

Long-term effects of nitrogen deposition on vegetation in a deciduous forest near Munich, Germany

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Abstract

Question: What are the main reasons for changes in the spatial distribution of vegetation types during the last four decades?

Location: Isolated small deciduous forest; surrounded by farmland in the northeast of Munich (Germany).

Methods: Based on sequential vegetation mapping from the last four decades the spatial development of the vegetation was analysed. Additionally, environmental parameters (soil parameters, PAR, N-deposition) have been analysed to describe the different vegetation types.

Results: By linking the vegetation types to environmental parameters, it was possible to identify N-deposition as the most important factor for the changes. In the 1960s to 1980s the replacement of vegetation types adapted to N-poor conditions by N-rich vegetation was very fast. A vegetation type containing species signifying soil impoverishment vanished totally, another vegetation type indicating nutrient poor conditions decreased dramatically. However, since 1985 up to now the decrease of N-poor vegetation types has slowed, but is still ongoing. As a reason for the decreased rate of replacement, we stressed changes in the vertical structure: From 1961 to 1985 both N-deposition as well as changes in vertical vegetation structure seem to be important. Since 1985 up to now only minor changes in vertical structure could be found; changes are mainly due to N-availability.

Conclusion: In this paper, the limitations of different methods to detect vegetation changes are discussed. We focus on the potentials of historical vegetation data and vegetation maps. It is shown that valuable information on N-induced vegetation changes can be retrieved from historical vegetation data.

Keywords: Forest herb layer; Nitrogen gradient; Photosynthetically active radiation; Sequential vegetation mapping; Soil analysis; Time series.

Nomenclature: Vascular plants: Wisskirchen & Haeupler (1998); bryophytes: Koperski et al. (2000).

Introduction

Today nearly every ecosystem has been influenced by human activities, often causing changes in plant and animal communities. Impacts on ecosystems that are easy to identify are for example lowering of the ground water table or clearing of forests; less visible impacts include immissions from the air. These impacts are of great interest for landscape management and nature conservation (Bobbink et al. 1998).

In industrialized and densely populated countries nitrogen deposition is one of the most important factors influencing ecosystems since the advent of industrial fertilizers. Therefore changes in vegetation composition and ecosystem function can be found particularly in nitrogen-limited ecosystems (Bobbink et al. 1998; Römermann 2006; Smart et al. 2003). The increased availability of nitrogen is of major importance for vegetation in forests, which are naturally nitrogen-limited (Tamm 1991). Indeed, many changes observed in forests during the last decades could be related to enhanced nitrogen availability (e.g. Bernhardt-Römermann & Ewald 2006; Brunet et al. 1998; Diekmann et al. 1999; Falkengren-Grerup & SchötteIndreier 2004). Generally, plant species requiring high amounts of nitrogen increase.

Most studies on nitrogen deposition are either based on permanent plot observations or on studies along environmental gradients (Brunet et al. 1998). Studies focusing on permanent plots have to deal with the problem that the area of a permanent plot is limited. By making lists of all occurring plant species and by estimating their cover at certain time intervals the changes in plant species composition can be described accurately. However, the results are strongly dependent on the position of the permanent plots within the study area. As to the choice

of plots on the basis of prior knowledge of the direction and scale of expected changes (Küchler & Zonneveld 1988), many permanent plots may not be representative for the entire area. The same problem occurs in studies along environmental gradients, which are mostly chosen with respect to an expected gradient. Hence the current study uses the method of sequential vegetation mapping for analysing vegetation changes; this gives spatially explicit information at the stand level.

For providing a synoptic view of an area and its vegetation, vegetation maps are frequently used (Janssen 2004). One way to describe the development of vegetation in space and time is the use of sequential vegetation maps. In this way vegetation patterns can be detected and the area covered by different vegetation types estimated. This method is often used for planning and monitoring management in nature conservation (Bakker 1979), but also for monitoring vegetation changes in time (e.g. Kudernatsch et al. 2004; Schmidt in press). However, approaches based on vegetation maps have limitations (Janssen 2001; Küchler & Zonneveld 1988), especially because they depend on vegetation types (fixed syntaxonomical units, Campetella et al. 2004). In the current literature many authors propose the use of statistical methods based on remote sensing for monitoring vegetation changes (Feldmeyer-Christe et al. 2004); they criticize the method of sequential vegetation mapping in the field as being too subjective (Sanders et al. 2004). However, sequential vegetation mapping may represent an alternative tool when aiming to define vegetation types in the sense of species assemblages, especially in forests, where remote sensing is less effective due to the dense canopy of the tree layer. Nevertheless, initiatives of vegetation monitoring starting today should follow statistically reliable methods. But to receive information on vegetation development for the last decades, we need to use the existing historical vegetation data, while of course taking the methodological limitations into account (see discussion in Ganio 2006 & Wildi et al. 2004).

Based on two historical vegetation maps from 1961 and 1985 and a present-day map, our goal is to study the development of the vegetation in a deciduous forest on a floristic basis. By linking the vegetation types used for vegetation mapping to measured environmental parameters related to the nitrogen status of the ecosystem, it is possible to receive information on nitrogen-induced vegetation changes and the spatial development of the vegetation types during the last four decades. Nevertheless, despite the methodological limitations, in the current study we want to address the question whether vegetation data and vegetation maps are useful to analyse and document vegetation changes.

Material and Methods

Study area

The study area Echinger Lohe is located in the north-east of München (11°43' E, 47°55' N, 465 m a.s.l.). It is a small deciduous forest of ca. 24 ha, isolated since more than two centuries and being surrounded by intensively used farmland. The mean annual temperature is ca. 9 °C, the average annual rainfall ca. 800 mm. The site is situated on the 'Münchener Schotterebene', a plain which was formed by gravel deposition at the end of the last ice age. The background level of nitrogen pollution is ca. 15-20 kg/ha (Anon. 2005). The forest can be characterized as a *Quercus petraea*-*Carpinus betulus* forest with *Acer pseudoplatanus* and *Fraxinus excelsior* on pararendzina soil. Up to the 19th century the forest was used as a woody pasture, while during the world wars litter raking was common, which both led to soil degradation. After the area had become a nature reserve in 1942, human influence on the forest decreased and it disappeared completely when the area became a forest nature reserve in 1984 – which implies that any direct impact of man is forbidden by law.

Vegetation sampling

To characterize the actual vegetation composition of the Echinger Lohe, 20 relevés were carried out in 2003. Sample plots measured 15 m × 15 m, which is a recommended size for characterizing the forest floor vegetation. Cover of vascular plants and bryophytes was estimated using the method of Braun-Blanquet (1964) with classes following Pfadenhauer et al. (1986): + = <1 %; 1a = 1-3 %; 1b = 3-5 %; 2a = 5-15 %; 2b = 15-25 %; 3 = 25-50 %; 4 = 50-75 %; 5 = 75-100 %. Field, shrub and tree layer were analysed separately. For data analysis the cover estimate of each species was transformed into the mean of each class (+ was calculated as 0.5).

Environmental conditions

Soil sampling

To characterize the main rooting space of the field layer, three soil samples were taken per sample plot from the Ah-horizon and pooled for further analysis. The samples were oven-dried at 45 °C and the fine earth fraction (< 2 mm) was separated by sieving. A part of each sample was ground using a Retsch MM 200 mill.

Soil analysis followed the German standard method for analysis of forest soils, i.e. the 'Bodenzustandserhebung im Wald', BZE (Anon. 1994). Soil pH was determined in 1 M KCl-solution at a solution:soil-mass ratio of 2.5:1. The concentrations of H₂O extractable

NH_4^+ was analysed on sieved soil samples using the auto-analyser SCALAR 400. Water extractable NO_3^- , Cl^- , H_2PO_4^- and SO_4^{2-} were analysed using the ICP DIONEX DX-120. Contents of Mg^{2+} , Ca^{2+} , K^+ , Na^+ , Al^{3+} , Fe^{2+} , Mn^{2+} were determined by batch extraction of 2.5 g soil with 100 ml 1 M NH_4Cl -solution and subsequent analysis of the extracted cations with the ICP-OES (Perkin Elmer Optima 3000). Additionally, concentrations of total C and total N in the soil samples were determined with the LECO analyzer CHN-1000. Using the results of the soil analyses, soil contents were calculated for each parameter.

PAR

To describe the light situation at the forest floor, the Photosynthetically Active Radiation (PAR) was calculated by the mean of three independent measurements in July 2003, realized with PAR-sensors (type LI-190, Li-Cor). From each measurement the ratio of radiation outside the forest and at the forest floor was calculated.

Deposition data

Dry nitrogen deposition (NH_3 and NO_2) was measured using passive samplers, one sampler at each vegetation type (Kirchner et al. 1999; Spangenberg et al. 2002). Wet deposition was calculated from the bulk precipitation in an adjacent non-wooded area, by using correction factors for each ion. The potential nitrogen deposition was calculated by adding up dry and wet deposition. For the calculation of potential nitrogen deposition, deposition velocities of 2.2 cm.s^{-1} for NH_3 and 0.35 cm.s^{-1} for NO_2 have been adopted from the literature (Kirchner et al. 2005; Schmitt et al. 2005; for details see Kirchner et al. 2005).

Data analysis

Using a cluster analysis (Ward's method with relative Euclidean Distance), the dataset was divided into three groups of relevés (the separation into three groups is comparable to former studies done by Pfadenhauer & Buchwald 1987 and Seibert 1962). Further the data were analysed using the indirect ordination method Detrended Correspondence Analysis, DCA – species responses were unimodal (Hill & Gauch 1980; additionally compare the discussion on the use of CA and DCA in McCune & Grace 2002). Plots and species frequencies were ordinated and, to present a bi-plot, vegetation and ln-transformed soil data (here: only parameters that significantly differ between the vegetation types) were correlated with the axes. All multivariate statistics were done using the program PcOrd 4.41 (McCune et al. 1999), except for the correlation analyses that were done in SPSS 12.0

(SPSS Inc.). To avoid an overestimation of common species for all multivariate analyses, vegetation data were transformed following the formula $y = x^{0.25}$.

For all normal distributed data with homogeneous variances, soil parameters were tested for differences by single-factor ANOVA with subsequent *post-hoc* Scheffé-tests. If the criteria of normal distribution and homogeneous variances were not met, transformations were applied.

To examine which soil parameters are most important for explaining the variance represented by the axes of the ordination diagrams, stepwise multiple regression analyses were carried out to see which variables remain in an optimum model. For all test statistics and multiple regressions SPSS 12.0 (SPSS Inc.) was used.

Spatial distribution of the vegetation types

To analyse the spatial distribution of the identified vegetation types, the vegetation was mapped in 2003. For each area in the forest the vegetation was assigned to one of the pre-defined vegetation types. These assignments were done by using indicator species, which were taken from an Indicator Species Analysis (ISA, Dufrene & Legendre 1997) carried out on the vegetation data separated into the groups found by the cluster analysis (see above). The species used for vegetation type identification were those that showed significant indicator values for one of the three groups and with a main occurrence within that group.

For the Echinger Lohe data of two historical vegetation maps were available from the years 1961 and 1985, respectively (Pfadenhauer & Buchwald 1987; Seibert 1962). These maps were digitalized by the use of GIS (ArcView 3.2, ESRI), and the proportion of each vegetation type was calculated by using the add-in 'Demo-tools'.

Results

The relevés of the vegetation sampling were divided into three groups similar in species composition by the cluster analysis. The same clear separation of the relevés into three groups was shown by the ordination (Fig. 1). These groups are arranged along the first axis representing a gradient in vegetation composition from vegetation types 1 to 3, being correlated to the following soil parameters: thickness of the Ah-horizon, C, N, Ca^{2+} , Mg^{2+} , Mn^{2+} and K^+ (for test statistics see Table 1). The vegetation types are labelled according to their composition (see Table 3) according to the terms suggested by Seibert (1962): 1: *Carex alba*-type; 2: *Arum maculatum*-type; 3: *Corydalis cava*-type.

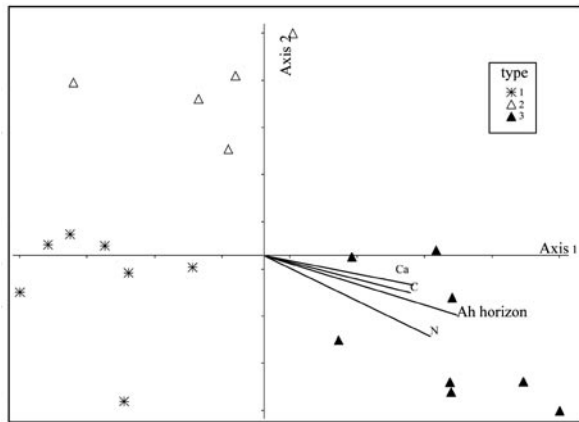


Fig. 1. Ordination diagram (DCA) of the forest floor vegetation. Matrix: 70 species, 20 relevés (axis 1: $r^2 = 0.65$, length of gradient: 1.916; axis 2: $r^2 = 0.03$); correlation threshold: $r = 0.7$. The separation of the relevés into three groups found by the Cluster analysis is indicated by different symbols. For correlations of soil parameters with the axes see Table 1.

Two possible models were generated by stepwise multiple regression analysis indicating the most useful soil parameters to describe the gradient in vegetation composition. In the first model only the thickness of the Ah-horizon is included ($r^2 = 0.84$; $df = 19$; $F = 43.93$, $p < 0.001$); the second model includes the thickness of the Ah-horizon as well as N-content of the soil ($r^2 = 0.89$; $df = 19$; $F = 30.00$, $p < 0.001$).

Differences between the three vegetation types were also found in other environmental parameters, such as Photosynthetic Active Radiation (PAR) and N-deposition (Table 2). PAR is highest in vegetation type 1 (*Carex alba*-type) and decreases to type 3 (*Corydalis cava*-type). A directly opposed gradient can be found for nitrogen deposition, which is highest in type 3.

Table 2. Photosynthetic Active Radiation (PAR) and nitrogen deposition given for the different vegetation types. Means, standard errors (SED) and number of measurements are reported for PAR. For N-deposition the annual deposition in 2004 is presented.

Vegetation type	PAR (%)		N-deposition kg.ha ⁻¹ .a ⁻¹
	Mean ± SED	N	
1: <i>Carex alba</i> type	3.75 ± 0.44	3	17.6
2: <i>Arum maculatum</i> type	2.65 ± 0.24	3	19.9
3: <i>Corydalis cava</i> type	1.89 ± 0.01	3	21.5

The result of the ISA shows distinct indicator species for vegetation types 1 and 3; noticeable is the missing of good indicators for the second vegetation type (Table 3). Type 1 is best described by *Fragaria vesca*, *Convallaria majalis*, *Viola hirta* and *Carex montana*. Type 3 can be characterized by *Corydalis cava*, *Asarum europaeum*, *Heracleum sphondylium*, *Elymus caninus*, *Chaerophyllum aureum*, *Eurhynchium swartzii* and *Plagiomnium undulatum*. Thus, these species are used as indicator species for the vegetation mapping.

The maps of the spatial distribution of the three vegetation types are shown in Fig. 2. In 1961 four different vegetation types were found, whereas in the following mapping vegetation type 0 (*Melampyrum pratense*-type) is missing. Comparing the three maps and Table 4 an increase of vegetation types 2 and 3 at the expense of type 1 can be estimated from 1961 to 2003. The increasing of vegetation type 3 took place especially at the borders of the forest, type 2 increased dramatically in the western part of the study site. Vegetation type 1 is unaffected in the centre of the forest only. Nevertheless, vegetation replacement is much higher from 1961 to 1985 compared with the second period.

Table 1. Results of soil sampling of the three vegetation types in the Echinger Lohe. Means, standard errors, F -values and significances (* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$, n.s. = not significant) are given. Correlations for significant parameters with axis 1 of the ordination (Fig. 1) and their significance are reported (r = Pearson's correlation-coefficient). Because soil contents for Al^{3+} and Fe^{3+} are below the limit of detection no results were reported for these contents.

Parameter	Unit	1	2	3	ANOVA	Corr. axis 1
Ah-horizon	cm	6.67 ± 0.54	7.47 ± 0.43	11.58 ± 0.66	$F = 21.45$	*** $r = 0.84$ ***
PH (KCl)		6.63 ± 0.09	6.62 ± 0.04	6.69 ± 0.03	$F = 0.49$	n.s.
C/N		11.00 ± 0.23	11.56 ± 0.26	10.82 ± 0.22	$F = 2.41$	n.s.
C	%	8.31 ± 0.42	8.35 ± 0.50	10.15 ± 0.19	$F = 9.60$	** $r = 0.73$ ***
N	%	0.76 ± 0.04	0.72 ± 0.04	0.94 ± 0.03	$F = 12.25$	** $r = 0.80$ ***
N-NO ₃ ⁻ + N-NH ₄ ⁺	mol IE / g	33.22 ± 3.42	26.87 ± 3.43	45.29 ± 6.22	$F = 3.40$	n.s.
Cl ⁻	mol IE / g	5.54 ± 0.67	6.13 ± 0.67	7.14 ± 0.56	$F = 1.86$	n.s.
P-H ₂ PO ₄ ⁻	mol IE / g	1.95 ± 0.82	3.30 ± 1.09	1.30 ± 0.28	$F = 1.89$	n.s.
S-SO ₄ ⁻²	mol IE / g	2.57 ± 0.82	1.16 ± 0.41	2.28 ± 0.74	$F = 0.85$	n.s.
Ca ²⁺	mol IE / g	430.93 ± 21.05	433.62 ± 18.00	521.13 ± 15.03	$F = 8.58$	** $r = 0.73$ ***
K ⁺	mol IE / g	6.40 ± 0.30	6.78 ± 0.29	8.17 ± 0.36	$F = 8.55$	** $r = 0.70$ **
Mg ²⁺	mol IE / g	87.05 ± 4.92	82.96 ± 4.77	109.53 ± 8.65	$F = 4.29$	* $r = 0.52$ *
Mn ²⁺	mol IE / g	1.13 ± 0.08	1.31 ± 0.11	0.92 ± 0.06	$F = 5.99$	* $r = -0.60$ *
Na ⁺	mol IE / g	0.96 ± 0.15	1.19 ± 0.19	1.58 ± 0.20	$F = 3.13$	n.s. $r = -0.60$ *

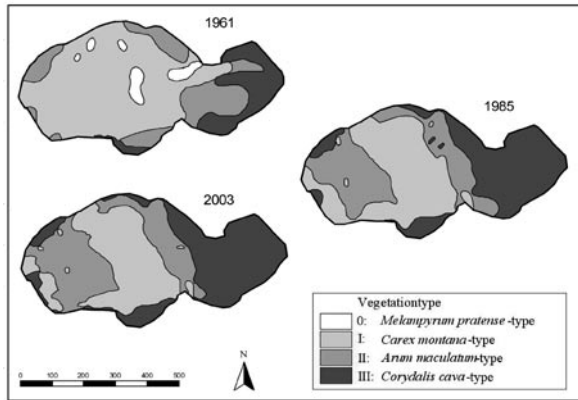


Fig. 2. Maps of the vegetation types in the Echinger Lohe for the years 1961, 1985 and 2003. The maps of 1961 and 1985 are redrawn from Pfadenhauer & Buchwald (1987), Seibert (1962), respectively. Colours were chosen with respect to nitrogen availability, the darker the higher the nitrogen status.

Discussion

The vegetation differentiation in the Echinger Lohe can be linked to a gradient in nitrogen availability. Following the results of the stepwise multiple regression analyses, thickness of the Ah-horizon as well as N-content of the soil seem to be the most important factors influencing the species composition. Three different vegetation types have been found, two of them characterized by good indicator species.

Table 4. Proportion (in %) and development trends of the vegetation types in the area of the Echinger Lohe in the years 1961, 1985 and 2003. The proportions were calculated from the maps shown in Fig. 2.

Vegetation type	1961	1985	2003	Development
0: <i>Melampyrum pratense</i> type	4	0	0	decreasing
1: <i>Carex alba</i> type	60	37	33	decreasing
2: <i>Arum maculatum</i> type	21	29	31	increasing
3: <i>Corydalis cava</i> type	15	34	36	increasing

Vegetation type 3 with its typical nitrogen-demanding species was positively correlated with the thickness of the Ah-horizon and contents of C and N. Due to the increased growth rates plants show a more intensive rooting, leading to an increased transfer of organic material into the soil (Scheffer & Schachtschabel 2002). Soil development is advanced by improved bioturbation as a consequence of stronger bioactivity in the soil (see close C:N-ratio; Lieberoth 1991 and Maraun et al. 2001); resulting in greater thickness of the rooting horizon. This process is intensified by many deep-rooting species (Dierschke & Briemle 2002; Kutschera & Lichtenegger 1992; Polomski & Kuhn 1998). The thickness of the rooting horizon and the nitrogen availability are strongly dependent on each other, in combination leading to a better availability of nitrogen.

In the Echinger Lohe two old vegetation maps exist from the years 1961 and 1985, respectively. In both old maps, the different vegetation types have been defined

Table 3. Results of the indicator species analysis (ISA) for the three vegetation types. For species with significant results, indicator values (IV) and relative abundances are given. Bold species have been used for vegetation mapping. Because vegetation type 2 does not have any good indicator species, the occurrence of this type was assumed when the indicator species of vegetation type 1 and 3 are missing.

	Vegetation type	Indicator value		Relative abundance in %		
		IV	p-value	1	2	3
<i>Fragaria vesca</i>	1: <i>Carex alba</i> type	75.4	0.001	88	0	12
<i>Convallaria majalis</i>	1: <i>Carex alba</i> type	72.2	0.001	72	0	28
<i>Viola hirta</i>	1: <i>Carex alba</i> type	57.1	0.012	100	0	0
<i>Carex montana</i>	1: <i>Carex alba</i> type	79.3	0.002	79	21	0
<i>Rhynchospora triquetra</i>	1: <i>Carex alba</i> type	50.8	0.050	51	45	4
<i>Hylocomium splendens</i>	2: <i>Arum maculatum</i>	57.5	0.022	28	72	0
<i>Asarum europaeum</i>	3: <i>Corydalis cava</i> type	87.5	0.001	0	0	100
<i>Corydalis cava</i>	3: <i>Corydalis cava</i> type	87.5	0.001	0	0	100
<i>Heracleum sphondylium</i>	3: <i>Corydalis cava</i> type	87.5	0.001	0	0	100
<i>Elymus caninus</i>	3: <i>Corydalis cava</i> type	75.0	0.003	0	0	100
<i>Chaerophyllum aureum</i>	3: <i>Corydalis cava</i> type	50.0	0.032	0	0	100
<i>Eurhynchium swartzii</i>	3: <i>Corydalis cava</i> type	50.0	0.029	0	0	100
<i>Plagiomnium undulatum</i>	3: <i>Corydalis cava</i> type	50.0	0.030	0	0	100
<i>Gagea lutea</i>	3: <i>Corydalis cava</i> type	63.0	0.005	16	0	84
<i>Arum maculatum</i>	3: <i>Corydalis cava</i> type	61.6	0.001	16	23	62
<i>Stachys sylvatica</i>	3: <i>Corydalis cava</i> type	59.0	0.016	5	17	79
<i>Allium carinatum</i>	3: <i>Corydalis cava</i> type	58.1	0.003	20	22	58
<i>Aegopodium podagraria</i>	3: <i>Corydalis cava</i> type	53.3	0.032	15	0	85
<i>Lilium martagon</i>	3: <i>Corydalis cava</i> type	47.8	0.070	34	12	55
<i>Polygonum multiflorum</i>	3: <i>Corydalis cava</i> type	46.8	0.016	30	23	47
<i>Lamium montanum</i>	3: <i>Corydalis cava</i> type	44.7	0.021	23	33	45

from groups of relevés taken from vegetation tables (Pfadenhauer & Buchwald 1987; Seibert 1962). Nevertheless, the definitions of the vegetation types as well as the used indicator species were comparable for all years. Considering the two historical vegetation maps and the actual map, covering a four decade's time period, the decrease of vegetation types adapted to low nitrogen availability in time is clearly visualized.

A strong increase in nitrogen deposition is well documented for Central Europe especially for the period since the 1960s (Galloway & Cowling 2002; van Egmond et al. 2002). However, measurements of nitrogen deposition during the last decade show a slight decrease in nitrogen loads per year (Meesenburg et al. in press), but the actual levels are still greater than the critical loads given by Bobbink & Roelofs (1995). At our study site, nitrogen availability is emphasized as the main reason for development of the different vegetation types during the last decades: From 1961 to 1985 vegetation type 0, containing indicators for soil impoverishment (e.g. *Melampyrum pratense*, *Carex alba*), vanished totally; type 1 (nutrient-poor conditions) decreased considerably – a development going on up to now. Furthermore, especially type 3 (*Corydalis cava* type) spread over large areas, at first along the borders of the forest, later in the inner part of the forest stand. As shown by the deposition data, a gradient in nitrogen deposition exists from the border of the forest to the centre; similar observations were made by Bernhardt-Rörmann et al. (2006a) and Spangenberg & Kölling (2004) at other forest borders near to nitrogen sources. In the middle of the forest the replacement of the low-nitrogen vegetation types has been slower due to the lower filter effect of the trees (Spangenberg & Kölling 2004; Spangenberg et al. 2004). However, following the argumentation of Diekmann & Dupré (1997) and Thimonier et al. (1992) especially the lower level of PAR in vegetation type 3 is a good indicator that the composition of the forest vegetation can be related to increased nitrogen availability: if the nitrogen availability in forests increases, trees will grow faster and more intensively (e.g. Emmett 1999), the canopy closes (Köchy & Wilson 2001) with the effect of lowered light levels at the forest ground.

However, the development from 1985 to 2003 seems to be different compared to the period from 1961 to 1985: during the first period the replacement of vegetation types adapted to nitrogen-poor conditions has been much faster than in the second period. Following the discussion on the method of sequential vegetation mappings, only strong differences between the years should be considered. When plotting the borders between the vegetation types as lines the fact that in nature normally smooth transitions between to vegetation types exist is ignored (Sanders et al. 2004); differences in the distribution of

vegetation types in 1985 and 2003 should not be over-interpreted. Nevertheless, the rate of vegetation changes in the Echinger Lohe during the second period is much lower compared to the first one. Recently, some authors stressed the hypothesis, that during the last decades the nitrogen pools in forest soils have been regenerated by depositions (Bernhardt-Rörmann et al. 2006b; Bernhardt 2005; Diekmann et al. 1999), leading to a decrease in rate of vegetation changes. Nevertheless, the development of forests subject to high nitrogen deposition is not only dependent on the amount of plant available nitrogen, but also on the vertical structure of the forest. Changes in this structure will be more pronounced, if a site is developing from former coppice to mature forests (Hakes 2001; Kuhn et al. 1987). Additionally this process leads to litter accumulation and increased N-availability, independently of N-deposition. It is hard to distinguish between the contribution of deposition and internal succession.

Taking the history of the study site into account – the soil nutrient pools were degraded by former land use-practices – plant growth was limited by nutrients and strongly influenced by better light conditions (Elemans 2004) in former times. Concerning the Echinger Lohe, from 1961 to 1985 speed of vegetation replacement is due to the impact of nitrogen deposition leading to better nitrogen availability for plants and to changes in vertical vegetation structure, respectively. Since 1985 up to now only minor changes in vertical structure can be found; changes in light availability are of minor importance. Nevertheless, nitrogen is still influencing vegetation development, but the meaning of other growth limiting factors must be stressed for predicting future development.

Conclusion

Our study shows that nitrogen deposition has an impact on the floristic composition of forest vegetation. The vegetation is clearly differentiated along a gradient of nitrogen availability; the development of the different vegetation types could be visualized by sequential vegetation maps. From 1961 to 1985 both N-deposition as well as changes in vertical vegetation structure seem to be important. Since 1985 up to now only minor changes in vertical structure could be found; changes are mainly due to N-availability.

It was shown that, despite methodological and statistical limitations, historical vegetation data can be used for a scientific approach to investigate the vegetation development during the last decades, when interpreted carefully.

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