMg						-02	06	-24	01	-29	20
Na							35	-18	11	27	19
lnZn								-07	13	32	39
lnFe									14	13	-18
Mn										-13	27
CU											02

n of cases: 24 -29, NG: dry mass of 1000 needles [g], level of significance: **: p ≤ 0.01, *: p ≤ 0.05.

Within pilot area 2, Norway spruce is the most important tree species, but only from 24 plots from Czech Republic and 5 plots from Germany foliar element concentrations are available. There might be species specific and area specific differences between the results from both pilot areas as shown by Table 4.1.2.6 in comparison to Tab. 4.1.2.1. Most striking is the lack of any correlation between heavy metals and sulphur contents, but instead S and Ca are positively correlated. This might be a hint on the combined emission of sulphur and basic cations due to the extensive combustion of base-rich coals within this area. Another difference is the positive correlation between S and N within spruce needles, which may reflect the often positive correlation between both components of air pollution (e.g. DE VRIES et al. 2000c). Like in pilot area 2, a significant positive correlation between Ca and Mg as well as Ca and Mn were also found by BECHER (1999) in current spruce needles within Schleswig-Holstein (Germany). Other correlation patterns are unique.
Since foliar data from pilot area 2 originate from two countries, simple bivariate correlations between foliar element composition and crown condition are not appropri-

ate. Therefore either a dummy variable for country would have additionally to be included or the calculations would have to be done separately for each country. Since an unbalanced distribution between both countries exists, only the Czech data have been evaluated.
Table 4.1.2.7 shows that for none of the foliar element concentrations any significant relationship with crown parameters of Norway spruce was found. Only the concentrations of Fe and Mn show a weak positive trend ($p \leq 0.10$) with the positive trend (= deterioration) of defoliation over time.

Tab. 4.1.2.7: Matrix of bivariate correlation coefficients (PEARSON, x 100) between chemical foliar contents of *Picea abies* (columns) and crown / stand related parameters (rows) and deposition for total nitrogen and acidity within the Czech part of pilot area 2.

	N	lnS	P	K	lnCa	lnMg	Na	lnZn	lnFe	lnMn	lnCu	Al
ltXMDEF	01	24	20	-29	14	30	23	-02	-31	-30	38	22
MSLODEF	-08	-17	-27	29	06	-23	-27	-04	40	40	-32	-22
ltXMDISCO	24	-22	22	22	-28	26	-34	14	-14	-39	06	-24
AGE	-06	-17	-17	-15	-30	-11	-16	19	-22	-15	08	02
ln (acidity)	-29	35	27	-02	28	08	43*	07	10	29	07	-01
nitrogen	-12	27	37	11	31	18	31	-12	10	15	-04	-01

n of cases: 24 - 21; ltXMDEF: logit mean defoliation 1990 - 1998, MSLODEF: mean slope of defolation 1990 - 1998, ltXMDISCO: logit mean discoloration 1990 - 1998, AGE: age class; level of significance: *: $p \leq 0.05$.

The relation between the foliar element concentration and the modelled deposition of air pollutants, again for the Czech part only is also given in Table 4.1.2.7. Only Na shows a significant correlation with total deposition of acidity, which cannot be interpreted conclusively. In spite of the strong modelled deposition gradient of acidity within pilot area 2 (comp. Fig. 3.3.6.1), no corresponding direct or indirect patterns of respective element concentrations within spruce needles could be found. Probably, the mountainous topography impedes air pollutants from a continuos spread according its modelled large-scale patterns, which can be recognised if the general high level of S needle concentration in pilot area 2 is compared to other regions (see Chapt. 3.3.4).
In how far foliar element concentrations are influenced by soil properties is given in Tab. 4.1.2.8. Only three elements reveal a more or less distinct correlation between their concentration within the organic soil layer and their respective concentration in spruce needles. In the case of the bi- or trivalent Mn the same result was also found for pine needles in pilot area 1 (Tab. 4.1.2.3). The other metals do not reveal any significant relationship. Different from pilot area 1, where soil calcium concentration is reflected by pine needle concentrations, within pilot area 2 magnesium concentration within the organic layer is reflected by spruce needles.
Obvious correlation patterns are given for nitrogen contents of spruce needles: A strong positive correlation exists between the total N concentration respective the concentration of organic carbon within the forest floor layer and the N concentration within needles. This points at a positive feed-back mechanism between needle N concentration and total N concentration of the organic layer. Concurrently there is a negative relationship between C_{org} resp. N_{tot} in both mineral soil and the N concentration in the spruce needles. Additionally cation exchange capacity of the mineral soil layer is also negatively correlated with nitrogen contents. Up to now, no conclu-

sive interpretation for this distinct differentiation between forest floor and the upper mineral soil layer with respect to foliar N concentration can be given.
Concentrations of sulphur within needles show almost equal patterns of relationships towards S needle concentrations. For sulphur additionally low pH values in all horizons are correlated with high S concentrations in needles. At least this finding suggests that soil acidification within this region could be related to S inputs in spite of the missing significant correlation between modelled deposition and S foliar contents mentioned above.

Tab. 4.1.2.8: Matrix of bivariate correlation coefficients (PEARSON, x 100) between foliar chemical contents of *Picea abies* (rows) and soil parameter (lines) of pilot area 2.

	N	lnS	P	K	lnCa	lnMg	Na	Zn	Mn	lnFe	CU	NG
WATERAV	01	-08	-17	-02	05	08	06	-27	32	21	-12	-33
ORGLAY	-01	26	02	-19	03	-02	23	10	-21	-48**	-09	-02
lnPH_0	-01	-46*	08	-15	11	35	-25	-22	21	-04	-18	27
lnPH_01	-36	-51**	30	-09	-12	25	-16	-44*	03	-03	-12	18
lnPH_13	-24	-44*	25	-06	-03	29	-15	-39*	12	12	-30	02
lnBASE_01	01	17	24	-08	50**	37*	-06	-15	-01	-00	-14	11
lnBASE_13	-13	07	21	-10	29	28	-04	-14	-10	04	-04	-19
lnBCE_01	-27	-22	20	-21	22	20	-14	-29	-14	-05	-11	-16
lnBCE_13	-35	-13	29	-25	15	23	01	-22	-22	-11	-03	-28
lnCEC_01	-46*	-51**	09	-26	-22	-07	-13	-28	-11	-26	01	-48*
lnCEC_13	-58**	-42*	27	-45*	-16	04	09	-27	-32	-33	01	-32
CORG_0	60***	26	-23	-05	23	25	-24	-06	-09	-02	01	07
CORG_01	-58**	-57**	19	-31	-56**	-24	01	-09	-46*	-19	-01	-23
CORG_13	-48**	-58**	19	-34	-51**	-11	-09	-36	-55**	-10	-03	-28
N_0	64***	21	-18	14	27	30	-39*	11	-08	21	11	29
lnN_01	-61***	-73***	26	-19	-57**	-15	-05	-37	-31	-07	-14	-40
lnN_13	-59***	-71***	30	-30	-48*	-07	04	-42*	-37*	09	30	-10
lnP	-17	07	10	-20	22	33	11	09	06	08	-02	-35
lnK	35	55**	-24	25	33	-08	-14	24	08	23	21	-07
lnCa	11	-32	20	-01	36	56**	-39	-10	08	-08	-29	35
lnMg	-12	-11	28	-13	11	37*	-13	-01	-09	-01	-02	-02
lnZn	-21	-14	-12	21	-06	-12	-26	11	-07	24	-15	-00
lnMn	-21	-43*	-06	-05	16	14	-22	-16	55**	18	-34	22
lnFe	-48**	-04	03	08	01	-07	-01	09	13	24	-02	-14
lnCu	-53**	-03	03	07	03	-11	23	10	08	15	05	-04
lnAl	04	39*	07	25	08	02	21	21	-05	-01	22	-14
lnPb	-13	18	-25	26	-06	-28	-01	27	-22	03	16	-12

n of cases: 24 - 29, abbreviations see Tab. 3.3.3.2, level of significance: ***: $p \leq 0.001$, **: $p \leq 0.01$, *: $p \leq 0.05$; corresponding elements within soil organic layer and within foliage are encircled.

Higher magnesium concentrations in spruce needles occur on soils with higher base saturation, as observed for pine needles in pilot area 1. In Norway spruce of pilot area 2 this is also the case for calcium. Concentrations of both elements are reflected by the Mg nutrition of needles. The reason for the adverse relationships between C_{org} and N_{tot} in the mineral soil layer and Ca concentration in needle remains unclear. Similar statistical behaviour was found for zinc and manganese.

4.2 Results of Principal Factor Analysis

4.2.1 Relationships among Soil Parameters within Pilot Area 1

Within pilot area 1, for 46 plots with either *Pinus sylvestris* or *Quercus robur et petraea* a set of 20 chemical soil parameters is available to perform a principal factor analysis. One oak plot (number 283) revealed very deviant chemical soil data and is excluded as an outlayer. Concentration data of heavy metals are omitted due to too many missing values.
Table 4.2.1.1 gives the resulting rotated score patterns. A distinct and comparatively well interpretable structure with 8 independent factors was obtained from the original 20 soil parameters. The first factor explains 21% of the total variance and is mainly determined by organic carbon concentration in the upper mineral soil layer. Closely related to it is the concentration of nitrogen in the same layer. Since this coupling of C_{org} and N is a general feature throughout all analyses within both pilot areas (see also DE VRIES et al. 2000c), it can be stated that most of the content of total nitrogen is to a large extent bound to the organic substance and may become available only after its mineralisation (see DE VRIES et al. 1998: 69).

Tab. 4.2.1.1: Pilot Area 1: Loadings (standardised regression coefficients) of the soil variables on the rotated (varimax) principal factors (factor patterns, F1 - F8) for all plots stocked with *Pinus sylvestris* and *Quercus robur et petraea.*

	F1	F2	F3	F4	F5	F6	F7	F8
explained variance	3.39	2.45	2.33	2.26	1.76	1.66	1.26	1.05
rel. expl. var. [%]	21	15	14	14	11	10	8	6
Corg_01	0.93							
ln_N_01	0.88							
ln_CEC_01	0.85							
ln_BCE_01	0.62		0.51					
ln_**N_13**		0.85						
Corg_13		0.81						
ln_CEC_13		0.77						
ln_**Base_13**			0.91					
ln_BCE_13			0.80					
ln_Base_01			0.60					
ln_**Ca_0**				0.92				
ln_Mg_0				0.90				
N_0					0.83			
Corg_0					0.74			
ln_pH_0			0.51			0.72		
ln_Orglay						-0.71		
ln_pH_01						0.57		
ln_**K_0**							0.78	
ln_**pH_13**								0.67
ln_P_0								

n = 45, outlayer plot 283 excluded, abbreviations see Tab. 3.3.3.2; for clearness only scores > |0.5| are given (F9 (expl. Var. = 0.46) has been omitted); total variance = 16.40, KAISER's measure of sampling adequacy (over-all MSA) = 0.60.

Soil factor 2 explains another 15% of the total standardised variation. It is mostly loaded by concentrations of total N and organic C of the lower mineral soil. This indicates with respect to mineralisation processes a distinct differentiation between 0 - 10 cm and 10 - 30 cm soil depth. The positive correlation of cation exchange capacity with the respective factors may indicate that a considerable amount of the CEC might be bound to the organic matter within the mineral soil. Figure 4.2.1.1 illustrates the relations of all available soil parameters to the first two rotated principal factors. Besides exchangeable basic cation concentrations of respective soil depths being slightly positively correlated to factor 1 respective factor 2, it becomes obvious that especially the pH values are slightly negatively correlated with the respective factors. This is also plausible, since low pH may decelerate mineralisation processes and promote humus accumulation.

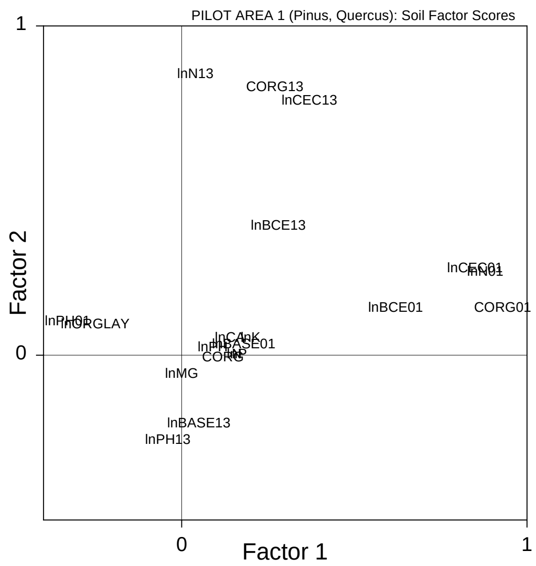

Fig. 4.2.1.1: Pilot Area 1: Scores of the original soil parameters with respect to factor 1 and factor 2 of the PCA for all plots with *Pinus* and *Quercus*.

Rotated principal factor 3, explaining another 14% of the total variance, characterises the base status of both mineral soil depths, but pH of the organic layer is also related to this factor. Factor 4 is highly loaded by Ca and Mg concentrations of the organic layer. The remaining factors explain a decreasing amount of the total variance, but can still be interpreted coherently. The loadings of factor 5 indicate that the concentrations of organic C and total N are also intercorrelated within the organic layer. The pH of the organic and surface mineral soil layer are related to each other and determine both in a negative way the weight of the organic layer (factor 6). Again, a decelerated mineralisation rate at low pH values delivers a plausible explanation. Potassium concentration and pH in the subsurface mineral soil load on separate factors each, indicating that they are uncorrelated to the other parameters. Finally, the concentration of phosphorous in the organic layer does not contribute significantly to any of the factors of the model.
Many approaches characterising soil properties, use different ratios of element concentrations (e.g. RIEK & WOLFF 1999). The limited number of plots within pilot area 1 prohibits any extensive use of such ratios as predictors. Therefore, only the generally accepted C/N ratios of the forest floor (organic layer) and the upper mineral soil layer are tentatively introduced into factor analysis. This ratio is often taken as an indicator of the N status (e.g. GUNDERSEN et al. 1998). The result is presented in Tab. 4.2.1.2. The overall factor structure strongly resembles the one from the analysis without the C/N ratios. The C/N ratio of the mineral surface layer is strongly correlated with carbon and nitrogen contents of the forest floor (factor 5 in Tab. 4.2.1.2) and not with one of its original parameters. This points at a certain dependency of the nitrogen and carbon status of the mineral soil from the respective status and dynamics within the forest floor. The C/N ratio of the organic layer, however, loads its own factor 6.

But this factor is also negatively loaded by total N of the organic layer. This structure is a result of a positive covariation between carbon and nitrogen contents of the organic layer, which leads to a comparatively independent C/N ratio. A negative aspect of this run is the low total of KAISER's measure about sampling adequacy, which is with 0.5 on its absolutely tolerable minimum (SAS 1990). This is a consequence from the fact that the C/N ratio is not strongly related to any of the other soil parameters, as predicted by conventional soil models. The resulting factors from this model have not been used in later approaches.

Tab. 4.2.1.2: Pilot Area 1: Loadings (standardised regression coefficients) of the soil variables on the rotated (varimax) principal factors (factor patterns) for all plots (pine and oak except outlayer plot 283); the C/N ratios of the organic layer (C/N_0) and the upper mineral soil layer (C/N_01) have been included.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
explained variance	3.54	2.41	2.37	2.34	2.01	1.85	1.62	1.11	1.03
rel. expl. var. [%]	18	12	12	12	10	10	8	6	5
Corg_01	0.93								
lnN_01	0.90								
lnCEC_01	0.87								
lnBCE_01	0.64		0.53						
ln**N_13**		0.85							
Corg_13		0.82							
lnCEC_13		0.76							
ln**Base_13**			0.92						
lnBCE_13			0.79						
lnBase_01			0.63					0.51	
ln**Ca_0**				0.93					
lnMg_0				0.91					
Corg_0					0.95				
C/N_01					0.73				
N_0					0.50	-0.82			
C/N_0						0.88			
lnpH_0				0.50			0.74		
lnOrglay							-0.65		
lnpH_01							0.64		0.76
ln**pH_13**								0.69	
ln**K_0**									
ln**P_0**									

n = 45, abbreviations see Tab. 3.3.3.2; for clearness only scores > |0.5| are given (F10 - F12 (expl. Var. = 0.40, 0.35, 0.29 resp.) have been omitted); total variance = 19.32, KAISER's measure of sampling adequacy (over-all MSA) = 0.50.

Another more general question is, whether to use all plots stocked with Scots pine and oaks in a combined approach or to keep the plots stocked by *Pinus sylvestris* separately. In the first case, soil properties influenced by stocking are necessarily integrated, in the second case effects from broad-leaved trees on soil properties are much less pronounced and are only based on different percentages of admixed broad-leaved specimens within the considered pine stands.

To check whether the influence of broad-leaved species is reflected by any of the soil parameters, logit-transformed Scots pine to oak ratio was regressed against soil parameters. Bivariate correlation coefficients of 0.28 resp. -0.29 ($p = 0.05$) with C_{org} resp. N_{tot} of the organic layer were found. However, if all the other soil parameters are considered, a partial correlation coefficients of 0.79 resp. -0,66 points to the fact that an increasing share of pine trees is accompanied with an increasing amount of

C, accumulated within the organic layer and a decreasing concentration of nitrogen. This interrelations become even more distinct if the C/N ratio is regressed against the pine/oak ratio. A highly significant correlation coefficient of 0.59 (R^2 = 0.35) characterises this relation (Fig. 4.2.1.2) and indicates an influence of tree species composition on humus and soil properties within pilot area 1.

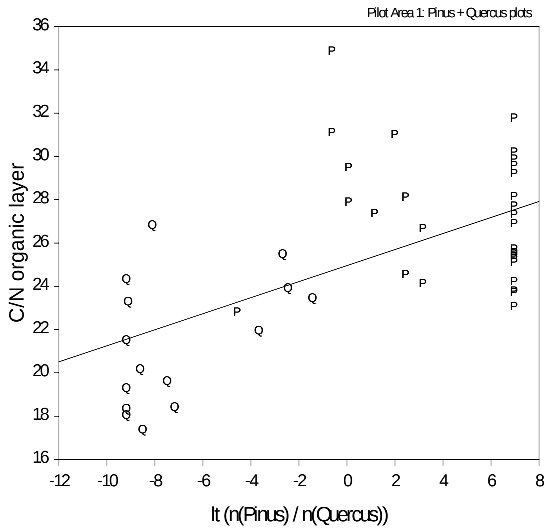

Fig. 4.2.1.2: C/N ratio of the organic layer against the logit transformed pine/oak ratios (tree data from 1998, n = 45, r = 0.59); P: predominantly Scots pine, Q: predominantly pedunculate or sessile oak; other species were not considered

Tab. 4.2.1.3: Pilot area 1: Loadings (standardised regression coefficients) of the soil variables on the rotated (varimax) principal factors (factor patterns) for all plots with *Pinus sylvestris*.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
explained variance	3.59	2.63	2.62	2.37	2.08	1.49	0.86	0.80	0.70
rel. expl. var. [%]	21	15	15	14	12	9	5	5	4
Corg_01	0.92								
lnCEC_01	0.89								
lnN_01	0.87								
lnBCE_01	0.63		0.60						
Corg_13		0.83							
lnN_13		0.83							
lnCEC_13		0.83							
ln**BCE_13**			0.84						
lnBase_13		-0.41	0.84						
lnBase_01			0.74						
ln**Ca_0**				0.92					
lnMg_0				0.91					
Corg_0					0.92				
N_0					0.89				
lnpH_0				0.53		0.72			
ln**Orglay**						-0.69			
lnpH_01	-0.44					0.59			
ln**K_0**							0.72		
ln**P_0**								0.70	
ln**pH_13**									0.58

n = 34, abbr. see Tab. 3.3.3.2; for clearness only scores > |0.4| are given (F10 (expl. Var. = 0.34) has been omitted); total variance = 17.36, KAISER's measure of sampling adequacy (over-all MSA) = 0.55.

Results from multiple regression models and other multivariate approaches of other authors indicate that only species specific approaches gain reasonable results so far

(SEIDLING 2000). For that reason it is worthwhile to have soil related principal factors only from those plots, stocked with *Pinus sylvestris* (a separate treatment of oak plots is not appropriate due to the low number of cases). This analysis could be performed with a total of 34 plots. The result is summarised in tabular 4.2.1.3. The outcome differs only in some minor aspects from the model which includes pine and oak plots (Tab. 4.2.1.1) and supports the consistency of the principal factor models and of the soil data within pilot area 1.
A model for the pine plots with the inclusion of C/N ratios clearly failed with 0.43 the over-all MSA criteria. The weakest single MSA values are calculated for C_{org}, N and C/N of the forest floor, indicating its close internal dependencies. This principal factor model was therefore excluded from further analyses.

4.2.2 Relationships among Soil Parameters within Pilot Area 2

The soil data from the plots within pilot area 2 stocked with Scots pine or Norway spruce were subject to the same type of principal factor analysis as the plots from pilot area 1. In a first approach all plots stocked with specimen of one or both focal tree species were analysed. Table 4.2.2.1 summarises the results.

Tab. 4.2.2.1: Pilot Area 2: Loadings (standardised regression coefficients) of the soil variables on the rotated (varimax) principal factors (factor patterns) for all plots stocked with either *Picea abies* or *Pinus sylvestris*.

	F1	F2	F3	F4	F5	F6	F7
explained variance	3.94	2.52	2.29	1.83	1.72	1.70	1.57
rel. expl. var. [%]	25	16	14	11	11	11	10
Corg_13	0.86						
lnN_01	0.85						
lnN_13	0.84						
Corg_01	0.84						
ln**Base_13**		0.86					
lnBase_01		0.86					
lnBCE_13		0.69	0.56				
lnBCE_01		0.57	0.63				
ln**CEC_01**	0.53		0.80				
lnCEC_13	0.59		0.71				
lnMg_0				0.81			
ln**P_0**				0.65			
ln**pH_13**					0.82		
lnpH_01					0.79		
Corg_0						0.85	
lnN_0						0.84	
ln**pH_0**							0.77
lnCa_0							0.75
lnK_0							

n = 96; for clearness only scores > |0.4| are given (F8 (expl. Var. = 0.35) has been omitted); total variance = 15.93, KAISER's measure of sampling adequacy (over-all MSA) = 0.64.

The first factor expresses 25% of the total variance and is highly loaded by organic carbon concentrations of the upper and lower mineral soil and the respective nitrogen concentrations. In contrast to pilot area 1, no strict differentiation exists between the organic substance within the mineral soil of the surface and the subsurface mineral soil layer. Cation exchange capacities of both mineral soil layers load also considerably onto the first axis. This again demonstrates some similarity with the factor struc-

ture of soil parameters within pilot area 1: a certain amount of the CEC seems to be delivered by the organic substance within the soils. However, it is supposed to be a general feature of pilot area 2 that - in difference to pilot area 1 - there is no distinct differentiation between both depths of the mineral soil. This might be due to higher turbation rates of substances in this mountainous region, probably due to heavier erosion processes in comparison to the rather flat orography of pilot area 1.
Factor 2 is loaded mainly by base saturation and the concentration of exchangeable basic cations, again in both mineral soil layers. The 3rd independent axis is determined by cation exchange characteristics, mainly of the upper mineral soil layer. The 4th axis is loaded by magnesium and phosphorous in the organic layer within both mineral soil layers, while the 5th factor is characterised by the pH of the two mineral soil layers. Concentration of organic carbon and again total nitrogen of the forest floor load on the 6th rotated factor, while calcium concentration along with pH of the organic layer load on the 7th factor. Potassium finally does not contribute to any of the relevant factors nor does it form a factor of its own.
If the parameter scores are plotted along with the plot related scores (bi-plot technique, TER BRAAK 1987) additionally denoted by country (Fig. 4.2.2.1), it becomes obvious that within pilot area 2, soil data differ systematically between countries. Plots from Germany and from Poland form distinct groups. The position within the graph indicates distinct lower organic carbon and nitrogen contents in both mineral soil layers within Germany compared with plots from the Czech Republic. It can however not decided, whether methodological or real differences have caused this 'country' specific distinction.

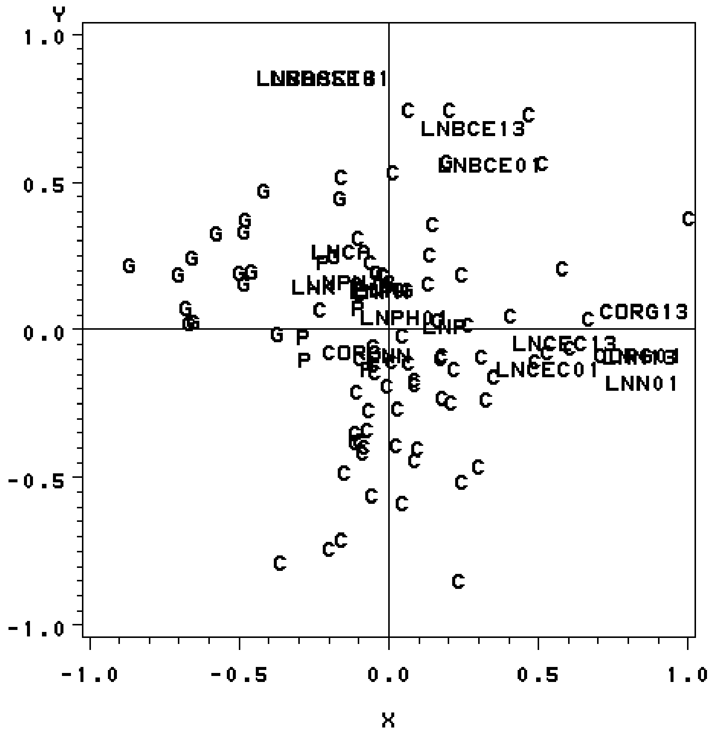

Fig. 4.2.2.1: Pilot area 2: Bi-plot of soil parameter scores of factor 1 against soil parameter scores of factor 2 for all *Picea* and *Pinus* plots combined with the scores of the sampling plots additionally denoted by country: C: Czech plots, G: German plots, P: Polish plots; X: Factor 1, Y: Factor 2.

If C/N ratios of the organic layer and the upper mineral soil layer are additionally introduced, they both load on own axis, like in pilot area 1. C/N ratios are only weakly negatively correlated with the N concentrations of the respective soil layers. Because C/N ratios are derived from C and N concentrations, their partial correlations to both original parameters are very high in comparison to their bivariate correlations. The

MSA values (KAISER's measure of sampling adequacy) of both ratios are therefore very low, which makes the inclusion of the ratios ambiguous in statistical terms. The respective table has therefore not been depicted.

If only those plots stocked by *Picea abies* are considered (Tab. 4.2.2.2), the resulting factor structure becomes even more distinct. Parameters describing the base supply of both mineral soil layers, load on the first factor, which accounts for 20% of the total variance. Another 20% load on factor 2 characterising the organic carbon and nitrogen concentration within both mineral soil depths. Within this model Mg, P, and K load together on the 3rd axis. The 4th factor represents cation exchange capacities of both mineral soil layers. The parameter compositions of the following factors are similar to those of the model which include pine and spruce plots together (Tab. 4.2.2.1), only the order of parameter groups are slightly deviant from the model above.

Tab. 4.2.2.2: Pilot Area 2: Loadings (standardised regression coefficients) of the soil variables on the rotated (varimax) principal factors (factor patterns) only for *Picea abies* plots.

	F1	F2	F3	F4	F5	F6	F7	F8
explained variance	3.28	3.28	2.02	1.97	1.73	1.70	1.63	0.45
rel. expl. var. [%]	20	20	13	12	11	11	10	3
ln**Base_01**	0.93							
lnBase_13	0.90							
lnBCE_13	0.82							
lnBCE_01	0.80			0.42				
Corg_13		0.87						
Corg_01		0.82						
lnN_13		0.82						
lnN_01		0.79						
ln**Mg_0**			0.79					
lnK_0			0.76					
lnP_0			0.70					
lnCEC_01				0.83				
lnCEC_13		0.43		0.76				
ln**pH_13**					0.84			
lnpH_01					0.76			
ln**pH_0**						0.82		
lnCa_0						0.78		
Corg_0							0.83	
ln**N_0**							0.82	

n = 72; for clearness only scores > |0.4| are given; total variance = 16.06, KAISER's measure of sampling adequacy (over-all MSA) = 0.60.

Within pilot area 2, only 29 pine plots are available, which is comparatively limited. The model of the respective soil specific principal factor analysis concentrates 24% of the total variance on the first axis, which is loaded by 7 original parameters, related to the amount of organic substances within both mineral depths, the cation exchange capacities and even the concentration of basic cations within the subsurface soil layer. The second rotated principal factor is correlated to pH, concentrations of magnesium, calcium, phosphorous within the forest floor and even the base saturation of the mineral is partly loading on this factor. The third factor covers mainly nitrogen and organic carbon of the organic layer, while the 4th factor represents pH values of both mineral layer. The patterns of the remaining factors are less clear. Only base saturation of both mineral layers dominates factor 6.

Tab. 4.2.2.3: Pilot area 2: Loadings (standardised regression coefficients ≅ correlations) of the soil variables on the rotated (varimax) principal factors (factor patterns) for all *Pinus sylvestris* plots.

	F1	F2	F3	F4	F5	F6	F7
explained variance	4.24	3.56	2.67	2.08	2.04	1.85	0.47
rel. expl. var. [%]	24	20	15	12	11	10	3

ln**N_01**	0.94						
lnN_13	0.92						
Corg_13	0.83						
Corg_01	0.73						0.44
lnCEC_13	0.62			-0.40			
lnBCE_13	0.55				0.49		
lnCEC_01	0.44				0.67	-0.42	
ln**pH_0**		0.88					
lnMg_0		0.85					
lnCa_0		0.72			0.42		
lnP_0		0.48	0.70				
N_0			0.93				
Corg_0			0.89				
lnK_0			0.82				
lnBCE_01			0.73		0.81		
ln**pH_01**				0.82			
lnpH_13				0.86			
ln**Base_13**						0.87	
lnBase_01		0.53				0.68	

(n = 29); for clearness only scores > |0.4| are given (F8 - F10 (expl. Var. = 0.36, 0.35, 0.19 resp.) have been omitted); total variance = 17.81, KAISER's measure of sampling adequacy (over-all MSA) = 0.57.

4.2.3 Relationships among Meteorological Parameters within Pilot Area 1

Within pilot area 1, for 46 Level I plots either stocked with Scots pine and/or pedunculate resp. sessile oak, a principal factor analysis was performed with interpolated and partly modelled of meteorological data (all averaged from 1985 to 1996). In Tab. 4.2.3.1 the resulting rotated principal factor patterns are given.

Tab. 4.2.3.1: Pilot Area 1: Loadings (standardised regression coefficients ≅ correlations) of the climatic variables on the rotated (varimax) principal factors (factor patterns) for all plots with *Pinus sylvestris* and/or *Quercus robur et petraea*.

	F1	F2	F3
explained variance	2.59	1.33	1.26
rel. expl. var. [%]	50	26	24
XTEMPR	-0.85		
XWINTER	0.81		-0.56
XLFROST	0.76	0.50	
MALFROST	0.72		
ln_**XHEAT**		0.74	
XPRECI			0.78
lt_XRELTR			

n = 46; only scores > |0.5| are given; total variance = 5.18, KAISER's measure of sampling adequacy (over-all MSA) = 0.63.

It is quite obvious that an overwhelming part of the total variance is concentrated on the first axis. This rather one-dimensional structure (Fig. 4.2.3.1) of the data becomes even more obvious if unrotated principal factors are regarded, where even 68% of the total variance is expressed by the first principal factor. This indicates the existence of a distinct climatic gradient with high intercorrelation of the meteorological parameters. This gradient is best represented by high values of the winter index and high mean temperature between the south-east region of the pilot area and vice versa for the north-western region (Fig. 4.2.3.2). This distribution of the values resembles the climatic gradient given by e.g. JÄGER (1968) with respect of oceanic influences onto deciduous forests.

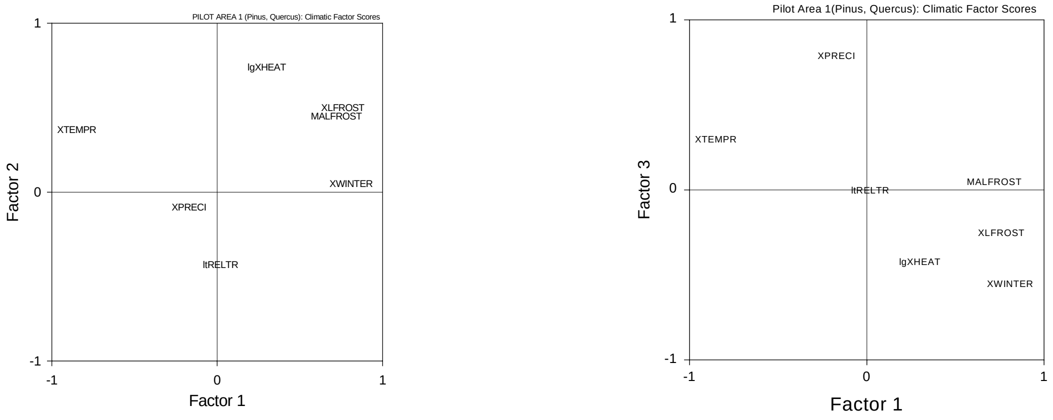

Fig. 4.2.3.1: Pilot Area 1: Scores of factor 2 against scores of factor 1 and scores of factor 3 against scores of factor 1 of the original meteorological parameters for all *Pinus* and *Quercus* plots (n = 46).

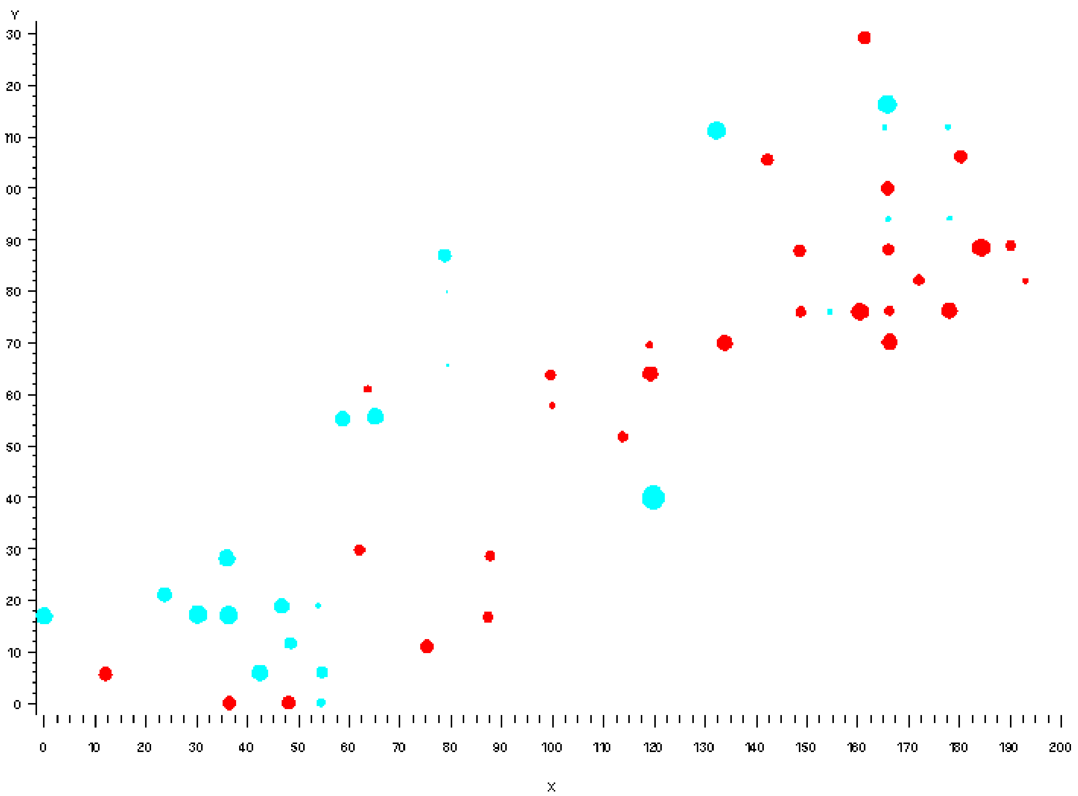

Fig. 4.3.2.2: Plot related scores of factor 1 within pilot area 1. Red (dark) bubbles represent positive and blue (light) bubbles negative values. Bubble area is proportional to the score. x-/y-position according to LAMBERT-azimuthal projection (1 unit = c. 2 km).

The highest scores on the first factor are reached by parameters closely related to the temperature regime of the plots. Mean annual temperature, mean winter index, mean late frost, and maxima of those events are all loading on the first principal factor. The second axis is dominated by temperature related parameters: The closest correlation shows the mean heat index and - correlated to it - the number of days with late frosts. On the third axis, explaining only another 12% of the total variance, only the annual precipitation is loading. The modelled mean relative transpiration rate as a potential indicator for climatic drought stress (calculated for the growing season according to HENDRIKS et al. 1997a: 225 ff.) does not significantly contribute to any of the axis.

4.2.4 Relationships among Meteorological Parameters within Pilot Area 2

Within pilot area 2, for 92 Level I plots stocked with Norway Spruce and/or Scots pine, a principal factor analysis was performed with the meteorological data. In Tab. 4.2.4.1 the resulting rotated principal factor patterns are given.

Tab. 4.2.4.1: Pilot Area 2: Loadings (standardised regression coefficients ≅ correlations) of the climatic variables on the rotated (varimax) principal factors (factor patterns) for all plots with *Picea abies* and/or *Pinus sylvestris*

	F1	F2	F3
explained variance	2.79	2.30	0.72
rel. expl. var. [%]	48	40	12
MALFROST	0.87	0.51	
XLFROST	0.83		
XTEMPR	-0.74	-0.54	
XWINTER	0.68		0.63
ln_**XHEAT**	-0.50	-0.81	
XPRECI		0.56	
lt_XRELTR		0.78	

n = 92; for clearness only scores > |0.5| are given; total variance = 5.18, KAISER's measure of sampling adequacy (over-all MSA) = 0.63.

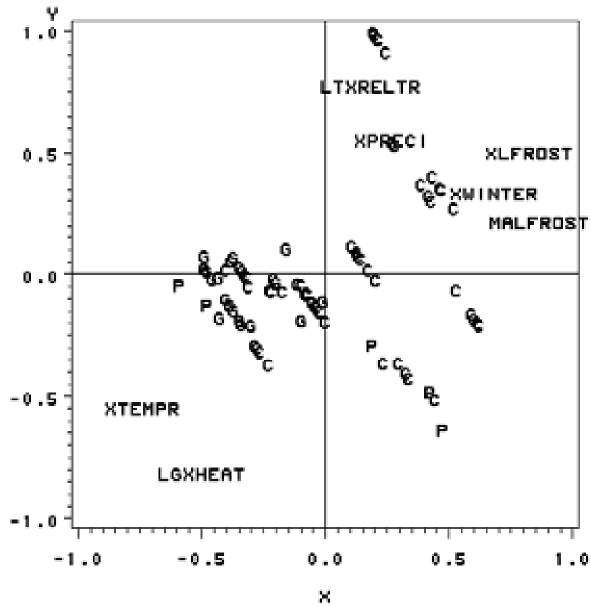

Fig. 4.2.4.1: Pilot Area 2: Scores of factor 2 against scores of factor 1 of the original meteorological parameters for all *Picea abies* and *Pinus sylvestris* plots (n = 92); additionally the scores of the plots are denoted; abbr.: C: Czech plots, G: German plots, P: Polish plots.

A intercorrelation structure different from those of pilot area 1 is obvious. This might be based on the fact that within this hilly and mountainous region altitude may have - besides the general climatic west-east gradient in Europe - a strong additional influence on the climatic situation. The first axis, explaining 48% of the total variance, is loaded by all temperature related parameters, while the second axis, explaining another 40% of the total variance, is also correlated with relative transpiration and mean precipitation. The main parameter, which determines factor 2 is however summer heat. The third factor expresses only 12% of the entire variation and is loaded alone by the winter index.

The different structures of meteorological factors of both pilot areas point at general differences of meso-scale modifications between a flat and a mountainous landscape. Climatic gradients are much more pronounced in a mountainous region with stronger windward and lee effects in comparison to flat regions.
Fig. 4.2.4.1 illustrates due to the clustered structure of the plot related scores that the these values might be biased by the interpolation routine of the meteorological data. This points at limitations of interpolated meteorological data especially for mountainous regions.

4.3 Relationships of Crown Condition

Following the hypothesis that degradation of forest soils, especially soil acidification, is one in a bundle of causes for poor crown condition of forest trees, statistical evaluations of medium-term means (1989 - 1998) of crown condition in relation to soil related factors have been carried out. Soil as a slowly reacting compartment of ecosystems can best be regarded within such medium-term to long-term approaches. Within this context, yearly and other short-term fluctuations are not focused at. Instead, influences from biotic agents or meteorological conditions are also regarded as medium-term means. This procedure does not generally contradict the short-time scale of such effects onto forest trees, because slow growing or unstable tree stands should potentially be more prone to infestations of insects or fungi (in this sense infestation rates by insects or fungi could also be seen as effect variables).
Two tree species occur in sufficient high numbers that multiple regression models could gain meaningful results. In the case of Scots pine (*Pinus sylvestris*) in total 34 plots are available, which would allow the introduction of a maximum of 8 variables within multiple regression models. For oaks (*Quercus robur, Q. petreaea*) only 16 plots are available. For these two species only very limited regression models are possible. Within pilot area 2, Norway spruce (*Picea abies*) is the most abundant tree species with data from a total of 65 plots. Scots pine is available from 29 plots within pilot area 2.

4.3.1 Scots pine (*Pinus sylvestris*) within Pilot Area 1

The multiple regression model for Scots pine was performed with a total of 14 predictors. This violates one of the preconditions of multiple regression analysis, but is tolerable within an exploratory context. The alternative would be a preselection of independent variables, which would arbitrarily exclude whole domains of ecological factors.
Table 4.3.1.1 presents the model results. Country effects explain almost 37% of the total variance (R^2, R^2_{adj}: adjusted for the degrees of freedom under the presumption that the sample represents a larger population). Age is the second important predictor explaining c. 14% of the total variance of defoliation, followed by the mean abundance of observed insect activities (5%). Another 3% of the variance is explained by the first soil factor. According to Tab. 4.2.1.3, it represents the concentrations of organic carbon and nitrogen in the upper mineral soil, the cation exchange capacity and the sum of basic cations. Due to the negative regression coefficient high values of these parameters partly coincide with lower defoliation values. Meteorological factors do not show any significant correlation nor does any of the other variables.

Tab. 4.3.1.1: Multiple regression model: Defoliation of *Pinus sylvestris* in pilot area 1.

dependent var.: ltXMDEF					
independent var.: C_DUM, exAGE, FSOIL1 - 5, WATERAV, ltINSECT, ltFUNGI, ltPFOCUS, D_NITRO, FCLIM1 - 3					
n of cases: 33					
resulting model (stepwise procedure)					
Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
C_DUM	0.365	0.365	0.345	0.0002	10.436
exAGE	0.144	0.509	0.477	0.0059	3.505
ltINSECT	0.047	0.556	0.510	0.0904	2.587
FSOIL1	0.034	0.591	0.532	0.1373	2.459
ltXMDEF = -4.231 + 0.768 C_DUM + 0.124 exAGE + 0.094 ltINSECT - 0.113 FSOIL1					

If the original soil parameters are used within a similar regression model, FSOIL1 is substituted by the amount of nitrogen in the upper mineral soil (nlN_01). It explains a slightly higher amount of variance (partial R^2 = 0.048) on the expense of a small reduction of the influence of insect infestations (partial R^2 = 0.036), and possesses a negative sign as well. Because nitrogen contents in the upper mineral soil layer is a constituent of the 1st principal factor this model confirms the above results. An additional inclusion of discoloration as further predictor did not result in a different model.
Country effects can be avoided by respective stratification. Due to the low number of pine plots in Flanders and The Netherlands only the German plots can be considered separately (Tab. 4.3.1.2). The result shows the same general predictor structure as the model above with an even better over-all fit. Age alone accounts already for more than 50% of the variation of defoliation and the influence of insect infestations as well as the negative influence of the 1st principal soil factor have both become more pronounced.

Tab. 4.3.1.2: Multiple regression model: Defoliation of *Pinus sylvestris* in pilot area 1, stratified according to country = Germany.

dependent var.: ltXMDEF					
independent var.: C_DUM, exAGE, FSOIL1 - 5, WATERAV, ltINSECT, ltFUNGI, ltPFOCUS, D_NITRO, FCLIM1 - 3					
n of cases: 22					
resulting model (stepwise procedure)					
Var	part R^2	model R^2	R^2_{adj}	prob>F	C(p)
exAGE	0.532	0.532	0.509	0.0001	12.126
ltINSECT	0.122	0.655	0.618	0.0298	6.246
FSOIL1	0.066	0.721	0.674	0.0541	4.000
ltXMDEF = -3.641 + 0.140 exAGE + 0.113 ltINSECT - 0.099 FSOIL1					

Statistical influences of country and age on crown condition are well known and expected. According to some studies done by RIEK & WOLFF (1999) and HENDRIKS et al. (1997b), age does not influence defoliation of Scots pine significantly. This might partly be due to narrow or strongly skewed ranges of stand age within the investigated samples of plots. The influence of mean activities of insects was not expected, but comparable studies rarely consider any indicators with regard to this cause of needle loss. Higher amounts of C_{org} and N_{tot} within the upper mineral soil can in ecological terms be interpreted as a consequence of higher bioturbation in soils with higher cation exchange capacities and higher concentrations of basic cations. Lower degrees of defoliation at those biologically more active sites are plausible.

Tab. 4.3.1.3: Multiple regression model: Trend of defoliation of *Pinus sylvestris* in pilot area 1.

dependent var.: SLODEF
independent var.: C_DUM, exAGE, FSOIL1 - 5, WATERAV, ltINSECT, ltFUNGI, ltPFOCUS, D_NITRO, FCLIM1 - 3
n of cases: 32
resulting model (stepwise procedure)

Var	part R^2	model R^2	R^2_{adj}	prob>F	C(p)
ltFUNGI	0.217	0.217	0.190	0.0073	5.402
FSOIL2	0.106	0.322	0.276	0.0418	2.886
exAGE	0.086	0.409	0.345	0.0529	1.208
FCLIM3	0.065	0.473	0.395	0.0796	0.449

SLODEF = -2.807 - 0.227 ltFUNGI + 0.419 FSOIL2 + 0.158 exAGE - 0.368 FCLIM3

outlayer plot no. 8137 has been omitted.

Trends of defoliation over time within pilot area 1 have also been investigated. According to Tab. 4.3.1.3 more than 20% of the total variation is negatively correlated to the infestation rate of fungi. Without a more sophisticated model including also the trends within the infestation rates of fungi this result cannot be interpreted conclusively. Why soils with higher contents of organic carbon and total nitrogen within the lower mineral soil tend to have increasing defoliation rates within the last ten years is unclear as well. Also the influence of age on the development of defoliation is difficult to understand. According to the result older stands tend to have a higher increase of defoliation than younger stands. This contradicts the general relationship between defoliation and crown condition shown in chapter 4.1. According to that, the foliage of younger stands should faster decrease than the foliage of older stands. If age is introduced as non-transformed variable, its influence on the slope of defoliation is even stronger (partial R^2 = 0.09), but the model is not generally altered. Also the negative influence of stronger winters on trends of defoliation is not plausible. On the whole the model with slopes of defoliation cannot be interpreted in a consistent ecological context. Similar to this result, regression models trying to explain differences in defoliation over time (e.g. KLAP et al. 1997), did also not gain conclusive results.

Discoloration is the second variable of crown condition, assessed within the monitoring network of Level I. Tab. 4.3.1.4 summarises the results with discoloration as effect variable. The predictor structure is quite different from that of defoliation. The 1^{st} meteorological factor, representing late frost events, high winter indices and low annual temperature, is the variable which explains alone more than 29% of the variance of discoloration estimates. The regression coefficient is negative, which means that warm winters (low winter indexes) resp. less late frost events on one side and generally high annual temperatures on the other side coincide with discoloured needles. Due to the intercorrelations among the meteorological parameters, it can not be decided which is the crucial cause. At the next two steps both country dummies are included, replacing the influence of the climatic factor (removed at step 4). In this case a distinct separation, whether different temperature regimes or methodological differences between countries are responsible for the spatial differentiation of discoloration cannot be decided without independent data on possible methodological differences of the assessment of discoloration between countries. Some additional variance is explained by the water availability rank and the 4^{th} principal soil factor. The positive regression coefficient indicates that increasing water availability is associated with increasing discoloration. This finding excludes the possibility of needle discoloration due to soil related dryness. In contrary, wet soils tent to promote discoloration. Considering inhibition of mineralisation process in wet soils, N deficiencies within needles can occur on wet soils and N deficiency is also a well known cause for needle yellowing. The positive influence of the 4^{th} soil factor, representing Ca and Mg concentrations in the litter layer, could only be explained conclusively, if calcareous soils would be in the range of this investigation. Since only acid soils are covered by the monitoring plots, this result remains unclear.

Tab. 4.3.1.4: Multiple regression model: Discoloration of *Pinus sylvestris* needles in pilot area 1.

dependent var.: ltXMDISCO
independent var.: CD1, CD2, exAGE, FSOIL1 - 5, WATERAV, ltINSECT, ltFUNGI, ltPFOCUS, D_NITRO, FCLIM1 - 3
n of cases: 33
resulting model (stepwise procedure)

Var	part R^2	model R^2	R^2_{adj}	prob>F	C(p)
FCLIM1 (-)	0.294	0.294	0.271	0.0011	8.780
DC1	0.109	0.403	0.364	0.0259	4.934
DC2	0.083	0.487	0.434	0.0382	2.469
remove FCLIM1	0.007	0.480	0.445	0.5455	0.823
WATERAV	0.094	0.574	0.530	0.0174	-2.183
FSOIL4	0.047	0.621	0.566	0.0732	-2.696

ltXMDISCO = -4.063 + 2.340 DC1 + 2.233 DC2 + 0.305 WATERAV + 0.299 FSOIL4

two independent country dummies (DC1, CD2) used, due to unclear ranking of countries according to discoloration; ():sign of regression coefficient of later removed predictor.

If the set of data is stratified according to country, again only German plots can tentatively be treaded. In this case water availability (partial R^2 = 0.27) and the 4th rotated principal soil factor (partial R^2 = 0.08) are the only significant predictors within this multiple regression model.

4.3.2 Oaks (*Quercus robur et petraea*) within Pilot Area 1

Within pilot area 1 a total of 16 oak plots is available. One was excluded as an outlayer. This low number of cases limits the applicability of multiple regression models severely. Therefore a more tentative model selection strategy was applied: From the list of available predictors those were chosen, which give the best one, two, three and four predictor models. Due to the low number of cases the routine was stopped at this point. There is of course a number of four predictor models which explain almost similar amounts of variance with different predictors, but these results cannot be considered to be stable. Principal soil factors from the combined Pinus/Quercus approach (Tab. 4.2.1.1) are used.

Principal soil factor 3 representing base saturation and cation exchange capacity in the lower and in the upper mineral soil layer, has a significant negative correlation with defoliation of oak trees. This indicates that soils richer in bases tend to have more leaves. Since it is mainly base saturation of the deeper mineral horizon which loads the third principal factor, higher natural base supplies might be the decisive factor. After the third soil factor, age explains another 28% of the variation of leaf loss in oak, which is in line with other findings. The second principal meteorological factor (mainly positively loaded by the summer heat index and late frost events) is the 3rd predictor introduced. According to this result, poor crown conditions are more common in colder rather than in warmer regions. The lower frequency of late frosts in these areas is not very plausible and contradicts the well known oak damages due to late frosts. The statistical positive influence of the 1st soil factor might be based on the same mechanism as in Scots pine: a low mineralisation rate in the upper mineral soil may lead to an accumulation of organic substances.

Tab. 4.3.2.1: Tentative multiple regression models with predictors from one ecological field: Defoliation of *Quercus robur et petraea* in pilot area 1.

dependent var.: ltDEFOL
independent var.: CD2, AGE, FSOIL1 - 5, WATERAV, ltINSECT, ltFUNGI, ltPFOCUS, D_NITRO, FCLIM1 - 3, FSOIL1 - 5
n of cases: 15

best one predictor model (maximised r)

Var	part R^2	model R^2	R^2_{adj}	prob>F
FSOIL3	0.200	0.200	0.138	0.0951

ltDEFOL = -1.651 - 0.152 FSOIL3

best two predictor model (maximised r)

Var	part R^2	model R^2	R^2_{adj}	prob>F
FSOIL3	0.200	0.200	0.138	0.0086
AGE	0.282	0.482	0.395	0.0253

ltDEFOL = -2.317 - 0.256 FSOIL3 + 0.152 AGE

best three predictor model (maximised r)

Var	part R^2	model R^2	R^2_{adj}	prob>F
FSOIL3	0.200	0.200	0.138	0.0019
AGE	0.282	0.482	0.395	0.0154
FCLIM2	0.141	0.623	0.520	0.0671

ltDEFOL = -2.303 - 0.345 FSOIL3 + 0.152 AGE - 0.154 FCLIM2

best four predictor model (maximised r)

Var	part R^2	model R^2	R^2_{adj}	prob>F
FSOIL3	0.200	0.200	0.138	0.0009
AGE	0.282	0.482	0.395	0.0275
FCLIM2	0.141	0.623	0.520	0.0090
FSOIL1	0.130	0.753	0.655	0.0442

ltDEFOL = -2.264 - 0.338 FSOIL3 + 0.121 AGE - 0.241 FCLIM2 + 0.166 FSOIL1

4.3.3 Norway spruce (*Picea abies*) within Pilot Area 2

Norway spruce is the dominating tree species in pilot area 2. A total of 66 plot could be evaluated. Because water availability ranks from plots in Poland are not available, this predictor has been omitted. Altitude has additionally been introduced because of complex climatic changes associated with it, which might not be covered by the available climatic variables like wind speed. As there is no consistent relationship between defoliation values and country over the whole period of observation (cf. Tab. 4.5.3.1), two independent country dummies were used.
The regression model (Table 4.3.3.1) assigns almost 35% of the variation to the country dummy, which denotes the general difference between the German and Czech plots. Age class explains another 11% of the variation of the effect variable. However, an objective differentiation between age and country effects is in this case not possible, because both are not independent.

Tab. 4.3.3.1: Multiple regression model: Defoliation of *Picea abies* in pilot area 2.

dependent var.: ltXMDEF
independent var.: CD1, CD2, exAGE, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3
n of cases: 66
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
DC1	0.346	0.346	0.336	0.0001	25.485

exAGE	0.109	0.456	0.439	0.0007	12.838
FSOIL4	0.044	0.500	0.475	0.0234	8.996
ALTITUDE	0.056	0.556	0.527	0.0071	3.444
FSOIL1	0.030	0.586	0.552	0.0408	1.407
DC2	0.019	0.605	0.565	0.0991	0.890
ltXMDEF = -2.031 +0.034 exAGE - 0.601 DC1 - 0.084 FSOIL4 + 0.033 ALTITUDE + 0.068 FSOIL1 + 0.342 DC2					

The 4th principal soil factor explains another 4% of the variation of defoliation, with a negative regression coefficient. This factor is loaded mainly by cation exchange capacities in both mineral soil layers. This result indicates that lower defoliation values partly coincide with soils rich in cation exchange capacity and to the amount of base cations in the upper mineral soil layer (compare Tab. 4.2.2.2). This reasonably relates poor crown conditions of Norway spruce to poor and possibly acidified soils. Altitude, the significant predictor selected next, can primarily be interpreted as a complex climatic factor. Not only the temperature and precipitation regime systematically alters with altitude, but also wind speed etc. It correlates positively with defoliation: with increasing altitude spruce is more defoliated, but the model is according to MALLOW's C(p) already over-specified. Soil factor 1, mainly loaded by base saturation (Tab. 4.2.2.2), explains another 3% of the defoliation. The positive sign of this relationship cannot conclusively be explained, as high base saturation partly coincides with high defoliation values. The second country dummy, denoting the differences between the Czech and Polish plots, explains only a diminishing amount of the variation of defoliation.

Tab. 4.3.3.2: Multiple regression model: Defoliation of *Picea abies* in pilot area 2; approach with consideration of country and discoloration.

dependent var.: ltXMDEF
independent var.: CD1, CD2, exAGE, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3, ltXMDISCO
n of cases: 66
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
DC1	0.346	0.346	0.336	0.0001	33.921
ltXMDISCO	0.145	0.491	0.475	0.0001	17.953
exAGE	0.111	0.602	0.583	0.0001	8.646
FCLI M2	0.030	0.632	0.608	0.0295	5.624
lgD-NITRO	0.023	0.655	0.626	0.0491	3.742
FSOIL4	0.017	0.673	0.639	0.0826	2.842
ALTITUDE	0.012	0.685	0.647	0.1360	2.764

ltXMDEF = -2.598 - 0.900 DC1 + 0.132 ltXMDISCO + 0.034 exAGE - 0.075 FCLIM2 + 0.197 lgD-NITRO - 0.065 FSOIL4 + 0.013 ALTITUDE

According to the literature discoloration is especially in Norway spruce often related to needle loss. Normally treated as a dependent variable, it was tentatively added as an independent variable in a model to explain defoliation (Tab. 4.3.3.2). The result shows a comparatively high correlation between discoloration and defoliation, which explains almost 15% of the variation of defoliation. Discoloration is of course not a real cause of defoliation processes, but can in spruce be seen as an accompanying or preceding effect. All other predictors, except age, stay below 4% of the explained variation and after the second climatic predictor has been introduced the model is over-specified according to MALLOW's C(p). The climatic factor represents precipitation and relative transpiration (positively) and the heat index (negatively, see Tab. 4.2.4.1). The negative regression coefficient indicates higher defoliation in dry and

hot regions, which is indeed plausible. The influence of the nitrogen deposition within the statistical model is very low (2% explained variance), but might be seen as a hint on possible effects. However, in general the explanatory power of the climatic, deposition and soil factors are comparatively limited within the model.
One alternative to tackle country effects is stratification according to country. From pilot area 2, only the Czech plots are available in a sufficient high number. The results of the respective model are given in Table 4.3.3.3. The most aggravating difference to the models above, is the fact that age does not play any significant role. This might largely be due to a comparatively narrow distribution of stand age of the Czech plots. Most of the variation of defoliation is explained by altitude and principal soil factor 4. Both are also part of the model shown by Tab. 4.4.1.1 supporting the already mentioned relations. Also the second principal climatic factor and the first soil factor have already been part of the models above.

Tab. 4.3.3.3: Multiple regression model: Discoloration of *Picea abies* in pilot area 2; approach only with Czech plots.

dependent var.: ltXMDEF, only Czech plots
independent var.: exAGE, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3
n of cases: 58
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
ALTITUDE	0.153	0.153	0.138	0.0024	4.707
FSOIL4	0.085	0.238	0.210	0.0165	0.835
FCLIM2	0.052	0.290	0.251	0.0520	-0.764
FSOIL1	0.033	0.323	0.272	0.1134	-1.059

ltXMDEF = -1.070 + 0.026 ALTITUDE - 0.040 FSOIL4 - 0.058 FCLIM2 + 0.040 FSOIL1

The usage of the trends of defoliation over 8 years (1990 - 1998), expressed by the mean slopes as effect variable, give comparatively weak models in terms of explained variance. The example in Fig. 4.3.3.4 shows that country effects are not among the significant predictors. The parameter explaining the trends of defoliation best, is the modelled nitrogen deposition. It is positively correlated to the trend of defoliation. It can be concluded that plots with high deposition rates have disapproved their foliage status from 1990 to 1998. In the last step nitrogen deposition is however substituted by the modelled deposition of total acidity, underlining the fact that deposition of nitrogen and total acidity are positively intercorrelated. Apart from deposition soil factor 3 explains almost 8% of the variance. This factor is positively loaded by magnesium, potassium and phosphorous (Tab. 4.2.2.2). Due to its negative regression coefficient, low concentrations of these elements in the forest floor coincide with an increase of defoliation. This could be interpreted as a distinct hint on a worsening of crown condition at sites poor of these elements. The positive regression coefficient of soil factor 4, mainly representing cation exchange capacity of the mineral soil, is not necessarily contradicting this result, since high values of CEC can also be due to high Al and H charges at the exchange. The positive regression coefficient of principal climatic factor 1 indicates an increase of defoliation from 1990 to 1998 in regions with a higher frequency of late frost events and/or reduced summer heat.

Tab. 4.3.3.4: Multiple regression model: Trend of defoliation of *Picea abies* in pilot area 2.

dependent var.: mSLODEF
independent var.: exAGE, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3
n of cases: 66
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
lgD_NITRO	0.148	0.148	0.135	0.0014	18.886
FSOIL3	0.076	0.224	0.199	0.0159	13.702
FCLIM1	0.044	0.268	0.233	0.0573	11.498
FSOIL4	0.033	0.301	0.255	0.0959	10.386
lgD_ACID	0.0295	0.3305	0.275	0.1093	9.585
remove lgD_NITRO	0.0032	0.327	0.283	0.5970	7.885
MSLODEF = -25.665 - 0.785 FSLOIL3 + 0.948 FCLIM1 + 0.531 FSOIL4 + 2.975 lgD-ACID					

Models with discoloration as effect variables are comparatively unstable. The effect variable itself has an unfavourably skewed frequency distribution (see Tab. 3.2.1). Table 4.3.3.5 shows the results of a respective run. After country dummy 1 (Czech - German differences), explaining 20% of the variance of discoloration, all substantial predictors explain less than 5%. Discoloration increasing with altitude is one of the most prominent and plausible results.

Tab. 4.3.3.5: Multiple regression model: Discoloration of *Picea abies* in pilot area 2; approach with consideration of country.

dependent var.: ltXMDISCO
independent var.: CD1, CD2, exAGE, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3,
n of cases: 66
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
DC1	0.204	0.204	0.192	0.0001	7.595
ALTITUDE	0.043	0.247	0.223	0.0622	5.827
DC2	0.053	0.300	0.267	0.0337	3.173
FCLIM1	0.028	0.328	0.284	0.1192	2.768
FSOIL2	0.024	0.351	0.297	0.1455	2.712
remove DC2	0.020	0.331	0.287	0.1742	2.500
FSOIL4	0.034	0.365	0.312	0.0776	1.517
FSOIL1	0.034	0.399	0.338	0.0737	0.564

ltXMDISCO = -5.653 + 0.894 DC1 +0.144 ALTITUDE + 0.325 FCLIM1 - 0.427 FSOIL2 - 0.260 FSOIL4 + 0.223 FSOIL1

4.3.4 Scots pine (*Pinus sylvesteris*) within Pilot Area 2

Scots pine is less abundant within pilot area 2, but a total of maximal 29 plots gives the opportunity of a general survey with multiple regression analysis.

The first variable in the model is the country dummy 1, representing the difference between Czech and German plots, however confounding with age has to be supposed, as will be seen a few steps later (Tab. 4.3.4.1). The next important predictor is soil factor 1, explaining an additional 14% of the variation of defoliation. Soil factor 1 includes for the pine plots all variables related to organic carbon and total nitrogen in both mineral soil layers (see Tab. 4.2.2.3). Additionally, cation exchange capacities in both soil depths and concentration of basic cations in the deeper mineral soil are loading to some extent on the 1st factor. Since the coefficient is positive, the result contradicts the respective finding for Scots pine within pilot area 1. Any causal explanation for that relationship cannot be given and the statistical model fall already short in terms of the MALLOW's criteria. After soil factor 2, representing Ca and Mg concentrations within organic layer has been introduced, country dummy 1 is removed from the model. Instead, age is taken into the model explaining an additional 7% of the variance. The introduction of soil factor 2 indicates that higher Ca or Mg concentrations are partly associated with lower defoliation values. However, the low partial correlation coefficient and the negative C(p) value prevents from any extensive interpretation. Different from Norway spruce, discoloration does not explain any additional amount of defoliation in Scots pine (model not shown).

Tab. 4.3.4.1: Multiple regression model: Defoliation of *Pinus sylvestris* in pilot area 2; approach with consideration of country. 2 outlayers (plot 8290 and 8356 from Germany) were excluded.

dependent var.: ltXMDEF
independent var.: DC1, DC2, AGE, ltPFOCUS, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3,
n of cases: 26
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
DC1	0.513	0.513	0.492	0.0001	2.911
FSOIL1	0.137	0.650	0.620	0.0063	-2.112
FSOIL2	0.038	0.688	0.646	0.1146	-2.067
remove DC1	0.031	0.657	0.627	0.1505	-2.460
AGE	0.070	0.727	0.690	0.0268	-4.034

ltXMDEF = -1.661 + 0.310 FSOIL1 - 0.189 FSOIL2 + 0.104 AGE

The trends of defoliation from 1990 to 1998 are mainly (positively) correlated with altitude. The already more pronounced defoliation in higher altitudes has hence even worsened. Additional parts of the variance of the trend is explained by the share of pine trees among the sample. This may indicate that monocultures of Scots pine show a more pronounced tendency towards higher defoliation values over the last ten years than mixed stands. Parallel approaches with other selection routines show however that both country dummies, climatic factors and altitude intermingle strongly with each other and a series of regression models with two or three predictors explain almost the same amount of variance.

Tab. 4.3.4.2: Multiple regression model: trend (slopes) of defoliation of *Pinus sylvestris* in pilot area 2; approach with consideration of country.

dependent var.: MSLODEF
independent var.: DC1, DC2, AGE, ltPFOCUS, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3,
n of cases: 26
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
ALTITUDE	0.448	0.448	0.425	0.0002	6.041
ltPFOCUS	0.109	0.556	0.518	0.0264	2.527

MSLODEF = -2.854 + 0.441 ALTITUDE + 0.248 ltPFOCUS

Mean discoloration in Scots pine reveals a distinct positive correlation with climatic principal factor 1, representing mainly cold winter temperature, late frosts and low average annual mean temperature. At the second step, a considerable country bias between the Polish and the Czech plots is found. In addition, soil factor 2, representing mainly pH, concentration of magnesium and calcium, gains high importance. Yellowing or browning of needles should be more pronounced on plots with higher amounts of these elements. On acid soils, on which this investigation is focusing, this cannot be interpreted congruently with general findings concerning needle discoloration. After inclusion of country dummy 1, denoting the difference between German and Czech plots, the climatic principal factor loses its significant contribution to the multiple regression model.

Tab. 4.3.4.3: Multiple regression model: Discoloration of *Pinus sylvestris* in pilot area 2; approach with consideration of country.

dependent var.: ltXMDISCO
independent var.: DC1, DC2, AGE, ltPFOCUS, ALTITUDE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, FCLIM1 - 3,
n of cases: 26
resulting model (stepwise procedure)

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
FCLIM1 (+)	0.316	0.316	0.288	0.0028	8.416
DC2	0.127	0.443	0.395	0.0313	4.755
FSOIL2	0.200	0.643	0.595	0.0020	-2.132
DC1	0.037	0.680	0.620	0.1333	-1.783
remove FCLIM1	0.024	0.657	0.610	0.2275	-2.737

ltDISCO = -4.491 + 4.594 DC2 + 0.701 FSOIL2 + 1.275 DC1

4.3.5 Discussion

Stepwise multiple regression is an effective method to depict the most important statistical relationships and has thus frequently been used within integrated studies on forest condition in Europe (SEIDLING 2000). Due to the substitution of soil related respective meteorological parameters by principal factors, the chances of confounding are minimised within these ecological domains. An over-all approach with all parameters put into one principal factor model failed, due to the low number of valid cases within both pilot areas and additionally, KAISER's criteria of sampling adequacy failed distinctively. The use of principal factors for separate ecological domains facilitates meaningful interpretations of the respective principal factors. In oak, a different selection routine within multiple regression was applied, because of the very low number of cases: The best one to four predictor models were searched.
The results with respect to defoliation show, with the exception of oak, a high statistical influence of the respective **country**. The use of a ranked country dummy saves one degree of freedom, but is only justified if the ranking is stable over the considered time period. Therefore only for defoliation of Scots pine within pilot area 1 this type of dummy was used. In all other cases two neutral dummies were applied if three countries were present. The most distinct country effect was found in Scots pine within pilot area 1. In this case, no confounding with any other known predictor was detected, but of course differences in forest management practices etc. can also influence crown condition and might be covered by "country effects". A considerable portion of the variation might be ascribed to methodological differences (e.g. DOBBERTIN et al. 1997, FERRETTI 1998). As will be shown in chapter 4.4, the influence of country is not necessarily constant over time. For the tree stands within pilot area 2, age obviously confounds with country. The stands of Norway spruce and Scots pine monitored within the Czech Republic are older than the average and do merely vary according to age class. Other international approaches (KLAP et al. 1997, 2000) have also detected influences of country in the same order of magnitude. Any transnational approach has therefore to cope with this constraint.
According to the results **age class** is the most important and most general 'real' predictor of defoliation. Age accounts between 7% of its variation (*Pinus sylvestris* in pilot area 2) and 35% (*Picea abies* in pilot area 2). Within pilot area 2, as already mentioned, some of the variance explained by age, might originate from other country specific peculiarities. In many studies, age has been found to be the most general

predictor of crown condition, but species and habitat specific differences may occur (e.g. NEULAND et al. 1990, THOMSEN & NELLEMANN 1994, GÖTTLEIN & PRUSCHA 1996, HENDRIKS et al. 1997b, KLAP et al. 2000). Also different kinds of stress may increase or accumulate with age (e.g. SOLBERG 1999). Therefore, interpretation of age as a predictor of defoliation is not a plain task. Some of the increase may be attributed to crown morphological features. In this context JALKANEN et al. (1994) report of a long-term reduction in the number of needle sets during the lifetime of Scots pine trees in England. An increasing degree of complexity and branch diameters of tree crowns may also contribute to older crowns, being or seeming less densely foliated.

All the other predictors do not reveal general importance for defoliation, independent of species and area, like age. Defoliation of Scots pine within pilot area 1 was found to be statistically positively dependent on **insect infestation** rate. Only MATHER et al. (1995) found insect damage also being a significant cause of needle loss in Scots pine, but most integrated studies done so far, did not include any comparable predictor. The indices on biotic agents used here, might be rough estimates of the abundance of leaf-eating insects or phytopathogeneous fungi, but no better data are available for Level I plots.

Higher defoliation values of Scots pine within pilot area 1 at sites with lower concentration of base cations, partly represented by principal **soil** factor 1, are conform with the soil acidification hypothesis (ULRICH et al. 1979, ULRICH 1986), but soil fertility in general may also coincide with base supply of the mineral soil. The higher amounts of organic carbon and total nitrogen within the upper mineral soil layer at those sites can be interpreted as an indicator for higher biological activities, related to different vertical gradients of decomposers (e.g. PONGE 1999). The result partly confirms RIEK & WOLFF (1999), who received significant correlations with negative regression coefficients between the share of damaged trees of Scots pine on non-calcareous sites and two principal factors, representing Ca and Mg concentrations/amounts in the mineral soil, base saturation and the amounts of N and C in the mineral soil (0 - 30 cm). For Scots pine within pilot area 2 soil related predictors show rather ambiguous or weak relationships with defoliation.

According to the regression model for Norway spruce in pilot area 2, high CEC in both mineral soil layers (FSOIL4) coincides with lower defoliation, while high base saturation and high concentrations of basic exchangeable cations (FSOIL1) is associated with higher defoliation values. These rather contradicting results are not confirmed by findings of other authors. GÄRTNER et al. (1990), HENDRIKS et al. (1994b), GÖTTLEIN & PRUSCHA (1996), and RIEK & WOLFF (1999) found, among other relationships, increasing defoliation in spruce in coincidence with low base saturation or pH in the mineral soil or in the organic layer. Only BECHER (1999) found a negative relationship between CEC and the amount of needles. Final interpretation of the results for Norway spruce in pilot area 2 seems difficult. MATERNA (1987) points out that a mixture of causes might be responsible for forest damages in Bohemia and Moravia. The positive relationship between altitude and defoliation corroborates older observations that spruce shows increasing degrees of crown damages in higher altitudes. Again a multitude of causes can be adduced. Above all, increasing climatic inclemency can be attributed to elevated sites, but ozone has also been shown to reach higher concentrations in higher altitudes (e.g. BAUMBACH & BAUMANN 1995, EWALD et al. 2000).

Regression models for oak attribute highest amount of explained variance to the principal soil factor 3, characterising base saturation and concentration of basic cations mainly in the deeper soil layer, but also to a less degree in the upper mineral soil. High base saturation coincides with lower defoliation. This finding is partly in agreement with results of NEULAND et al. (1990), who found high degrees of defoliation on dystric and spododystric cambisols from quarzitic sandstone. Also GÖTTLEIN & PRUSCHA (1996) found lower defoliation on soils with higher portions of clay and loam. Principal soil factor 1 (loaded by C_{org}, N_{tot}, CEC, BCE in the upper mineral soil) explains another 13% of the variance of defoliation in the four factor model. Because of the positive relationship with defoliation, this result contradicts the relation just mentioned, but the low number of plots and the herewith associated violation of statistical preconditions, limit the model. The same applies to the considerable amount of defoliation, explained by the principal climatic factor 2. Regions with colder summers or less late frosts should be more prone to show defoliation. This relationship contradicts general knowledge of ecological behaviour of oak, especially its well-known sensitivity against late frosts.

If discoloration was taken as a predictor for defoliation and is additionally introduced into the multiple regression models (applied only for coniferous tree species), discoloration was able to explain a considerable part of the variance of defoliation in Norway spruce, but not in Scots pine. Obviously, only in *Picea abies* a positive correlation between the two different features of crown condition exists. Different chloroses are known precursors of needle loss (e.g. HARTMANN et al. 1988). At least some of the browned or yellowed needles of spruces seem to end up with their death. This discoloration might in pilot area 2 partly be caused by acute damages due to episodic high air concentrations of SO_2, but a number of infections by fungi also begins with discoloration of needles. Since no correlation between deposition of acidity and defoliation nor discoloration was found, this conclusion must remain hypothetical.

Regression models, with trends of defoliation as effect variable were comparatively poor in terms of the amount of explained variance. However, the positive relationship between plot-related trends of defoliation in Norway spruce within pilot area 2 and nitrogen deposition is remarkable. It suggest a worsening of crown condition of spruce from 1990 to 1998 due to atmospheric inputs. Because of the tight positive relationship between deposition of nitrogen and total acidity, this correlation may at least partly be attributed to acidic deposits or even signify direct impacts onto spruce needles. Since trends of concentrations of air pollutants, especially SO_2, are rather decreasing within central Europe (WGE 1999), the last hypothesis is however poorly supported. The negative correlation with principal soil factor 3 (Mg, K, P in org. layer) is also in line with the proposed development of crown condition resulting from soil acidification processes. Positive correlation with principal climatic factor 1 (frequent late frosts, cold winters, low average temperature) points in the same direction as in Scots pine: Increase of defoliation in the colder parts of the area, which is mainly attributable to sites at higher altitudes.

In pine within pilot area 2 altitude is positively correlated with increasing trends of defoliation. Confounding with winter index and country effects may occur. The trend of defoliation was positively responding towards the share of pine trees within the samples. This indicates that pine trees in monocultures are more likely to have disproved their crown condition than in mixed stands. Differences between countries in trends of defoliation were not revealed, however, KLAP et al. (1997) found country effects in models with short-term trends or differences between defoliation values over time. For Scots pine within pilot area 1, no plausible relationships were found. Generally, the evaluation of medium-term trends (1989/1990 - 1998) has revealed some interesting results with respect to current discussions about worsening of crown condition.

Discoloration is one of the symptoms annually assessed during crown condition monitoring. The regression models generally show lower qualities in statistical terms compared with models with defoliation as effect variable. The only predictors with some overall relevance are country dummies explaining up to 21% of the variance of discoloration. At least some of this variance might be attributed to methodological differences between countries. Another predictor, which gain higher partial R^2 values, is in *Pinus sylvestris* within pilot area 1 the climatic factor 1. The regression is negative. Mild winters or lower gravity of late frosts resp. low mean annual temperatures should promote discoloration. Summer heat and processes associated to it like ozone production or climatic drought can therefore be excluded to be strong causal agents of discoloration for pine within pilot area 1. As this climatic variable is entirely replaced by the two country dummies, data about discoloration might also include methodological or other systematic differences between the three countries. Water availability with an explained variance of 9% is positively correlated with discoloration, but a negative C(p) value depreciate the model. Again soil born drought is not probable to promote discoloration, since Scots pine on wet sites is more prone to show discoloration. Due to the weak statistical significance, interpretation of the results should be done with care. For Scots pine within pilot area 2, the results concerning the influence of soil pH or Ca concentration cannot be interpreted in accordance with the knowledge about the behaviour of pine on acidic soils. Promotion of discoloration due to cold winters or late frosts is possible, however confounding with country may occur.

Discoloration of *Picea abies* in pilot area 2 shows a considerable country effect. The remaining significant predictors explain only small proportions of the variance, but increasing discoloration with higher altitude seems at least plausible. However, the real cause remains open. According to SOLBERG & TØRSETH (1997) the share of green needles of *Picea abies* in Norway is related to longitude, which might also be based on temperature effects. The remaining climatic and soil related predictors explain only small amounts of the variance (2.4 - 3.4%); any substantial interpretation should be avoided.

Other integrated studies with concern of discoloration are infrequent and relations with environmental factors detected are rather weak. For Norway spruce INNES & WHITTAKER (1993) found browning of older needles and yellowing of current and older needles unrelated to any of the available environmental parameter. Only browning of older needles and total discoloration was - along with needle loss - related to a composite 'ill-health index', which was related to deposition of NO_3, NH_4 and climatic, orographic and geographic parameters. However, these relationships were rather distorted. SOLBERG & TVEITE (2000) found a relation between the share of green needles and a site productivity index. RIEK & WOLFF (1999) got a significant correlation between discoloration and a high ratio of Mg amounts of the organic layer and Mg amounts within the total profile (org. layer plus mineral soil up to 30 cm), proposed as an indicator for an unstable Mg nutrition. Up to now, discoloration can not be explained easily and further research is needed.

4.4 Multiple Regression Models with Annual Assessments

For deciduous trees crown condition is a distinct annual phenomenon and for evergreens more or less partly. Leaves and needles are born annually, mainly based on last year's formation of primordia, which in turn is dependent on weather condition and other influences on the tree's total carbon gain like insect feeding. Needle retention in Pinaceae (conifers) is also dependent on a variety of current and probably historical environmental conditions.

The annually observed amount of needles or leaves should therefore show relationships to the actual weather conditions and the status of the insect and fungi activities. However, annual crown condition should also depend on more or less constant soil condition or average deposition rates. The detection of direct influences of air pollutants like SO_2 or ozone on the foliage might also be possible, but the spatial and temporal resolution of the deposition data are neither scaled adequately, nor do they allow simple conclusions on gaseous impacts onto leaves or needles.

4.4.1 Scots Pine (*Pinus sylvestris*) within Pilot Area 1

To describe the statistical relationships between weather conditions and biotic conditions of the current and previous year along with water availability, principal factors derived from chemical soil conditions, and stand parameters, multiple regression was performed with annual data. Country was considered by use of a ranked country dummy (approaches with two neutral country dummies did not achieve better results). As the series of meteorological data end up in 1996, only data from 1989 to 1996 were evaluated with the full set of independent variables; 1997 and 1998 are evaluated with a restricted set of predictors. Another limitation of the results is given due to the high number of predictors in comparison to the number of cases (26 : 33). The resulting models have therefore only orientating character and can by no means be taken for predicative purposes.
The results in Tab. 4.4.1.1 show some consistent patterns of statistical relationship. At first, a differentiation between the years 1989 to 1993 and from the year 1994 onward can be observed: In the first period there is only a slight influence of the ranked country dummy, which in the second period gains high importance. This is astonishing, because intercalibration courses, held in between, should rather promote tendencies towards mutual adjustments. Also the influence of age has become more pronounced in the last few years. The share of pine trees among the sample does not show a consistent correlation over time. In 1992 there was a positive regression coefficient with annual defoliation values, which might indicate expected negative influences from monocultures. However, for 1994 and 1997 negative relationships were found.
Among the soil related variables factor 5 keeps not only the most continual relationship to annual defoliation values, but achieves also the highest partial R^2 values (explaining 8 to 25% of the variance of the annual defoliation). This factor is highly positively loaded by organic carbon and total nitrogen in the organic layer (see Tab. 4.2.1.3). Pine trees stocking on soils with a organic layer rich in carbon and nitrogen, seem in a series of years be prone to higher defoliation values. Soils with high carbon and nitrogen content at the forest floor might be biologically rather inactive. Interestingly, this factor does not play a role within the general regression model with medium time averages of defoliation (chap. 4.3.1). Another predictor with three occurrences between 1989 and 1994 is soil factor 2. This factor denotes mainly organic carbon and nitrogen contents in the deeper mineral soil layer. It possesses negative regression coefficients, indicating lower defoliation values with increasing amounts of carbon resp. nitrogen. Higher organic carbon contents on fresh soils are indicative for a higher biological activity (bioturbation), but the statistical signal might be too weak to draw far-reaching conclusions. Some of the remaining soil factors exhibit significant statistical relationships only in single years and might not have much importance.

Tab. 4.4.1.1: Multiple regression series 1989 - 1998 without auto-correlation for *Pinus sylvestris* within pilot area 1; effect variable: mean annual defoliation.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
C_DUM	13 (+)	7 (+)	13 (+)	10 (+)		31 (+)	35 (+)	47 (+)	30 (+)	38 (+)
EXAGE			4 (+)				4 (+)	12 (+)	33 (+)	23 (+)
ltPFOCUS				10 (+)		4 (-)			8 (-)	
FSOIL1										
FSOIL2	13 (-)		10 (-)			5 (-)				
FSOIL3										4 (-)
FSOIL4			7 (-)							
FSOIL5		12 (+)			24 (+)	15 (+)	13 (+)		8 (+)	
WATERAV						5 (-)				
D_NITRO					8 (+)					
ltINSECT								4 (+)		
ltINSECT -1			12 (+)		6 (+)	9 (+)		10 (+)		4 (+)
ltFUNGI		24 (-)			7 (+)					
ltFUNGI -1										
TEMP	6 (-)		4 (+)							
TEMP -1										
HEAT							5 (-)			
HEAT -1			27 (+)							
WINTER	11 (-)									
WINTER -1					15 (+)					
LFROST										
LFROST -1			4 (+)		6 (+)					
PRECIP										
PRECIP - 1				5 (-)						
RELTRA		9 (+)								
RELTRA -1				17 (+)						
model R^2	43	52	81	43	66	68	57	73	78	68

n = 32 - 33, suffix -1: value of the previous year (delayed effects), numbers give partial R^2 values, in brackets the respective sign of the regression coefficient is given; max. sign. level: 0.10; 1997 and 1998 meteorological data not available.

Spatial differentiation of long term atmospheric nitrogen input do only play a minor part in one year within the models to explain annual defoliation. Since modelled deposition rates fluctuate synchronously at all plots within pilot area 1, calculations with temporally resolved deposition data would not deliver substantially different results.

Among the biotic factors the most continuos influence on annual defoliation values emanates from insect observations of the previous year. Since there is no specification of the involved insects, no further conclusions on the cause-effect relations can be drawn, but in 5 from 10 years a considerable amount of variance is explained by this rather crude estimate of insect activities. In only one year a weak correlation between actual activities of insects seems to influence needle mass directly. These results do not only confine the finding in the general model with medium-term means in chapter 4.3.1, were 'insects' also gains some relevance, but specifies them in so far that delayed effects are of great importance. The results concerning fungi are not consistent and in one year are even contradicting expectations.

The statistical influence of weather conditions of the current or previous year on annual defoliation values are of comparatively sporadic nature and not always consis-

tent with expectations. For instance, in 1989 regions with lower winter temperatures (high winter index) coincide with regions with low defoliation, which cannot be interpreted on the background of the general ecological behaviour of Scots pine. In the same year there is a negative statistical influence of temperature on defoliation. This weaker statistical signal would indicate better defoliation in warmer years. Since annual mean temperature within Europe is mainly determined by winter temperature, this result partly contradicts the just mentioned statistical relationship. Two years later in 1991 the opposite was found. Also in 1991 there is a strong statistical influence of the heat index of the previous year 1990. As this is a spatially differentiated approach, in areas with high summer temperatures in the previous year higher defoliation rates are observed in the following, which is consistent with expectations. In the same year the late frost index of the previous year explains also some of the variance, but the result is due to its low partial R^2 value not very convincing.
In most parts of Europe, the summer 1992 was hot and dry. Especially for this year the correlation structure is obviously poor. Why relative transpiration of 1991 gains the highest amounts of explained variance on the whole, is entirely unclear. At least, the regression coefficient should have been negative in order to cope with expectations. As it is, the result can only be interpreted as a typical case of a specious correlation. In 1993 some influences of the 1992 drought would be expected, but there is considerable influence of cold winter temperature from 1992 and late frost events also from 1992. Although this statistical relationships are ecologically meaningful (cold winter and late frosts should enhance defoliation) but there is no obvious reason for the delayed effect. In the years after 1993 meteorological factors are almost excluded from the multiple regression models.
The inconsistent behaviour of the meteorological data with respect to annual defoliation of Scots pine does not necessarily reflect the absence and ineffectualness of climatic stress. It is to expect that its role within the dynamics of crown condition will become evident only in true time series analysis. Reasons are: 1) Trees are adapted to the local climate, therefore spatially differentiated models are generally less efficient to discover climatic stress. 2) Meteorological conditions do spatially differ to a lesser extent on spatial scales of a few hundred kilometres. The main differentiation is expressed along the time scale.

Besides ecological factors influencing tree crown condition, it is to suppose that there is a large amount of auto-correlation within the annual defoliation of forest trees. As noted above, at least ecological conditions of the previous year influence the tree crown performance in the current year. It is to expect that the amount of foliage of the previous year also influences the current year's tree crown condition by several feedback mechanisms (e.g. storage of volatile organic carbon compounds). For that reason the values of defoliation of the previous year were additionally introduced into the models already presented above.
Table 4.4.1.2 shows the results. The strong influence of the previous year's plot-wise mean defoliation on the current defoliation is quit obvious. In the period from 1990 to 1992 less than 50% of the variance of defoliation of the actual year is explained by the defoliation of the previous year. From 1993 onwards the percentage is throughout above 50% reaching as much as 68% in 1994. One has to consider that these models are spatially differentiated and resolved at plot level. In chapter 4.6 auto-correlation on tree level is shown.

Tab. 4.4.1.2: Correlation series 1990 - 1998 with auto-correlation for *Pinus sylvestris* within pilot area 1; effect variable: mean annual defoliation.

	1990	1991	1992	1993	1994	1995	1996	1997	1998
DEFOL -1	47 (+)	15 (+)	41 (+)	51 (+)	68 (+)	58 (+)	57 (+)	67 (+)	58 (+)
C_DUM		7 (+)			10 (+)		4 (+)		7 (+)
EXAGE		3 (+)						7 (+)	
ltPFOCUS	6 (+)								
FSOIL1							9 (+)		
FSOIL2		8 (-)						4 (+)	
FSOIL3	4 (+)								5 (-)
FSOIL4		12 (-)				2 (+)			
FSOIL5	8 (+)	3 (-)	10 (+)	5 (+)	2 (+)				
WATERAV									
ltINSECT					5 (+)	3 (-)			
ltINSECT -1		2 (+)					7 (+)		5 (+)
ltFUNGI						4 (-)			
ltFUNGI -1									
D_NITRO							5 (+)		
TEMP									
TEMP -1									
HEAT	3 (+)								
HEAT -1		27 (+)							
WINTER				4 (-)					
WINTER -1				7 (+)					
LFROST									
LFROST -1									
PRECIP						8 (+)	4 (-)		
PRECIP - 1		3 (-)			2 (+)				
RELTRA									
RELTRA -1				5 (-)					
tot model R^2	69	81	51	71	86	76	86	79	75

n = 32 - 33, max. sign. level: 0.10; number give partial R^2 values (explained variance of mean annual defoliation), in brackets: sign of the regression coefficient; suffix -1: value of the previous year (delayed effects); xDEFOLP -1: mean annual defoliation of the previous year; 1997 and 1998 meteorological data not available.

The auto-correlation effect distinctively minimises both, country and age effects. After partialling out auto-correlation of defoliation, both effects are suppressed, because they are already part of the last year's defoliation. The remaining structure of predictors is comparatively different from the models without auto-correlation. This is not astonishing because the residuals from the dominant relation denote the actual change from the previous to the current year. There is only one distinct exception: in 1991 the heat index of 1990 is the most important predictor, reducing the influence of the 1990 defoliation to 15% explained variance.

Soil factor 5 is again a predictor with some relevance. However, compared to the models without auto-correlation, it gains influence in different years. All the other relationships found, are of more or less sporadic nature and may in some cases reflect real cause-effect relations, in others they might be the result of spurious correlations or of interactions among predictors.

Taking each year's defoliation values independently, while neglecting the auto-correlative nature of defoliation, it is possible to enlarge the sample considerably. The increase in cases allows - from a statistical point of view - on one hand the inclusion of all predictors without violation of the limitation of the number of predictors, but violates on the other hand the general presupposition of independence of each sample (plot). Probably a LISREL approach (linear structural relationship) would be more adequate (e.g. HÖKKA & PENTTILÄ 1999).

Tab. 4.4.1.3: Multiple regression model: Annual defoliation values of *Pinus sylvestris* from 1991 to 1998 in pilot area 1 without consideration of auto-correlation within defoliation data.

dependent var.: ltDEFOL
independent var.: C_DUM, exAGE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, ltINSECT, ltINSECT-1, ltINSECT-2, ltFUNGI, ltFUNGI-1, ltFUNGI-2, WATERAV, TEMP, TEMP-1, TEMP-2, HEAT, HEAT-1, HEAT-2, WINTER, WINTER-1, WINTER-2, LFROST, LFROST-1, LFROST-2, PREC, PREC-1, PREC-2, RELTRA, RELTRA-1, RELTRA-2
n of cases: 196
resulting model (stepwise procedure); max. sign. level: 0.10

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
C_DUM	0.209	0.209	0.204	0.0001	97.850
exAGE	0.087	0.296	0.288	0.0001	68.007
ltINSECT-1	0.061	0.357	0.346	0.0001	47.669
ltINSECT-2	0.044	0.401	0.388	0.0002	33.503
FSOIL1	0.040	0.441	0.426	0.0003	20.765
FSOIL5	0.017	0.458	0.441	0.0154	16.481
FSOIL2	0.016	0.474	0.454	0.0195	12.791
ltPFOCUS	0.012	0.485	0.463	0.0419	10.558
PREC-1	0.0095	0.495	0.470	0.0637	9.096

further small sign. part. R^2: ltFUNGI-1, FSOIL3, ltINSECT
ltDEFOL = - 4.163 + 1.025 C_DUM + 0.122 exAGE + 0.109 ltINSECT-1 + 0.104 ltINSECT-2 - 0.235 FSOIL1 + 0.186 FSOIL5 - 0.170 FSOIL2 - 0.291 ltPFOCUS + 0.001 PREC-1.

Besides rotated soil factors, water availability classes, deposition data (nitrogen and total acidity), age, and share of Scots pine, all climatic and biotic factors were included. From the last two categories not only the influence from the current year, but also from the previous year (-1) and the pre-previous year (-2) was introduced.
As table 4.4.1.3 shows, the country dummy is also in this approach the most important predictor followed by age. Together they explain almost 30% of the variance from all the annual plot-related mean defoliation values over the whole period from 1991 to 1998. The next highly significant predictors are insect activities of one and of two years before explaining together more than 10% of the variance of the dependent variable. This result underlines the importance of this biotic factor for crown condition.
Soil factor 1, like in the model with medium time means (chap. 4.3.1), is the most important soil factor, again introduced with negative sign. Since this factor is loaded by organic carbon and nitrogen in the upper mineral layer, soil with high organic matter in the mineral soil tends to have lower defoliation. Additionally soil factor 5 is positively correlated to defoliation. All the other predictors play only very small roles. Only one of the climatic data became part of the model explaining less than 1% and can be neglected in this context.
As expected the defoliation values of the previous year explain a large amount (35%) of the defoliation of the current year. Additionally there is a considerable influence of the defoliation value two years ago. Only mere 4% are left for country effects and another 3% for age. As mentioned above in connection with the models on an annual basis, most of the variation produced by these two predictors are included in after-effects of defoliation. Again the indication of insects of the previous year and even from two years before plays a considerable role. The negative sign of water availability rank indicates a poorer crown condition on dry soils, but partial R^2 of 0.013 does

not give much emphasis on this predictor. The remaining significant predictors explain less than 1%.

Tab. 4.4.1.4: Multiple regression model: Annual defoliation values of *Pinus sylvestris* from 1991 to 1998 in pilot area 1 with consideration of auto-correlation within defoliation data.

dependent var.: ltDEFOL
independent var.: ltDEFOL-1 ltDEFOL-2, C_DUM, exAGE, lgD_NITRO, lgD_ACID, FSOIL1 - 5, WATERAV, ltINSECT, ltINSECT-1, ltINSECT-2, ltFUNGI, ltFUNGI-1, ltFUNGI-2, TEMP, TEMP-1, TEMP-2, HEAT, HEAT-1, HEAT-2, WINTER, WINTER-1, WINTER-2, LFROST, LFROST-1, LFROST-2, PREC, PREC-1, PREC-2, RELTRA, RELTRA-1, RELTRA-2
n of cases: 194
resulting model (stepwise procedure); max. sign. level: 0.10

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
ltDEFOL-1	0.353	0.353	0.350	0.0001	94.169
ltDEFOL-2	0.073	0.426	0.420	0.0001	64.043
C_DUM	0.038	0.465	0.456	0.0003	49.174
exAGE	0.027	0.491	0.481	0.0020	39.504
ltINSECT-1	0.029	0.520	0.508	0.0009	28.694
ltINSECT-2	0.016	0.536	0.521	0.0129	23.822
WATERAV	0.013	0.549	0.532	0.0247	20.352

further small sign. part. R^2(<0.01): LFROST, ltINSECT, PREC-2, LFROST-2
ltDEFOL = - 1.672 + 0.221 ltDEFOL-1 + 0.282 ltDEFOL-2 + 0.466 C_DUM + 0.120 exAGE + 0.078 ltINSECT-1 + 0.072 ltINSECT-2 - 0.089 WATERAV.

4.4.2 Oaks (*Quercus robur et petraea*) within Pilot Area 1

Pedunculate and sessile oak is represented by only a total of 16 plots within pilot area 1. Due to this low number of cases regression models on an annual basis have not been applied. Due to the inclusion of all surveys over the years, a higher number of cases are achieved, but the independence of each case is not fully warranted (see above). In order to achieve an overview on possible predictors, results are given in Table 4.4.2.1, in spite of this violation. Considering the still low number of cases, only delayed effects concerning meteorological and biotic data of one year have been taken into account. Due to inconsistent differences between countries two independent country dummies have been used.

Soil factor 3 explains 29% of the variance of the annual crown performance of oak. Within the combined pine and oak principal factor model this factor is highly loaded by base saturation within the lower mineral soil (see Tab. 4.2.1.2) and additionally by base saturation in the upper mineral soil layer and the amount of exchangeable base cations in both mineral soil layers as well. This clearly shows that oaks on soils rich in base cations exhibit less defoliation or in other words, have more foliage. Country dummy 2 denotes the general difference between Flanders and Germany with systematic higher values in Flanders. Principal soil factor 5 is highly loaded by organic carbon and total nitrogen. This predictor has a negative regression coefficient, which means that high carbon and nitrogen content coincides with low defoliation values. This result is quite contrary to the finding for Scots pine, were defoliation is higher in case of high carbon and nitrogen contents of the forest floor. The observation of insects in the previous years seems to have some impact on the recent crown condition, but the partial R^2 is with 0.034 comparatively low. A higher temperature in the recent year coincides with lower defoliation values and a high relative transpiration rate in the previous year co-occurs with high defoliation values. Both results contradict the hypotheses of climatic drought stress in oak. After introduction of the climatic variables, principal soil factor 5 is removed, indicating inter-correlations between these predictors. As a further weak but plausible predictor, observations of insects within the recent year are taken into the regression model.

Tab. 4.4.2.1: Multiple regression model: Annual defoliation values of *Quercus robur et petraea* from 1991 to 1998 in pilot area 1 without consideration of auto-correlation within defoliation data.

dependent var.: ltDEFOL
independent var.: DC1, DC2, exAGE, lgD_NITRO, FSOIL1 - 5, WATERAV, ltINSECT, ltINSECT-1, ltFUNGI, ltFUNGI-1, TEMP, TEMP-1, HEAT, HEAT-1, WINTER, WINTER-1, LFROST, LFROST-1, PREC, PREC-1, RELTRA, RELTRA-1
n of cases: 95
resulting model (stepwise procedure); max. sign.level: 0.10

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
FSOIL3	0.290	0.290	0.282	0.0001	95.153
DC2	0.110	0.400	0.387	0.0001	68.295
FSOIL5 {-}	0.050	0.450	0.432	0.0052	57.270
ltINSECT-1	0.034	0.484	0.461	0.0165	50.288
TEMP	0.039	0.523	0.496	0.0088	42.181
RETRA-1	0.021	0.544	0.513	0.0455	38.589
remove FSOIL5	0.007	0.537	0.511	0.2647	38.301
ltINSECT	0.023	0.560	0.530	0.0360	34.357

ltDEFOL = - 0.254 - 0.442 FSOIL3 + 0.945 DC2 + 0.049 ltINSECT-1 - 0.275 TEMP + 1.277 RELTRA-1 + 0.049 ltINSECT.

{}: sign of regression coefficient of a later removed predictor.

Tab. 4.4.2.2: Multiple regression model: Annual defoliation values of *Quercus robur et petraea* from 1991 to 1998 in pilot area 1 with consideration of auto-correlation within defoliation data.

dependent var.: ltDEFOL
independent var.: ltDEFOL-1, DC1, DC2, exAGE, lgD_NITRO, FSOIL1 - 5, WATERAV, ltINSECT, ltINSECT-1, ltFUNGI, ltFUNGI-1, TEMP, TEMP-1, HEAT, HEAT-1, WINTER, WINTER-1, LFROST, LFROST-1, PREC, PREC-1, RELTRA, RELTRA-1
n of cases: 93
resulting model (stepwise procedure); max. sign. level: 0.10

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
ltDEFOL-1	0.378	0.378	0.371	0.0001	72.846
FSOIL3	0.090	0.469	0.457	0.0002	51.311
DC2	0.035	0.504	0.487	0.0136	44.118
TEMP	0.047	0.551	0.530	0.0033	33.992
ltINSECT-1	0.030	0.580	0.556	0.0149	28.238
RETRA-1	0.019	0.600	0.572	0.0446	25.206
ltINSECT	0.015	0.615	0.583	0.0682	23.185

ltDEFOL = 0.530 + 0.297 ltDEFOL-1 - 0.339 FSOIL3 + 0.725 DC2 -0.261 TEMP + 0.041 ltINSECT-1 + 0.864 RELTRA-1 + 0.044 ltINSECT.

Like in Scots pine auto-correlative effects can be supposed to occur in oak as well. Tab. 4.4.2.2 gives the result of the respective regression model. Most of the explained variance (38%) goes onto the account of the previous years' defoliation status. The other variables also play a role in the model without consideration of the last years' defoliation status, where they contribute greater amounts to the overall model in terms of explained variance of the effect variable.

4.4.3 Norway Spruce (*Picea abies*) within Pilot Area 2

Table 4.4.3.1 summarises the results of all runs of multiple regression with available data from pilot area 2. During the first years, especially in 1991, high fluctuations of

plots can be observed within this area. Therefore results from this year have been omitted.
The predictor with the highest partial R^2 in 1990 is deposition of total acidity, but with a negative sign. This is quite contrary to expectations, especially in this area with its highly polluted parts (see Fig. 3.3.6.1). The positive correlation coefficients of the late frost index in the current and in the previous year is however plausible. Soil factor 6 represents Ca concentrations and pH values in the organic layer. Its positive relationship with defoliation does not agree with expectations. The negative statistical influence of the previous year's heat index is also not plausible and the positive correlation coefficient of the temperature of the year before is at least ambivalent. In total the results from the year 1990 are not convincing.
From 1992 on more consistent patterns can be observed, at least for some of the predictors. The highest amount of explained variance gains the heat index of 1991. Since this relationship is negative like two years before, it cannot be supposed that climatic drought conditions are expressed by this index. It seems more likely that warm summers in the previous years promote an increased growth of needles in the following year. This would suggest that temperature could be a limiting factor for spruce within this mountainous region. The positive regression coefficient of altitude points into the same direction, because air temperature is generally decreasing with increasing altitude. The same relationship can be observed in the following years. The comparatively high amount of variance explained 1992 by the share of spruce trees within the sample may indicate a positive feed back mechanism more active in monocultures. Since such a result is only observed in one year, it should not be overemphasised. Soil principal factor 3 denotes Mg, P, and K concentrations of the organic layer (see Tab. 4.2.2.2). Due to its negative regression coefficient this result is ambiguous. Especially Mg deficiency has been made responsible for poor crown condition (e.g. HEINSDORF et al. 1988, RIEK & WOLFF 1999) at least for needle discoloration (e.g. HAUHS & WRIGHT 1986, SCHULZE 1989). The negative statistical influence of principal soil factor 4 (mainly CEC) is at least ambivalent, since it includes charges hold by acidic cations like Al and H as well.
In 1993 and 1994 the patterns of significant predictors are comparatively similar. In both years modelled deposition of total acidity is the most important predictor. Episodic high SO^2 air concentrations do occur in this region especially during frost periods in winter (according to HARTIG et al. 1998 in winter 1995/96). Whether similar events have occurred in 1993 or 1994 cannot be derived from the available data, but might be possible. Also obvious is the high and positive influence of altitude on defoliation in both years. Novel is the positive effect of country dummy 2, which describes the systematic differences between Czech Republic (0) and Poland (1). The effect of age on defoliation is first observed in 1993, increases in 1994, and becomes more and more important in the following years. Soil factors 3 and 4 do also explain small amounts of the variance of defoliation consistent with the previous years, while signals from climatic parameters are comparatively weak and inconsistent.

Tab. 4.4.3.1: Multiple regression series 1990 - 1998 without auto-correlation for *Picea abies* within pilot area 2; effect variable: mean annual defoliation.

	1990	1991	1992	1993	1994	1995	1996	1997	1998
n	56	22	55	63	65	66	66	66	66
DC1					4 (-)	12 (-)	4 (-)	17 (-)	15 (-)
DC2				10 (+)	9 (+)	4 (+)			
EXAGE				3 (+)	11 (+)	43 (+)	16 (+)	51 (+)	48 (+)

ltPFOCUS			10 (+)						6 (+)
FSOIL1									
FSOIL2									
FSOIL3			14 (-)	4 (-)					
FSOIL4			7 (-)		3 (-)	2 (-)	3 (-)	1 (-)	
FSOIL5				2 (+)					
FSOIL6	6 (+)							2 (-)	
FSOIL7									
D_NITRO					2 (+)				
D_ACID	15 (-)			21 (+)	15 (+)				
ALTITUDE			7 (+)	11 (+)	10 (+)	3 (+)			
TEMP			7 (+)						
TEMP -1	7 (+)								
HEAT									
HEAT -1	7 (-)		18 (-)						
WINTER					5 (-)				
WINTER -1				4 (-)		2 (-)			
LFROST	14 (+)								
LFROST -1	11 (+)				3 (+)				
PRECIP									
PRECIP - 1					6 (-)				
RELTRA						9 (+)	56 (+)		
RELTRA -1									
model tot R^2	61	X	66	55	68	75	79	72	68

numbers give partial R^2 values, in brackets the respective sign of the regression coefficient is given; suffix -1: value of the previous year (delayed effects); 1997 and 1998 meteorological data not available; max. sign level: 0.10; age could not be calculated on a yearly basis, because of many missing data in earlier years: it was taken from the 1999 data.

In 1995 age is the dominant predictor followed by country dummy 1, representing the difference between the Czech Republic (0) and Germany (1), with systematic lower defoliation values in Germany. However, as mentioned earlier (Chap. 4.3.3), there is some interference between age and country in this case. In 1995 a partial R^2 of 0.09 was found for the actual relative transpiration rate. Since a high relative transpiration rate stands for a good supply of trees with water, this result does not support needle loss due to climatic drought. Since in 1996 even 9% of the explained variance is concentrated on this relationship, it seems highly probable that a fictitious statistical correlation has to be supposed. The rest of the structure of significant predictors of 1996 resembles those of 1995, but altitude and country dummy 2 have entirely ceased their statistical influence within this and the following regression models.

Tab. 4.4.3.2: Multiple regression series 1990 - 1998 with auto-correlation for *Picea abies* within pilot area 2; effect variable: mean annual defoliation.

	1991	1992	1993	1994	1995	1996	1997	1998
n	21	32	55	63	65	66	66	66
ltDEFOL-1			25 (+)	76 (+)	67 (+)	75 (+)	75 (+)	86 (+)
DC1					9 (-)		2 (-)	
DC2							1 (-)	
EXAGE			3 (+)		3 (+)		2 (+)	
ltPFOCUS				1 (+)	3 (-)			3 (+)
FSOIL1								

FSOIL2								
FSOIL3								
FSOIL4								
FSOIL5			3 (+)					
FSOIL6					1 (-)			
FSOIL7								
D_NITRO				1 (+)			1 (+)	
D_ACID			19 (+)				1 (-)	
ALTITUDE								
TEMP								
TEMP -1								
HEAT				1 (+)		3 (+)		
HEAT -1				11 (+)		1 (+)		
WINTER								
WINTER -1								
LFROST						2 (+)		
LFROST -1			2 (-)					
PRECIP				1 (-)				
PRECIP - 1								
RELTRA						9 (+)		
RELTRA -1								
model tot R^2	X	X	64	91	83	90	81	98

numbers give partial R^2 values, in brackets the respective sign of the regression coefficient is given, suffix -1: value of the previous year (delayed effects); 1997 and 1998 meteorological data not available; max. sign level: 0.10; age could not be calculated on a yearly basis, because of many missing data in earlier years: it was taken from the 1999 data.

The runs with the 1997 and 1998 data are not fully comparable due to the lack of meteorological data, but age gains an overwhelming dominance among the available predictors. Another considerable part of the explained variance goes onto the account of systematic differences between the Czech Republic and Germany. The remaining principal soil factors 4 and 6 are of subordinate importance in 1997. In 1998 again the share of spruce trees within the sample accounts for 6% of the variation.

If the mean plot values of defoliation of the previous year are considered as additional predictors of defoliation values of the current year (Tab. 4.4.3.2), a high degree of auto-correlation within defoliation of Norway spruce becomes obvious, similar to Scots pine in pilot area 1. In 1993 last year's defoliation accounts for 25% of the actual values, but again, deposition of total acidity explains also a considerable part of the variance. Each of the remaining independent variables explains less than 5% of the variance. In 1994 last year's defoliation accounts even for 76% of the actual crown condition. The heat index of the previous year does statistically explain some of the remaining variance. All the other significant predictors remain around 1%. Because 1992 was the driest and hottest year, some kind of interference with other variables may determine defoliation after partialling out last year's defoliation in 1994 and in 1993 as well.

In 1995 a considerable country effect was left, after the 1994 defoliation had been regressed on the actual defoliation. In that year, age and stand density (neg. sign) explain statistically some amount of the defoliation values from 1994 to 1995. In 1996 again a high auto-correlation within defoliation occurs, but relative transpiration, like in the approach without auto-correlation, accounts for another 9% of the variance. The positive regression coefficient disproves however that drought stress could be the current cause. Whether the small statistical influences of the current (and last

year's) heat index or the late frost index can be taken as a real sign of drought stress respective frost damage could not be corroborated.
For the following two years no climatic data are available. High amounts of auto-correlation characterise the performance of tree crowns in these two years. In 1997 five predictors explain an additional 1 to 2% of the variance each. Both deposition parameters are among them, but with only 1% they cannot be considered seriously. In 1998 the positive influence of the share of spruce trees may express a weak influence of stand structure onto defoliation change from 1997 to 1998.

Like in the pilot area 1 (Chap. 4.4.1) all available plots with soil data have been pooled over the years and a multiple regression has been applied. Again the presumption of independence is violated, but in order to gain an overview onto general relationships the approach is adequate.

Tab. 4.4.3.3: Multiple regression model: Annual defoliation values of *Picea abies* for the whole period from 1990 to 1998 in pilot area 2.

dependent var.: ltDEFOL
independent var.: DC1, DC2, ALTITUDE, exAGE, lgD_NITRO, FSOIL1 - 7, TEMP, TEMP-1, TEMP-2, HEAT, HEAT-1, HEAT-2, WINTER, WINTER-1, WINTER-2, LFROST, LFROST-1, LFROST-2, PREC, PREC-1, PREC-2, RELTRA, RELTRA-1, RELTRA-2
n of cases: 393
resulting model (stepwise procedure); max. sign. level: 0.10

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
exAGE	0.145	0.145	0.143	0.0001	128.620
DC1	0.064	0.209	0.205	0.0001	91.856
lgD_ACID	0.027	0.236	0.230	0.0003	77.819
TEMP-2	0.036	0.272	0.265	0.0001	57.793
FSOIL4	0.017	0.290	0.280	0.0022	49.259
ALTITUDE	0.025	0.315	0.304	0.0002	35.946
FSOIL1	0.011	0.326	0.314	0.0126	31.285
DC2	0.009	0.335	0.322	0.0239	27.888
HEAT-1	0.007	0.342	0.328	0.0466	25.738
TEMP-1	0.009	0.350	0.335	0.0255	22.558
LFROST	0.007	0.357	0.341	0.0397	20.208
TEMP	0.017	0.374	0.356	0.0016	12.174

ltDEFOL = -7.394 + 0.047 exAGE - 0.697 DC1 + 0.291 lgD-ACID + 0.029 TEMP-2 - 0.081 FSOIL4 + 0.035 ALTITUDE + 0.074 FSOIL1 + 0.338 DC2 -0.009 HEAT-1 + 0.082 TEMP-1 + 0.107 LFROST + 0.134 TEMP

age could not be calculated on a yearly basis, because of many missing data in earlier years: it was taken from the 1999 data.

Obviously the model shown in Tab. 4.4.3.3 is less precise than the approaches with single years or with long term averages. The most important predictor is again age, followed by the country difference between Czech Rep. and Germany. The third important predictor with a partial R^2 of only 0.027 is modelled total deposition of acidity. This can be taken as a weak hint on direct or indirect effects of SO_2 immissions onto the foliage of spruce trees within pilot area 2. Annual mean temperature is according to the model positively correlated with defoliation, but with a delay of two years, which is less meaningful. With increase in the CEC (principal soil factor 4) partially a decrease of defoliation is combined. This seems reasonable, however the effect is small. Altitude accounts for another 2.5% of the variance of defoliation. Most of the remaining significant predictors stay below 1% and interpretation in ecological terms seems rather unsure.
If defoliation estimates of the two previous years are regarded within the multiple regression model (Tab. 4.4.3.4), this variables gain much of the explained variance.

The last years defoliation explains alone 63.5% of the variance of the actual defoliation. Additional 4% are explained by country dummy 1 (Czech Rep. - Germany) and the defoliation two years ago accounts for another 3.6%. Together almost 70% of the defoliation can therefore explained by after-effects. Age is also correlated to the residuals after partialling out auto-correlation and country effects and a very small amount (< 1%) can be explained by the index with 2 years of delay.

Tab. 4.4.3.4: Multiple regression model: Annual defoliation values of *Picea abies* for the whole period from 1990 to 1998 in pilot area 2 with consideration of auto-correlation in defoliation data.

dependent var.: ltDEFOL
independent var.: ltDEFOL-1, ltDEFOL-2, DC1, DC2, ALTITUDE, exAGE, lgD_NITRO, FSOIL1 - 7, TEMP, TEMP-1, TEMP-2, HEAT, HEAT-1, HEAT-2, WINTER, WINTER-1, WINTER-2, LFROST, LFROST-1, LFROST-2, PREC, PREC-1, PREC-2, RELTRA, RELTRA-1, RELTRA-2
n of cases: 226
resulting model (stepwise procedure); max. sign. level: 0.10

Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
ltDEFOL-1	0.635	0.635	0.633	0.0001	131.409
DC1	0.041	0.676	0.673	0.0001	94.030
ltDEFOL-2	0.036	0.709	0.705	0.0001	63.608
exAGE	0.026	0.735	0.730	0.0001	40.913
HEAT-2	0.007	0.741	0.735	0.0188	36.537

ltDEFOL = -0.958 + 0.557 ltDEFOL-1 - 0.328 DC1 + 0.247 ltDEFOL-2 + 0.034 exAGE + 0.004 HEAT-2.

age could not be calculated on a yearly basis, because of many missing data in earlier years: it was taken from the 1999 data.

4.4.4 Scots Pine (*Pinus sylvestris*) within Pilot Area 2

Because of the limited number of plots per year, annual approaches are not appropriate. Therefore only an overall model was applied, with the same limitations concerning the statistical preconditions as for *Quercus robur et petraea* (Capt. 4.4.2). Within the resulting model (Tab. 4.4.4.1) an extraordinary high amount of variance of defoliation is explained by age. It is to suppose that a part of this relationship is due to confounding with other country specific peculiarities, because country and age do not vary independently. Another almost 10% of the variation of the effect variable is explained by country effects. Finally, soil factor 1 (base saturation and exchangeable basic cations in both mineral soil layers, see Tab. 4.2.2.2) and deposition of nitrogen are responsible for 2% resp. 1% of the defoliation values. The nitrogen deposition exhibits even a negative regression coefficient. Substantially this result could only be interpreted in ecological terms, if the area were widely characterised by nitrogen deficiency, which is hardly the case.
Models with the inclusion of the defoliation values from the previous two years reveal also in Scots pine within pilot area 2 a considerable amount of auto-correlation. In comparison to Norway spruce the statistical influence is smaller and covers only the previous year. Due to the much lower number of needle sets of pine in comparison to spruce, this result is to expect. In comparison to Scots pine in pilot area 1, after-effects of pine in pilot area 2 are however stronger.

Tab. 4.4.4.1: Multiple regression model: Annual defoliation values of *Pinus sylvestris* for the whole period from 1990 to 1998 in pilot area 2.

dependent var.: ltDEFOL

independent var.: DC1, DC2, ALTITUDE, exAGE, lgD_NITRO, FSOIL1 - 7, TEMP, TEMP-1, TEMP-2, HEAT, HEAT-1, HEAT-2, WINTER, WINTER-1, WINTER-2, LFROST, LFROST-1, LFROST-2, PREC, PREC-1, PREC-2, RELTRA, RELTRA-1, RELTRA-2					
n of cases: 174					
resulting model (stepwise procedure); max. sign. level: 0.10					
Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
exAGE	0.408	0.408	0.405	0.0001	56.326
DC1	0.077	0.485	0.479	0.0001	28.757
FSOIL1	0.029	0.514	0.506	0.0104	23.227
DC2	0.020	0.525	0.514	0.0079	17.472
lgD-NITRO	0.009	0.534	0.520	0.0792	16.164
ltDEFOL = -1.866 + 0.206 exAGE - 0.209 DC1 + 0.190 FSOIL1 + 0.333 DC2 - 0.362 lgD-NITRO					

age could not be calculated on a yearly basis, because of many missing data in earlier years: it was taken from the 1999 data.

Tab. 4.4.4.2: Multiple regression model: Annual defoliation values of *Pinus sylvestris* for the whole period from 1992 to 1998 in pilot area 2 with consideration of auto-correlation in defoliation data.

dependent var.: ltDEFOL					
independent var.: ltDEFOL-1, ltDEFOL-2, DC1, DC2, ALTITUDE, exAGE, lgD_NITRO, FSOIL1 - 7, TEMP, TEMP-1, TEMP-2, HEAT, HEAT-1, HEAT-2, WINTER, WINTER-1, WINTER-2, LFROST, LFROST-1, LFROST-2, PREC, PREC-1, PREC-2, RELTRA, RELTRA-1, RELTRA-2					
n of cases: 117					
resulting model (stepwise procedure); max. sign. level: 0.10					
Var	part. R^2	model R^2	R^2_{adj}	prob>F	C(p)
ltDEFOL-1	0.565	0.565	0.561	0.0001	34.727
DC1	0.086	0.651	0.645	0.0001	27.901
exAGE	0.024	0.674	0.666	0.0049	1.621
WINT-1	0.012	0.686	0.675	0.0424	-0.393
RETR_0	0.009	0.695	0.681	0.0730	-1.449
ltDEFOL = -1.973 + 0.444 ltDEFOL-1 - 0.272 DC1 + 0.090 exAGE + 0.003 WINT-1 - 0.405 RETR.					

age could not be calculated on a yearly basis, because of many missing data in earlier years: it was taken from the 1999 data.

Besides an additional effect of age, only small resp. very small statistical influences result from the regression analysis. With the inclusion of age, MALLOW's C(p) sinks already below its critical limit (C(p) should be > n predictors (incl. intercept) + 1). Both, increasing defoliation with winter index and with decreasing relative transpiration is plausible in ecological terms, however the low statistical signal makes any far-reaching interpretation questionable.

4.4.5 Discussion

Integrated studies based on data referring to single years, have already been applied earlier (e.g. INNES & BOSWELL 1989, KLAPP et al. 1997, 2000), but were not studied systematically for a longer period of time, like in the current approach. It was expected that mean annual defoliation values are more determined by short- to medium-term influences like extreme weather conditions or insect outbreaks, than mean defoliation values over a couple of years.

Against this background in connection with plot-wise annual defoliation data, the available **meteorological factors** have revealed comparatively little influence. For Scots pine within pilot area 1 only sporadic statistical influences could be found, sometimes not even consistent with theoretical expectations (e.g. for the relative transpiration rates). Only the statistical influence of the previous year's heat index in 1991 is considerable strong and ecologically sound. Above this, the heat index in

1990 was higher than the average. The severe climatic drought of 1992 does however not show any statistical effects on defoliation of the same or the two following years. If the auto-correlation within crown condition data are additionally considered, the situation concerning meteorological factors does not change in principal. Within the multiple regression models with all available plots sampled over the years, climatic data are not among the predictors with higher explanatory power as well. In the regression models for *Pinus sylvestris* within pilot area 2 meteorological parameter do also play no, or a very small role.

Also for Norway spruce, climatic parameters show in both year-wise approaches a comparatively inconsistent correlation structure. Only for the late frost index in 1990 a distinct and plausible statistical influence on defoliation is found. All the other statistical relations are not plausible in ecological terms. Especially the high R^2 values of the actual relative transpiration rate contradict the assumption of a possible drought stress. Probably hot weather even facilitates crown condition within the mountainous parts of the pilot area. This is supported by the long-lasting positive correlation of altitude with defoliation indicating effects of harsher climatic conditions in the upper mountainous parts. Most of the other climatic parameters stay below R^2 values of 1%. Also within the two oak models, climatic variables do play subordinate roles and the best predictor in this species (temperature) is also negatively correlated with defoliation.

Since all models are based on regionally differentiated data, only spatial meteorological differences can be expressed by these models. Differences caused by spatial climatic variation should partly be compensated by the choice of local reference trees. Moreover, local tree stands are genetically adapted to regional climatic conditions or differ systematically in the case of tree plantations with extraneous provenance (KAVVADIAS & MILLER 1999, SVOLBA & KLEINSCHMIT 2000). An insufficient spatial resolution of the modelled meteorological data (compare Fig. 2 in KLAPP et al. 1999), especially within the mountainous pilot area 2, might also contribute to the poor predicative power of these data. All these causes interfere with reactions of trees according to short- and long-term meteorological changes. Therefore, as already mentioned, approaches with climatic differentiations according to space offer only small possibilities to detect climatic influences onto crown condition. The use of meteorological extremes or exceedances from means etc., which could eventually give better estimates of climatic stress, may hardly give better results within spatially differentiated approaches, since their spatial differentiation might closely correlate with means in space. It can be concluded from the results that true time dependent models cannot adequately be substituted by year-wise approaches with climatic data spatially differentiated on a large- to meso-scale.

Another group of predictors with high temporal variation embrace the **biotic complex**. It is striking that *Pinus sylvestris* within pilot area 1 shows almost every second year a statistical relationship with the observation of insects with a delay of one year. Different from climatic parameters, gradations of insects are spatially much more differentiated. This might be the reason, why in spite of the limited quality of the data on insect infestations, respective statistical signals could be found. Significant correlations with the observation of fungi are scare and contradictory; the same is true for the portion of Scots pine trees within the samples. If auto-correlation within the defoliation data is considered, the importance of insects shrinks. A part of its statistical influence shifts to the last year's defoliation, which is however to expect. The same can be seen in the temporal over-all model (Tab. 4.4.1.3). Without auto-correlation, observations of insects explain more than 10% of the variation of defoliation. After inclusion of auto-correlation only 4.5% are explained. Interestingly, in none of the

models the actual insect damage is reflected by tree crown condition, but the last year's activities and even the activities two years ago seem to be more relevant. *Quercus robur* and also *Q. petraea* are well known for their high susceptibility towards a large number of insects. Therefore a higher influence of the estimation of insect activity was expected. Again the influence of the previous year's observation was more distinct, but in contrast to *Pinus sylvestris* the current year's observation plays also a small, but significant role.
Within pilot area 2 the observations of biotic factors are very scarce and were omitted. Within the year-wise approach without auto-correlation the share of *Picea abies* trees within the samples gains some relevance only in two years, but ceases if autocorrelation is considered. Since this variable might probably express stand-level insect outbreaks, this can be interpreted as a weak hint on those processes. This results underline the necessity of an improved assessment of insects activities. In other integrated studies on crown condition, phytophageous insects and other biotic factors were only sporadically involved (SEIDLING 2000). This might partly be due to well-known difficulties with the assessment of reliable data (e.g. KREHAN 1992), but the results of this study show that even crude estimates of insect infestations can attribute to a more complete understanding of defoliation processes.
Age as a predictor with intrinsic (different physiological and architectural properties of trees with age), and external aspects (different stand dynamics with age, higher deposition rates with age) is the most constant predictor over the years. In Scots pine within pilot area 1 and Norway spruce within pilot area 2 however, it becomes distinctively apparent only in the last years. If defoliation of the previous year is introduced, it absorbs significant parts of the predictive power of age class. The same effects can be observed if the models for the whole periods are considered. Only for pedunculate and sessile oak age does not play any significant role. The role of age within defoliation processes has often been found in different regions and in different tree species within Europe (cf. SEIDLING 2000). Since natural and anthropogenic stress effects accumulate in older stands (SOLBERG 1999), it can be supposed that different mechanisms are behind this relation. The present results rise the question, why age class has increased its importance as a predictor in the second half of the 90s.
Soil conditions are better traced in approaches with medium- to long-term data on crown condition, but may in combination with predictors varying on a short-term scale like climatic factors directly or indirectly influence yearly defoliation rates. Contents of organic carbon and total nitrogen in the organic layer (soil factor 5) was the most constant predictor for *Pinus sylvestris* in pilot area 1 in yearly approaches. It was also one of the significant predictors in the regression models with overall means (chap. 4.3). GÖTTLEIN & PRUSHA (1996), who found a positive correlation between pine defoliation and thickness of humus layer, can be interpreted as a similar result. Both outcomes might denote aspects of complex processes not fully understood (e.g. VANMECHELEN et al 1997) and related to decelerated mineralisation within acidic soils. Negative relationships between defoliation and pH, Ca and Mg concentrations and base saturation resp. a positive correlation with concentration of Al found for Scots pine by RIEK & WOLFF (1999), GÖTTLEIN & PRUSHA (1996) and partly HENDRIKS (1994) might refer to the same complex of accompanying or decisive factors. Principal soil factor 2, loaded by C_{org} and N_{tot} in the mineral soil between 10 and 20 resp. 30 cm depth, is negatively correlated with defoliation. Base saturation has a tendency to be low at sites with high C_{org} or N_{tot} (see Tab. 4.2.1.3). It can be supposed that this relation represents a different but unclear mechanism.
Since 1989 and 1991 were years with rather low precipitation, probably sites with higher amounts of organic substance in the mineral soil may tend to be less dry, pos-

sibly due to their higher water holding capacity. This idea gets additional support, due to the finding that in 1994 water availability ranks are additionally negatively correlated with defoliation. RIEK & WOLFF (1999) also found a negative correlation between defoliation and the amount of C in 10 to 30 cm soil depth, and according to MATHER et al. (1995), soil water deficit contributes to a redundancy axis, which represents change in crown condition. More generally this might be interpreted that sites with a higher supply of soil water may have lower defoliation values in dry years.
If auto-correlation is additionally regarded, only principal soil factor 5 keeps partly its importance within the year-wise models. Influences from other soil factors are sporadically. Within the overall regression models with annual defoliation values for Scots pine, carbon content in upper mineral soil (soil factor 1) is the most prominent soil related predictor in the model without auto-correlation, and water availability in the model with auto-correlation. Both have negative regression coefficients, which gives additional support to the drought hypothesis mentioned above. For *Pinus sylvestris* in pilot area 2, the low partial R^2 of soil related parameter prevents any far-reaching interpretation.
For Norway spruce in pilot area 2 mainly CAC in the mineral soil layers (soil factor 4) is the most constant soil related predictor, but the low amounts of explained variance restrict interpretations. Since low cation exchange capacities may also depend on natural site conditions, a simple conclusion with respect to anthropogenic changes of chemical soil conditions cannot be derived from this result. If auto-correlation within the defoliation data is considered additionally, almost none of the soil factors reaches significance in the year-wise regression models. In the overall approach without auto-correlation, again principal soil factor 4 and additionally soil factor 1 (mainly base saturation in both mineral soil layers) account for small amounts (R^2 = 1 - 2%) of defoliation. These results give only small support to the results of RIEK & WOLFF (1999), who found a negative correlation between defoliation and base saturation and even pH in the mineral soil and the litter layer. GÄRTNER et al. (1990) report also a negative relationship between Ca concentration in the forest floor and defoliation.
According to the two models concerning oak, high defoliation values coincide with low base supply. Since mineralisation is accelerated at sites with high base supply, a negative relationship with C_{org} + N_{tot} in the litter layer is in line with this finding. This result reveals that on poor (probably acidified) soils, oaks within pilot area 1 are likely to have thinner crowns. NEULAND et al. (1990) found high degrees of defoliation of oak on dystric and spododystric cambisols from quarzitic sandstone, which roughly indicates a similar relationship. Other authors (HENDRIKS et al. 1994, 1997b, GÖTTLEIN & PRUSHA 1996, KLAP et al. 1997) got very weak or no results with respect to chemical soil properties. Since this study relies on a small number of oak plots, the results have to be interpreted cautiously.
Another complex of potential predictors are concentrations and depositions of **air pollutants**. Since modelled medium-term deposition of total acidity and total deposition of nitrogen compounds were available for each plot, it can be investigated, whether any long-term influence can be detected within a spatially differentiated approach. Direct influences of high SO_2 air concentrations are merely covered by this approach. However, it can be assumed that in regions with high deposition of sulphur, which is part of the total acidity, episodes of high air concentrations of SO_2 are more probably. Therefore direct damages of needles or leaves by high concentrations of SO_2 can indirectly be covered by this approach. The same can be supposed for nitrogen compounds, but direct damages of leaves or needles are not likely.
Within pilot area 1, defoliation of Scots pine is only in 1993 positively correlated with nitrogen deposition (or deposition of total acidity, which is highly inter-correlated with

N deposition). For this year generally a deviant correlation structure was found. If auto-correlation is considered, in 1996 deposition of air pollutants explains 5% of the variance of defoliation. As distinct statistical signals have been found in two years only, a general long-term influence of deposition of nitrogen or acidity cannot be derived from the results. Whether short-term influences in distinct years are responsible for the correlation, cannot be proved without additional data on short- or medium-term episodes of high SO_2 air concentration within the respective periods.
For Norway spruce in pilot area 2 acidic deposition gains high positive correlations in two subsequent years. In 1993 after partialling out last year's defoliation a considerable amount of the residual variance correlates positively with deposition of acidity. A negative correlation in 1990 was also found, but cannot be interpreted. The positive relationships may result from direct damages of needles in connection with short- or medium-term episodes of high SO_2 air concentrations if the presumption of a narrow correlation between air concentration and deposition holds true.
In the approaches without auto-correlation **country** specific effects are one of the main predictors, but systematic changes can be observed in the course of time. For Scots pine before 1994 R^2 values between 0% and 13% are found, while from 1994 onwards, values vary between 30% and 47%. For Norway spruce in pilot area 2 from 1993 to 1995 the difference between the Czech Republic and Poland is more significant, while after 1996 the difference between the Czech Republic and Germany becomes more pronounced. If defoliation from previous years is included, country bias is strongly reduced. Because changes between years primarily determine the models in these cases, this result is to be expected. Similar results derived from statistical models were found by KLAP et al. (1997). The distinct changes of the relationship in the course of time is remarkable. Substantial interpretations of country specific behaviour within the regression models are not possible without additional informations (see DOBBERTIN et al. 1997). An objective adjustment for systematic country specific differences remains an important issue (FERRETTI 1998).

4.5 Autocorrelation within Defoliation based on Individual Trees

4.5.1 Approach

The amount of the living leaf or needle biomass of trees at a given time has complex causes. This status may not only depend on the actual environmental condition (which includes natural as well as anthropogenic factors), but also from its own status within the previous year or years (MARKOWian properties). The existence of a considerable amount of auto-correlation has already been shown in the previous chapter (4.4) on the plot level. In order to document the behaviour on tree level defoliation of identical trees (same plot and same tree number) was correlated over all available time spans. Because up to 24 trees per plot are available much larger numbers of cases are at hand. For that reason oak within pilot area 2 could also be included. Environmental data, available only on plot level, have not been used.

4.5.2 Results

For all species in both pilot areas auto-correlation has been found in bivariate correlation analysis (Fig. 4.5.2.1 to 4.5.2.5), but correlation structures differ considerably between species and areas. Within pilot area 1 correlation coefficients between the current years and the previous years for Scots pine can reach 0.78 (between 1996 and 1995) and for the two common oaks species together even 0.84 (between 1991 and 1990). The respective values for pilot area 2 are: 0.89 for Norway spruce (between 1998 and 1997), for Scots pine 0.92 (between 1997 and 1996), and for oak 0.73 (between 1996 and 1995). The correlation coefficients are generally decreasing with increasing temporal distance.

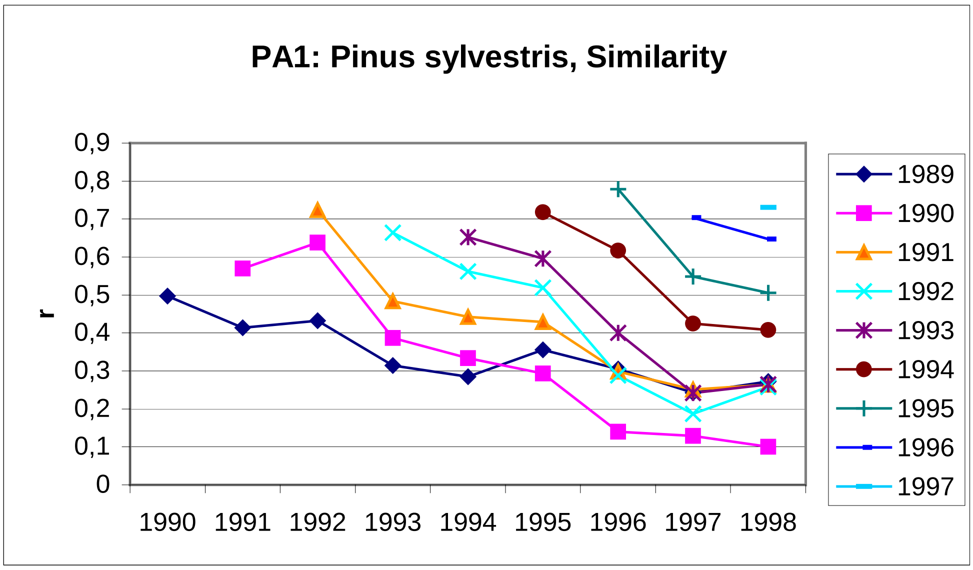

Fig. 4.5.2.1: Correlation coefficients (r, PEARSON) between defoliation values of current years (abscissa) and of all earlier years for all *Pinus sylvestris* trees within pilot area 1. Connected values belong to a temporal series (trajectories) denoted by the year, the data are from.

In Scots pine within pilot area 1 in the first two years correlation coefficient between defoliation of immediately succeeding years is below 0.6, but oscillates mainly between 0.7 and 0.8 in later years. In *Pinus sylvestris* within pilot area 2 at the early phase of the monitoring a similar effect can be observed and is even much more distinct in *Picea abies* within pilot area 2. For oak a similar effect cannot be observed. This increasing similarity of defoliation between directly succeeding years in the course of time is probably due to learning effects of the assessment teams.
Interpreting the correlation structure of Scots pine within pilot area 1 in more detail, decreasing auto-correlation effects can be observed over a time span up to 5 to 6 years. After that time a small correlation with earlier crown conditions remains constant, which can be interpreted as a constant dissimilarity related to site specific influences, not subject to short- of medium-term fluctuations caused by factors like insect infestations, flowering, or weather conditions. Genetically fixed differences between individual trees may also contribute to this constant correlation level. Up to now, only 1990 falls distinctly short with an r of 0.2, indicating this year as an extraordinary one.

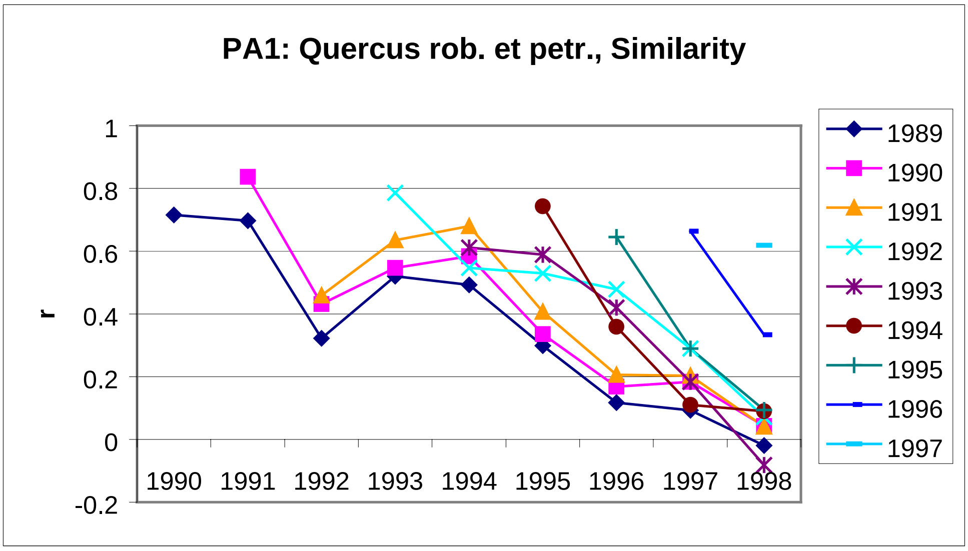

Fig. 4.5.2.2: Correlation coefficients (r, PEARSON) between defoliation values of current years (abscissa) and of all earlier years for all *Quercus robur et petraea* trees within pilot area 1. Connected values belong to a temporal series (trajectories) denoted by the year, the data are from.

Oak trees within pilot area 1 behave quite different from pines. There is a slightly decreasing similarity between directly consecutive years from the beginning of the monitoring towards 1998. In the last years after-effects decrease faster than in earlier years and there is almost no constant similarity of crown condition left. A striking exception to the decreasing trend can be observed in 1992. All trajectories show a local minimum in this year, which was a very dry and hot one. Scots pine in the same area did not react in the same way. Only weak reactions seem to occur in pine with one year delay: in 1993 a somewhat higher loss of auto-correlation can be observed. Also different from Scots pine, is the almost entire loss of any similarity of the defoliation status of individual trees after some years. Neither individual nor plot specific environmental conditions seem to stabilise a certain degree of similarity between the defoliation status of individual oak trees in the long term.

For *Picea abies* in pilot area 2, a pronounced increase of the temporal auto-correlation between the immediately consecutive years can be observed till 1994. The 1990 data set behaves differently throughout the whole observation period. This gives the impression that partly different assessment methods might have been applied or trees might have been assessed in this very year (comp. Tab. 4.4.3.1). The defoliation of individual trees of the two following years reveals an almost constant correlation with crown condition of all the coming years. The level of this constant auto-correlation is comparatively high, indicating a constant relation of defoliation among trees (and plots). Due to its higher number of needle sets, spruce might generally be less prone to strong annual fluctuations, but constant environmental conditions at the plot level may also cause constant high degrees of auto-correlation.

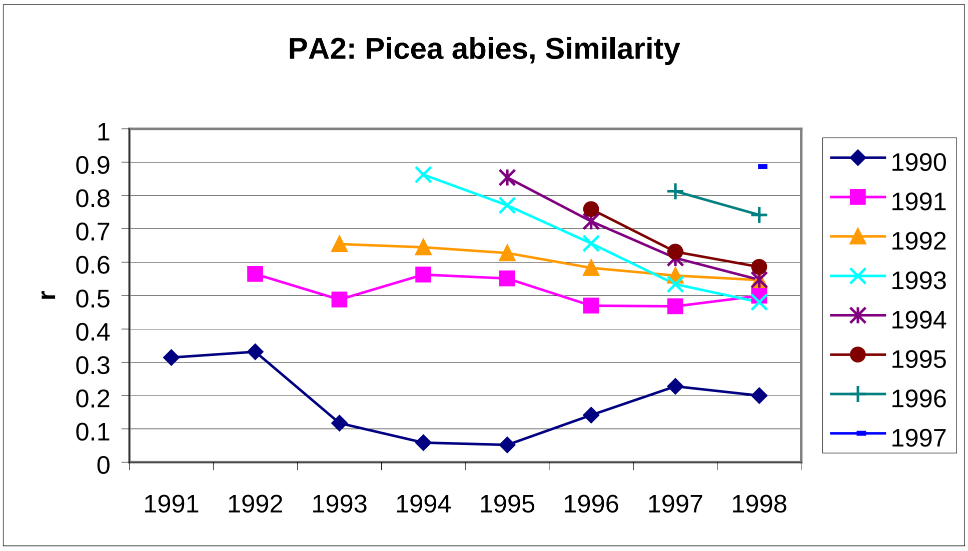

Fig. 4.5.2.4: Correlation coefficient (r, PEARSON) between defoliation values of current years (abscissa) and of all earlier years for all *Picea abies* trees within pilot area 2. Connected values belong to a temporal series (trajectories) denoted by the year, the data are from.

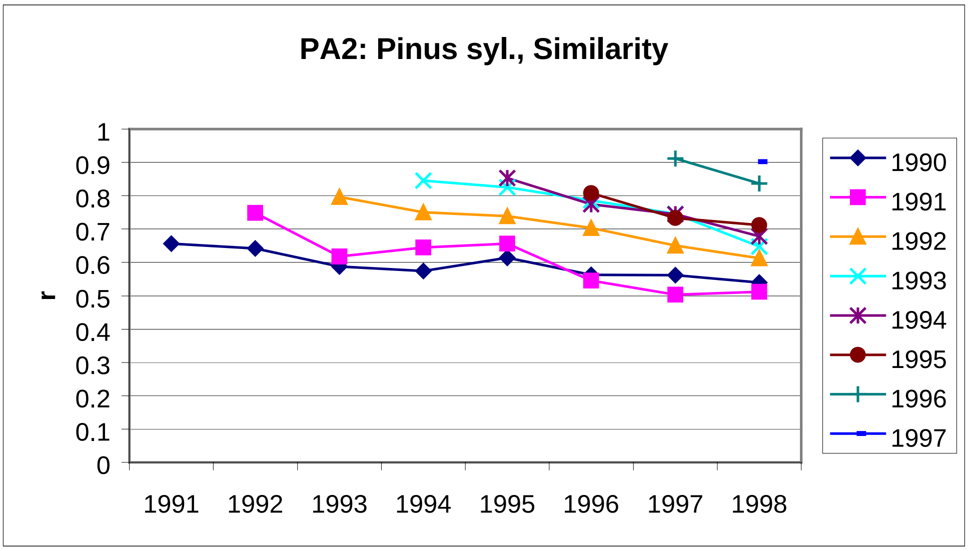

Fig. 4.5.2.3: Correlation coefficients (r, PEARSON) between defoliation values of current years (abscissa) and of all earlier years for all *Pinus sylvestris* trees within pilot area 2. Connected values belong to a temporal series (trajectories) denoted by the year, the data are from.

For Scots pine within pilot area 2 the same pattern of an increasing auto-correlation between directly consecutive years can be observed. However the similarity starts already on a comparatively high level between 1990 and 1991. In 1997 and 1998 even r values higher than 0.9 are reached. The amount of auto-correlation also ceases slowly in the course of the years. Both suggests that Scots pine within pilot area 2 is largely determined by constant plot and tree specific features. Local adaptations might in a mountainous region be generally more pronounced. Different expositions towards solar irradiation or storms, or large differences in altitudes may generally cause higher constant differences in crown conditions. Also constant

methodological differences during the field surveys can contribute to a constant level of auto-correlation.
Trajectories of auto-correlation of oaks within pilot area 2 start generally at lower levels. However defoliation values from the years 1992 and 1994 reveal even lower correlations with the respective subsequent year. Both summers were hot and dry. Interestingly, the reaction towards this climatic peculiarity occurs in pilot area 2 with a delay of one year in comparison to pilot area 1, were the current defoliation of the year 1992 already deviates distinctively from the 1991 data. In oak in pilot area 2 auto-correlation effects last c. 5 to 7 years, but after that time for the earlier years almost no auto-correlative structure is left. Due to the low number of cases this result has however a tentative character.

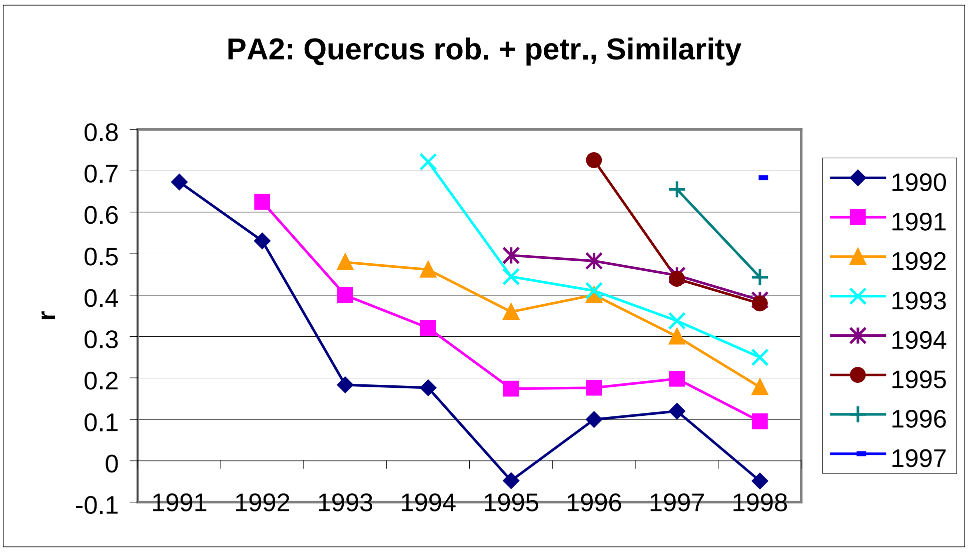

Fig. 4.5.2.5: Correlation coefficients (r, PEARSON) between defoliation values of current years (abscissa) and of all earlier years for all *Quercus robur et petraea* trees within pilot area 2. Connected values belong to a temporal series (trajectories) denoted by the year, the data are from.

4.5.3 Discussion

The high degree of temporal auto-correlation is striking. Production and allocation of carbohydrates of trees are complex pro??cesses and may be influenced by weather conditions (droughts, frosts) of the current and the previous years, as well as by biotic infestations and expenses of trees for defence and repair (SEIDLING et al. 1996, BLANK & RIEMER 1999). Mechanisms after e.g. foliar damage due to high ozone air concentrations or other anthropogenic stresses may also reduce the carbon gain of trees (e.g. BAUMGARTEN et al. 2000).
The results show species and region specific patterns of auto-correlation. Oak, as a deciduous tree species, starts with moderate amounts of auto-correlation with the previous year, but especially within pilot area 1 defoliation patterns are entirely unrelated after some years. For pine and especially spruce the defoliation patterns remain longer constant. In pilot area 2 for both coniferous species a high amount of auto-correlation remains constant even after longer time spans. This behaviour can partly be

attributed to the needle retention over some years and a higher environmental differentiation between sites.
Needle or leaf loss in earlier years, due to insect feeding (results chapter 4.5, see also MATHER et al. 1995, KALLWEIT 1999, FISCHER 1999) does have delayed effects on apparent crown condition. High flowering and fruiting abundance, especially in Scots pine (INNES 1994, INNES & BOSWELL 1989, MATHER et al. 1995) may also lead to memory effects within the density of needles or leaves. These biotic influences may cause delayed effects together with special meteorological conditions like climatic droughts or severe frosts in previous years (e.g. NEULAND et al. 1990, INNES & WHITTAKER 1993, KLAP et al. 1997, GÖTTLEIN & PRUSCHA 1996). Different site conditions in connection with genetic features of individual trees or of whole stands may provide a certain amount of long-term stability of spatial defoliation patterns. Following that way, further analysis of auto-correlation structure with more advanced statistical methods should contribute to our knowledge about spatial differentiation of defoliation processes. In how far future approaches should take defoliation values of previous years into consideration as independent variables (cf. GÖTTLEIN & PRUSCHA 1996), as it is already common in tree ring analysis (SCHWEINGRUBER 1983), should be investigated.

5 Conclusions

The relationships between crown condition parameters as dependent variables and environmental factors as predictor variables were explored by multivariate statistics. Two pilot areas were delineated in a way that parent materials were comparatively similar within each, but spatial gradients of nitrogen deposition in pilot area 1 resp. deposition of acidity in pilot area 2 were considerable. While natural variability is minimised, impacts from anthropogeneous air pollutants should become more accentuated.

Tab. 5.1: Overview of significant relationships ($p < 0.10$) between medium-term mean defoliation at plot level (logit-transformed except for *Pinus sylvestris* in pilot area 2) and predictor variables of the focal tree species within both pilot areas.

	Pinus sylvestris Pilot Area 1	Pinus sylvestris Pilot Area 2	Picea abies Pilot Area 2	Quercus robur et petraea, Pilot Area 1
'country' (C_DUM, DC1, DC2)	✌✌	(✌✌)	✌✌	
exAGE / *AGE	++	+*	++	++
ltINSECT	+			
ltFUNGI				
ltFOCUS				
WATERAV				
FSOIL (soil factor) 1		++ [1)]	+[2)]	++[4)]
FSOIL (soil factor) 2				
FSOIL (soil factor) 3				--[5)]
FSOIL (soil factor) 4			-[3)]	
FSOIL (soil factor) 5				
FCLIM (climatic factor) 1				
FCLIM (climatic factor) 2				-- [6)]
FCLIM (climatic factor) 3				
ALTITUDE			++	
D_NITRO (N deposition)				
D_ACID (acidic deposition)				
model R^2/R^2_{adj}	0.59 / 0.53	0.73 / 0.69	0.61 / 0.57	0.75 / 0.66
number of valid cases	33	26	66	14

✌✌/✌: significant at p = 0.05/0.10 level correlated to dummy variable
++/--: significant at p = 0.05 level and positively/negatively correlated with response variable
+/-: significant at p = 0.10 level and positively/negatively correlated with response variable
( ): removed later, due to confounding with age;
✆: not available or not used in specific approach;
1): representing C_{org} and N_{tot} in both mineral layers and CEC and BCE in deeper mineral soil layer;
2): representing base saturation and BCE in both mineral soil layers;
3): representing CEC in both mineral soil layers;
4): representing C_{org}, N_{tot}, CEC and BCE in upper mineral soil layer;
5): representing base saturation and BCE in both mineral soil layers;
6): representing heat index and late frost index.

✁ When medium-term (1989 - 1998) mean defoliation of coniferous species are regressed against measured, modelled or deviated environmental parameters, a considerable part of the explained variance is accounted by **country effects**. Only for oak no such effect could be detected. The results are in line with KLAP et al. (1997, 2000), who found for most tree species on the European level 35-40% of the variance of defoliation explained by country effects. For pine within pilot area 1, no systematic ordering of the defoliation levels according to geographic location could be found and the ranking of countries is stable over the whole time of observation. Therefore methodological differences between defoliation assessments are highly probable. Within pilot area 2 year-wise regression analyses have shown that relations of defoliation values between the involved countries vary over time. Therefore no simple conclusions about probable causes can be drawn. Interacting methodological and real differences have to be taken into consideration.

✁ **Age** is the only factor which accounts for a considerable part of the variance of mean defoliation within all tree species. However, some confounding may occur, since country and age, especially in Scots pine and Norway spruce, is intercorrelated within pilot area 2. Almost all investigations done so far on transnational, national or even regional levels using multiple statistics reveal age as a significant predictor of defoliation (SEIDLING 2000). Age is on one hand an intrinsic property of trees. On the other hand stress from anthropogeneous and natural sources may accumulate or intensify with stand age. Probably accelerated ageing might be a reaction of trees exposed to multiple stress, but differentiation into its components might be an ambitious task for the future.

✁ Among **biotic stress** factors the estimate of insect activities gains some significance for Scots pine within pilot area 1. Moreover, the models with annual defoliation data show that with a time lag of one year effects can be observed in some years. For oak with its rich predator community, no relationships between defoliation and observations of insects were found. This might be due to differentiated resprouting of leaves after insect damage in early summer and delaying effects. Further biological factors gained no or minor significance, but is has to be kept in mind that the data quality of these predictors is rather poor.

✁ **Soil** related predictors, as temporally more constant ecological factors, do statistically play a role in pine and spruce of pilot area 2 as well as in oak within pilot area 1. An increase of mean defoliation in Scots pine (pilot area 2) and oak (pilot area 1) is associated with higher organic carbon, nitrogen contents and cation exchange capacities within the mineral soil layers. In Norway spruce (pilot area 2) defoliation partly increases on soils with higher base saturation. Interpretation cannot be straight forward, because those soils should be biologically more active at one hand, but mineralisation of organic substances might be impeded at the other hand. The negative association between cation exchange capacity in the mineral soil and defoliation in spruce is at least an ambiguous result, because Al or H ions also contribute to a high cation exchange capacity. All these results are not completely in line with hypotheses concerning soil acidification or eutrophication processes and their supposed impacts onto trees. Therefore other soil-based processes might additionally influence the status of crown condition. For oak in pilot area 1, base saturation and cation exchange capacity in both mineral soil layers are also inversely related to defoliation, indicating better crown conditions on richer soils.

Since soil is a crucial compartment with respect to ongoing forest ecosystem changes, the elaboration of key parameters gains high priority, especially in the view of a possible repetition of the European-wide soil survey. Results from this epidemiological study emphasise the statistical importance of the organic substance in different soil layers and the related mineralisation processes. Functionally integrated to the organic complex are both, the cation exchange capacity and concentrations of the exchangeable basic cations (comp. DE VRIES et al. 2000c: 117 ff.). Integrated approaches as well as process-oriented modelling, especially with respect to the pools of carbon, nitrogen and basic cations seem necessary for a deeper understanding of the soil related aspects of tree condition.

✁ **Climatic variables** gain only in *Quercus* species some statistical relevance for mean defoliation, but the inverse relation contradicts the sensitivity of oak against late frosts. Altitude, which accounts for some variance in *Picea abies* in pilot area 2 may indirectly reflect impacts of climatic harshness increasing with altitude, but confounding with e.g. elevated ozone impact at higher altitudes may occur. As some national investigations have shown, drought stress can affect crown condition, but those findings could hardly be corroborated with the approaches based on annual crown condition data. In some years cold winters or late frosts seem to enhance defoliation in Scots pine and Norway spruce.

Any statistical signals from the modelled deposition rates of **air pollutants** (total acidity, nitrogen) could not be found within medium-term mean defoliation values. However, in annual approaches for some years (esp. 1993, 1994 in spruce) positive correlation between defoliation and medium-term mean deposition is found. Under the presumption that regions with high deposition of total acidity have higher frequencies of episodes with high air concentrations of SO_2, damages from direct impacts of air pollutants might be reflected by these results. However, reported damages from short-term episodes of very high SO_2 air concentrations in winter 1995 in Saxony (SMUL 1999) are not reflected by the findings. However, spatially differentiated long-term probabilities for the occurrence of elevated SO_2 air concentrations must not necessarily coincide with spatial patterns of short-term episodes. Therefore modelled deposition data are more prone to detect long-term influences onto forest ecosystems than direct impacts of air pollutants onto leaves or needles.

✁ Regression models with **trends in defoliation** reveal for *Picea abies* in regions with higher deposition of nitrogen and acidity a notable deterioration of crown condition. At sites poor in Mg, K and P this is also the case. Plots with higher frequency of late frosts, cold winters and low mean and summer temperature also slightly coincide with an increase of defoliation. Although the models leave a large amount of variance unexplained, these results give a hint on medium-term effects of respective coincidences between deterioration of crown condition in Norway spruce at one hand and deposition of acidifying substances, reduction of magnesium, and cold weather conditions at the other hand. NELLEMANN & FROGNER (1994) suggested and substantiated a link between cumulative effects of air pollution and defoliation of spruce in southern Norway. Within an area of very high deposition loads of acidifying substances like pilot area 2, trends of defoliation of *Picea abies* seem partly to support the results of the Norwegian study. The trend of defoliation of *Pinus sylvestris* within pilot area 1 could not plausibly be explained. Within pilot area 2 sites in higher altitudes Scots pine disproved their crown condition. Additionally, monocultures are more likely to have an increasing defoliation.

✁ An important feature of crown condition data is their medium-term **auto-correlation** with earlier conditions, which could be detected for all treated tree species, similar to the results found by GÖTTLEIN & PRUSCHA (1996). Auto-correlation over time could be shown in plot-wise and tree-wise approaches. In the latter approach species and area specific behaviour over time became evident and indicates after-effects for up to 6 years.

✁ Regression models with **discoloration** as effect variable reveal a different predictor structure compared to models with defoliation (Tab. 5.2). Within pilot area 1 for Scots pine higher discoloration values were observed in regions with warm winters and less frequency of late frosts, but confounding with methodological differences between countries is likely. An increase of water availability partly corresponds with an increase in discoloration, contradicting drought hypothesis. Besides a strong country bias, discoloration in *Pinus sylvestris* and *Picea abies* within pilot area 2 does not reveal interpretable results with respect to soil factors. In Norway spruce only a loose positive correlation with altitude exists, which could be substantiated in terms of climatic or ozone-induced damages. In this species with its long-living needles, discoloration and defoliation are markedly correlated. In Scots pine cold winters may promote discoloration, however confounding with other country specific peculiarities is likely.

Tab. 5.2: Overview of significant relationships ($p < 0.10$) between medium-term mean logit-transformed discoloration at plot level and predictor variables of the focal tree species within both pilot areas.

	Pinus sylvestris Pilot Area 1	Pinus sylvestris Pilot Area 2	Picea abies Pilot Area 2
'country' (DC1, DC2)	✌✌	✌✌	✌✌
exAGE / *AGE			
ltINSECT			
ltFUNGI			
ltFOCUS			
WATERAV	++		
FSOIL (soil factor) 1			+[2)]
FSOIL (soil factor) 2		++[1)]	
FSOIL (soil factor) 3			
FSOIL (soil factor) 4	+[1)]		-[3)]
FSOIL (soil factor) 5			
FCLIM (climatic factor) 1	(--)[4)]	(++)[4)]	
FCLIM (climatic factor) 2			
FCLIM (climatic factor) 3			
ALTITUDE			+
D_NITRO (N deposition)			
D_ACID (acidic deposition)			
model R^2/R^2_{adj}	0.62 / 0.57	0.62 / 0.58	0.40 / 0.34
number of valid cases	33	28	66

✌✌/✌: significant at p = 0.05/0.10 level correlated to dummy variable;
++/--: significant at p = 0.05 level and positively/negatively correlated with response variable;
+/-: significant at p = 0.10 level and positively/negatively correlated with response variable;
( ): removed after inclusion of country dummies;
✆: not available or not used in specific approach;
1): representing Ca, Mg, pH in organic layer;
2): representing base saturation and BCE in both mineral soil layer;
3): representing CEC in both mineral soil layers;
4): representing reverse mean annual temperature, cold winters and frequent late frosts.

✄ Results from bivariate statistics with **foliar element concentrations** show within pilot area 1 significant correlations between concentrations of sulphur and heavy metals (Fe, Cu, Zn) indicating associations of respective air concentrations. In spruce of pilot area 2 nitrogen and sulphur concentrations of current needles are obviously associated as well as magnesium and calcium concentrations. Spatial distributions of foliar element concentrations like nitrogen within pilot area 1 may seem to represent spatial patterns of respective air concentrations, however data are not sufficiently dense within both pilot areas to perform multivariate statistics. The negative bivariate correlation between phosphorous needle concentration and defoliation of Scots pine gives some support to the P deficiency hypotheses as a consequence of high N inputs.
The delineation of comparatively homogeneous regions with distinct differences of deposition of air pollutants, indeed reveals some substantial results. However, limitation of data availability and quality seems to limit the precision of the regression models. Optimisations of multiple approaches should be achieved if differences between

countries were more precisely defined and quantified e.g. as a result of international intercalibration courses (cf. FERRETTI 1998).

Since defoliation is a rather unspecific symptom of tree condition, the consideration within statistical models of key parameters representing all major influences onto tree crowns seems necessary. Otherwise strong effects from neglected factors may cover substantial relationships with less obvious effects. Due to ecological interactions within forest ecosystems simple relationships can hardly be expected and even minor predictors can give hints on important processes.

6 Summary

According to the hypothesis that crown condition is responding to different natural and anthropogeneous stress factors, multivariate statistics, mainly multiple regressions analysis, have been applied to medium-term and annual mean defoliation, medium-term mean discoloration and medium-term trends of defoliation as effect parameters. Predictors cover all domains of relevant ecological factors: measured soil data, rough estimates of biotic factors, modelled meteorological and deposition data. In order to minimise effects from natural factors on forest tree crown condition and maximise differences of supposed impacts from deposition of air pollutants, two **pilot areas** were delineated. Pilot area 1 comprises Flanders (Belgium), The Netherlands and north-western Germany. It contains regions with high nitrogen deposition. Pilot area 2 embraces the northern part of the Czech Republic, south-western Poland and the southern part of Saxony (Germany). Parts of this mountainous region are well known for very high concentrations of SO_2 and high deposition of total acidity. Within pilot area 1 *Pinus sylvestris* and *Quercus robur et petraea* were investigated, within pilot area 2 mainly *Picea abies* and *Pinus sylvestris*. Due to the limited numbers of plots with full sets off parameters, restrictions of the number of predictors were necessary, which was achieved by the use of principal factors for soil and climatic conditions.

Medium-term **mean defoliation** show in all coniferous species country specific effects, which may include methodological and real differences. Age was the second important predictor. For Scot pine (pilot area 1) a minor but significant and plausible relationships with the estimate of insect infestations were found. In Norway spruce high altitudes and minor cation exchange capacity in both mineral soils depths were plausible predictors of poor crown condition (pilot area 2). Due to the low number of cases, results for oak are tentative: Soils rich in bases and low mean temperature may promote leaf loss. However, for all species some statistical relationships have been found which are less plausible, like an increase of defoliation with higher amounts of organic carbon and total nitrogen concentrations of the mineral soil (Scots pine in pilot area 2).

According to regression models with **trends of defoliation** as response variable, crown condition of Norway spruce deteriorated in regions with higher deposition of nitrogen and total acidity and sites poor in Mg, K, and P. Also at sites with low mean and low summer temperature, cold winters and late frosts, defoliation has increased. Defoliation of Scots pine in higher altitudes of pilot area 2 has increased. Also monocultures are more likely to have an increasing defoliation status.

Regression models with **discoloration** as response variable are comparatively weak. Only in Norway spruce a correlation with defoliation exists. Hints corroborating drought hypothesis could not be found.

The structure of the correlative relationships between defoliation and available predictors changes more or less from year to year. However, distinct temporal autocorrelative properties within defoliation values, peculiar for species and areas, could be shown.

Correlations between **foliar element concentrations** of sulphur and heavy metals indicate associations between respective air pollutants. In spruce nitrogen and sulphur concentrations are associated as well as magnesium and calcium. Spatial distributions of foliar element contents may represent spatial patterns of respective air concentrations, however data are not sufficiently dense to perform multivariate statistics. The negative correlation between phosphorous needle concentration and defo-

liation in Scots pine gives some support to the hypothesis of P deficiency as a consequence of high N inputs.
The delineation of homogenous transnational pilot areas has proved to be a promising approach. It accomplishes studies performed at regional or national levels at one side and at the European level at the other side. However, the necessity to improve data quality especially with respect to the comparability of crown condition estimates between countries has become obvious.

7 Literature

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Annex

Water availability ranks derived from soil type corroborated by expert's opinions (Barbara Gelinck, Gent University, Winfried Riek, University of Applied Science, Eberswalde)

Pilot Area 1

code	soil type	water availability rank
215	haplic podzols	1
219	gleyic podzols	3.5
216	cambic podzols	1
218	carbic podzols	1.5
110	dystric gleysols	4.5
113	umbric gleysols	5
108	eutric gleysols	4.5
147	dystric cambisols	3 (2 - 4)
198	gleyic luvisols	3 (2 - 4)
197	stagnic luvisols	2.8 (2 - 3.5)
230	stagnic alisols	2.8 (2 - 3.5)
129	haplic arenosols	1
250	aric anthrosols	3 (2 - 4)
251	fimic anthrosols	2

Pilot Area 2

code	soil type	water availability rank
110	dystric gleysols	4.5
113	umbric gleysols	5
130	cambic arenosols	1
135	gleyic arenosols	4
146	eutric cambisols	3 (2 - 4)
147	dystric cambisols	3 (2 - 4)
153	gleyic cambisols	4
189	haplic greyzems	2
205	eutric planosols	2.8 (2 - 3.5)
206	dystric planosols	2.8 (2 - 3.5)
208	umbric planosols	2.8 (2 - 3.5)
212	stagnic podzoluvisols	2.8 (2 - 3.5)
213	gleyic podzoluvisols	4
215	haplic podzols	1
216	cambic podzols	1
217	ferric podzols	1
219	gleyic podzols	3.5