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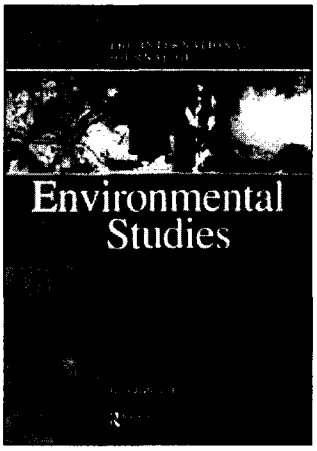

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Relationships between forest floor vegetation on ICP Forests monitoring plots in Europe and basic variables in soil and nitrogen deposition

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Forest floor vegetation is repeatedly assessed on intensive monitoring plots of the ICP Forests programme along with environmental parameters such as deposition and soil factors. Based on the floristic composition of the herb layer, detrended correspondence analyses (DCA) were performed. The first axis of a DCA based on 720 forest plots across Europe revealed a phytogeographic differentiation of the Mediterranean plots and may moreover partly reflect nationally deviating plot selection criteria. In a DCA with a reduced data set of 488 plots restricted to the nemoral zone of Europe the acidity status of the soil was the most decisive environmental factor. None of the available environmental factors was correlated with plot scores of the second and third DCA-axis. However, scores of the fourth axis were significantly correlated with plot specific throughfall deposition of total nitrogen ($R^2 = 0.27$). Nitrogen indicating species like *Ceratocapnos claviculata* obtained high scores on that axis corroborating eutrophication effects of atmospheric nitrogen deposition on forest floor vegetation. The results of a DCA based on 97 plots with at least three repetitions in the years 1994–2003 did not reveal consistent temporal trends in plant species composition of the observed plots.

Keywords: Detrended correspondence analysis; Floristic composition; Vascular plants; Nitrogen deposition

1. Introduction

Forest floor vegetation is an important component of forest ecosystems. It is linked to nutrient cycling and interacts directly and indirectly with other biotic and abiotic components. Ground floor vegetation contains and determines large parts of the biological diversity of forest ecosystems. The monitoring of ground floor vegetation is therefore a relevant and important component within the forest condition monitoring activities of the International Co-operative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). This programme operates under the umbrella of the UNECE Convention on Long-range Transboundary Air Pollution in close co-operation with the European

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Union (EU). Intensive Monitoring started in the 1990s and has until today been carried out on more than 800 so-called Level II sites, selected from the most important forest ecosystem types of 29 participating countries. All surveys within the programme are based on extensively harmonized methods documented in a regularly updated manual [1].

European deposition data show that large areas of Europe still suffer from high loads of nutrient nitrogen and acidity [2]. Forests filter pollutants from the air [e.g. 3–5] and are thus especially susceptible. In the last two decades, Europe has experienced the first effects of emission reductions, but 45% of forests still suffer from nitrogen inputs that exceed critical loads [2].

Both atmospheric deposition and soil condition are measured and forest floor vegetation is assessed on many of the monitoring plots of ICP Forests. The data of the monitoring programme thus offer the unique possibility to evaluate directly the relationships between parameters derived from the floristic composition of the ground floor vegetation and from the atmospheric deposition respectively from the soil survey at plots spread over large parts of Europe.

The hypothesis of this study is that species composition of ground vegetation is responding to nitrogen deposition. In addition, it was of interest to find out whether the repeated ground vegetation assessments allow for a detection of directional changes in vegetation composition that might be driven by changing environmental conditions.

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2. Data and evaluation methods

For the current evaluation, information from vegetation assessments was available for a total of 720 ICP Forests Level II sites for the years from 1994 to 2003. Vegetation assessments were carried out by national experts at one marked plot or on a series of marked subplots per monitoring site. Plot sizes differ from 10 to 11,000 m^2. Of these, 90% had sizes between 40 and 2500 m^2. In 27%, the size was 400 m^2. Only in 2002 it was decided by the ICP Forests 'expert panel on ground vegetation and biodiversity' to use a common sampling area of 400 m^2. Due to repeated surveys on a number of plots, the total number of vegetation relevés was 1460. Some 243 plots had been sampled only once, while other plots had been sampled up to six times. Vegetation surveys were performed in different years [6].

Cover-abundance values of the plant species had been assessed using different scales like those of Braun-Blanquet [7], Londo [8], or percentage cover. The different scales were transformed into cover percentages following the ICP Forests manual [1] accepting inaccuracies due to irregular graduations of the scales.

The total percentage cover for the moss, herb, and shrub layers was also assessed for each plot. The moss layer, which included terricolous bryophytes and lichens, was not further considered within the following evaluations. The herb layer included all vascular plants below a height of 0.5 m. The height of the shrub layer was defined between 0.5 and 5 m. If individuals of herbaceous species or dwarf shrubs (e.g. *Pteridium aquilinum* or *Vaccinium myrtillus*) grew higher than 0.5 m, they were also assigned to the herb layer. The same procedure was followed for slightly lignified shrubs like species of the genus *Rubus*. All intra-annual repetitions (spring and summer aspects) were merged into one composite assessment (relevé) per plot. In such cases the maximum cover degree was chosen if one species was present in more than one assessment. If information on a series of sub-plots was given, cover degrees at the plot level were calculated as arithmetic means. As taxonomic reference, Tutin *et al.* [9,10] was used for vascular plants.

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Intensive Monitoring at ICP Forests plots includes continuous deposition measurements [3] and a soil survey [11]. Deposition data were available for the years from 1991 until 2001. The soil survey for most of the Level II plots was carried out in 1995. Variables that were used to characterize the soil solid phase and throughfall deposition on the plots are listed in table 1.

An ordination was performed on the basis of the floristic composition in order to reduce the high dimensionality of the floristic space [12, 13]. The vegetation assessments from across Europe cover wide biogeographical (macroecological) and ecological gradients, which is adequately expressed by a gradient length of 8.0 units of standard deviation of species turnover on the first DCA axis for the data set covering the whole Europe and 5.7 units for the nemoral part of Europe. Values greater than 4 SD units indicate unimodal

Table 1. Variables characterizing the soil solid phase and throughfall deposition.

Domain	Variable	Unit	Explanation
Soil solid phase	C	g kg^{-1}	Organic carbon concentration in the upper 10 cm of the mineral soil layer; different layers (0–5 cm, 5–10 cm, 0–20 cm) have been merged
	N	g kg^{-1}	Total nitrogen concentration in the upper 10 cm of the mineral soil layer; different layers (0–5 cm, 5–10 cm, 0–20 cm) have been merged
	BCE	cmol (+) kg^{-1}	Sum of basic exchangeable cations in the upper 10 cm of the mineral soil layer
	CEC	cmol (+) kg^{-1}	Cation exchangeable capacity of the upper 10 cm of the mineral soil layer
	Basesat	%	Base saturation of the upper 10 cm of the mineral soil layer
	C_{org}	g kg^{-1}	Organic carbon concentration of the organic layer
	C/N_{min}		C/N ratio of the upper 10 cm of the mineral soil layer
	C/N_{org}		C/N ratio of the organic layer
	pH_o		pH value in 0.01 molar $CaCl_2$ of the organic layer; in cases where pH of the organic layer was missing, it was substituted according to the empirical relationship: $pH_O = -1.0145 + (1.5425\ pH_{m0-10}) + (0.2068\ pH_{m0-10}^2)$
	pH_{m01}		pH value in 0.01 molar $CaCl_2$ for the upper 10 cm of the mineral soil layer; in cases were only a value for the upper 5 cm was available, the respective value for 10 cm depth has been calculated according to empirical regressions: $ph_{m0-10} = 0.3449 + (0.9415 * pH_{m0-5})$ or: $pH_{m0-10} = 0.0593 + (0.9769 * pH_{m5-10})$; if only pH_{0-20} was available, it was equalled to pH_{0-10}; if measurements were conducted in different years, the latest datum was taken; in cases of moor soils pH of the upper h-horizon was equalled to the upper mineral horizon; if only pH of the organic layer was given and a value for the mineral layer was missing, the following empirical relationship was used: $pH_{m0-10} = 4.6856 - (1.0375 * pH_O) + (0.2068 * pH_O^2)$.
Annual throughfall deposition	xN_{depo}	kg ha^{-1} a^{-1}	Mean annual N throughfall deposition as sum of NH_4-N deposition and NO_3-N deposition; calculated for all years available before 2001; only for plots with at least 273 days per year sampled; if sampling period was shorter than 365 days, missing periods were completed by mean values derived from the remaining days
	xNH_4-N_{depo}	kg ha^{-1} a^{-1}	Mean annual NH_4-N throughfall deposition; calculated for all years available before 2001; only for plots with at least 273 days per year sampled; if sampling period was shorter than 365 days missing periods were completed by mean values derived from the remaining days
	xNO_3-N_{depo}	kg ha^{-1} a^{-1}	Mean annual NO_3-N throughfall deposition; calculated for all years available before 2001; only for plots with at least 273 days per year sampled; if sampling period was shorter than 365 days missing periods were completed by mean values derived from the remaining days

response characteristics of some or many species [14]. Therefore detrended (by segments) correspondence analysis (DCA [13,14]) was applied. This unconstrained version of a multivariate ordination approach was chosen [15] in view of the large spatial extend of the data, and because the approach of the study is exploratory. In addition, a well-settled combination of cause-effect based hypotheses rectifying any redundancy analyses (RDA) was not yet available. CANOCO [14] was used for the multivariate analyses in combination with EXCEL and SAS for data editing. Species cover-abundance information was kept within the analyses, in order to minimize effects from different plot sizes on the resulting ordination patterns [16]. Nevertheless, square-root transformation before DCA is recommended, in order to scale down differences between cover-abundance estimates from different surveyors (e.g. [17]). Species that occurred in fewer than five relevés were excluded. To avoid bias from different numbers of repetitions per plot, only the last assessment of each plot was used, if repetitions were available.

In a first approach – called DCA_{total}, – all 720 plots were used. In a second approach – $DCA_{nemoral}$ – all plots south of 46° latitude were excluded in order to reduce a considerable part of the floristic variability caused by the Mediterranean plots. This latitude is widely in accordance with a line given by Whittaker *et al.* [18], which denotes the breakpoint between a water-dependent gradient of the vascular plant flora in southern Europe and a respective energy-dependent gradient in middle and northern Europe. In order to eliminate floristically deviant influences of boreal and sub-alpine climates, all plots north of 61° latitude and those above 750 m a.s.l. were excluded as well. The remaining data set with 488 plots mainly represents the nemoral forest zone of Europe, which is floristically more homogeneous, but shows considerable differences in nitrogen deposition [19].

Plot-related scores on the first four DCA axes are used as response variables in a series of bivariate regression analyses in order to post empirically backed hypotheses about the main determinants of the floristic composition on a large geographical scale. Independent variables characterizing the condition of the soil solid phase and deposition are described in table 1. All regression analyses were performed with SAS 9.

Level II plots with repeated surveys of forest floor vegetation were used to evaluate potential changes in ground vegetation composition. For 106 plots at least three repetitions were available. As plots south of 46° latitude, north of 61° latitude and above 750 m a.s.l. were again excluded, a total of 97 plots with 427 relevés were left for this analysis. All repeatedly surveyed plots were jointly analysed by DCA, later called DCA_{trend}. Within this DCA no constancy threshold for species numbers was set, in order to consider the total species turnover in time.

3. Results

In the ground layer of the 1460 vegetation relevés, a total of 2003 vascular plant species was identified. Additionally, 91 unidentified taxa were registered. For the total dataset the maximum was 131 species within one relevé, the median was 19 species per relevé, the third and first quartile were 37 and 12 species respectively, while the minimum was one species (Lorenz *et al.* [6] for more general results). For all plots used within the $DCA_{nemoral}$ the respective values were only slightly lower with 127 (maximum), 18 (median), 27 (third quartile), 10 (first quartile), and one species (minimum). Because a large number of rare species occur within both datasets (cf. [20]) the number of effectively used species is much lower in both DCAs (table 2).

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The explained variance of the first four axes of the DCA_{total} (figure 1, table 2) summed up to 10%. One extreme of the first axis was characterized by species from Mediterranean shrublands (maquis) like species of the *Cistaceae* family. On the opposite end there were typical undergrowth species of nemoral and boreal forests, like *Deschampsia flexuosa* or *Vaccinium myrtillus* on acidic or *Anemone nemorosa* on rather base-rich soils. Correspondingly high scores of the first DCA axis are found on many plots of the Iberian Peninsula (figure 1).

The $DCA_{nemoral}$ give only slightly higher values of the explained variance on the first four axes than DCA_{total} (table 2). Highest scores for plant species were obtained on the first DCA axis by acidophytic species like *Vaccinium spec.* (table 3). At the other end of the same axis species typically growing on base-rich/calcareous soils occurred, like *Arum maculatum*, *Mercurialis perennis*, or *Primula elatior*. For the species characterizing the second and third axis it was hardly possible to give any simple ecological interpretation. This possibly accounts for spatial large-scale (macroecological) patterns and their interaction with site-related ecological factors (e.g. [21–23]). However, on the fourth axis nitrogen indicating species like *Ceratocapnos claviculata*, *Galeopsis bifida*, or *Stellaria media* (table 4) reached high scores.

In correlation analyses with key factors from the soil solid phase and from deposition measurements, the first $DCA_{nemoral}$ axis revealed a close and significant relationship with

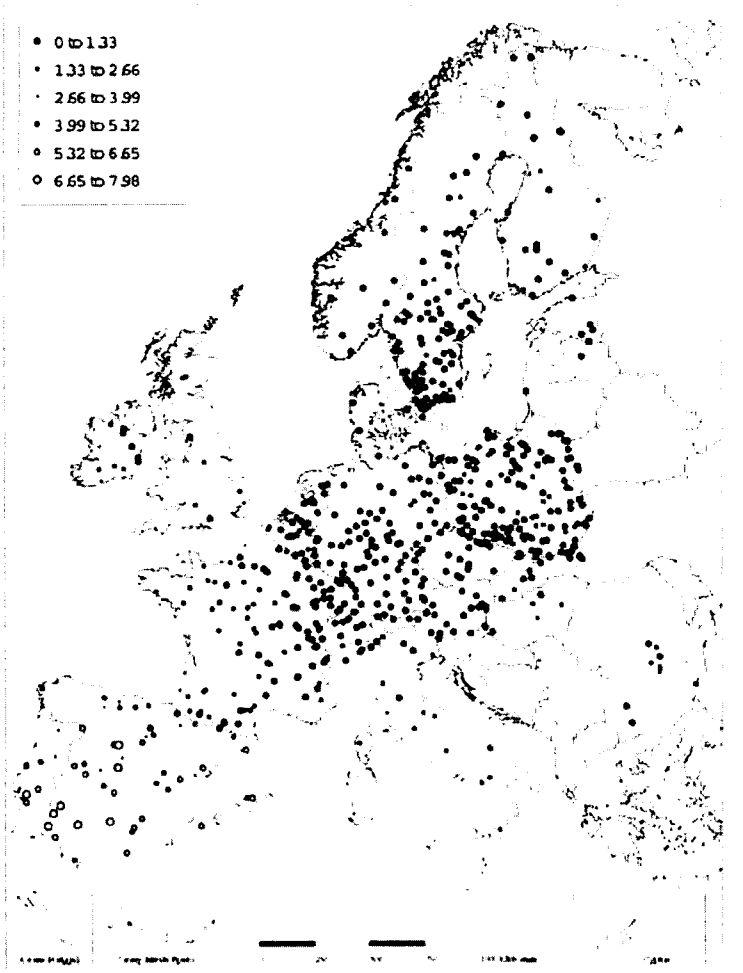

Figure 1. Geographic distribution of Level II plots with vegetation relevés and scores of the first axis of the DCA_{total}.

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Table 2. Summary statistics for species numbers of the different approaches and for the total data set and DCA summary diagnostics.

				Percentage variance of species data				
	n of relevés	*n* of active species	Total inertia	axis 1	axis 2	axis 3	axis 4	axis 1 to 4
Total dataset	1460	2003 + 91 unidentified						
DCA_{total}	720	563	28.2	3.1	2.6	2.3	2.0	10.0
$DCA_{nemoral}$	488	305	15.0	4.3	2.5	2.2	1.8	10.7
DCA_{trend}	427 from 97 plots	822	15.7	4.5	2.9	2.2	1.8	11.4

pH_{CaCl2} values of the organic soil layer (r = 0.789, table 5 and figure 2). In addition, there were a number of soil parameters that also showed significant relationships like base saturation in the upper mineral layer (0 to 10 cm depth), or the cation exchange capacity (CEC). It has to be taken into account that these soil parameters are significantly inter-correlated. The second and third DCA axes revealed weaker relationships with the amount of organic carbon respectively carbon and nitrogen contents in the mineral layers of the Level II sites. A close correlation was found between nitrogen and ammonium throughfall deposition and the scores of the fourth axis of the DCA (table 5, figure 3). The only soil parameter significantly related to the fourth axis was the C/N ratio of the organic layer.

The first axis of the DCA_{trend} with 96 plots explained 4.0% of the total floristic variance (table 2). Again this axis is differentiated by species that are characteristic for calcareous soils on one side (low scores) and acidic soils (high scores) on the other side. For the second and third axis again no obvious ecological interpretation was found. The fourth axis specifically listed species that show relations to nitrogen deposition. In general, DCA_{trend} corroborates the findings of $DCA_{nemoral}$.

The first and fourth axes of DCA_{trend} are the ones that carry the ecologically most relevant information. Thus, the scores of all relevés of these axes were plotted against each other and

Table 3. Species of the forest floor vegetation with highest and lowest scores on the first axis of $DCA_{nemoral}$.

Species	Constancy	DCA 1 score	Species	Constancy	DCA 1 score
Vaccinium vitis-idaea	113	6.1609	*Vicia sepium*	22	−0.1651
Vaccinium uliginosum	5	6.1594	*Ranunculus ficaria*	24	−0.4019
Empetrum nigrum	8	5.9426	*Arum maculatum*	18	−0.4473
Carex ericetorum	13	5.5999	*Euonymus europaeus*	13	−0.5002
Calluna vulgaris	119	5.2408	*Acer campestre*	23	−0.5644
Melampyrum sylvaticum	24	4.9799	*Sonchus oleraceus*	5	−0.6393
Carex nigra	13	4.9359	*Quercus cerris*	9	−0.6479
Linnaea borealis	23	4.889	*Mercurialis perennis*	21	−0.6542
Betula sp.	27	4.8739	*Cardamine bulbifera*	16	−0.6761
Hypericum perfoliatum	22	4.7989	*Ranunculus auricomus*	9	−0.6962
Sorbus intermedia	6	4.798	*Cardamine pratensis*	6	−0.7195
Festuca ovina	46	4.776	*Alliaria petiolata*	9	−0.7346
Monotropa hypopitys	14	4.7315	*Primula elatior*	10	−0.7371
Vaccinium myrtillus	267	4.6717	*Cyclamen purpurascens*	5	−0.7441
Amelanchier grandiflora	6	4.6441	*Hypericum hirsutum*	7	−0.7716

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Table 4. Species of the forest floor vegetation with highest and lowest scores on the fourth axis of $DCA_{nemoral}$.

Species	Constancy	DCA 4 scores	Species	Constancy	DCA 4 scores
Empetrum nigrum	8	4.5847	*Orthilia secunda*	23	−0.4666
Ceratocapnos claviculata	9	4.424	*Sorbus aria*	8	−0.4961
Pseudotsuga menziesii	18	4.1899	*Pulmonaria obscura*	7	−0.5129
Amelanchier grandiflora	6	4.0857	*Gymnocarpium dryopteris*	23	−0.5533
Senecio sylvaticus	6	4.0665	*Galium boreale*	7	−0.6704
Epilobium spec.	5	3.8963	*Melampyrum sylvaticum*	24	−0.6858
Galeopsis bifida	6	3.7711	*Vicia cracca*	8	−0.6863
Prunus serotina	55	3.732	*Campanula rotundifolia*	8	−0.7114
Equisetum arvense	13	3.6021	*Polygonatum odoratum*	14	−0.7203
Poa angustifolia	9	3.6004	*Hypericum perfoliatum*	29	−0.7414
Picea spec.	6	3.5981	*Galium verum*	5	−0.793
Calamagrostis canescens	5	3.5689	*Linnaea borealis*	23	−0.8453
Fallopia dumetorum	8	3.5542	*Viola mirabilis*	6	−0.8502
Conyza canadensis	5	3.495	*Viola palustris*	5	−0.8535
Rubus plicatus	9	3.4527	*Hepatica nobilis*	14	−0.8814
Impatiens noli-tangere	24	3.4445	*Carex brizoides*	15	−0.938
Stellaria media	27	3.4398	*Geranium sylvaticum*	5	−0.9541
Impatiens parviflora	34	3.4118	*Equisetum sylvaticum*	7	−0.976

those belonging to the same plot were connected (figure 4). The resulting trajectories indicate a considerable dynamic of the floristic composition, but results show that related to axis 1 and 4, there is no obvious general trend.

4. Discussion

The monitoring programme and the specific evaluations cover typical forest sites from large parts of Europe. Therefore, macroecological principles have to be taken into account when

Table 5. Correlation coefficients between $DCA_{nemoral}$ axes and key variables of soil solid phase and deposition. *$(Prob > |r|) \leq 0.05$, **$(Prob > |r|) \leq 0.01$, ***$(Prob > |r|) < 0.0001$.

		DCA axis 1	DCA axis 2	DCA axis 3	DCA axis 4
Soil solid phase	C (n = 461)	−0.2462***	−0.0971*	−0.2481***	0.0174
	N (n = 471)	−0.4094***	0.0029	−0.2379***	0.0662
	BCE (n = 469)	−0.4659***	0.1004*	−0.0327	−0.0554
	CEC (n = 467)	−0.4357***	0.0709	−0.1883***	−0.034
	Basesat (n = 464)	−0.6439***	0.1692**	0.1205**	0.0171
	C_{org} (n = 465)	0.1516**	−0.2889***	−0.2115***	−0.0027
	C/N_{min} (n = 461)	0.3752***	−0.2479***	0.0342	−0.0560
	C/N_{org} (n = 465)	0.2199***	−0.0534	0.0421	−0.2205***
	pH_o (n = 472)	−0.7893***	−0.0022	0.0020	−0.0075
	pH_{m01} (n = 472)	−0.4661***	0.1736***	0.1481**	−0.0485
Annual throughfall deposition	xN_{depo} (n = 224)	−0.1228	−0.1969**	−0.0150	0.5204***
	xNH_4-N_{depo} (n = 224)	−0.0610	−0.2748***	0.0586	0.5140***
	xNO_3-N_{depo} (n = 224)	−0.2431**	−0.0031	−0.1105	0.4218***

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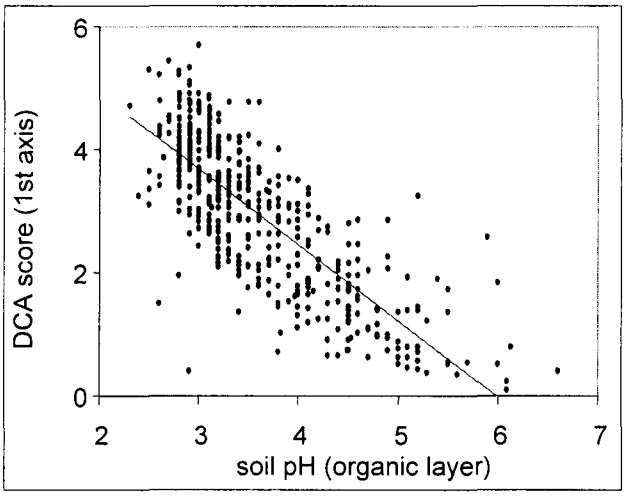

Figure 2. Relationship (linear regression) between the first DCA axis and pH_{CaCl2} in the organic layer; $R^2 = 0.623$, (Pr > F) < 0.0001, $n = 472$ plots.

interpreting the results, although this study in view of its small grain (i.e. plot sizes normally distinctively below one hectare) can hardly contribute to the macroecological debate [22–24]. Within the DCA_{total} embracing all available relevés from European Level II plots, 90% of the total variance could not be assigned to the first four axes. This reflects a high floristic variability across these plots, which might be caused by varying phytogeographical conditions in combination with numerous site and stand specific factors as well as local processes. In this respect, regional or national forest management practices have to be seen as a source of floristic diversity.

The floristic distinctness of many plots from the Iberian Peninsula as expressed by high scores on the first axis (see figure 1) may partly be caused by such differences or even by different plot selection criteria in Spain and Portugal in comparison to other Mediterranean countries. Plots from these two countries are mostly characterized by low stand density and

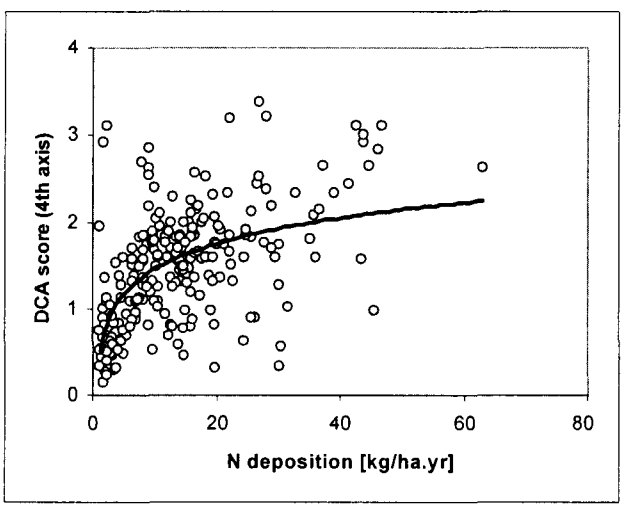

Figure 3. Relationship (quadratic regression) between the fourth DCA axis and annual N throughfall deposition; $R^2 = 0.271$, (Pr > F) < 0.0001, $n = 224$ plots.

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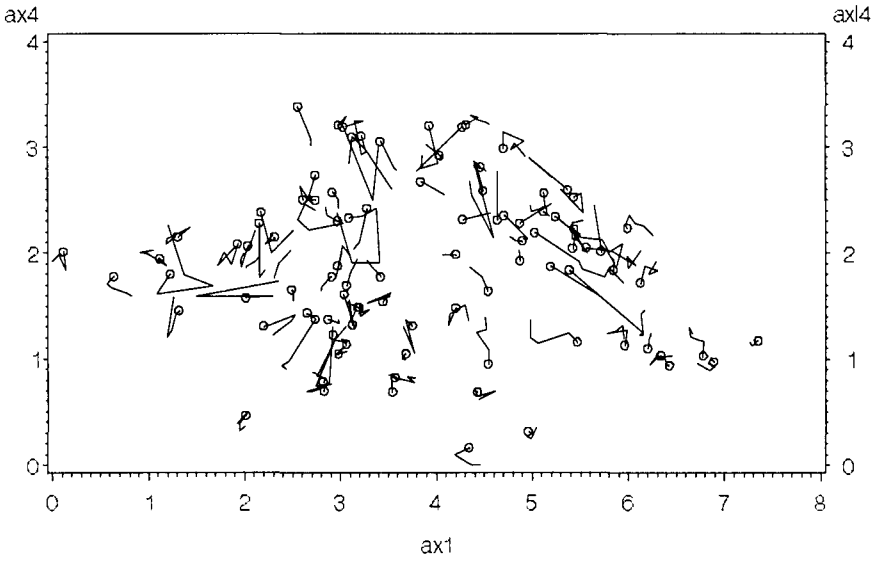

Figure 4. DCA-scores of the first and the fourth axes of serial vegetation assessments from permanent Level II plots. All assessments belonging to a series are successively interconnected by a trajectory; the temporally last point is marked by a small circle.

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high light supply at the forest floor. In addition, the composition of ground vegetation on the Iberian Peninsula may differ for general climatic and/or phytogeographic reasons (e.g. macroecolgical factors like temperature and general availability of water [23]). These findings confirm de Vries *et al.* [25], who had evaluated an earlier stage of the European Level II data set. Even if DCA and other ordination methods imply the potential to distinguish between specific floristic responses from several driving environmental factors [e.g. 26] it is reasonable to minimize phytogeographical effects by partialling out or, as in this case, by stratifying respective data sets in order to concentrate on more specific questions like effects from air-borne deposition.

The first axis of the $DCA_{nemoral}$ separates calcifuge species from calcicole species and thus shows a strong influence of soil acidity and related factors like base saturation or cation exchange capacity on the floristic composition of the forest floor vegetation. This well-known influence of soil acidity on species composition (e.g. [27–30]) is corroborated by the tight and significant relationship of the DCA scores with measured soil pH, especially of the humus layer (table 5, figure 2). This relationship confirms soil pH and closely related soil factors as a main ecological driver for the floristic composition of the forest floor vegetation (e.g. [31,32]), even within the frame of a tremendously wide spatial scale covering large parts of Europe.

Within the nemoral zone of Europe forest productivity and plant performance is usually limited by nitrogen [e.g. 33]. Therefore nitrogen inputs have the potential to cause changes within those ecosystems [34] and thus may alter the floristic composition of the forest floor vegetation [e.g. 35–38]. This hypothesis is supported by the fact that the DCA scores of the fourth axis are linked to nitrogen deposition and that species listed on the fourth DCA axis are predominantly those which are known to respond positively to higher nitrogen availability within the soil. A prominent example is *Ceratocapnos claviculata*. Its spreading in recent decades has been related to nitrogen eutrophication of forest [39].

For a number of these species (cf. table 3) there is considerable evidence that they are favoured by higher availability of nitrogen often in connection with disturbances (e.g. *Galeopsis bifida*: [40,41], *Stellaria media*: [42]). Deposition can surely replace aspects of disturbances in terms of a higher availability of nitrogen. That nitrogen deposition is important for the occurrence of a number of species listed on the fourth axis is underlined by the fact that correlations between the plot scores on the fourth axis and other soil factors are low. The C/N ratio is in this respect the only exception, and it was also found to correlate negatively with atmospheric nitrogen input in Germany by Augustin *et al.* [43]. In accordance with this, plots with high scores on the fourth axis are predominantly located in areas known to receive high nitrogen inputs [4, 5]. However, there are also species among those with high scores on the fourth axis (table 4) that are not specifically linked to higher nitrogen availability. Such coincidences have thus to be taken into account: the introduced forest tree species *Pseudotsuga menziesii* and *Prunus serotina*, which have both frequently been planted in The Netherlands or Flanders (e.g. [44]) have naturalized in these regions and yield therefore also high scores on the fourth axis. *Empetrum nigrum*, a species which is hardly favoured by higher nitrogen can be seen as an element of the original vegetation of that particular area and might probably decrease in its abundance over time. However, such processes can only be substantiated by long-term monitoring. The relationship between DCA scores and measured deposition (figure 3), suggests that there is at least some influence of atmospheric nitrogen inputs on the composition of the forest floor vegetation on monitoring plots with high scores at the fourth DCA axis.

DCA and other ordination methods (e.g. CCA, cf. [16]) can be seen as tools for detecting deposition effects on forest floor vegetation. DCA is an approved method for analysing not only spatially structured data, but succession data as well [e.g. 45, 46] and was in this study applied to analyse changes of floristic compositions on many plots. The DCA scores for plots with repeated vegetation surveys did not show general consistent changes of ground vegetation composition over the evaluated time intervals. This is in line with results from a German-wide approach [29]. This may be explained by the fact that either i) the time series are still rather short, and/or ii) that the time series start at times in which nitrogen deposition has already occurred for decades, so that the ground vegetation had already been widely adapted when the assessments began, and/or iii) that other site and stand specific factors (e.g. anthropogenic or natural disturbances like activities of wild boars, weather extremes) changed inconsistently over time (e.g. [44]). A gradual influence of nitrogen deposition on floristic composition can also be superimposed by effects of increased shading due to stand development.

In contrast to the findings presented above, changes in forest floor vegetation composition related to atmospheric deposition of nitrogen have, for example, been reported by Kuhn *et al.* [35] in Switzerland, and by Thimonier *et al.* [37] for a forest in eastern France over a time interval of 20 years; and also by Seidling [36], Diekmann and Dupré [38], Fischer 1999 [47] for parts of Germany or van Dobben *et al.* [48] for the Netherlands. Others have performed medium to long-term comparisons. Such investigations have thus a larger potential to detect changes [47, 48]. However, within these studies no plot-related measured data on environmental influences were available. Therefore hardly any straight statistical relationships between possible causes and responses of the forest floor vegetation could be established.

5. Conclusions

The results suggest that nitrogen deposition may at least partly determine ground vegetation composition at the investigated plots and it can be assumed that deposition of ammonium and

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nitrate is continuously changing forest vegetation. Nitrogen inputs are therefore rightly in the focus of environmental policy in Europe [49]. However, effects of nitrogen deposition are not easy to detect within any short- or medium-term approach, because of its high mobility and its involvement within multiple ecosystem processes. In this respect, the time series of the ICP Forests programme are an important source of information: they cover large parts of Europe and they include measurements for relevant compartments of forest ecosystems. Thus, they allow the establishment of empirically backed hypotheses on cause-effect relationships. On the other hand, the available observations are obviously still too short to detect directional changes in forest ground floor vegetation composition at the European scale.

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