ForestBIOTA:

First Approaches towards Integrated Evaluations of Project Data

Work Report

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1 Introduction

The ForestBIOTA project aims at a further development of monitoring and evaluation methods for selected aspects of forest biodiversity. Data concerning four major ecological domains have been collected according to harmonized protocols:
- Data on stand structure (Anonymus 2004)
- Deadwood assessment (Anonymus 2004)
- assessment of ground floor vegetation (PCC 1998 and later amendments)
- assessment of epiphytic lichens (Stofer et al. 2003, Asta et al. 2002, Scheidegger et al. 2002).

Moreover, a forest type classification based on the outcomes of the BEAR project (Barbati et al. 2002) and the EUNIS forest type classification has been applied.

Basic sectoral evaluations are documented in: Meyer (2006) for the stand structure assessment, in Accademia Italiana di Scienze Forestali (2006) for the deadwood assessment, in Granke (2006) for the ground vegetation assessment and in Stofer (2006) for the assessment of the epiphytic lichens.

The assessments have mostly been performed at existing Level II plots. Therefore a large number of parameters from different ecosystem compartments and environmental domains are additionally available (e.g. de Vries et al. 1997). A total of 135 plots from 14 European countries are part of the data base. Since data from 3 countries (France, Slovenia, Russia) lack many parameters, they have been excluded from respective evaluations.

The Level II plots of the ForestBIOTA project were selected by each country according to its own requirements and ideas. Therefore no general sampling strategy across Europe with regard to main tree species, management type or intensity, etc. was applied. At higher level the data set can be confessed as a typical 'found set' (following Overton et al. 1993, cf. Ferretti et al. 2000) with restricted pretension in terms of representativeness for area or any type of forest.

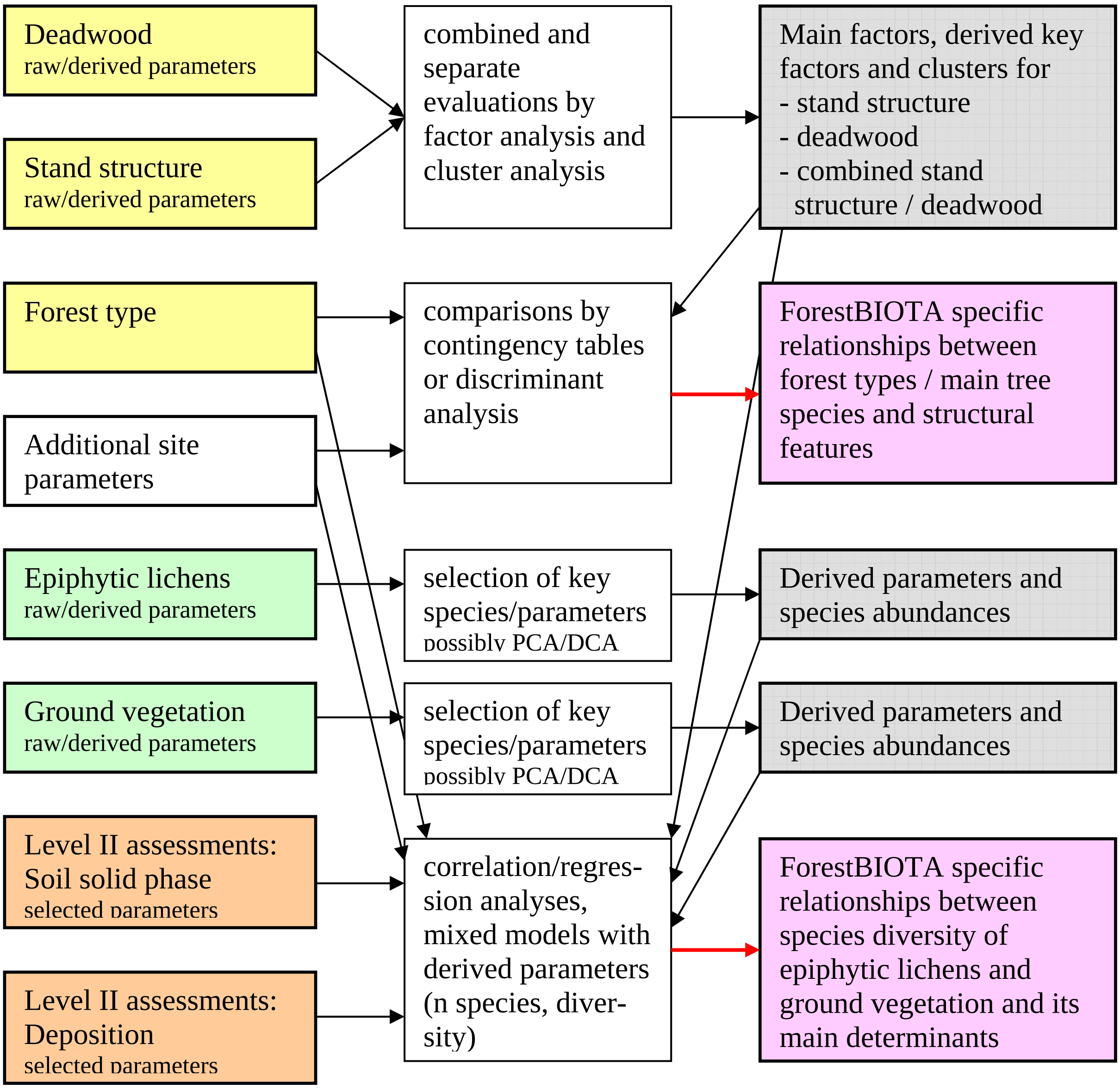
In terms of statistical modelling these preconditions include that there is no respective claim for any kind of large-scale representativeness. All models apply only for the included plots and may at utmost only be valid for similar plots in the surroundings of those plots. Any spatial interpolation is not indented, and is inappropriate alone due to the low spatial density of plots.

What the integrative models can be used for, is:

- corroboration of results from similar models about forest ecosystems;
- demonstration of possible assessment and evaluation methods within the context of Level II or even Level I;
- generation of hypotheses on appropriate forest ecosystem compartments or domains (incl. selection of key factors for assessments, evaluation, and eventually up-scaling approaches, e.g. Schall & Seidling 2004).

One further general challenge in connection with data from the ForestBIOTA plots is the disparity between comparatively low number of cases and a high number of available parameters. The number of predictors (or degrees of freedom in covariance models) within each model should not exceed one quarter of the number of cases (e.g. Bortz 1993). Therefore effective strategies of parameter reduction with minimised loss of information are needed.

Scheme 1 summarizes main pathways for integrated evaluations of ForestBIOTA data. These pathways are thought to depict possible cause-effect chains. Most of the pathways shown are not reversible or only partly reversible as part or feed-back mechanisms.



Scheme 1: Main pathways for combined and integrated evaluations of ForestBIOTA data sets.

2 Stand structure and dead wood assessments

Both, stand structure and deadwood assessments have produced a wealth of data on structures respective entities at or below the plot level. Even aggregation towards introduced indices led to a considerable number of parameters for both ecosystem compartments. The aggregated parameters for the deadwood assessment have been calculated by Travaglini & Chirichi (Accademia Italiana di Scienze Forestali 2006), for the stand structural parameters by Meyer (2006). Additionally to both sectoral evaluations on stand structure and deadwood, data on forest types (Barbati et al. 2002), forest history, and categories concerning management intensity and practices were collected.
Both compartments are substantially dependent on natural growth conditions and forest management practices. For instance, basal area depends on site and growth conditions as well as on stand regulation measures. Thinning and other management

operations have effects on the number and volume of stumps, snags or standing deadwood. Even the distribution of stem diameters depends on both, the management system and natural thinning processes (e.g. Whittington 1984) within tree stands.
Two approaches to combine both data sets have been applied: Principal component analysis (PCA) was used to extract a limited number of components integrating most of the information covered by the original parameters measured within or derived from the stand structural and dead wood assessment. A second approach used the same information in order to construct clusters (distance measure: Euclid, agglomeration algorithm: Ward) with similar stand structural and deadwood characteristics.

2.1 Results of a combined factor analysis

The parameters were selected after sectorial PCAs had been performed. The most important and best differentiating parameters from each model were selected for the combined model (see explanations in Fig. 2). The PCA with a total of 13 dead wood and stand structure parameters results in a model which concentrates 34.74% of the total variance at the first axis, 27.9% at the second, 17.6% at the third, 14.2% at the fourth and finally 5.7% on the fifth axis. The remaining axes do not account for any additional information. The relative importance of the axes is demonstrated by a scree plot (Fig. 1).

Fig. 1: Scree plot of eigenvalues of PCA axes (1 to 13) based on all stand structural and dead wood parameters at plot level. The first five axes have been taken for further evaluations.

The scatter plot in Fig. 2 displays the parameter scores of the first two axes. The first axis is mainly loaded by the total amount of deadwood. High amounts of total deadwood coincide with both, deadwood fractions bigger and smaller than 10 cm in diameter and the mean diameter differentiation of the living tree stand. This axis correlates (regression analysis) positively with stand age (R^2 = 0.27, (p > F) < 0.0001; see Fig. 3). This shows, that older stands contain higher amounts of deadwood and have a higher differentiation of dbh.
The highest loadings on the second axis (Fig. 2) are reached by the number respectively volume of tree stumps. Concomitantly with a high number of stumps a low Shannon diversity of tree species composition on the basis of tree numbers is observed. In a retrospective view this can be interpreted that thinning or other harvesting operations tend to reduce the richness of tree species within the observed forest stands and producing at the same time tree stumps. This second PCA axis represents indirectly the intensity of past cutting operations, which is corroborated by its positive relationship with forest management intensity (R^2 = 0.16, (p > F) = 0.001).

The negative relationship of this axis with soil pH (R^2 = 0.15, ($p > F$) = 0.001) may mainly be based on a generally higher number of species on base-rich soils in comparison to acidic soils.

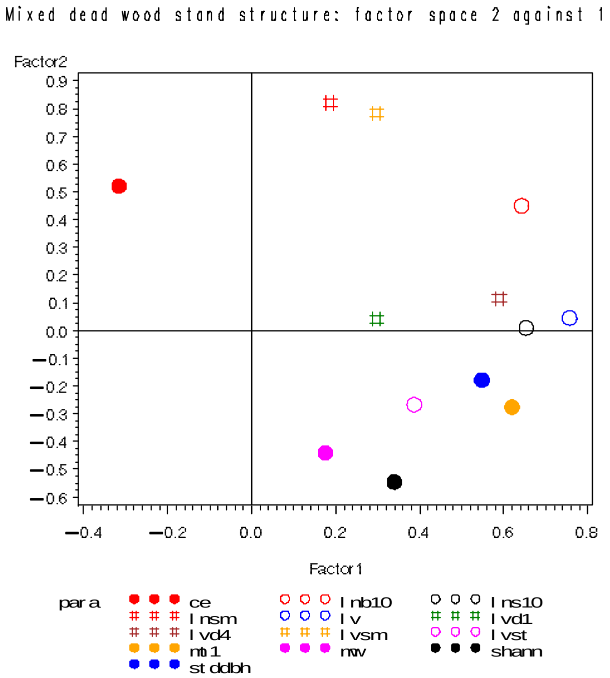


Fig. 2: Axis 2 (vertical) against axis 1 (horizontal) of a combined PCA with dead wood / stand structural parameters at plot level;
ce: Clark-Evans index
mt1: mean diameter differentiation
mw: mean contagion
shann: Shannon diversity on basis of stem number
stddbh: standard deviation of stem diameter
lnb10: log (n) of deadwood peaces above 10 cm diameter
lns10: log (n) of deadwood peaces below 10 cm diameter
lnsm: log (n) of stumps
lv: log. of total deadwood volume
lvd1: log (vol) of deadwood decomposition class 1
lvd4: log (vol) of deadwood decomposition class 4
lvsm: log (vol) of stumps
lvst: log (vol) of standing deadwood

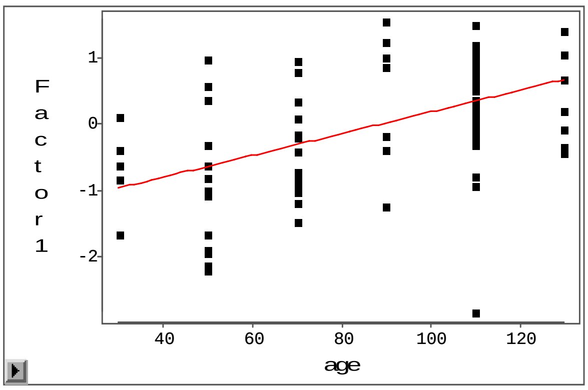


Fig. 3: Relationship between PCA axis 1 (factor 1) and stand age. The outlayer is plot 11 from Spain; R^2 = 0.27, ($p > F$) < 0.0001.

The third axis (Fig. 4) is mainly characterised by the Clark-Evans index (positively) and mean contagion (negatively). This axis represents the polarity between clumped and regular space distributions of trees within the observed forest stands. Interestingly, this axis - which combines measures of irregularity of tree positions within stands at two spatial scales - is negatively correlated with altitude (R^2 = 0.20, ($p > F$) = 0.001): This shows that stands in high altitudes reveal more clustered horizontal distribution at both spatial scales. Higher ammonium wet throughfall deposition coincides with more regular stand structures (R^2 = 0.17, ($p > F$) = 0.001), however, this relationships seems to be a typical pseudo-correlation, since younger plantations in low altitudes in large parts of Europe are frequently situated in landscapes dominated by agricultural land use.

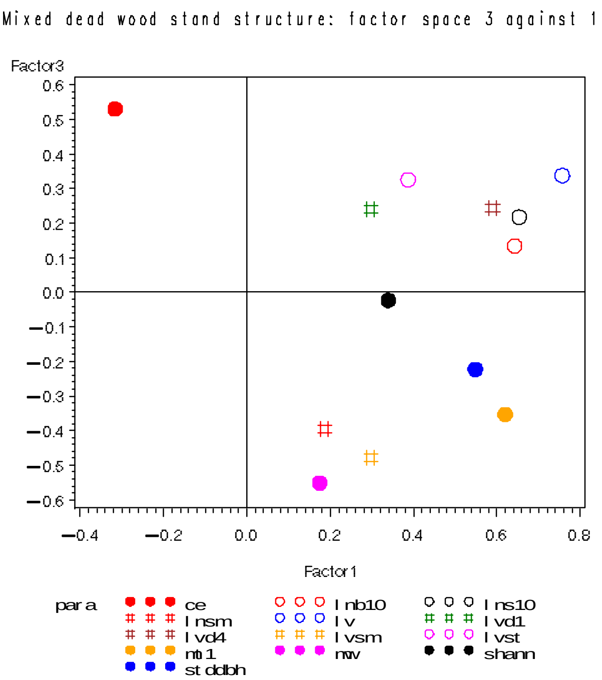


Fig. 4: Axis 3 (vertical) against axis 1 (horizontal) of a combined PCA with dead wood / stand structural parameters at plot level; for abbreviations see Fig. 2.

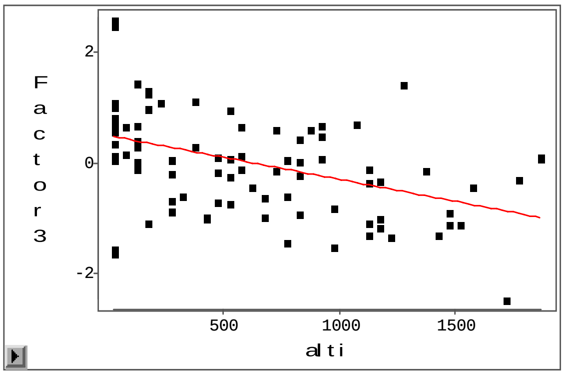


Fig. 5: Relationship between PCA axis 3 (factor 3) and altitude (alti); $R^2 = 0.20$, $(p > F) = 0.001$.

The fourth axis reflects the antagonism between diameter spread (standard deviation of dbh) of the investigated tree stands (negative relationship) and to a lesser extent mean contagion (positive relationship). This indicates that diameter distribution of trees varies largely independently from the horizontal clumping, measured by the Clark-Evans index, while mean contagion is related to both stand structural features. The fourth axis reveals the closest relationship with management intensity. More intensive management is related to a lower diameter spread.

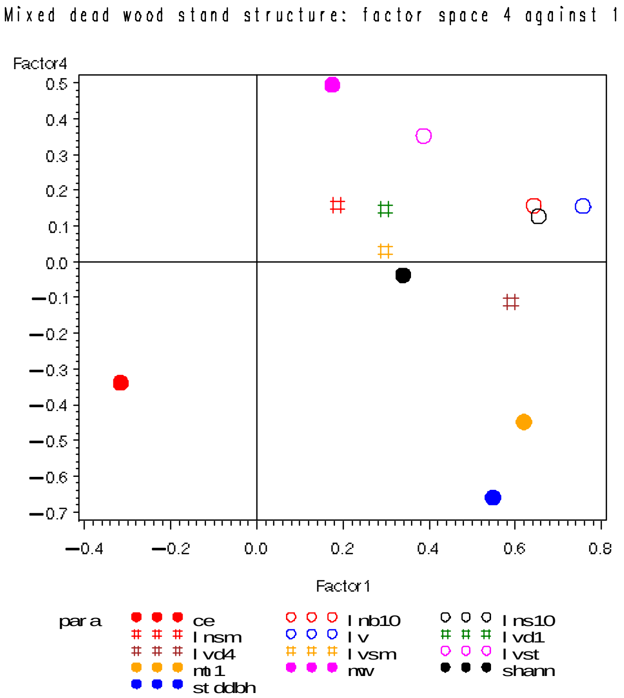


Fig. 6: Axis 4 (vertical) against axis 1 (horizontal) of a combined PCA with dead wood / stand structural parameters at plot level; for abbreviations see Fig. 2.

The fifth axis is characterised by the volume of decay class 1 and – less distinct – decay class 4. There is neither any abiotic or management factor correlated to this gradient, nor did the forest types reveal a significant relationship to the decay degree of deadwood. It may be assumed that the time since the last major disturbance (artificial of natural) which had produced some amount of deadwood is primarily responsible for this feature, even if it is known from studies in primeval forest (e.g. Korpel' 1995) that the decay of dead trunks proceeds differently fast in various tree species.

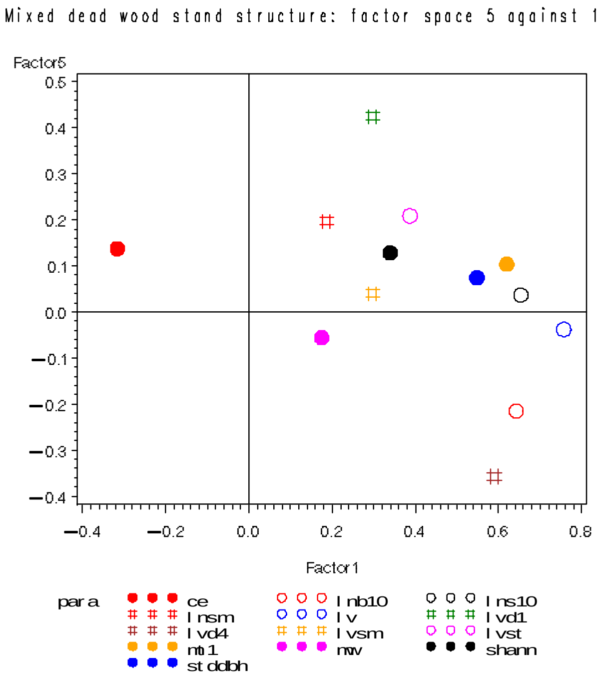


Fig. 7: Axis 5 (vertical) against axis 1 (horizontal) of a combined PCA with dead wood / stand structural parameters at plot level; for abbreviations see Fig. 2.

Tab. 1: Significant relationships (variance models (Proc GLM in SAS), given are R^2 values with p > F) between factors from the combined analysis of deadwood and stand structures of the ForestBIOTA plots and one class variable as predictor.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
main internal driver(s); see text and Fig. 2, 4, 6, 7	amount of deadwood	number / volume of tree stumps	Clark-Evans, mean contagion	diameter spread (-), mean contagion	decay class 1, decay class 4 (-)
forest type	0.48 ***	0.34 **	0.32 *	0.39 ***	
Eunis type	0.50 ***	0.38 *	0.38 *	0.37 *	
main tree species	0.47 ***	0.41 **		0.56 ***	
management type	0.14 *	0.19 *		0.25 *	
cluster AAA – BB, cf. Fig. 8	0.74 ***	0.63 ***	0.45 ***	0.49 ***	0.24 **

Tab. 2: Significant relationships (regression models (Proc REG in SAS), given are R^2 values with p > F) between factors from the combined analysis of deadwood and stand structures of the ForestBIOTA plots and one numeric variable as predictor.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
main internal driver(s); see text and Fig. 2, 4, 6, 7	amount of deadwood	number / volume of tree stumps	Clark-Evans, mean contagion	diameter spread (-), mean contagion	decay class 1, decay class 4 (-)
significant relationship (R^2, p>F, sign of slope), regression models (Proc REG in SAS) with numeric variables					
age	0.27 *** (+)			0.08 * (-)	
absolute yield	0.11 ** (+)			0.08 * (-)	
n of tree layers		0.11 ** (-)	0.17 *** (-)	0.10 ** (-)	
canopy closure					
intensity forest management		0.16 *** (+)			
altitude			0.20 *** (-)		
latitude		0.05 * (+)	0.14 *** (+)		
pH org. layer		0.15 *** (-)	0.10 ** (-)		
pH min. layer 0 –10 cm depth		0.15 *** (-)	0.06 * (-)		
S throughfall deposition			0.10 ** (+)		
total N throughfall deposition			0.12 ** (+)		
NH_4-N throughfall deposition			0.17 *** (+)		

Tab. 1 and 2 give a summary of important relationships between the five main axes (factors) from the combined factor analysis of deadwood and stand structures and external stand and plot parameters. For the first and the forth factor the highest relationship with both forest type classification systems – (BEAR, see Barbati et al. 2002 and EUNIS see … Citation xxx) is found. Factor 2 and 3 are less related to forest type classification and seem to be more influenced by local or regional forest practices. The 5th factor, which represents the state of deadwood decay is not at all related to one of these classifications. As the predominant tree species is part of both forest type classification systems, it is not astonishing that it follows the same patterns of relationship. A cluster analysis done on the basis of the same stand and deadwood parameters as the factor analysis revealed an almost constantly decreasing relationship with all extracted factors. The classification result of this mathematical procedure is the only class variable, which is also significantly related to the 5th factor.

The most important and plausible relationships between the combined deadwood and stand structural factors and external site and stand parameters were already mentioned above. Like all rather explorative statistics with parameters from the ForestBIOTA plots some may reflect more general relationships while others can only be interpreted as a pseudo-relationship based on the rather small and erratic selection of the plots. Especially the relationship between the 3rd factor and the deposition estimates can be view as a typical pseudo-correlation. It seems to be based on a coincidence between areas with high nitrogen and sulphur deposition loads and the spatial distribution of certain forest types respectively or deadwood or stand structural features related to them. On the other side the consistently and plausible negative relationship between the number of tree layers and factors 2, 3 and 4 seems to reflect basic relationships. The more layers a tree stand contains the higher is the probability of a lower number of stumps (no recent thinning operations), the less regular is the horizontal distribution of the trees (no exclusion of concurrence in space and therefore higher vertical differentiation of individuals) and the higher is the diameter spread of the trees.

2.2 Results of a cluster analysis

Cluster analysis is an alternative or supplementary approach to factor analysis. The result (Fig. 8) is a grouping based only on the measured deadwood and stand structural parameters and contains therefore no subjective elements.

The distinction of eight groups is comparatively distinct, however, there is no single outstanding parameter among the original parameters describing the deadwood and stand features, which clearly discriminates the clusters (Fig. 9). Plots belonging to the ‘A-part’ of the cluster-diagram have the tendency for higher volumes of deadwood, however, there is considerable overlap between the clusters with respect to this variable. The remaining parameters produce even more overlap within comparable evaluations. Simple discriminant functions can under those conditions not be developed. Since the factor analysis already delivers a multivariate solution of this problem, a further proceeding in this direction is obsolete.

Projecting the clusters into geographical space, it becomes clear that cluster membership is considerably influenced by both country and its geographical position (Map 1). For instance all three plots from Ukraine form a cluster of their own (ABB) and most plots from Spain belong to cluster BB, which generally contains the least amount of deadwood (cf. Fig. 9). Other clusters reveal a geographically wide distribution (BAAB), which geographically overlap largely with other clusters.

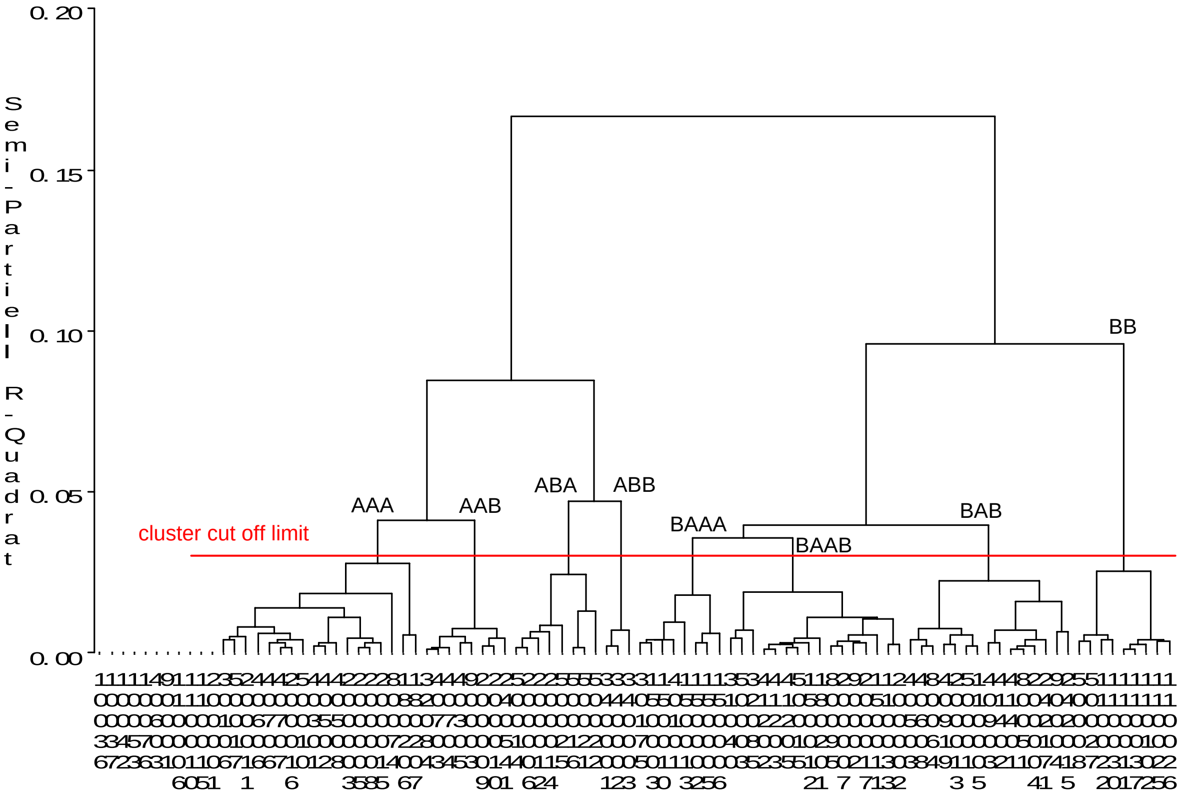


Fig. 8: Result of a cluster analysis (Euclid distance, Ward agglomeration algorithm) with parameters related to stand structure and deadwood assessment (cf. PCA above).

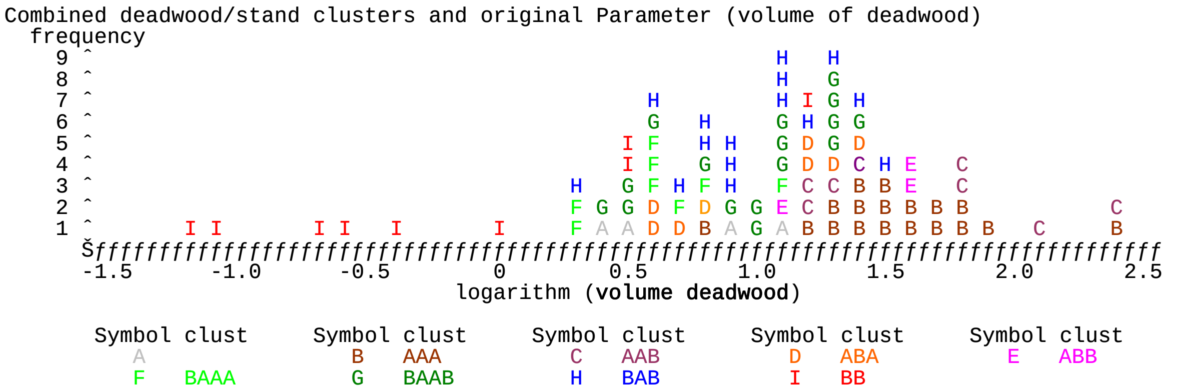
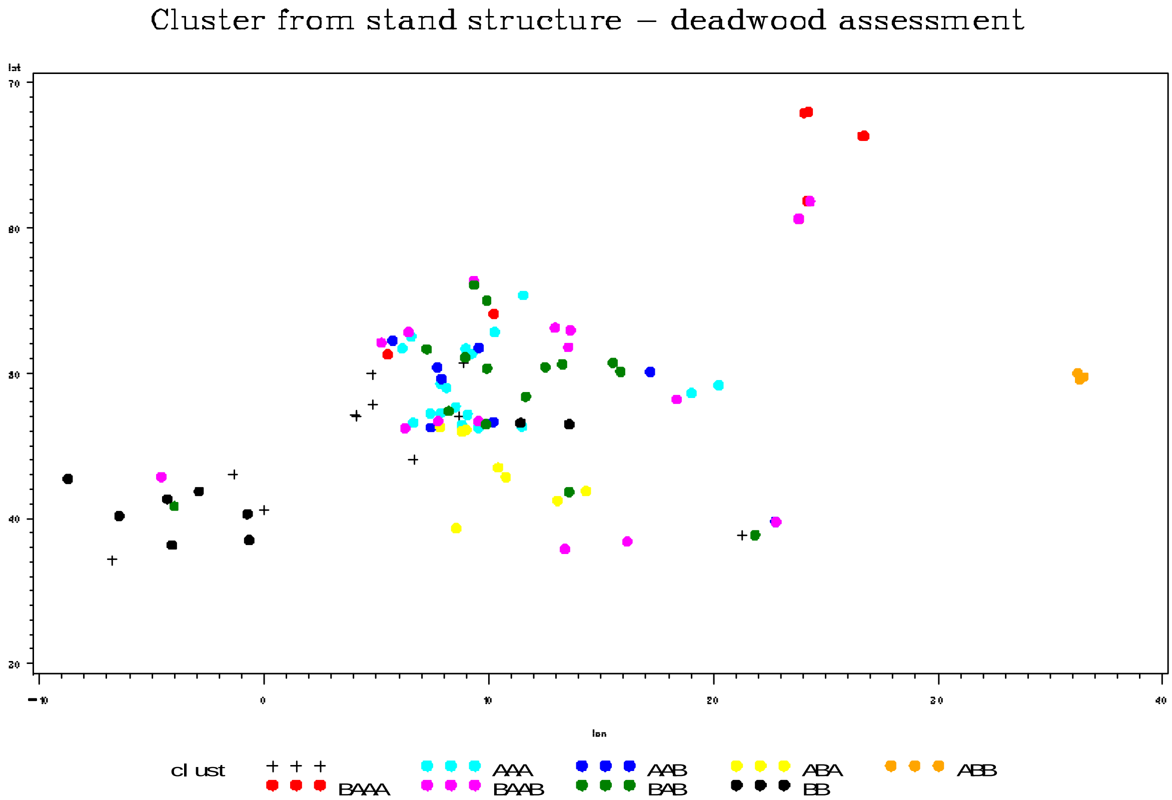


Fig. 9: Cluster distribution along one of the main factors (logarithm of volume of deadwood).



Map 1: Geographic distribution (latitude against longitude) of clusters from a combined analysis of stand structure and deadwood assessment.

3 Relationships focussing on the floristic composition of the forest floor

The ground floor vegetation of forests observed in the project consists of the herb and the moss layer. The basic properties in terms of species numbers and further diversity measures of both layers of the ForestBIOTA plots are described in Granke (2006). In the following, three approaches to analyse and select or derive aggregates from the floristic composition of the ground floor vegetation are given, which are based on the so called common sample plot size of 400 m^2 (for smaller deviations from this standard size, see Granke 2006):

- a multivariate approach with an ordination method (detrended correspondence analysis, DCA)
- calculation of indicator values according to Ellenberg (1992)
- correlation analyses between DCA scores respectively indicator values with stand and site factors
- correlation analyses between diversity estimates of the herb and moss layer and important stand and site factors.

3.1 Numerical analysis of the floristic composition of the herb layer

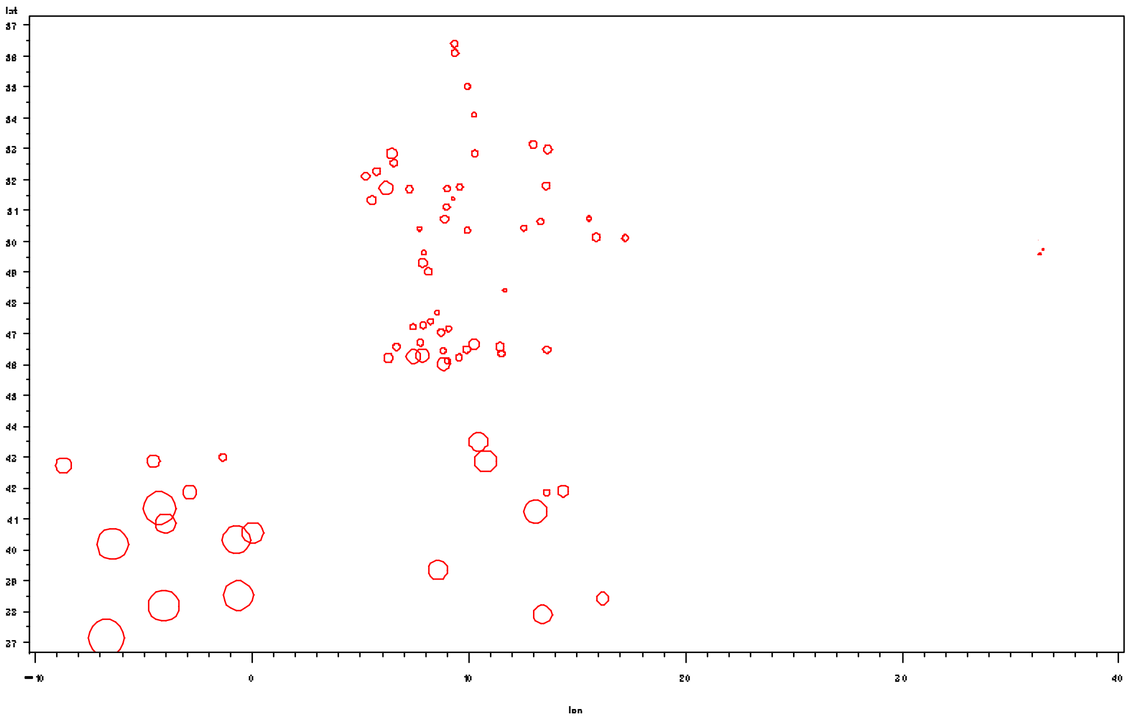
In order to gain a relative order of the plots based on their floristic composition an ordination method has been applied (see ter Braak 1987). Besides SAS routines for data management and filtering (only vascular species with more than two occurrences within the total data set have been involved) CANOCO (ter Braak & Šmilauer 1998) was used for the virtual analysis. Since the ecological gradient

covered by the ForestBIOTA plots and hence the overall statistical variance is rather large (total inertia = 14.01) detrended correspondence analysis (DCA) has been used, which is based on a unimodal response model. Cover percentages have been square root transformed in order to scale down dominant species. Detrending has been done by segments.
191 vascular species from a total of 701 species met the formal requirement. Table 3 displays on the left side those species which gained high scores on the first axis. Most of these species are typical for Mediterranean maquis, different grassland types and Mediterranean oak and pine brush and woodlands. Therefore, on the first axis Mediterranean plots, especially the plots from Spain, gain high scores (Map 2). Additionally, species listed on the first axis often grow on calcareous substrates. Species with low values are not explicitly listed; they are mostly unspecific and occur on a wide variety of site conditions across central Europe. In general, the first DCA axis is interpreted as characterizing a phytogeographical gradient and partly edaphic conditions.

Tab. 3: Species with 30 highest scores on DCA axis 1 and species with 15 highest and 15 lowest scores on DCA axis 2

DCA axis1			DCA axis 2		
rank	species	score	rank	species	score
1	*Briza maxima*	11.3941	1	*Luzula lactea*	6.3734
2	*Andryala integrifolia*	10.1304	2	*Arenaria montana*	5.512
3	*Pinus pinea*	10.1304	3	*Conopodium bourgaei*	5.512
4	*Lavandula stoechas*	9.7424	4	*Poa pratensis*	5.512
5	*Tuberaria guttata*	9.7424	5	*Cruciata glabra*	5.4911
6	*Logfia gallica*	9.6425	6	*Trientalis europaea*	5.3765
7	*Tolpis barbata*	9.6425	7	*Pinus sylvestris*	5.1329
8	*Hypochoeris glabra*	9.3924	8	*Pseudotsuga menziesii*	5.0844
9	*Ornithopus compressus*	9.3839	9	*Galium saxatile*	4.9627
10	*Asterolinon linum-stellatum*	9.3014	10	*Nardus stricta*	4.8471
11	*Leontodon taraxacoides*	9.125	11	*Cynosurus echinatus*	4.7757
12	*Brachypodium retusum*	8.6219	12	*Prunus serotina*	4.7135
13	*Sanguisorba minor*	8.4086	13	*Deschampsia flexuosa*	4.6673
14	*Cynosurus echinatus*	8.3774	14	*Cerastium gracile*	4.5849
15	*Rumex acetosella*	8.3431	15	*Castanea sativa*	4.4836
16	*Galium sp.*	8.285	176	*Veronica montana*	-0.1113
17	*Thymus vulgaris*	8.2483	177	*Galium odoratum*	-0.1382
18	*Cerastium gracile*	8.0931	178	*Circaea lutetiana*	-0.1491
19	*Asparagus acutifolius*	8.0292	179	*Urtica dioica*	-0.1605
20	*Festuca sp.*	7.8982	180	*Arum maculatum*	-0.1629
21	*Cruciata glabra*	7.0927	181	*Potentilla sterilis*	-0.1755
22	*Dactylis glomerata*	7.0146	182	*Lilium martagon*	-0.1933
23	*Quercus ilex*	6.9584	183	*Melica uniflora*	-0.2331
24	*Fraxinus ornus*	6.4585	184	*Cardamine kitaibelii*	-0.2408
25	*Rubia peregrina*	6.386	185	*Galeopsis tetrahit*	-0.3613
26	*Phillyrea latifoglia*	6.3768	186	*Rubus sp.*	-0.4494
27	*Luzula lactea*	6.3182	187	*Carpinus betulus*	-0.512
28	*Smilax aspera*	6.2836	189	*Lamiastrum galeobdolon*	-0.5525
29	*Arbutus unedo*	6.2231	190	*Cardamine bulbifera*	-0.5628
30	*Silene nutans*	6.2114	191	*Hordelymus europaeus*	-1.0804

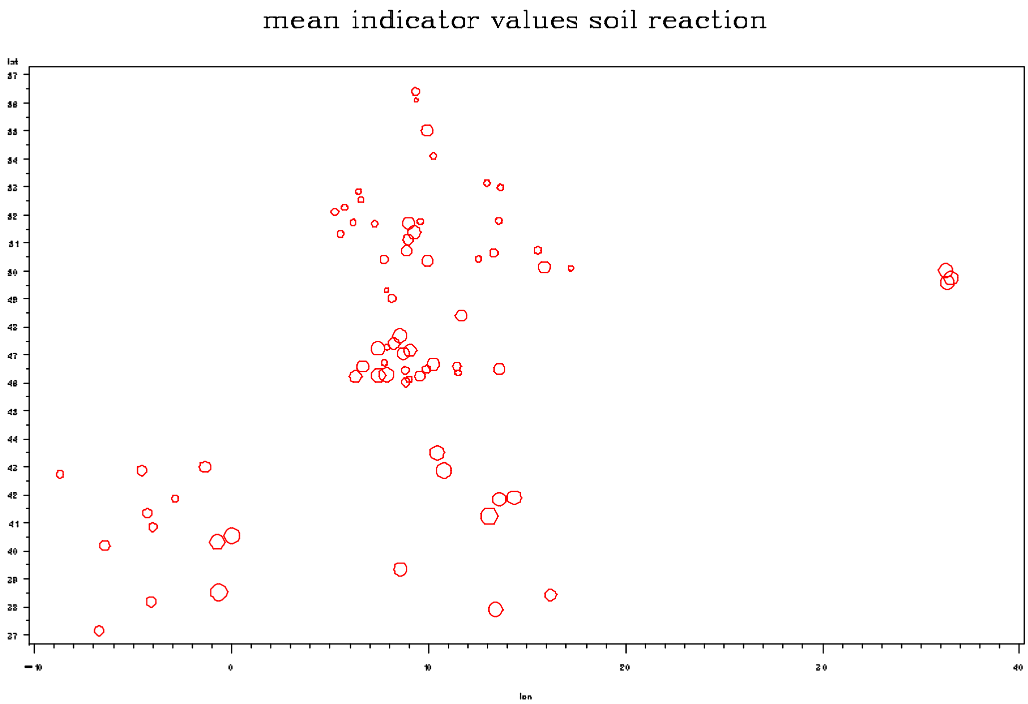
The second axis is mainly determined by species listed in Tab. 3 (right side). There is no simple assignment of the species with very high or very low scores to a certain ecological group. However, species with high scores tend to prefer rather acid and/or nutrient poor sites, while species with very low scores are mostly found on sites rich in nutrient and basic cations (Ca, Mg). Species with low scores indicate as well a better and more constant water supply. The axes of higher order do not reveal any simple ecological patterns. Such an unspecific ordination in ecological terms reflects the rather heterogeneous sample covering a large variety of different forest types from boreal to open Mediterranean forests. Nevertheless, the method is able to stratify the sample into less heterogeneous sub-samples, which can be separately analysed (cf. Lorenz et al. 2006 for a respective analysis of the Level II data set). Adequate approaches of cluster analyses (e.g. Wildi & Orlóci 1996) would be another option but are not applied here.



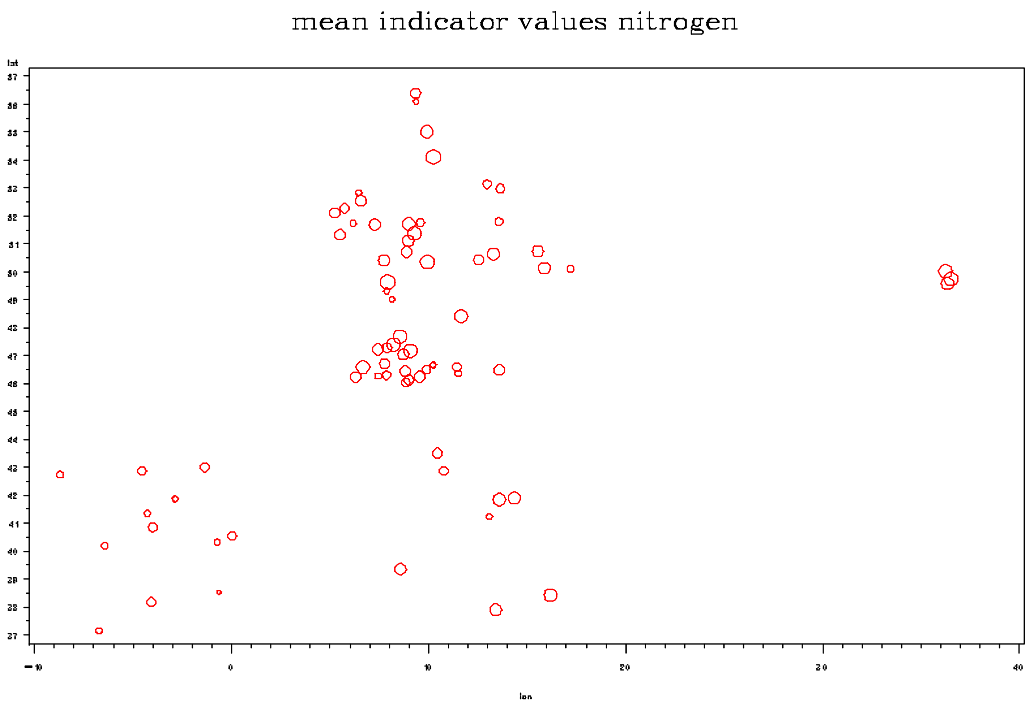
Map 2: Geographic distribution (latitude against longitude) of the plot-related scores of the 1. axis of ForestBIOTA plots.

3.2 Indicator values for light condition, moisture, soil reaction and nitrogen

Indicator values after Ellenberg (1992) are widely used in applied science for a rapid rating of site qualities with respect to soil acidity, plant available nitrogen, soil moisture and light supply. Additionally, values are available for salt concentration, temperature regime and position within the gradient between oceanic and continental climate in Europe. There has been a long debate, what and how precise and how specific single taxa of plants or different taxa growing together at a certain place or area can indicate (Kowarik & Seidling 1989, Diekmann 2003, Ellenberg 1992). For instance, the discussion related to factors separating calcifuge and calcicole species has a long tradition, however, shall not be reflected here. Especially values for the availability of nitrogen, soil reaction, moisture and light conditions are of interest within the context of biological diversity in forests. In this study, weighting by cover degrees did not improve the results, thus unweighted means were used.



Map 3: Geographic distribution (latitude against longitude) of the plot-related mean indicator values for soil reaction.

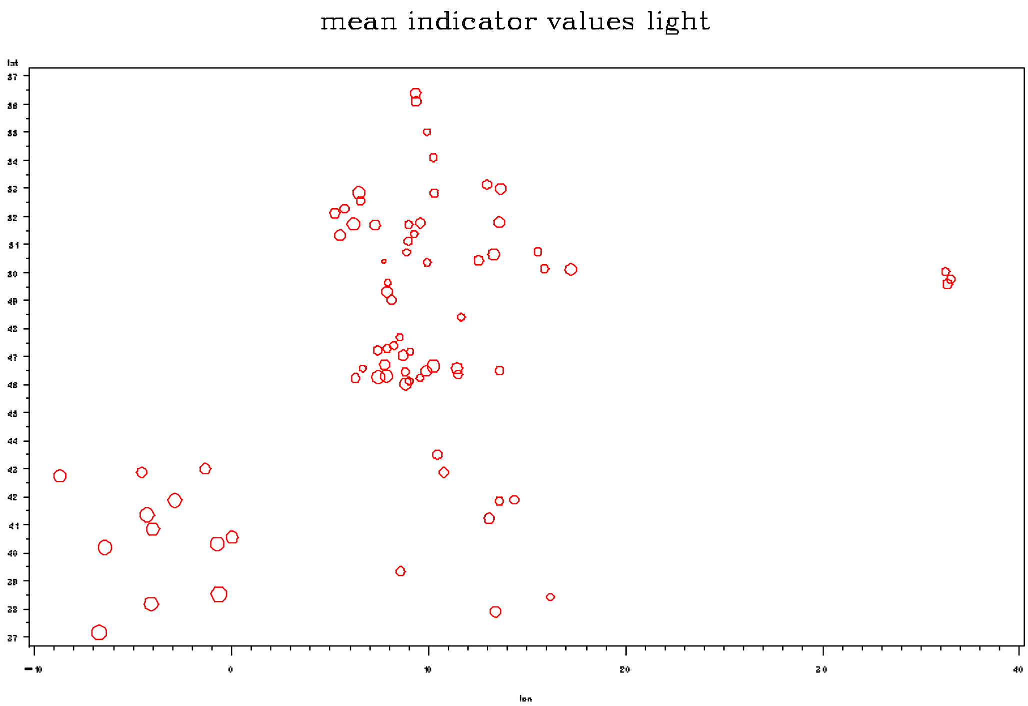


Map 4: Geographic distribution (latitude against longitude) of the plot-related mean indicator values for plant available nitrogen.

Map 3 to 5 give the results for mean indicator values for soil reaction, plant available nitrogen, and light supply within the geographical context. Mean indicator values for soil reaction (mR, Map 3) are high for many plots in the Mediterranean region, in the Ukraine and in a part of the Swiss plots. The most acidic plots in terms of indicator values are located in central Europe. This spatial distribution of mR indicator values reflects widely the chemical properties of soil parent materials across Europe.

Map 4 shows the indicator values for plant available nitrogen (mN) of each ForestBIOTA plot in their geographical context. No distinct coherent geographical pattern is recognizable at the large scale, even if it seems that in central Europe plots with higher values are concentrated while in Spain many plots with rather low mN values are found.

Indicator values for light (mL) reveal a similar spatial pattern than the scores of the DCA axis 1 (see also Tab. 3). The high mL values in Spain reveal that those plots are the least shaded ones. This coincides with the high amount of species from maquis and grassland habitats within these forests. However, unlikely to the ordination results, plots with higher mL values can be found as well in Switzerland and scattered throughout Europe.



Map 5: Geographic distribution (latitude against longitude) of the plot-related mean indicator values for light.

3.3 Relationships between DCA plot scores and different site and stand factors

Basic relationships between DCA scores and site and stand factors have been screened by correlation analysis. The calculation of those relationships can serve as a basis for more advanced statistical models and gives first hints about possible cause-effect chains. Because there are many intercorrelations between the parameters, the interpretation of the correlation matrixes needs to be done very carefully and needs external knowledge about general dependences within forest ecosystems and the organization of plants at larger scales (phytogeographical relationships). In the case of the ForestBIOTA project these interpretations must be done especially cautiously, since there is no spatial or closer ecological coherence between the plots scattered over large areas of Europe. Nevertheless, it was expected that well known relationships would be corroborated by the data set from different European forest types.

In a first approach **DCA plot scores** of the first four axes were correlated with **mean indicator values**, both derived from the floristic composition of the herb layer. (Tab. 4). The high positive correlation coefficient between the scores of first DCA axis and the mL values corroborates the main phytogeographical gradient with open forests in the Mediterranean area and denser forests in the north. The likewise, however negative relationship between the indicator value for moisture and the first DCA axis points into the same direction: translucent forests in the Mediterranean region, often growing on calcareous substrates, are in many cases characterized by a limited water supply. Also plant available nitrogen may be limited at those sites (negative relationship with mN).
The second DCA axis reveals the closest relationship with mean reaction values. High scores at this axis coincide with low mR respectively low pH values of the soil (see also Lorenz et al. 2006). Those plots with acidic soils have normally also low mineralization rates of nitrogen, which is indicated by the negative relationship with the respective indicator values. The higher DCA axes show less clear or no significant relationships with mean indicator values, which again shows a rather vague meaning of these DCA axes in terms of simple ecological features.

Tab. 4: Pearson correlation coefficients (plus level of significance and number of valid cases) between scores from DCA axis 1 to 4 and mean indicator values both calculated from the floristic composition of the herb layer.

	mean indicator value for			
	light	moisture	soil reaction	plant available nitrogen
plot scores DCA axis 1	0.738***; 74	-0.792***; 74	0.289*; 72	-0.554***; 73
plot scores DCA axis 2	0.494***; 74	0.008; 74	-0.654***; 72	-0.569***; 73
plot scores DCA axis 3	0.248*; 74	-0.320**; 74	0.150; 72	-0.183; 73
plot scores DCA axis 4	0.089; 74	-0.045; 74	-0.074; 72	-0.145; 73

Tab. 5: Pearson correlation coefficients (incl. levels of significance, n: number of valid cases) between plot scores of DCA axis 1 to 4 and selected site factors; pH_O: pH in the organic layer, xNH_4: annual throughfall ammonium deposition [kg ha^{-1} a^{-1}], xNO_3: respective nitrate deposition, xS: respective sulphur deposition.

DCA plot scores	latitude n = 74	longitude n = 74	altitude n = 74	pH_O n = 62	stand age n = 74	xNH_4 n = 58	xNO_3 n = 59	xS n = 59
axis 1	-0.732***	-0,602***	0.034	0.383**	-0.388**	-0.300*	-0.401**	-0.244
axis 2	0.133	-0.139	0.104	-0.510***	-0.140	0.296*	0.075	0.250
axis 3	-0.199	0.008	0.507***	0.235	0.118	-0.507***	-0.372**	-0.331*
axis 4	0.081	-0.440***	-0.213	-0.039	-0.094	0.479**	0.203	0.171

In a further approach DCA plot scores were related to major geographical, site, and stand related features. Tab. 5 and 6 display the respective results. In accordance with previous findings there is a highly significant correlation between latitude and scores of DCA axis 1, which underlines the geographical differentiation of the ground floor vegetation in Europe. This relationship has already been shown in Lorenz et al. (2006) for the larger data set of more than 700 Level II sites. Interestingly, there is also a distinct west-eastern relationship, indicated by a negative coefficient between DCA axis 1 and longitude. The correlations with pH in the organic layer, with stand age, and deposition of reduced and oxidized nitrogen might at least be partly due to pseudo-correlations, since all these parameter reveal more or less strong geographical differentiations within Europe, which can within the ForestBIOTA project methodically neither be covered due to the poor geographical representation of the plots nor can it be tackled by simple correlation analysis.

Tab. 6: Pearson correlation coefficients (plus level of significance and number of valid cases) between DCA axis 1 to 4 calculated from the herb layer (ground vegetation) and selected stand structural parameters and deadwood parameters (those with high explanatory power according to a PCA, cf. Capt. 2).

DCA plot scores	canopy closure	n. tree layers	trees density	basal area	mean conta-gion	Clark-Evans index	stddbh	vol. dead-wood	vol. decay class 1	vol. decay class 4	vol. stumps
axis 1	-0.009 65	0.153 65	0.231 *, 73	-0.380 **, 73	0.210 72	-0.152 72	-0.434 **, 72	-0.262 *, 72	-0.114 72	-0.139 72	-0.129 72
axis 2	-0.505 ***, 65	-0.049 65	-0.094 73	0.031 73	-0.095 72	0.124 72	-0.347 **,72	0.169 72	0.252 *, 72	0.142 72	0.105 72
axis 3	-0.533 ***,65	-0.112 65	0.024 73	-0.136 73	0.105 72	-0.207 72	-0.139 72	0.164 72	0.118 72	0.111 72	0.034 72
axis 4	0.184 65	0.230 65	0.048 73	-0.087 73	0.036 72	0.030 72	0.155 72	-0.129 72	-0.068 72	-0.088 72	-0.115 72

Correlation analysis can also give hints about possible relationships between species composition and stand structure respective deadwood parameters. Tab. 6 reveals a small number of statistically significant bivariate relationships. Canopy closure reveals higher negative correlation with axis 2 and 3. In case of axis 2, there might be a causal relationship since more acid habitats in central Europe may have less dense crowns in comparison to forests on base-rich substrates. For axis 3 a relationship between higher altitudes and less closed canopies might be also realistic, however, in both cases more in-depth studies are necessary. All other significant correlations are rather weak and may be based on different inter-correlations between geographically determined floristic relationships (e.g. axis 1 and latitude) on one hand and also geographically varying stand and deadwood structures (like total basal area or tree density) on the other hand.

Tab. 7: Pearson correlation coefficients (plus level of significance and number of valid cases) between DCA axis 1 to 4 calculated from the herb layer (ground vegetation) and summary estimates from the assessment of the ground floor vegetation and the survey of the epiphytic lichens.

	species number (richness)					evenness				
DCA plot scores	herb layer	moss layer	all lichens	macro-lichens	custac. lichens	herb layer	moss layer	all lichens	macro-lichens	custac. lichens
axis 1	0.415 **, 74	-0.339 **, 71	0.116 65	0.275 *, 65	-0.024 65	0.066 74	-0.144 55	0.156 62	-0.024 38	0.118 62
axis 2	-0.130 74	0.373 **,71	-0.307 *, 65	-0.098 65	-0.383 **, 65	-0.384 **, 74	0.193 55	-0.332 **, 62	-0.378 *, 38	-0.310 **, 62
axis 3	0.408 **, 74	0.102 71	0.096 65	0.314 *, 65	-0.080 65	0.117 74	-0.051 55	0.238 62	0.057 38	0.208 62
axis 4	-0.130 74	0.123 71	-0.102 65	-0.287 *, 65	0.052 65	-0.066 74	0.148 55	-0.080 62	0.015 49	-0.128 62

DCA axes may also reveal some more or less direct relationships with diversity measures of the forest floor vegetation and probably also the richness and diversity of the epiphytic lichen flora. Tab. 7 displays the respective correlation coefficients. As expected, axis 1 is positively correlated with species number of the herb layer reflecting the higher number of species, which can be found on the ForestBIOTA plots in the Mediterranean zone in comparison to the nemoral zone. Quite contrary to this relationship is the negative correlation between species number of the moss layer and DCA 1. This is not only due to plots from Finland with their rich and puissant moss layers but is as well related to the fact that epigeic mosses and lichens are generally more abundant on more northerly situated plots. As concerns relationships between the floristic structure of the ground floor vegetation and the epiphytic lichen flora, DCA axis 2 (reflecting an acidity gradient of the soil) is of specific interest. It is positively correlated with species richness of the moss layer and negatively correlated with species richness of the epiphytic lichen flora and the evenness values of almost all strata. This underlines the strong relationship between the soil pH, especially in the organic layer, and the epigeic and indirectly also the epiphytic vegetation. The finding that axis 3 with is positively correlated with species number of herb layer and epiphytic macro-lichens may indirectly reflect the positive relationship between this axis and altitude (see Tab. 4). This seems to corroborate findings that in comparison to planar habitats higher species numbers are often found in higher altitudes (cf. Seidling 2005 for German Level II plots).

3.4 Relationships between basic biodiversity estimates of the ground floor vegetation (herb and moss layer) and external parameters

There is considerable interest in causal drivers for different biodiversity aspects of forest ecosystems. Therefore direct relationships in terms of correlation coefficients are in the focus of this chapter. It has already been shown that there are some relationships between the floristic composition of the herb layer and species richness (last chapter). This underlines the general ecological knowledge that species richness partly is determined by edaphic factors.

Tab. 8: Pearson correlation coefficients (plus level of significance and number of valid cases) between selected summary estimates derived from the herb and moss layer and geographic, edaphic (pH_O,: pH in the organic layer), stand and deposition related (annual rates of wet throughfall deposition of ammonium (xNH_4), nitrate (xNO_3) and sulphate (xS)) parameters .

	latitude n = 74	longitude n = 74	altitude n = 74	pH_O	stand age n = 74	xNH_4 n = 58	xNO_3 n = 59	xS n = 59
species number herb layer	-0.524 ***, 74	-0.206 74	0.391 **, 74	0.543 ***, 62	-0.114 74	-0.389 **, 58	-0.292 *, 59	-0.348 **, 59
species number moss layer	0.412 **, 71	0.154 71	0.076 71	-0.430 **, 61	0.016 71	0.284 *, 58	0.108 59	0.090 59
evenness herb layer	-0.227 74	0.085 74	0.117 74	0.227 62	0.180 55	-0.216 58	-0.103 59	-0.177 59
evenness moss layer	0.333 *, 55	0.132 55	-0.163 55	-0.353 *, 49	-0.194 55	0.190 45	-0.087 46	-0.003 46

Tab 8 gives an overview on all major bivariate relationships between species number (richness) respectively the eveness of the involved species and major environmental and geographical factors. Again, lower latitudes (the Mediterranean zone) show higher numbers of vascular species and in contrast lower numbers of epigeic mosses and lichens. From all macro-ecological factors only altitude has a significant positive relationship with species richness of vascular plants, a relationship which has already been mentioned and might be caused by a generally higher small scale site variability in mountainous regions (cf. Schmidtlein & Ewald 2003, Seidling 2005). The positive relationship between the pH value in the organic layer and species richness of vascular plants might partly be based on the large-scale differentiation between the Mediterranean and the nemoral zone, however also within the nemoral or even sub-boreal zone, the species number on the forest floor generally increases with higher pH values (cf. Ewald 2003). Again, for mosses the opposite is true. Lower species numbers of vascular plants at sites with higher N and S wet throughfall deposition might largely by based on coincidence with atmospheric inputs and the actual geographical distribution of the ForestBIOTA plots, even if a part of the relationship may express direct or indirect effects of N and/or S deposition. The evenness values of the herb layer seem not to be related to any involved factor and the evenness of the moss layer is partly a poor replication of the relationship between moss species richness and latitude respective pH_O. For a more precise formulation of the multiple relationships more advanced statistical modelling - under consideration of the close limits given by the small and unbalanced ForestBIOTA data set - would be necessary.

Between diversity estimates of the herb and moss layer and stand structural as well as deadwood related parameters there are conspicuously few significant relationships (Tab. 9), which corroborates partly findings from Neumann & Starlinger (2001) and Ewald (2002), who found no simple relationships between tree stand diversity and diversity of the ground floor vegetation at regional to national scales. Only the number of tree layers shows a positive and the stand basal area a negative relationship with species richness of the herb layer at an European scale. These rather poor results may not be interpreted in a way that stand management may have no influence on ground floor vegetation diversity, however, the relationships are not obvious and straight forward.

Tab. 9: Pearson correlation coefficients (plus level of significance and number of valid cases) between selected summary estimates derived from the herb and moss layer and selected stand structural parameters and deadwood parameters (those with high explanatory power according to a PCA, cf. Capt. 2).

	canopy closure	n. tree layers	trees ha^{-1}	basal area ha^{-1}	mean conta-gion	Clark-Evans index	stddbh	vol. dead-wood	vol. decay class 1	vol. decay class 4	vol. stumps
species number herb layer	-0.231 65	0.341 **, 65	-0.040 73	-0.321 **, 65	0.214 72	-0.197 72	-0.107 72	-0.168 72	-0.167 72	-0.088 72	-0.155 72
species number moss layer	-0.112 65	-0.008 65	-0.198 70	0.223 70	-0.141 69	0.133 69	0.098 69	0.133 69	0.019 69	0.136 69	-0.039 69
evenness herb layer	0.226 65	-0.104 65	0.131 73	-0.088 73	0.050 72	-0.161 72	0.095 72	-0.066 72	0.048 72	-0.140 72	-0.034 72
evenness moss layer	-0.125 49	-0.192 49	0.058 54	0.157 54	-0.252 53	0.153 53	-0.192 53	0.074 53	-0.112 53	0.081 53	0.267 53

4 Relationships focused on epiphytic lichens

4.1 Interference patterns of basic biodiversity estimates from the epiphytic lichen assessment with ecological factors

Plot related biodiversity estimates for epiphytic lichens have been calculated by Stofer (2006) within a more sectoral apporach. A differentiation has been made according to the gross morphology of the lichens: macro-lichens, crustaceous lichens and the joint sample of both categories. The present study correlates these estimates to a number of external parameters mainly available from the ICP Forest Level II programme. Age and stand classification have been taken directly from the ForestBIOTA assessments. The correlation analyses give a first impression about general relationships and offer a basis for more advanced approaches like multiple regression, covariance models or other multivariate methods.

Tab. 10: Pearson correlation coefficients (plus level of significance and number of valid cases) between selected summary estimates derived from the epiphytic lichens vegetation and geographic, edaphic (pH_O,: pH in the organic layer), stand and deposition related (annual rates of wet throughfall deposition of ammonium (xNH_4), nitrate (xNO_3) and sulphate (xS)) parameters .

	latitude	longitude	altitude	pH_0	stand age	xNH_4	xNO_3	xS
species number all lichens	-0.528 ***, 65	0.203 65	0.409 **, 65	0.461 **, 56	-0.102 65	-0.378 *, 53	-0.267 53	-0.290 *, 53
species number macro-lichens	-0.617 ***, 65	0.093 65	0.575 ***, 65	0.436 **, 56	-0.229 65	-0.411 **, 53	-0.394 **, 53	-0.260 53
species number crust. lichens	-0.342 **, 65	0.233 65	0.196 65	0.359 **, 56	0.012 65	-0.168 53	-0.091 53	-0.231 53

evenness all lichens	-0.506 ***, 62	-0.059 62	0.491 ***, 62	0.443 **, 53	0.271 *, 62	-0.555 ***, 50	-0.282 *, 50	-0.521 **, 50
evenness macro-lichens	-0.342 *, 38	0.053 38	0.274 38	0.113 31	0.222 38	-0.161 28	0.186 28	0.114 28
evenness crust. lichens	-0.373 **, 62	0.085 62	0.412 **, 62	0.438 **, 53	0.388 **, 62	-0.379 **, 50	-0.140 50	-0.389 **, 50

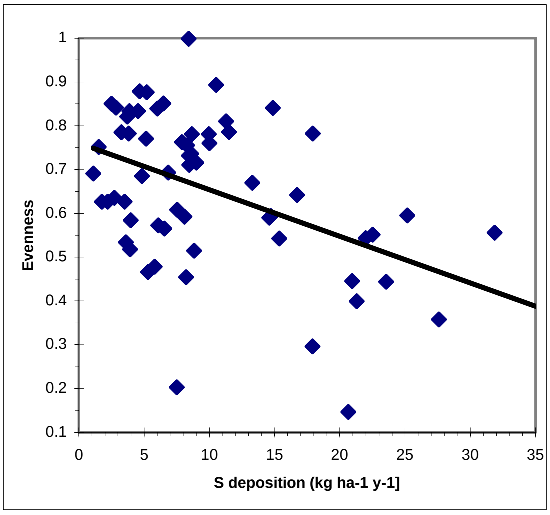


Fig. 10: Evenness of epiphytic lichens in relation to annual throughfall deposition of sulphur.

Table 10 reveals significant negative correlations between all determined diversity parameters and latitude. This shows a higher diversity of this species group on ForestBIOTA plots at lower latitudes. The concurrent negative relations and strength of the relationships especially for the species numbers reflects the high inter-correlation between the species numbers of the involved lichen categories, however macro-lichens seem to reflect this relationship best. Longitude does not differentiate species numbers or evenness estimates of epiphytic lichens (in spite of the precipitation gradient). Altitude is another (well-known) significant driver of epiphytic lichen diversity, especially for macro-lichens. Number of crustaceous lichens does not increase with altitude, however, its small-scale variation (expressed by evenness) is also higher at higher altitudes. Higher pH values of the organic soil layer obviously foster higher epiphytic lichen diversity at the observed plots. This may be indirectly caused by higher shares of tree species with calcareous (less acidic) barks at sites with higher pH values. Stand age is astonishingly of no significant influence onto species richness of epiphytic lichens, only the evenness of crustaceous lichens responds positively to higher stand ages. This might mainly be caused by the more intense structured barks of older trees in comparison to young trees.

Since a considerable time a large amount of literature about the SO_2 sensitivity of epiphytic lichens exists (e.g. Gilbert 1968, Hawksworth & Rose 1970, Wirth & Türk 1975, Liebendörfer et al. 1988, van Dobben & ter Braak 1999). On the background of the well documented sensitivity of epiphytic lichens especially towards sulphur dioxide and its derivates, it is not astonishing to find a decreasing number of lichens at plots with a higher deposition load (respectively gaseous immission load), even if the sample is by far not optimised for such an investigation and a considerable amount of interferences from other predictors like latitude, altitude etc. has to be assumed. In order to take into account at least some of those interferences in an additional approach with forest-type as additional categorical predictor is performed

(Chapt. 4.3). Interestingly, evenness as a measure of small-scale equitability is also sensitive towards nitrogen and/or sulphur deposition respectively immission (Fig. 10).

Tab. 11: Pearson correlation coefficients (plus level of significance and number of valid cases) between selected summary estimates from the assessment of the epiphytic lichen flora and parameters form the surveys on stand structure and deadwood.

	canopy closure	n. tree layers	trees density	basal area	mean conta-gion	Clark-Evans index	stddbh	vol. dead-wood	vol. decay class 1	vol. decay class 4	vol. stumps
species number all lichens	0.110 59	0.192 59	0.453 **, 64	0.097 64	0.382 **,64	-0,547 ***, 64	0.071 64	-0.086 63	-0.116 63	-0.130 63	0.023 63
species number macro-lichens	-0.095 59	0.198 59	0.260 *, 64	-0.053 64	0.267 *, 64	-0.418 **, 64	-0.140 64	-0.131 63	-0.088 63	-0.128 63	-0.015 63
species number crust. lichens	0.223 59	0.144 59	0.484 ***, 64	0.184 64	0.374 **, 64	-0.510 ***, 64	0.203 64	-0.036 63	-0.108 63	-0.101 63	0.044 63
evenness all lichens	0.003 56	0.226 56	0.280 *, 61	0.001 61	0.466 **, 61	-0.545 ***, 61	0.272 *, 61	-0.070 61	-0.035 61	-0.164 61	0.026 61
evenness macro-lichens	0.154 35	0.027 35	0.176 37	0.296 37	0.288 38	-0.371 *, 38	0.364 *, 38	0.105 37	-0.082 37	0.112 37	0.031 37
evenness crust. lichens	-0.101 56	0.221 56	0.228 61	-0.128 61	0.355 **61	-0.457 **, 61	0.273 *, 61	0.151 61	0.256 *, 61	-0.093 61	0.266 *, 61

The interference patterns with stand structural and deadwood parameters are displayed as correlation coefficients by Tab. 11. Parameters which are supposed to be rough proxies for light conditions within the stands show astonishingly no positive correlation with epiphytic lichen diversity. Instead, tree density is positively correlated with lichen diversity, especially with species number of crustaceous lichens. Probably a higher number of tress species with different bark properties is present at those sites. Even more interesting are the distinct correlations between horizontal distribution of the trees within the stands and the species number respectively evenness, again most distinct for crustaceous lichens or for both morphotypes together. The sign of the relationship indicates that stands with more clustered distributions of stems have higher numbers of lichens than stands with evenly distributed individuals. Part of this quite close relationship may be distorted by altitude, which has also a strong effect on species number of lichens (Tab. 9). Another finding is the throughout positive relationship between the diameter spread of the trees expressed as standard deviation of the diameter at beast height (stddbh) and the evenness of all three categories of lichens. Of course, in all cases it could be possible that large scale differences e.g. between forest types may distort the found relationships. Therefore, these results have to be taken as preliminary and need further in-depth analyses. The occurrence of deadwood on the plots does not seem to influence the lichen diversity parameters at the plots.

4.2 Multivariate statistical modelling of basic biodiversity estimates from the epiphytic lichen assessment under inclusion of forest type

As already mentioned in the previous chapter, there is need of more advanced modelling of the rather complex dependencies of diversity parameters, because – as usual within ecological data sets – there is a considerable amount of inter-correlations between predictors. One possibility to cope with this situation is the outlining of theory based cause-effect models and their subsequent realisation with the available data sets. Within the present evaluation phase a few examples have been elaborated so far for lichen diversity as response variable and a number of promising environmental parameters as predictors within a multiple regression approach.

Tab. 12: Results of multiple regression models with diversity measures for epiphytic lichens with common Level II parameters for the soil solid phase and for throughfall deposition; models stepwise forward selection with a probability limit of 0.05; **: (Prob > F) ≤ 0.05, **: (Prob > F) ≤ 0.01, ***: (Prob > F) < 0.0001*, implausible statistical relationships are denoted in italics.

	altitude	age	pH_O	pH_{M01}	latitude	longitude	S deposition	NH_4-N deposition	NO_3-N deposition	total R^2/ Pr > F = 0.05
species number all lichens n = 61	0.23 *** +		0.10 *** +							0.33
species number macrolichens n = 61	0.24 *** +	_0.18 *** -_							0.08 ** -	0.49
species number crustaceous lichens n = 61		0.13 ** +	0.16 ** +							0.29
evenness all lichens n = 57	0.31 *** +						0.11 ** -			0.43
evenness macrolichens n = 34		0.14 * +								0.14
evenness crustaceous lichens n = 53		0.26 *** +	0.26 *** +							0.52
Heip all lichens n = 57	0.26 *** +						0.08 * -			0.34
Heip macrolichens n = 34									_0.20 ** +_	0.20
Heip crustaceous lichens n = 53		0.24 *** +	0.26 *** +							0.50

Tab. 12 displays the result of 9 models with species number, evenness and heip index for the two macro-morphs separately and together as response variable and all listed variables as predictors. Often a lower number of the involved cases is observed compared to the bivariate approaches (Tab. 10), because missing cases add up in multiple approaches. Such sometimes even small changes of the involved cases can lead to shifts in the strength of relationship. For the model with species number of all lichens as response factor the best predictor is now altitude (against latitude in Tab. 10). Together with pH of the organic layer the model explains 33 percent of the variation of the total number of lichens. The best model in terms of explained R^2 is the model with number of macro lichens. However, the negative relationship of stand age points to an important unknown factor, which is not yet included, but should have a distinct negative relationship with age too.

An example for a significant covariance model is given in Tab. 14. In order to avoid over-parametrisation, a reduction of forest type categories had to be conducted prior to actual modelling. As can be seen in Tab. 13, forest types with only one or two cases have first been joined with similar forest types or even more suitable types.

Forest types with similar properties with regard to habitat adequacy for lichen settlement were also joined, even if there might be greater ecological differences with regard to other features. After this procedure eight appropriate forest type categories remain.

Tab. 13: Forest type aggregation table.

	Forest type	n of case	aggregated forest type	n of cases
FT1N.3a	Lowland beech forest	16	FT1N.3a	16
FT1N.3b	Mountain beech forest	6	FT14N.3b5	8
FT4N.5	Mixed fir-spruce-beech woodland	2		
FT1N.5	Acidophilous oak-dominated woodland	4	FT1N.5	4
FT1N.7	Meso / eutrophic oak, hornbeam, ash, sycamore, lime. elm and related woodland	5	FT1N.71	6
FT1N.1	Fluvial and riparian woodland *	1		
FT2N	Natural and semi-natural broadleaved Mediterranean / Macaronesian sclerophyllus woodland	7	FT2N	7
FT3N.4	Black pine, Mediterranean / Macaronesian pine and pine-juniper woodland	4	FT3N.4	4
FT3A	Coniferous plantations	7	FT34AN.23	12
FT3N.3	Scots pine woodland	4		
FT4N.2	Hemiboreal forest **	1		
FT3N.1	Fir and spruce woodland	14	FT3N.126	25
FT3N.2	Alpine larch-Arolla and mountain pine woodland	3		
FT3N.6	Taiga woodland	8		
-	not defined	1	-	(1)
FT1N.4	Thermophilous deciduous woodland	0	-	(0)

*: probably miss-classified since stand is dominated by oak, **: probably miss-classified since plot is situated in south-western Germany in an altitude of 500 – 550 m;

```
SAS System, Procedur GLM, Number of Observations Used         66
Dependent variable: SN_macro (species number of macro-lichens)
                                           sum of            mean
  source                         df       squares          squares          F-value     Pr > F
  model                          16    1010.494961       63.155935            3.25     0.0008
  error                          49     951.459585       19.417543
  corrected sum                  65    1961.954545
                R-square      var coeff       root MSE     SN_macro mean
                0.515045       99.94201       4.406534        4.409091

  source                         df        typ I SS      mean square        F-value     Pr > F
  ft_agg                          8     602.3045455       75.2880682            3.88     0.0013
  xN*ft_agg                       8     408.1904152       51.0238019            2.63     0.0177

  source                         df      typ III SS      mean square        F-value     Pr > F
  ft_agg                          7     372.3893015       53.1984716            2.74     0.0176
  xN*ft_agg                       8     408.1904152       51.0238019            2.63     0.0177
```

Tab. 14: Statistics for a covariance model with species number of macro-lichens as dependent variable and aggregated forest types (according to Tab. 13) and the interaction term between forest type and throughfall deposition of total nitrogen.

Using these aggregated categories of forest types together with the interaction terms between these aggregates and total nitrogen throughfall deposition as predictors within a covariance approach with species number of macro-likens as response 52% of the variance of the species number can be explained by these specific combination of the variables (see Tab. 14 for the explicit model results). Forest type alone explains 30% (p > F = 0.0005) of species number of the macro-lichens (Tab. 15). According to Tab. 15 the relationships between forest type and species numbers of the crustaceous and between forest type and all lichens together are somewhat lower, but still significant. The interaction term is neither for crustaceous nor for all epiphytic lichens together significant. Evenness values do not significantly relate to aggregated forest type.

Tab. 15: Summary statistics of variance and covariance models with aggregated forest types and interaction terms between aggregated forest types and total nitrogen throughfall deposition.

	predictor / predictor combination	
response variable	aggregated forest type	aggregated forest type and interaction term aggregated forest type * total N deposition
species number all lichens	0.28 **	0.42 * (interaction term n.s.)
species number macro-lichens	0.30 **	0.52 **
species number crustaceous lichens	0.25 **	0.39 * (interaction term n.s.)
evenness all lichens	0.17 n.s.	-
evenness macro-lichens	0.15 n.s.	-
evenness crustaceous lichens	0.17 n.s.	-

Another possibility to investigate relationships within heterogeneous data sets is stratification. The comparatively low number of cases within most forest types hinders an effective overall stratification strategy. However, the aggregated type FT3N.126, with includes different coniferous woodlands in central and northern Europe (see Tab. 13) offers with a total of 25 cases the possibility to conduct some basic multivariate approaches. Therefore, within this aggregated class a multiple regression was performed with altitude and throughfall deposition of total nitrogen, nitrate, ammonia and sulphur as predictors and species numbers respectively evenness values of all three categories of lichens as response variable.
Tab. 16 shows that higher S deposition less species and with increasing altitude a higher number of marco-lichen species are found. If all lichen species are evaluated together, altitude is the better predictor and annual sulphur deposition the second important one. For crustaceous lichens no respective relationship was determined. For evenness again the macro-lichens are more responsive against both predictors, however altitude is always more important than sulphur deposition. The total amount of explained variance of evenness is generally higher than the explained variance of species number.

Tab. 16: Summary statistics (R^2, significance level, sign of relationship) from multiple regression models for coniferous woodlands from central and northern Europe (aggregated forest type FT3N.126, n = 25, cf. Tab. 13). Species numbers of different gross morpho-types of epiphytic lichens are the response variables and altitude, sulphur throughfall deposition, total nitrogen nitrate and ammonia nitrogen throughfall deposition are the predictor variables; stepwise selection at $p < 0.05$.

response variable	1 step selection	2. step selection	total R^2
species number all lichens	altitude: 0.228 * (+)	xS: 0.158 * (-)	0.376 *
species number macro-lichens	xS: 0.371 ** (-)	altitude: 0.184 * (+)	0.555 **
species number crustaceous lichens	-		-
evenness all lichens	altitude: 0.535 ** (+)	xS: 0.235 ** (-)	0.770 ***
evenness macro-lichens	altitude: 0.330 * (+)	xS: 0.484 *** (-)	0.814 ***
evenness crustaceous lichens	altitude: 0.684 *** (+)		0.684 ***

The selected and exemplarily evaluated relationships of lichen richness aspects and basic environmental parameters which are measured at Level II plots reveals the potential for integrated evaluations of data from the Level II monitoring in connection with additionally surveyed features of biodiversity. If some of the parameters assessed within the ForestBIOTA project would be applied at a broader scale, even more specific questions regarding the biodiversity issue as well as impacts of atmospheric deposition onto aspects of forest diversity could be tackled.

5. Excursus: Species-area relationships within the herb layer

Since considerable time, the species-area relationship (SAR) has been a matter of interest in theoretical ecology (e.g. Arrhenius 1920). Along with the ongoing debate about biodiversity and its drivers, a need for harmonisation and standardisation has become obvious especially in monitoring networks, because numbers of biological entities are only meaningful for a defined space or area. One common formula to describe the SAR is based on the increase of species numbers against area, both given as logarithms (e.g. Willianson 1981):

$$\log S_b = \log S_a + z\,(\log A_b - \log A_a),$$

where S_b is species number at area size b, S_a is species number at area size a, A_b is area of b and A_a is area of a. This relationship is kept to be linear over some magnitudes and the slope z describes the respective increase of species number with area on a log-log scale, even if it was recently found that linearity does not extend over several magnitudes (e.g. Dolnik 2003). Moreover the slope itself seems to be dependent on different ecological features and the assumption (Seidling 2005) seems not to be true that it is a constant in all types of woodland.

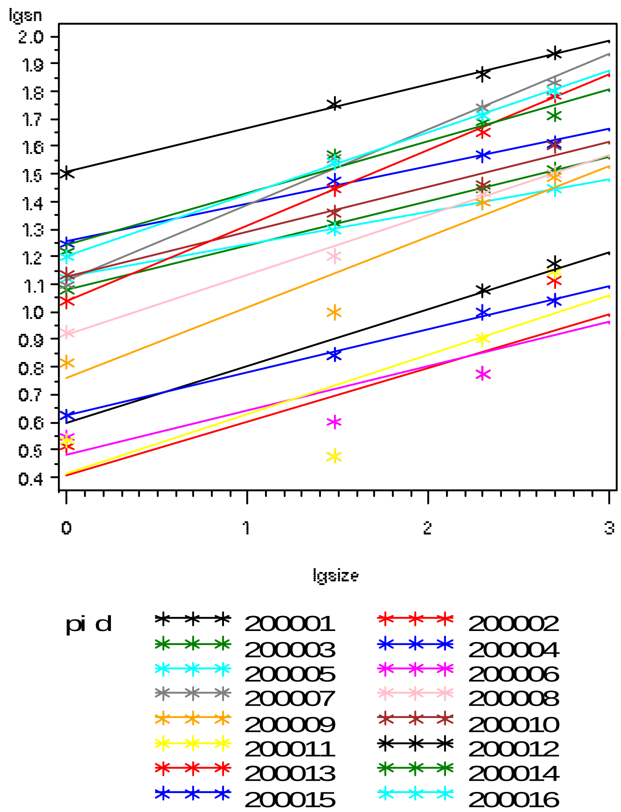


Fig. 11: Plot-wise regression lines of logarithms of species number (herb layer) over logarithms of area (only Swiss plots); pid: plot identification (combination country code and plot number).

The data set of the ground floor vegetation from the Swiss plots within the ForestBIOTA project easily allows for comparisons of areas ranging from 1 to 500 m^2 and for the calculation of respective z-values. Fig. 11 displays the SARs for the ground floor vegetation (herb layer) for 16 Level II / ForestBIOTA plots from

Switzerland. The respective z-values range from 0.12 (plot 5) to 0.27 (plot 13). All z-values are distinctively lower compared to respective values calculated for plots from German woodland (0.32 to 0.34 in Seidling 2001, 0.26 to 0.37 in Seidling 1990). There are a more z-values published, however, many lack consistency with regard to involved plant categories (e.g. with or without mosses or/and lichens), spatial scales, or different microstructures taken into account (e.g. with or without epiphytes). Data from the ForestBIOTA project together with those from the ICP Forest Level II monitoring programme give an excellent opportunity for further evaluations on this aspect of diversity itself and its causes.

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