WORKREPORT

Institute for World Forestry

Temporal and spatial variation of crown condition of main Norway spruce and oak species

by

VOLKER MUES

Federal Research Centre
for Forestry and Forest Products

Bundesforschungsanstalt für Forst- und Holzwirtschaft Hamburg
(Federal Research Centre for Forestry and Forest Products)
Address: Leuschnerstr. 91, D-21031 Hamburg, Germany
Postal address: P.O. Box: 80 02 09, D-21002 Hamburg, Germany

Phone: +40 / 73962-101
Fax: +40 / 73962-480
E-mail: weltforst@holz.uni-hamburg.de
Internet: http://www.bfafh.de

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Work report of the Institute for World Forestry 2003 / 10

This work report was published in November 2002.

Hamburg, September 2003

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Summary

The aim of this Internal Report is to analyse the spatial and temporal development of defoliation for Norway spruce (*Picea abies*) as well as for European and Sessile oak (*Quercus robur* and *Q. petraea*) in Europe by means of the transnational Level I data set of ICP Forests and the European Union's "Scheme on the Protection of Forests against Atmospheric Pollution". Additional external deposition and meteorological data are used to describe the influence of single stress factors.

According to the methodology published in LORENZ et al. (2002) the medium term mean defoliation is used to describe the spatial variability whereas the plot and year specific differences to the medium term mean are used to describe the temporal variability. Possible refinements of the methodology are outlined as well.

In line with expectations the analyses of the spatial variability of Norway spruce and oak species show significant correlations of insects, age and country with annual mean defoliation. In general, the deposition of sulphur was positively correlated with medium term mean defoliation. The models revealed no consistent results for the nitrogen components but nitrate deposition was significant in the model for Norway spruce with negative regression coefficients. The index for fungi infestation was negatively correlated with medium term mean defoliation of oak species. This was not expected from the understanding of fungi as damaging effect but was also found for beech (*Fagus sylvatica*) in earlier evaluations (LORENZ et al. 2002). The index for insect pests was significant in the models for Norway spruce as well as for oak. Additionally, plausible but not significant correlations were found with precipitation.

Time trends were mapped for Norway spruce and oak species as a description of the mean development in the evaluation period. The analyses of the temporal variation of defoliation for Norway spruce and oak will be carried out for the Technical Report Level I 2003. Additionally, alternative methods and amendments to the method published by LORENZ et al. (2002) will be tested.

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 crown condition survey is conducted on a large-scale transnational gridnet (Level I) of the ICP Forests, which was established in 1986. It is conducted in close co-operation with the European Union's "Scheme on the Protection of Forests against Atmospheric Pollution". The survey aims to assess the spatial and temporal variation of forest condition in relation to natural and anthropogenic factors, particularly air pollution.

Following the analyses for Scots pine (*Pinus sylvetris*) and beech (*Fagus sylvatica*) presented in chapters 2.5.3, 4, and 6 of the Technical Report Level I 2002 (Lorenz et al. 2002) the temporal and spatial variation of defoliation for Norway spruce (*Picea abies*) as well as for European and sessile oak (*Quercus robur* and *Q. petraea*) were for the first time presented in this Internal Report. After thorough discussions at editorial meetings and possible refinements the evaluations and results have been published in the Technical Report Level I in 2003. The medium term mean defoliation is used to describe the spatial variability of defoliation while the annual differences to the plot specific medium term means are used to analyze the temporal variability of defoliation. The slopes of linear regressions with time are used for a description of the mean development of crown condition during the evaluation period.

The Internal Report 2002 depicts first results of the analyses and to outlines possible amendments concerning the used methodology especially with respect to the temporal variation of defoliation and effects of temporal auto-correlation.

The presented work report is the unmodified version of the Internal Report 2002.

Dr. Volker Mues is scientist at the Institute for World Forestry.

2 Data and Methods

Spatial variation describes the diversity of values at different locations. Anlyses of the medium term mean defoliation revealed for nearly all of the analyzed main tree species in Europe (*Pinus sylvestris*, *Picea abies*, *Pinus pinaster*, *Fagus sylvatica*, *Quercus robur* and *Q. petraea*, and *Quercus ilex*) a country-wise age-effect which could explain a part of the spatial variation. It was expressed by linear regression that locations ("plots") with older trees – on average – take higher defoliation values than those with younger ones (LORENZ et al. 2001). Differences of the medium-term (1994 to 1999) mean plot defoliation to those country-wise linear regressions of defoliation over stand age are called preliminarily adjusted defoliation (PAD) and maps of this parameter are used in chapter 3 to depict the spatial variation of defoliation. It can be interpreted as the mean deviation of the mean plot defoliation from that model value which is expected for a stand of the respective age in the respective country.

Additionally indices for fungal and insect infestations could explain some part of the spatial variation of medium-term mean defoliation (LORENZ et al. 2001). The expansion of the database by the integration of precipitation data of the Global Precipitation Climatology Centre (GPCC) and of deposition data of the Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) enables a more detailed analysis to examine supposed cause-effect relationships according to the analyses presented in the Technical Report Level I 2002 (LORENZ et al. 2002). The aim of the analyses concerning spatial variation is to explain the differences in defoliation at varying locations.

In addition and as a basis for detailed analyses of the *spatial* variation, the description of the *temporal* variation of defoliation will be in the focus of the integrative evaluations of the Technical Report Level I 2003. Questions to be answered are:

- Why is defoliation higher (lower) in year t+n than in year t?
- Is there a temporal trend in the data, maybe changing with location?
- Are there any correlations of defoliation values over time with predictor variables?
- Do these correlations with time varying variables confirm hypotheses derived from former studies and evaluations?

Although only a low part of temporal variation could be explained within earlier case studies, they showed that temporal variation of defoliation is influenced by biotic, meteorological and deposition factors. These factors themselves are varying over time in contrast to other factors, which are more or less constant over time (e.g. soil type). For the years 1993 to 1999 EMEP-data could be used for the estimation of the deposition rates at the Level I plots for sulphur (SO_x-S) and nitrogen (NO_x-N as well as NH_x-N). Additionally the monthly precipitation could be quantified for the Level I plots using digital information layers from the Global Precipitation Climatology Centre (GPCC, 1986 to 2000). Because of the temporal limitations of the auxiliary database (EMEP) and due to the fact that a substantial increase in transnational Level I plots was observed before 1994, the evaluation period was fixed from 1994 to 1999. Due to changes in methodology, data from France and Italy could not be integrated in these evaluations. Thus, for the evaluations concerning Norway spruce (oak) data of 1 046 (291) plots could be used.

Regression techniques are used to detect those time-varying predictor variables, which are correlated with the temporal development of defoliation.

Predictor variables and the dependent variable defoliation are basically transformed to differences to the plot specific medium term means which were calculated over the evaluation period (1994 to 1999) from the annual values. These transformed variables are called "referenced" values. The value of this referenced variable ref(X) for location i and year j is calculated for the years 1994 to 1999 and the n locations as described in the following equation:

$$\mathrm{ref}(X)_{ij} = X_{ij} - \overline{X}_i = X_{ij} - \frac{\sum_{j=1994}^{1999} X_{ij}}{6} \qquad (1)$$

i = 1, 2, 3, … n ; n = number of locations
j = year of observation

The benefit of this referencing procedure is the separation of spatial and temporal variation. Thus, e.g. the medium-term mean defoliation ($\mathrm{MMD}_i = \overline{X}_i$ of defoliation) was already used in the integrative evaluation of the Technical Report Level I 2001 (LORENZ et al. 2001) for quantifying the spatial variation of defoliation. The MMD_i is the mean level of defoliation at each survey plot (location). Annually changing deviations from this mean level comprise the temporal variation at the respective plot.

For e.g. the 1 046 plots which are available for Norway spruce with on average more than 2 trees of the respective tree species per plot, 1 046 mean values were calculated. The 6 276 (= 1 046 * 6 years) differences from the respective 1 046 plot-wise mean values are the observations for the evaluation of temporal variation. Figure 1 and Figure 2 show an example for one plot location with 6 defoliation observations from 1994 to 1999. The temporal variation remains the same when expressed by the referenced values, which are the differences between the six observed values and the mean values 22%, and 1996.5 years respectively. Linear regressions over the predictor variable and over its referenced values lead to identical regression coefficients ("slopes") in both cases. When calculating with referenced predictor variables the additional component (intercept) is always the plot-wise mean defoliation (MMD).

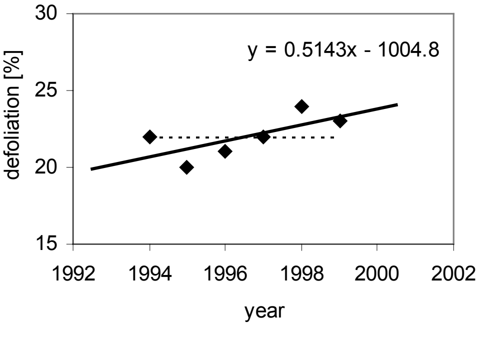


Figure 1: Linear trend of defoliation vs. year (untransformed)

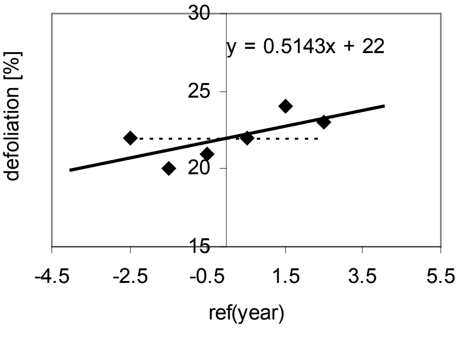


Figure 2: Linear trend of defoliation vs. referenced year, ref(year)

The model, which is used in the example of Figure 2 (only one of many plots is shown there) is a simplified case of equation 2b without meteorological or deposition predictor variables. Equation 2b can be derived from a pure model, in which referenced defoliation is explained by referenced predictor variables:

$$\begin{aligned} ref(D)_{ij} = {} & \beta_1\, ref(dSOx)_{ij} + \beta_2\, ref(dNOx)_{ij} + \beta_3\, ref(dNHy)_{ij} \\ & + \beta_4\, ref(precind)_{ij} + \beta_{5i}\, ref(year)_{ij} + \varepsilon_{ij} \end{aligned} \tag{2}$$

D_{ij} – defoliation in year j at location i

$dSOx_{ij}$ – deposition of SOx in year j at location i ; analogue for NOx and NHy

$precind_{ij}$ – precipitation index in year j at location i

$year_{ij}$ – year j of observation at location i

ε_{ij} – residuum (unexplained error) in year j at location i

By analogy to equation 1, equation 2 can be transformed on the left side to 2a:

$$\begin{aligned} D_{ij} - MMD_i = {} & \beta_1\, ref(dSOx)_{ij} + \beta_2\, ref(dNOx)_{ij} + \beta_3\, ref(dNHy)_{ij} \\ & + \beta_4\, ref(precind)_{ij} + \beta_{5i}\, ref(year)_{ij} + \varepsilon_{ij} \end{aligned} \tag{2a}$$

MMD_i – medium-term mean defoliation (1994-1999)

Taking the medium-term mean defoliation MMD_i to the right side results in equation 2b:

$$\begin{aligned} D_{ij} = {} & MMD_i + \beta_1\, ref(dSOx)_{ij} + \beta_2\, ref(dNOx)_{ij} + \beta_3\, ref(dNHy)_{ij} \\ & + \beta_4\, ref(precind)_{ij} + \beta_{5i}\, ref(year)_{ij} + \varepsilon_{ij} \end{aligned} \tag{2b}$$

In equation 2b the plot-wise medium-term mean defoliation MMD_i as time-constant spatial variation is used to "explain" a part of the variation of defoliation. The part, which is explained by the plot-wise variable medium-term mean defoliation, was used in a modification of split-plot analyses to test the significance of the other predictor variables (compare DIGGLE et al., 1994). The same statistical test was used by HENDRIKS et al. (2000) for a similar analysis of data from The Netherlands for the period 1984 to 1994. This error model was used to allow for repeated measures data (i.e. the defoliation assessments in the same plots over years).

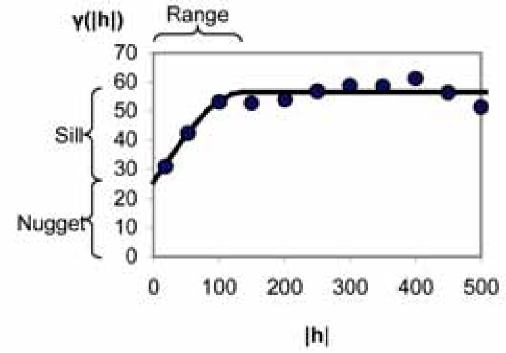
However, the probably existing temporal autocorrelation, the dependence of an observation x in year t, x_t, from the earlier observed value x_{t-n} of former years is not evaluated by this method. The possibilities for a consideration of such temporal autocorrelation will be investigated in more detail and hopefully lead to an improvement of the analyses of temporal variation of defoliation.

The regression coefficients β_1 to β_5 can be interpreted as gradients for the respective predictor variable describing the amount of defoliation changing with an increase of one unit of the predictor variable. Maps of the plot-wise calculated regression coefficients of the referenced observation year, β_{5i}, are used in chapter 3 to describe the mean temporal trend of defoliation.

For the evaluation of temporal variation as well as that of spatial variation a model with all possible predictors is calculated first. From the precipitation indexes with plausible (negative) regression coefficients only that was used, which showed the highest explanation power, or the highest Type III sum of squares respectively. Thus, the first model includes the following predictors: Sum of precipitation, fungi index[1], insect index[1], deposition of sulphur, oxidised and reduced nitrogen or alternatively the sum of both types of nitrogen deposition, the year of observation and the medium-term mean defoliation. The next step is to reduce the model by the predictors with implausible regression coefficients. From the resulting model, which includes all plausible predictors, the predictor variable with the lowest explanation potential will be rejected until only statistically significant predictor variables are remaining in the model. Additionally the model, which is built by the only predictor variable YEAR of observation will be calculated and used for a descriptive mapping of the temporal development of defoliation (Figure 4 and Figure 7).

In addition to the plot-wise presentation the results are interpolated with geostatistical kriging following the methodology described in more detail in the Technical Report Level I 2001 (LORENZ et al. 2001). The fundamental assumption of geostatistics is that a regionalised variable may consist of a deterministic, a correlative and a random component (RIPLEY, 1981; see also SCHALL, 1999). The deterministic component, the "drift", can be described e.g. by regression or covariance models. The correlative component means that points located close together show smaller differences concerning the value of the regionalised variable than points with a large spatial distance. Because this is a spatial correlation of values from **one** variable, it is called spatial (intravariable) autocorrelation. This component can be used, to calculate weights for an interpolation by the data themselves instead of those subjectively chosen, like e.g. inverse squared distance weighted interpolations.

The spatial autocorrelation of the regionalised variable (e.g. plot-wise slope of linear temporal trend of defoliation) can be described by an empirical semivariogram which expresses the dissimilarity increasing with distance h between (sample) points x_i and $x_i + h$ (Figure 3). Each point in the empirical semivariogram is calculated using equation (3) for the particular distance or class (lag) of distance h. The semivariance is the mean squared difference between i pairs of values of the regionalised variable from i pairs of points/locations within the spatial distance h.



$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (3)$$

$N(h)$ – number of point pairs with distance h
$z(x_i)$ – regionalized variable at sample point x_i

Figure 3: Experimental semivariogram of average dissimilarities over spatial distance |h| [m] and a modelled spherical semivariogram: nugget: 25.5 sill: 31.0 range: 136 km.

Three parameters are usually used to describe the shape of the semivariogram: nugget, sill and range. The nugget is the semivariance, which is observed for the

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[1] share of plot trees with identified damage due to fungi or insects, respectively (s. Table 2.3.1-1)

distance h = 0. It can be interpreted as the random component of the regionalised variable. Mainly two conditions lead to a nugget value greater than zero:

- The underlying measurement gridnet has a too low density, so that the spatial structure/autocorrelation could not be detected completely.
- The underlying spatial structures are hidden by inaccuracies of data assessment or other "noise".

The sill is quantifying the autocorrelative component of the regionalised variable. The range is the distance in which spatial autocorrelation is observed. The closer a plot is lying to an estimation (target) point x_i, the lower is the particular value of the semivariogram $\gamma(h)$ and the higher is – in general – the (kriging-) weight of this plot for the interpolation (kriging) of the regionalised variable at any estimation point $z^*(x_i)$.

The kriged maps allow a quicker overview. Only for those points a value of the regionalised variable was estimated, for which at least 12 Level I plot values are available in a radius of 800 km and for which at least 4 plot values are available within a radius of 100 km. The latter precondition was defined in order to reduce the area of extrapolation beyond the sample area. For the calculation of the kriging values however plots within the 800 km radius were used.

3 Results

3.1 Norway spruce

For Norway spruce maps of the temporal trend of mean defoliation are presented in 3.1.1. Spatial variation in terms of mean defoliation maps of the preliminarily adjusted defoliation (PAD) and first results of the regression analyses are presented in 3.1.2.

3.1.1 Temporal variation

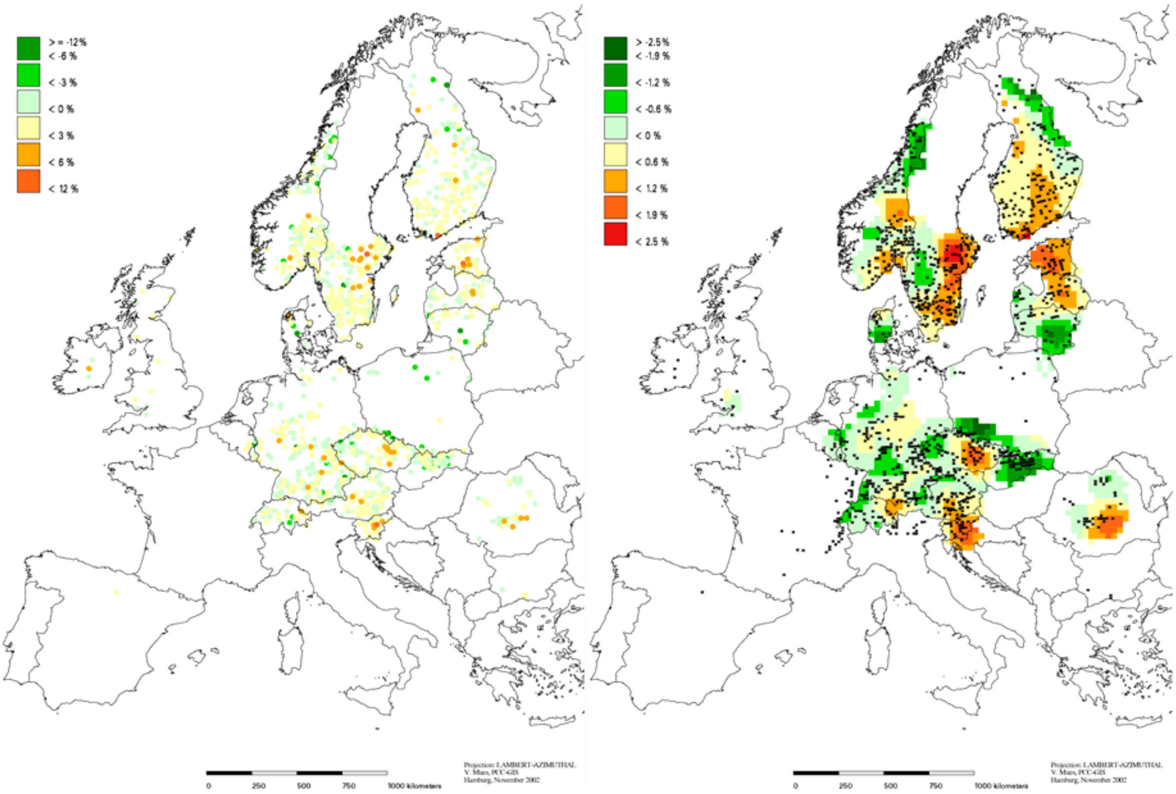

Figure 4: Plot-wise (left) and interpolated (right) time trend of mean defoliation of Norway spruce (1994 to 1999)

A deterioration of crown condition as described by the slope of a regression of annual mean defoliation by time (Figure 4) took place in large parts of eastern Sweden, the south of Finland and the north of the Baltic countries. But also in parts of Norway, the Czech Republic, Romania, Germany, and Slovenia defoliation increased during the evaluation period.

3.1.2 Spatial variation

The plot-wise mean defoliation (1994 – 1999) of the raw data shows some extreme plot values in the middle of Norway. For the respective Trøndelag region SOLBERG

(1999) found that needle (*Chrysomyxa abietis*) and root (*Heterobasidion annosum*) affecting fungi are quite common. Also in Czech and Slovak Republic defoliation values are higher compared to the surrounding countries (see Figure 5). The preliminarily adjusted defoliation (PAD) (see Figure 6) still shows the high defoliation in middle Norway, but less country effects in central Europe. In particular, the border effect which seems to be obvious between Germany and the Czech Republic disappears using the PAD.

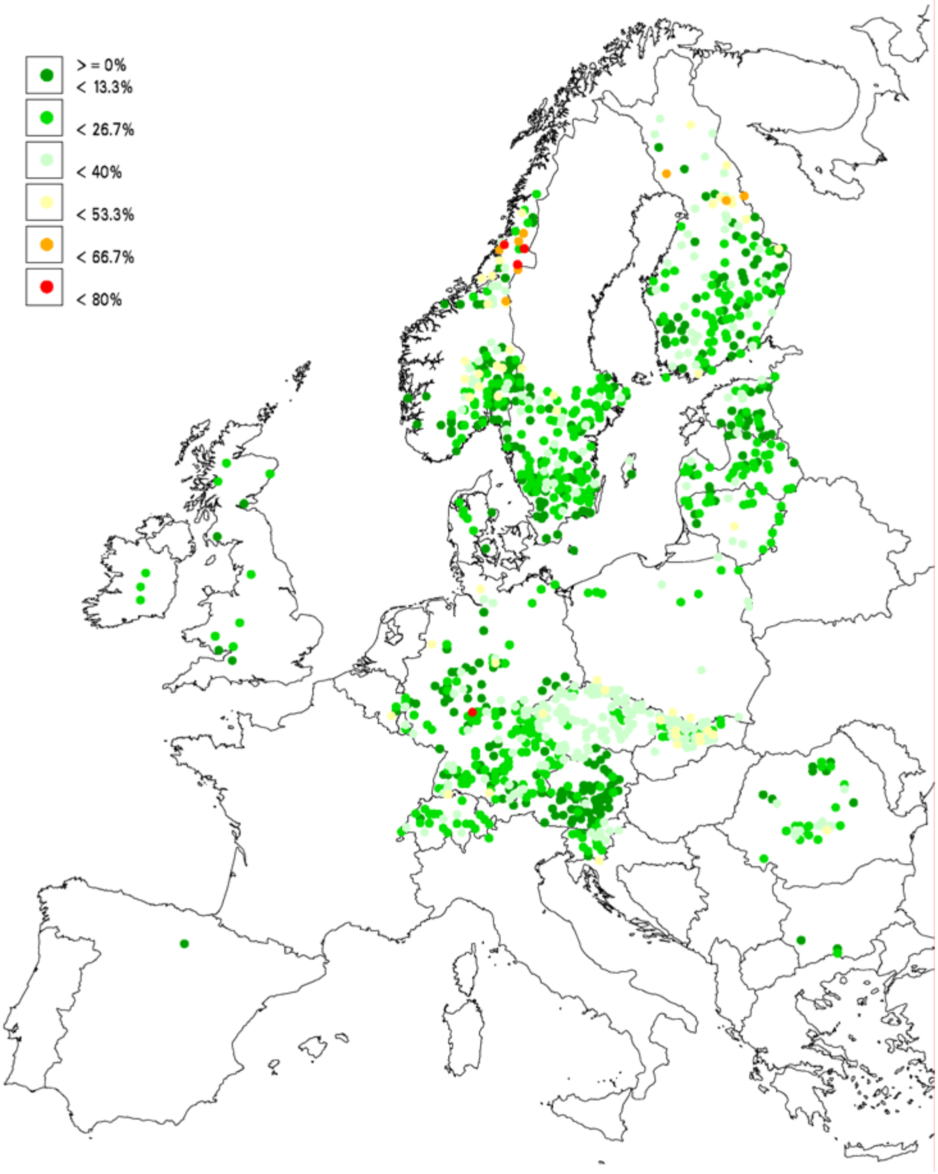

Figure 5: Plot-wise medium term mean defoliation of Norway spruce 1994 to 1999

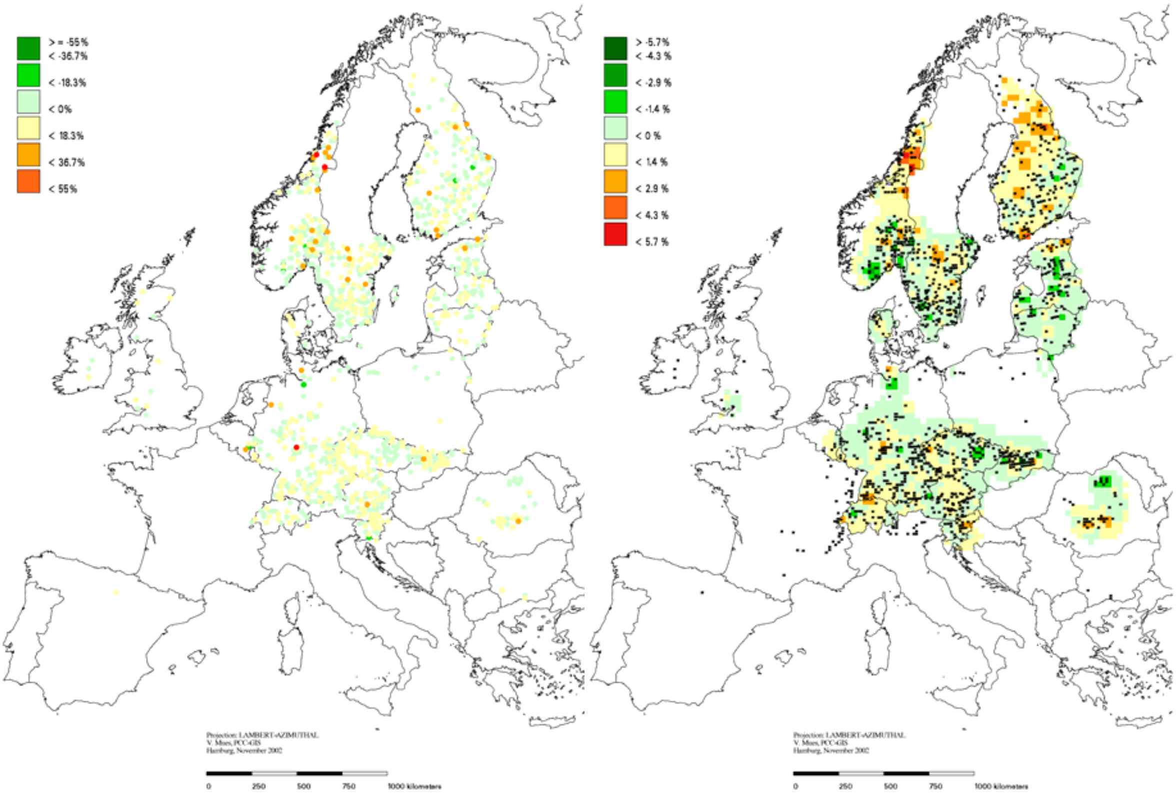

Figure 6: Plot-wise (left) and interpolated (right) differences to country specific model for age trend (preliminarily adjusted defoliation, PAD) of Norway spruce

Table 1: Linear regression models for spatial variation of medium-term mean defoliation of Norway spruce; statistically significant predictors shaded.

No.	R^2	precipitation [mm]	insect	fungi	deposition [g/m^2]			country	age$_{country}$
	[%]	Jan.-Jun.			S	NHy	NOx		[year]
1	58.7	-0.008349	29.0	3.4	2.1	4.6	-25.8	x	x
2	58.6	-0.00728	30.2				-18.9	x	x
3	58.5		29.5				-19.1	x	x
4	56.8							x	x

prec jan-jun	difference of mean precipitation from January to June in the years 1994 to 1999 from the long term mean precipitation in the same months in the years 1961 to 1990
insect, fungi, deposition	plot-wise means of the values for the years from 1994 to 1999
country	class variable
age$_{country}$	age of stand in years, calculated country-wise

The R^2 values of all models for spatial variation of defoliation of Norway spruce are relatively high (see Table 1). A model only including the class variable country as predictor variable leads to a R^2 value of 23.3% (not depicted). The much higher value of model 4 (Table 1) which includes the country specific age trend seems to confirm the strong relationship between defoliation and age which is described also in the Technical Report Level I 2001 (LORENZ et al. 2001).

From the tested precipitation indices only those for differences between means in the evaluation period to the long term means lead to plausible negative regression coefficients. The distinct precipitation sums for the evaluation period or for the long term means lead to positive regression coefficients.

Models including total nitrogen instead of separate nitrogen and nitrate components often result in implausible negative regression coefficients for deposition of sulphur. Also the R^2 values are slightly lower.

3.2 Oak

For oak (*Quercus robur* and *Q. petraea*) maps of the temporal trend of mean defoliation are shown in 3.2.1. Concerning the analyses of the spatial variation of mean defoliation maps of the preliminarily adjusted defoliation (PAD) and first results of the regression analyses are presented in 3.2.2. A joint interpretation of oak maps for temporal and spatial variability of defoliation showed that for regions with relatively high defoliation (Figure 9) an improvement of defoliation could be observed (Figure 7) whereas the opposite is true for regions with relatively low defoliation.

3.2.1 Temporal variation

Crown condition of oak as described by the slope of a regression of annual mean defoliation over time shows the strongest deterioration in Romania, Croatia, and southern and northern Germany (Figure 7). Especially for northern Germany an increase of defoliation during the evaluation period is detected for a large region. For other parts of Europe an improvement of crown condition was observed. In particular, the improvement of crown condition in southern Poland has to be underlined especially when related to the high level of defoliation in this region as presented in Figure 9.

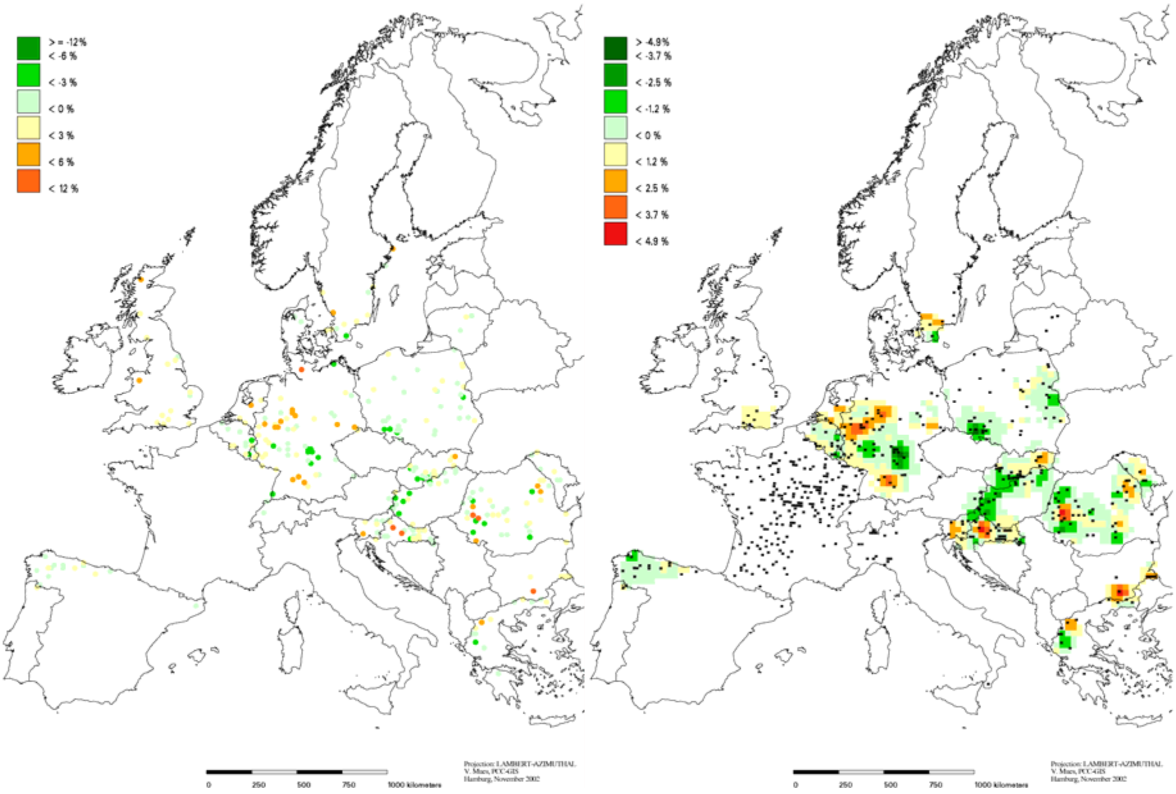

Figure 7: Plot-wise (left) and interpolated (right) time trend of mean defoliation of oak (1994 to 1999)

3.2.2 Spatial variation

A high spatial variation of medium term mean defoliation is shown in Figure 8, and of the preliminarily adjusted defoliation (PAD) in Figure 9.

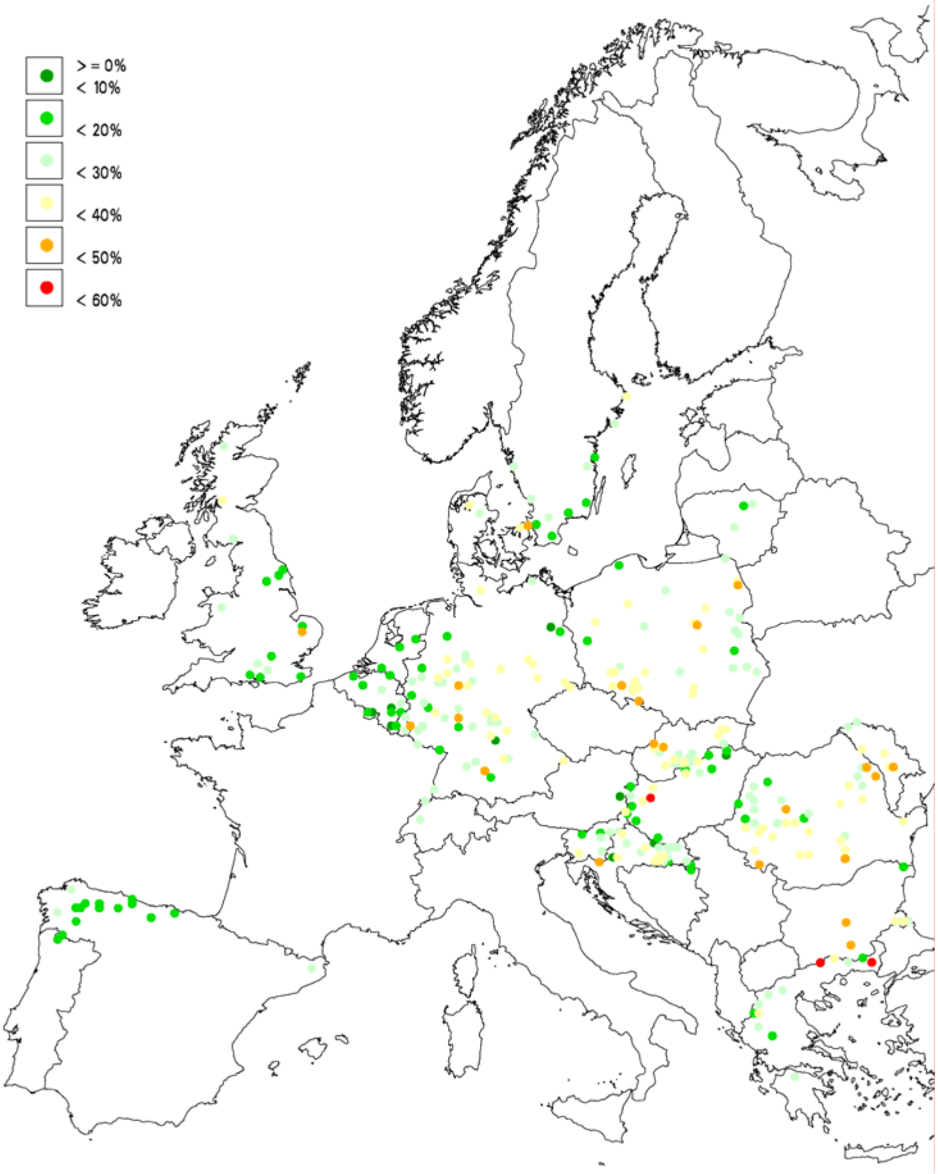

Figure 8: Plot-wise medium term mean defoliation of oak 1994 to 1999

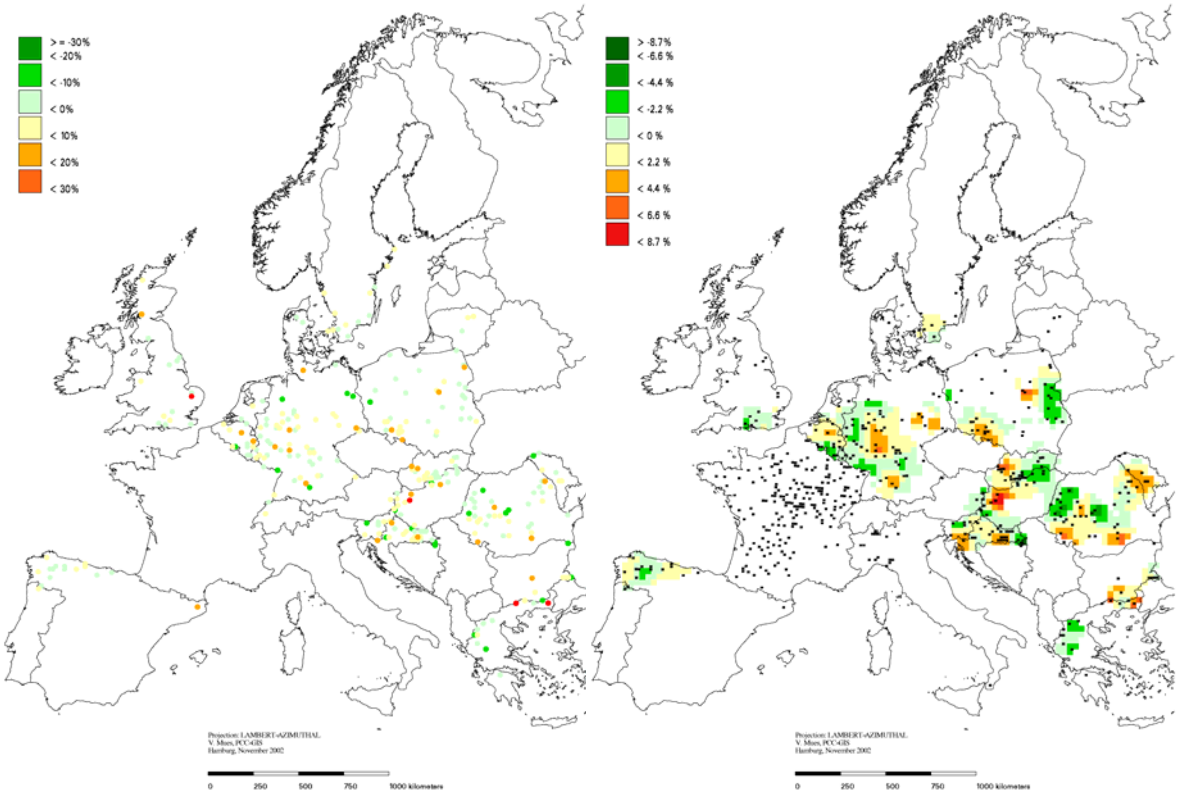

Figure 9: Plot-wise (left) and interpolated (right) differences to country specific model for age trend (preliminarily adjusted defoliation, PAD) of oak

Table 2: Linear regression models for spatial distribution of medium-term mean defoliation of oak; statistically significant predictors shaded.

No.	R^2 [%]	precipitation [mm] Jan.-Jun.	insect	fungi	deposition [g/m^2] S	NHy	NOx	country	age$_{country}$ [year]
1	43.3	-0.0023	6.0	-8.5	-0.025	-7.6	7.8	x	x
1a	43.1	-0.0019	5.9	-8.5	0.8	-2.5		x	x
2	42.9		6.0	-8.6				x	x
3	41.7		5.3					x	x
4	40.3							x	x

prec jan-jun	sum of mean precipitation from January to June in the years 1961 to 1990 from the long term mean precipitation in the same months in the years 1961 to 1990
insect, fungi, deposition	plot-wise means of the values for the years from 1994 to 1999
country	class variable
age$_{country}$	age of stand in years, calculated country-wise

The R^2 values of all models for spatial variation of defoliation of oak are lower than those for Norway spruce (Table 2). A model including only the class variable country as predictor variable leads to R^2 value of 32.0% (not depicted). In addition to age and country the only significant predictor variables are insect and fungi. The negative regression coefficient for fungi is not in line with expectations. A possible explanation by inter-correlations with insects should be examined in more detail. Similar observations were made earlier for beech (LORENZ et al. 2002).

From the tested precipitation indices only those for the sums of long term means for the first six months in the year and for the annual precipitation (both for 1961 to 1990) lead to plausible negative regression coefficients. All other tested precipitation indices lead to unexpected positive regression coefficients, perhaps due to inter-correlation effects.

Most models including total nitrogen instead of separate nitrate and ammonium components result in plausible positive regression coefficients for deposition of sulphur (e.g. model 1a in Table 2). The R^2 values, however, are lower.

4 Outlook

Earlier evaluations of the Level I data set (Seidling, 2001) clearly showed the temporal autocorrelation in the data which means that defoliation values of a certain year are statistically related to the defoliation values of the preceding year. It is foreseen to refine the presently applied method through an inclusion of auto correlative effects, in order to improve the multiple regression models.

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