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Bryophytes and lichens as indicators for changes of air pollution in the Serrahn Natural Forest Reserve (Mueritz National Park)

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Abstract: FRIEDEL, A. & MÜLLER, F. 2004. Bryophytes and lichens as indicators for changes of air pollution in the Serrahn Natural Forest Reserve (Mueritz National Park). – Herzogia **17**: 279–286.

The main objective of this study was to evaluate the influence of changed atmogenic depositions (sulphur and nitrogen compounds) on the bryophyte and lichen flora in a near-natural beech forest in northern Germany (Mueritz National Park).

The study is based on comparative analyses of the epiphytic bryophytes and lichens in a permanent plot in 1990 and 2003. In both years, the composition of 47 trunks 0–2 m above ground was inventoried and the cover and abundance of the epiphytes were investigated in 6 releves per trunk (in total 564 releves). The frequency differences of the epiphytic species as well as cover differences among the species in the releves between 1990 and 2003 were tested. The significant change in species composition seen between 1990 and 2003 is a likely result of the strongly reduced sulphur deposition during the last years. Acidophytic species clearly declined while moderately acid indicators and subneutrophytic species increased significantly. In addition an increase of nitrophytic species can be observed which seems to be brought due to remaining high levels of nitrogen inputs. The conservation and promotion of a habitat-specific and species-rich bryophyte and lichen flora is therefore only possible with reduced nitrogen pollution.

Zusammenfassung: FRIEDEL, A. & MÜLLER, F. 2004. Moose und Flechten als Bioindikatoren von Luftgüteänderungen im Naturwaldreservat Serrahn (Müritz-Nationalpark). – Herzogia **17**: 279–286.

Die vorliegende Studie untersucht den Einfluss sich verändernder atmogener Stoffeinträge (Schwefel- und Stickstoffverbindungen) auf die Moos- und Flechtenflora eines naturnahen Buchenwaldstandortes in Norddeutschland (Müritz-Nationalpark). Die Auswertungen basieren auf vergleichend erhobenen Analysen zur Epiphytenflora in einer Dauerbeobachtungsfläche aus den Jahren 1990 und 2003. Zu beiden Zeitpunkten wurde das Arteninventar an 47 Bäumen im Bereich von 0 bis 2 m Höhe und die Artmächtigkeit epiphytischer Moose und Flechten in 6 Vegetationsaufnahmen pro Baum (insgesamt in 564 Vegetationsaufnahmen) ermittelt. Es wurden die Frequenzunterschiede der Epiphyten sowie die Veränderungen der Artmächtigkeit der einzelnen Arten in den Aufnahmen zwischen 1990 und 2003 geprüft.

In der Untersuchungsfläche wird eine signifikante Veränderung der epiphytischen Moos- und Flechtenflora beobachtet, die wahrscheinlich auf die in den letzten Jahren stark reduzierten Schwefelimmissionen zurückzuführen ist. Während säuretolerante Arten deutlich zurückgingen, haben Mäßigsäurezeiger und subneutrophytische Arten deutlich zugenommen. Andererseits wird eine Ausbreitung nitrophytischer Arten beobachtet, vermutlich infolge andauernd hoher eutrophierender Stickstoffeinträge, vornehmlich Stickoxide aus dem Straßenverkehr und Ammoniak aus der Landwirtschaft. Die Erhaltung bzw. Förderung einer lebensraumspezifischen und artenreichen Moos- und Flechtenflora ist daher nur unter reduzierten Stickstoffeinträgen möglich.

Key words: Air quality, beech forest, bio-monitoring, epiphytes, nitrogen, Northern Germany, sulphur dioxide.

Introduction

Due to their sensitivity to air pollution, particularly to SO_2, NO_x, NH_3 and aerosol, bryophytes and lichens have been used for several decades as indicators of air quality (synopsis in MASUCH 1993, GRIES 1996, FRAHM 1998, BATES 2000, MULGREW & WILLIAMS 2000). A series of studies has pointed to the decline of subneutrophytic species as well as to an increase of acidophytic species up to the nineties of the last century (e.g. BARKMAN 1958, HAWKSWORTH & ROSE 1970, MUHLE 1977, FRAHM 1998, STAPPER 2000). However, probably as a consequence of drastically reduced acidic pollution, sensitive species have recolonised and spread of into formerly impoverished areas in the last decade (STAPPER et al. 2000, FRAHM 2001, STAPPER 2002, OTTE 2002). A few studies also observed an increase of nitrophytic species (e.g. FRAHM & SOLGA 1999, VAN HERK 1999, FRANZEN 2001b). The remaining high level of eutrophication due to atmospheric nitrogen deposition seems to affect sensitive bryophytes and lichens and needs further investigation (FRAHM & SOLGA 1999, DOLNIK & WIRTH 2003).

The bryophyte and lichen flora in near-natural, undisturbed forests is particularly suitable for long-term air monitoring. Because of having been protected since mid 1900 (section 2), the beech forest at Serrahn is one of the few places in the northern lowlands of Central Europe where long-term changes in species composition can be analysed.

In this study, differences between records of the bryophyte and lichen species composition in a permanent plot in the years 1990 (MÜLLER 1993) and 2003 are analysed and related to changes in atmospheric pollution (tab. 1). The results are discussed with special reference to the following questions:

1. Are there species or species groups which show changes in their frequency or cover?
2. Which stand parameters do they prefer?
3. Can a decline of acidophytic species and an increase of subneutrophytic species be observed which is related to a decrease of atmospheric sulphur depositions during the last decade?
4. What impact does the persistent high level of nitrogen deposition have on the species composition of bryophytes and lichens?

Methods

Study area

The field studies were carried out in the Serrahn Natural Forest Reserve (Mueritz National Park), situated circa 10 km south-east of Neustrelitz in the federal state of Mecklenburg-Vorpommern, Germany. The study area covers approximately 426 ha. The reserve is an ancient beech woodland which has been under protection since the mid 19th century as a game reserve, since 1950 as a nature reserve, and since 1990 as a national park (VON OHEIMB et al. 2003). The area has thus experienced mainly undisturbed natural dynamics for more than two centuries. The area was affected by the last (Weichsel) glacial period. Soil conditions are characterised by the deposition of sandy and loamy glacial deposits developed into Cambisols and Podzols. The climate is suboceanic-subcontinental, with a mean annual precipitation of 593 mm and a mean annual temperature of 7.8 °C (NATIONALPARKAMT MECKLENBURG-VORPOMMERN & NATIONALPARKAMT MÜRITZ 1995/96). The investigations were carried out in a permanent plot with an area of 80×100 m (forest community: *Galium-Fagus* forest), which was established in 1990.

Tab. 1 shows the loads of suphur and nitrogen compounds as well as dust recorded at the measuring stations closest to the study area, at Neubrandenburg, Neuglobsow and Löcknitz during the period 1992–2002. The data set clearly showed a decline in loads of sulphur and dust down to clean-air levels. During the same period the nitrogen inputs also declined, but to a lesser extent.

Tab. 1: Values of sulphur, nitrogen and dust pollution (measuring station Neubrandenburg, city, 20 km to the north of Serrahn and measuring station Neuglobsow, rural, woody area, 20 km to the south of Serrahn) as well as nitrate and ammonium (measuring station Löcknitz, rural, agrarian area, 65 km to the northeast of Serrahn) for the period 1992–2002 (German Federal Environmental Agency 1998, 2002, 2003, unpublished datas of the Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern), clean-air values from Hobohm (1998).

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	
	Measuring station Neubrandenburg (mean values in μm/m^3 based on 293 K)											**Clean-air value**
SO_2	-	18	12	10	11	7	6	5	4	3	-	5
Dust	-	47	43	29	27	27	24	23	23	21	-	20-40
NO_2	-	40	42	35	35	35	32	30	31	30	-	3-5
NO	-	40	38	36	36	31	28	26	28	24	-	0
	Measuring station Neuglobsow (mean values in μm/m^3 based on 293 K)											**Clean-air value**
SO_2	8	10	7	7	10	4	3	4	4	2,5	1,9	5
Dust	23	21	20	19	21	16	15	13	14	11	16	20-40
NO_2	9	8	7	8	8	-	10	9	9	8	10	3-5
NO	2	1	1	2	1,7	0,7	0,8	0,5	0,7	0,4	0,5	0
	Measuring station Löcknitz (mean values in kg/ha)											
NO_3	-	-	-	23,1	17,8	14,1	16,1	16	15,8	16,6	12,4	3-5
NH_4	-	-	-	10,1	9,3	8,3	8,7	10,1	8	9,7	6,4	0,1-3

Data collection

In 2003, we re-investigated all 50 *Fagus sylvatica*-trees that were surveyed in the 1990 study by one of us (Müller 1993), except for three trees that had died during the last 13 years. As in 1990, the epiphytic bryophytes and lichens were systematically sampled in 6 microplots of 20×20 cm^2 on each trunk. The recording was carried out in three height-classes on the trunk (0–0.5 m, 0.5–1 m and 1–1.5 m), and on north and south exposures. Cover-abundance-indices for each species were estimated according to Braun-Blanquet (Dierssen 1990). Furthermore, the epiphytic bryophytes and lichens were recorded from the trunk base to a height of 2 m. Species that could not be identified with certainty on location were brought to the laboratory for identification. Specimens are deposited in our private herbarium.

The nomenclature of lichens follows Scholz (2000), and that of bryophytes Koperski et al. (2000). Some species were combined or treated collectively due to difficulties of identification in the field: *Plagiothecium laetum* var. *laetum* and *P. denticulatum*, as well as all *Cladonia* species.

Data analysis

In order to determine and describe changes in frequency of bryophyte and lichen species during the observation period, the chi^2-test over presence/absence data of the complete trunk inventories was used. The Wilcoxon test was carried out to test and quantify changes of cover of the epiphytes (mean cover values per trunk) from 1990 and 2003. This non-parametric test is used to test whether the distribution of two paired variables in two related samples is the same. The test takes into account the magnitude of the differences between the two paired variables (Sachs 1999). The Wilcoxon test needs ordinally scaled data, and so the Braun-Blanquet-Index was transformed into an ordinal scale from 1 to 7 according to Jongman et al. (1987) (tab. 2). Species occurring with less than five records are excluded from the analysis.

Tab. 2: Transformation of Braun-Blanquet cover values according to JONGMAN et al. (1987).

Braun-Blanquet-Scale of cover values (DIERSSEN 1990)	r	+	1	2	3	4	5
Transformation according to JONGMAN et al. (1987)	1	2	3	4	5	6	7

Several parameters were used to characterise the habitat preferences of the bryophyte and lichen species: the Ellenberg indicator values (ELLENBERG et al. 2001) for light conditions (from 1 occurring in deep shade, to 9 occurring in full light), substrate reaction (from 1 occurring on an extremely acidic substrate, near or below pH 3, to 9 occurring exclusively in the neutral to basic range, around ph 7 and higher) and the tolerance to air pollution, mainly SO_2 and NO_2, according to FRAHM (1998), ELLENBERG et al. (2001) and FRANZEN (2001a) (1 very low, to 9 very high). We did not take the nutrient values into consideration because they are problematic for lichens (ELLENBERG et al. 2001) and do not exist for bryophytes. Differences between the medians of the Ellenberg indicator values were checked with the Kruskall-Wallis-test (SOKAL & ROHLF 1995). Data analysis was carried out using the statistical program SPSS for Windows version 11.5 (ANON. 2001).

Results

The epiphytic vegetation on the 47 trunks in 1990 included 36 taxa: 22 bryophyte species and 14 lichen species. In 2003, 22 bryophytes and 13 lichens were recorded.

Tabs 3 and 4 show significant differences in the frequency and cover of lichens and bryophytes on the 47 trunks between 1990 and 2003. According to changes in frequency and cover-abundance-indices, two species groups can be distinguished:

1. Species with a significant decrease in the frequency/cover-abundance-index, and
2. Species with a significant increase in the frequency/cover-abundance-index.

Tab. 3: Epiphytic bryophyte and lichen species with significant frequency changes in Serrahn (n = 47 trunks) between 1990-2003 and their indicator values for light conditions, substrate reaction (ELLENBERG et al. 2001) and tolerance to air pollution (toxitolerance) (ELLENBERG et al. 2001, FRAHM 1998, FRANZEN 2001a). Significance levels: *: p<0.05, **: p<0.01, ***: p<0,005. Significant differences (p<0,05) between the median of indicator values in bold.

	frequency		**Ellenberg indicator values**		
	1990	2003	light	reaction	toxitolerance
Significant decrease in frequency					
Cladonia spec. ***	46	30	-	-	-
Lecanora conizaeoides ***	46	0	7	2	9
Lophocolea heterophylla **	24	10	4	3	7
Scoliciosporum chlorococcum **	9	0	6	3	8
Dicranum scoparium *	42	32	5	4	8
			median 5.5	**median 3.0**	**median 8.0**
Significant increase in frequency					
Brachythecium rutabulum ***	3	37	5	x	8
Brachythecium salebrosum ***	1	15	6	6	-
Dimerella pineti ***	0	31	3	4	6
Pyrenula nitida ***	4	22	3	5	5
Arthonia spadicea **	0	8	2	4	5
Isothecium alopecuroides *	5	15	5	6	4
Metzgeria furcata *	3	9	5	6	3
			median 5.0	**median 5.5**	**median 5.0**

There are signficant differences in the median Ellenberg reaction and toxitolerance values between the two groups with changed frequency (tab. 3). All the species that have disappeared or have decreased indicate very acid to rather acid substrate conditions (median reaction value 3.0). The toxitolerance of these species varies from rather high to very high (median toxitolerance value 8.0). In this species group, the complete loss of the extremely toxitolerant crustose lichens *Lecanora conizaeoides* and *Scoliciosporum chlorococcum* is remarkable.

By contrast, the species that are increasing or are new occurrences are indicators for moderately acid to subneutral conditions (median reaction value 5.5). They show a rather low to moderate resistance to atmospheric pollution (median toxitolerance value 5.0). An exception is the proliferation of the ubiquitous and highly toxitolerant bryophyte *Brachythecium rutabulum.*

The median light values between the species groups do not differ significantly. The species occur under half-light to half-shade conditions.

Tab. 4 lists taxa with significant cover changes during the period of observation. Comparison of the cover-abundance-indices of the species on the trunks in 1990 and 2003 gives almost the same results as the comparison of frequency (tab. 3). The set of decreased species is identical and that of increased species is to more than 50 % overlapping.

Tab. 4: Epiphytic bryophyte and lichen species with significant changes in cover-abundance indices (according to Braun-Blanquet in DIERSSEN (1990)) in Serrahn (n = 282 relevés) between 1990 and 2003. Significance levels: *** = p <0,005, ** = p<0,01, * = p<0,05.

Species	**Cover 1990**							**Cover 2003**						
	r	**+**	**1**	**2**	**3**	**4**	**5**	**r**	**+**	**1**	**2**	**3**	**4**	**5**
Significant decrease														
Cladonia spec.***	15	18	18	15	5	1		5	14	5				
*Lecanora conizaeoides****		5	29	37	39	10	9							
*Dicranum scoparium**	5	14	9	7	3	2	1	5	14	11	2			
*Lophocolea heterophylla**	1	5	5	2				1	1					
*Scoliciosporum chlorococcum**			3	9	6	3								
Significant increase														
*Brachythecium rutabulum****				1	1			1	2	3	13	5	1	
*Dimerella pineti****									14	9	6			
*Hypnum cupressiforme****	3	5	14	20	20	14	8	4	8	11	29	41	28	6
*Metzgeria furcata**			1	3		1			5	5	2	1		
Plagiothecium laetum var. *laetum/denticulatum****		3							5	5	9	1		
*Pyrenula nitida****				2					6	5	4	3		

Discussion

The formation and dynamics of epiphytic communities in woodlands are significantly determined by the forest history, microclimate and substrate specificity (e.g. AUDE & POULSEN 2000, PETERSON & MCCUNE 2001, VANDERPOORTEN & ENGELS 2002). Furthermore, the hitherto under-investigated capacities of species for dispersal and colonisation also play an important role (GILBERT 1992). The pH-value of the bark is a key factor for the performance of epiphytic species (HAUCK 1998, HOBOHM 1998, KOPERSKI 1998, SCHUHMACHER 2000), and in recent decades it has been strongly influenced by high SO_2- and N-pollution (FRAHM & SOLGA 1999, STAPPER 2000).

The analysis of the epiphyte-mapping in 1990 and 2003 shows significant changes in species frequency and cover (Tables 3 and 4). Acidophytic species have clearly declined while subneutrophytic and nitrophytic species have increased significantly. The declining frequency of acidotolerant species correlates with the strongly reduced sulphur loads in recent years. In particular, the toxitolerant lichens *Lecanora conizaeoides* and *Scoliciosporum chlorococcum* occurred commonly in 1990, but have disappeared during the last decade. We interprete this as a sign of declining sulphur pollution. WIRTH (1995) states that the crustose lichen *Lecanora conizaeoides* flourishes under acid atmospheric pollution. This is in line with findings by DOLNIK & WIRTH (2003) in woodlands of Baden-Wuerttemberg or by STAPPER (2002) in woodlands of North Rhine-Westphalia.

The significant increase both in frequency and cover of the liverwort *Metzgeria furcata* as well as of the crustose lichen *Pyrenula nitida* may reflect an improvement in the substrate conditions for subneutrophytic species, i. e. an increase in the bark-pH-values. Both species are considered as indicators for moderately acid to subneutral substrate conditions and are low-moderate toxitolerant to air pollution. Measurements of the pH-value of their localities on *Fagus sylvatica* in Serrahn resulted in median values of 6.2 (*Pyrenula nitida*) and 5.5 (*Metzgeria furcata*) (VON OHEIMB et al. 2003). *Metzgeria furcata* spreads particularly with the aid of vegetative dispersal units (adventitious thalli) (FRAHM & FREY 1992). This effective dispersal mode enables this species to spread rapidly under favourable habitat conditions (NEBEL & PHILIPPI 2001). KOPERSKI (1998) also observed that *Metzgeria furcata* and other bryophytes with a high dispersal power had increased in Lower Saxony.

The bryophytes *Hypnum cupressiforme, Brachythecium rutabulum* and *Plagiothecium laetum var. laetum/denticulatum* have significantly increased too. These species fruit frequently and abundantly. In addition, they flourish under nitrogen pollution (NEBEL & PHILIPPI 2001). *Brachythecium rutabulum* is known as a nitrophytic species (FRAHM & SOLGA 1999) which grows on eutrophic woodland sites (DIERSSEN 2001). The expansion of nitrophytic species has been interpreted as a consequence of constantly high nitrogen inputs by FRAHM (1998) and DOLNIK & WIRTH (2003). Furthermore, experimental investigations have shown that growth of these and other expanding species were stimulated by nitrogen compounds (SOLGA 2003).

The increase of nitrophytic species suggests that the problem of air pollution due to sulphur inputs may have shifted to a problem of nitrogen fertilization (FRAHM 2001). Although high nitrogen loads promote nitrophytic species, an indirect deleterious effect can be observed on epiphytic bryophytes and lichens. Nitrogen-stimulated algal growth may affect or even prevent the development of sensitive lichens (SCHÖLLER 1997). ARUP et al. (1996) observed in Swedish forest stands a decrease in the vitality of the lichen *Pyrenula nitida* due to increased algal cover. Moreover, high nitrogen inputs lead to a widening growth of the trees and consequently to a disruption of slow-growing lichen thalli (ERNST & HANSTEIN 2001).

The conservation and encouragement of a habitat-specific and species-rich bryophyte and lichen flora is therefore only possible with reduced nitrogen pollution. There is a direct link between this and the problems with eutrophication which are now being intensively discussed by conservationists (e.g. CARROLL et al. 2000, BERGAMINI & PAULI 2001, LANDESAMT FÜR ÖKOLOGIE 2003).

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