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A COMPARISON OF BIOMONITORING METHODS FOR THE ESTIMATION OF ATMOSPHERIC POLLUTANTS IN AN INDUSTRIAL TOWN IN AUSTRIA

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Abstract. In the period between 1999 and 2000 epiphytic bryophytes were taken as bioindicators for air pollution by use of the IAP method (Index of Atmospheric Purity) and the VDI method within the Association of Engineers standards list (adapted from guideline 3799, 1995) in the heavy industrialized town of Linz, Austria. 52 study sites (265 trees) were analysed regarding species richness, coverage, and vitality. Q-values (sensitivity factors), calculated for each species showed significant differences for the various host tree species. The results gained by the IAP and the VDI methods were diverse, regarding the various sites where only 25% were classified identical. These differences can mainly be attributed to the differing host tree species and the size of the recording area on the various trees. Clusters of similar pollution levels were calculated and drawn as maps for both methods tested. Comparing the results of the IAP and the VDI methods with data derived from technical measurements (SO_2, NO, NO_2, and dust) a correlation between IAP-indices and SO_2 concentrations could be observed. No correlation was detected between the results derived from VDI recording and for NO, NO_2, and dust.

Keywords: atmospheric pollution, bioindication, bryophytes, Index of Atmospheric Purity (IAP), urban area, VDI-guideline

1. Introduction

The estimation of atmospheric pollutants and its effects on human beings, animals and plants has been a major task in environmental sciences for at least two centuries. Bioindication and biomonitoring are perfect tools to obtain these aims (e.g. Manning and Feder, 1980; Markert *et al.*, 2003).

According their morphological and physiological characteristics cryptogams like lichens and bryophytes have proofed to be excellent indicators for a wide range of contaminants. Lacking a root system and a persisting cuticle, water, nutrients and toxic substances are mainly absorbed via the entire plant surface from air and precipitation and to a minor extent from the substratum via capillary effects (e.g. Wolterbeek *et al.*, 2003; Brown, 1984; Brown and Bates, 1990; Ötvös *et al.*, 2003). Bryophytes show a strong resistance against various toxic compounds (e.g. heavy metals, ozone), but are sensitive for others, such as sulfurous or nitrogenous compounds. They display various modes of reproduction and long distance dispersal (Longton, 1997), which is a main feature for quick re-colonisation of habitats.

Bryophytes were used to quantify depositions deriving from the accumulation of single groups of substances or chemicals like sulfur (for reviews see Frahm, 1998; Zechmeister *et al.*, 2003), nitrogen (e.g. Pitcairn and Fowler, 1995; Solga *et al.*, 2005), polycyclic aromatic hydrocarbons (Viskari *et al.*, 1997; Holoubek *et al.*, 2000; Gerdol *et al.*, 2002), or heavy metals (for recent reviews see Onianwa, 2001; Zechmeister *et al.*, 2003). Single pollutants mostly show different patterns of reaction than mixtures of these pollutants, which is the usual case in the atmospheric environment. Bryophytes mainly respond to air pollution by changes in their distribution and abundance (e.g. LeBlanc and DeSloover, 1970), with changes in biomass (e.g. Bengtson *et al.*, 1982), health (e.g. Nash and Nash, 1974; Rao, 1982; Greven, 1992; Otnyukova, 1995), and structure of communities. Compared to lichens, the application of bryophytes for bioindication has the advantage that a correlation between deposition and time can be made.

Within the last two decades a remarkable change in the atmospheric chemistry could be observed. Whereas some pollutants like CO_2, PAHs, NH_4, and NO_3 have been increasing, others decreased (e.g. heavy metals), some even remarkable (e.g. SO_2). Simultaneously a change in bryophyte growth and colonisation could be observed (e.g. Jónsdóttir *et al.*, 1995; Stapper *et al.*, 2000).

Assessing air quality, a series of methods using cryptogames as bioindicators have been involved to estimate the overall air pollution. Adequate methods have been developed by LeBlanc and De Sloover (1970), who introduced a standardised method which estimates the 'Index of Atmospheric Purity' (IAP). This method is based on the quantitative and qualitative distribution of epiphytes in the investigated area. Another quantitative method was developed within the Association of Engineers Standards in Germany (VDI, 1995, guideline 3799) which is based on the calculation of frequency of species within a sampling grid. Each of these methods was applied in a large range of investigations (e.g. Sergio, 1987; Inui and Yamaguchi, 1996; Dilg, 1998; Franzen, 2001; Conti and Cechetti, 2001; Gombert *et al.*, 2004). When comparing the results obtained from these methods difficulties arise, as a direct relation of results is missing.

Consequently, the underlying questions of this study are : (1) can results obtained by the IAP-method and the VDI-method be compared and (2) which main environmental pollutants are detected by these methods? The inquiry of these issues was based on the investigation of air quality in Linz, Austria, a heavy industrialized town.

2. Materials and Methods

2.1. Study area

The city of Linz is situated at the Danube river in the northern part of Austria. The population ranges to 200,000. The climate is characterised by an average annual rainfall of 844 mm and an average annual temperature of 8, 9 °C . The elevation varies from 250 m a.s.l. to 600 m a.s.l. Linz is a heavy industrialised town harbouring one of Europe's largest steel plants and chemical industries.

2.2. Sampling design

Site selection was based on a stratified random sampling design covering the total area of the town. For stratification, information on the distribution of host trees was added. Site selection was also restrained by the availability of host tree species in a pre-selected grid. From a total of 350 grids (size: 500 × 500 m) sites in 52 grids were investigated. The selection of host trees was based on terms and conditions of the "Index of Atmospheric Purity (IAP)" and the "VDI" methodology. The following tree species were investigated: ash (*Fraxinus excelsior*), basswood (*Tilia cordata*), maple (*Acer negundo, A. platanoides, A. pseudoplantanus*), oak tree (*Quercus robur*), pear (*Pyrus communis*), walnut tree (*Juglans regia*) and poplar (*Populus nigra*). Only trees growing in courtyards, fields, on roadsides or small groups were studied, assuring that there was no total shading by each other. The stems of the investigated trees had to be erect. The position of the selected trees was not larger than 100 m from one to each other. The determining factor for tree selection within a single site was the availability of a tree meeting the conditions described above but not necessarily bryophyte covering. The number of trees investigated was 265.

Samples were taken between October 1999 and April 2000. Nomenclature followed Grims (1999a) for mosses, and Grolle and Long (2000) for liverworts.

2.3. Index of atmospheric purity (IAP)

At each sampling site five host trees were investigated. Comparable light, wind and humidity conditions were relevant for selecting the host trees. No restriction to a certain tree species was made. Nevertheless, at each grid only one tree species was chosen. In contrast to investigations of LeBlanc and De Sloover (1970) which included both bryophytes and lichens, only bryophytes were studied in Linz. Epiphytic species on an area of approximatly 5000 cm^2 were sampled up to a height of two meters. Bryophytes growing on the base of trees were not considered (up to approximatly 80 cm). A wide range of adaptations to the initial method of LeBlanc and De Sloover (1970) exist (e.g. Gombert *et al.*, 2004). In this study we applied the alignment as described below.

2.3.1. *Q-value*

The Q-value is calculated by a defined method taking the number of co-occurring species at each site into account (LeBlanc and De Sloover, 1970). It represents the overall resistance or sensibility of a bryophyte species against pollutants. Q-values are an indispensable part of the IAP value, but were also calculated in the present study for species sampled by the VDI-method.

Calculation of the IAP-value:

$$\mathrm{IAP} = \sum_{i=1}^{n} (Qixfi)$$

Where n =number of species at each sampling plot, Qi = ecological index of each species recorded, f = the coverage value at each sampling plot given in a defined scale.

The IAP-index was calculated separately for each sampling site. The categories for the "f" value for single species were different. For the present study we used three scales:

- 1 rare species and/or species with a low abundance
- 2 ± abundant species and/or species with a moderate abundance
- 3 common species and/or species with a high abundance

For the total of all IAP-indices, statistical analyses was performed which included the calculation of percentile classes. Based on this, the IAP-indices were classified into four Air Quality Classes. Quality Class one represented heavy polluted sites.

2.4. VDI-METHOD

Although developed for lichens, the VDI method (VDI 1995, guideline 3799) was also applied for bryophytes by several authors (e.g. Dilg, 1998; Franzen, 2001). Within each sampling site, five trees with comparable bark properties (e.g. pH-value, water storing capacity, nutrient contents), age, diameter of the stem, and shape/dimension of the crown were selected (see also VDI-guidelines). A grid net (size: 20 × 50 cm, divided into 10 subplots of 10 × 10 cm) was placed at eye level on the most luxuriantly overgrown side of the stem. The grid was kept in place by means of four nails. Frequency for each bryopyhte species was counted. Frequency was defined as the number of subplots in which the species was present (max. frequency = 10). Beside frequency, average vitality, and coverage of each species was recorded.

2.4.1. *Calculation of the Air Quality Values (LGW)*

For each species recorded at one site the mean frequency (including standard deviation and confidence interval) was calculated. The average of the total sum of the frequencies was the Air Quality Value (LGW) within one grid square.

The following formula was used to calculate the Air Quality Value (LGW):

$$\mathrm{LGW}_j = \frac{\sum Fij}{nj}$$

i = number of the individual tree in the examined grid square j; j = number of examined unit; Fij = sum of the frequencies of occurrence on the tree i in the examined unit; nj = number of surveyed trees within the investigated unit j.

The calculation was performed for each host tree species separately as well as for comparable groups of trees. The Air Quality Values (LGW) derived from the sampling sites were assigned to Air Quality Classes (LGK) which were calculated as following for the whole investigation area:

$$\mathrm{LGK} = t_p * S_p/\sqrt{np}$$

where t_p = critical value of the Student's t-distribution, for n degrees of freedom, S_p =mean standard deviation of all sampling sites, and np =mean value of trees sampled per sampling site. A small standard deviation enables a more differentiated distinction between various degrees of pollution.

To compare the VDI-values with the IAP-values, the Air Quality Values (LGW) were additionally divided into four categories. The classification ranged, as for the IAP-values, along the main-percentile limits.

2.5. Data on atmospheric pollutants

For eleven sites, data on SO_2, NO, NO_2, and dust obtained by technical measurement were available. The distance between these measurement devices and the biomonitoring sites was not more than 200 m. Monthly measurement data covered the period from 1995 to 2000. The annual sum as well as the 3, 4 and 5 year averages of SO_2, NO, NO_2 and dust at each station were compared to the IAP and VDI classes of the corresponding sites. Measurement data were provided by the municipality of Linz.

2.6. Statistical analysis

Mean values, median, standard deviation, variance and percentile were calculated. A t-test was performed to compare the mean values, a Mann–Whitney test for testing the median, a F-test to compare the standard deviations and a Kolmogorov–Smirnov-test for data distribution.

ANOVA and multiple range test were calculated to compare Q-values of various sources. A Spearman Rank Test was performed to calculate the correlation of ordinal data (e.g. IAP classes) and a Pearson's correlation coefficient for metric data. Wilcoxon Ranked Sum Test, a nonparametric test was applied for the comparison of the transformed Air Quality Classes with the IAP classes. Data analyses utilised

SPSS. Significance level for all statistical analyses was $P \leq 0.05$, if not stated explicitly.

3. Results

In total, 50 bryophyte species were recorded (45 mosses and 5 liverworts) by the IAP method and 38 by the VDI method (34 mosses and 4 liverworts). The number of species for single trees ranged from zero to 17 for the IAP method and from one to 13 for the VDI method. 35 (IAP method) and respectively 45 (VDI method) host trees investigated, did not show bryophyte cover. Most bryophytes were common species, although four species could be classified as rare or endangered (Grims, 1999b).

3.1. Q-values of bryophyte species and air quality classes

In Table I an overview of the Q-values for the most common bryophyte species ($n \geq 10$) is given. Species showing a low-Q-value implicate a higher resistance than those with a high Q-value.

Comparing the mean Q-values of all trees derived from the IAP as well as the VDI method statistically significant differences could be detected (t-statistic, -15.33; $P < 0.000$).

Furthermore, we compared Q-values of bryophytes growing on various host tree species, which were represented in a sufficient number of sites (*Fraxinus excelsior*, *Acer pseudoplatanus* and *Acer platanoides*). Q-values of bryophytes growing on *F. excelsior* showed significant differences compared to those of bryophytes on *Acer* species (t-statistic, -3.22; $P < 0.004$). t-Test, sign-test and Kolmogorov–Smirnov test did not show a difference when comparing the results of *F. excelsior* with those gained from all other host trees. No significant difference of Q-values was detected between *A. pseudoplatanus* and *A. platanoides* (Table I).

Regarding the mean Q-values of IAP and VDI in this study, *Platygyrium repens, Hypnum cupressiforme, Orthotrichum diaphanum, O. pumilum*, and *Leucodon sciuroides* can be classified as relatively resistant against air pollution, although in heavy polluted areas (e.g. steel plant area) even these species disappear. In Table I a comparison is presented between the Q-values derived from the present study and the toxi-tolerance-values indicated by Frahm (1998) and Sauer (2000).

There was a significant difference in species richness for the number of species found by both methods on the same sites (t-statistic -7.67; $P < 0.000$). No significant difference of bryophyte species richness was detected for *Acer pseudoplatanus* and *A. platanoides* (Table II). Regarding this and the previously given results both species were therefore clustered in one *Acer* sp. group. In consequence the following calculations were divided into two substrate classes: *Fraxinus excelsior* and all the other species beside *Acer* sp., representing group two.

TABLE I

Bryophyte species richness, Q-values derived from the results of the present study and toxitolerance of bryophytes obtained by literature

Species	*n*	VDI Q-value	IAP Q-value	Mean of IAP and VDI Q-value	Q-value *Fraxinus excelsior*	Q-value *Acer* sp.	Sauer	Frahm
Platygyrium repens (Brid.) B., S. & G.	47	1.74	3.65	2.70	3.70	6.33	1	6
Orthotrichum diaphanum Brid.	100	2.80	3.97	3.38	5.17	3.73	2	8
Leucodon sciuroides (Hedw.) Schwaegr.	10	2.88	3.90	3.39	2.00	4.00	4	3
Orthotrichum pumilum SW.	74	3.13	4.37	3.75	4.42	4.55	3	2
Hypnum cupressiforme Hedw.	69	3.04	4.57	3.81	4.31	6.33	1	8
Ulota crispa (Hedw.) Brid.	20	3.13	4.52	3.83	4.63	5.50	4	4
Pylaisia polyantha (Hedw.) Kindb.	104	3.16	4.50	3.83	4.42	5.36	3	5
Orthotrichum affine Brid.	111	3.17	4.55	3.86	4.50	5.52	3	6
Tortula papillosa Wils.	42	3.58	4.96	4.27	4.60	4.20	2	3
Dicranoweisia cirrata (Hedw.) Lindb. ex Milde	12	3.40	5.50	4.45	*	5.44	0	7
Radula complanata (L.) Dumort	21	3.67	5.41	4.54	5.37	5.67	3	2
Orthotrichum stramineum Hornsch. ex Brid.	12	3.75	5.58	4.67	5.25	6.33	5	2
Leskea polycarpa Hedw.	38	4.07	5.29	4.68	4.52	7.00	4	-
Tortula ruralis (Hedw.) Gaertn., Meyer & Scherb.	26	4.37	5.75	5.06	8.00	5.68	2	-
Orthotrichum speciosum Nees ex Sturm	26	4.36	5.79	5.08	5.00	7.00	5	3
Orthotrichum lyellii Hook. & Tayl.	11	4.11	6.15	5.13	5.40	9.00	5	3
Amblystegium serpens (Hedw.) B., S. & G.	14	5.10	5.41	5.26	4.70	8.70	1	7
Orthotrichum obtusifolium Brid.	30	4.48	6.06	5.27	5.71	7.33	4	4
Bryum subelegans Kindb.	15	4.88	6.25	5.56	6.33	6.25	2	7
Tortula virescens (De Not.) De Not.	13	5.22	6.00	5.61	4.00	6.38	3	-
Orthotrichum pallens Bruch ex Brid.	19	4.00	6.00	5.00	5.93	6.00	-	-

n = number of investigated populations (only $n \geq 10$ were considered in the table); low Q-value = resistent against air pollution; high Q-value = sensitive to air pollution; **Dicranoweisia cirrata* was not found on *Fraxinus excelsior*. VDI Q-value = Q values calculated for sampling according the VDI method; IAP Q-value = Q values calculated for sampling according the IAP method; Sauer = toxitolerant values defined by Sauer (2000) ranging from 1 (resistent species) to 6 (very sensitive species); Frahm = toxitolerant values defined by Frahm (1998) ranging from 1 (not toxitolerant) to 9 (toxitolerant).

TABLE II

Number of bryophytes at the different sites detected by the IAP and the VDI method and values corresponding to the air quality obtained by both methods

Quad	IAP *n*	VDI *n*	IAP-value	IAP-class	LGW	LGK	VDI class	IAP-host trees species	Quad	IAP	VDI	IAP-value	IAP-class	LGW	LGK	VDI class	IAP-host trees species
C29	10	9	88	3	15.2	2	3	*Quercus robur*	L19	9	4	78	2	5	1	1	*Populus nigra*
D23	9	6	83	2	16.6	2	2	*Fraxinus excelsior*	L27	6	6	63	2	9	1	1	*Acer platanoides*
D26	15	10	157	4	27.4	3	4	*Acer platanoides*	L29	8	8	89	2	21.4	3	3	*Fraxinus excelsior*
D31	14	9	136	4	17	2	2	*Fraxinus excelsior*	L32	10	8	114	3	21.8	3	3	*Fraxinus excelsior*
E21	12	9	131	3	15.2	2	2	*Acer platanoides*	L35	12	10	139	4	8.4	1	1	*Fraxinus excelsior*
E28	8	8	82	2	21	3	4	*Tilia cordata*	M05	11	7	108	4	15	2	2	*Fraxinus excelsior*
F23	12	9	138	3	18	2	3	*Acer platanoides*	M30	9	8	86	2	11.6	2	3	*Juglans regia*
F34	7	7	59	2	7.2	1	2	*Juglans regia*	N12	8	4	74	1	3.8	1	1	*Fraxinus excelsior*
F37	17	6	173	4	10.6	2	2	*Acer pseudoplatanus*	N14	11	7	111	3	8.2	1	1	*Fraxinus excelsior*
G12	4	4	34	1	9.4	1	3	*Tilia cordata*	N17	4	0	24	1	7	1	1	*Acer negundo*
G13	13	13	145	4	19.4	2	4	*Acer negundo*	O08	12	5	117	3	6.8	1	1	*Fraxinus excelsior*
G27	11	9	120	3	5.96	1	1	*Salix sp.*	O20	6	6	53	1	5	1	1	*Populus nigra*
G28	10	8	112	3	18.4	2	3	*Acer platanoides*	O30	9	6	80	2	13	2	2	*Fraxinus excelsior*
G31	12	9	133	3	25	3	4	*Acer pseudoplatanus*	P15	9	6	27	1	11.4	2		*Fraxinus excelsior*
G33	6	4	60	1	10.6	2	2	*Fraxinus excelsior*	P34	2	2	81	2	1.2	1	2	*Fraxinus excelsior*
H09	11	7	103	3	-	-	3	*Fraxinus excelsior*	P9	3	1	15	1	-	-	1	*Juglans regia*
H17	5	4	52	2	5.4	1	1	*Acer pseudoplatanus*	PFA	8	8	72	1	0	1	1	*Fraxinus excelsior*
H23	1	1	10	1	4.4	1	1	*Acer pseudoplatanus*	PFB	0	0	0	1	0	1	1	*Fraxinus excelsior*
H37	12	12	117	4	18.2	2	2	*Fraxinus excelsior*	PFC	0	0	0	1	0	1	1	*Quercus robur*
I17	13	10	142	2	19	2	3	*Acer pseudoplatanus*	Q10	6	4	51	1	3.2	1	1	*Fraxinus excelsior*
I25	14	10	152	3	28.8	3	4	*Tilia cordata*	Q12	6	2	50	1	5	1	1	*Fraxinus excelsior*
I26	8	5	73	2	8.6	1	2	*Tilia cordata*	R17	13	6	129	4	3	1	1	*Fraxinus excelsior*
I35	5	4	51	2	-	-	-	*Juglans regia*	U10	11	7	127	3	12.6	2	2	*Fraxinus excelsior*
I36	8	8	85	2	15.4	2	2	*Fraxinus excelsior*	U15	10	6	92	2	-	-	-	*Pyrus communis*
K11	15	8	157	4	12.4	2	2	*Fraxinus excelsior*	U16	13	10	141	4	30.4	3	3	*Fraxinus excelsior*
K24	4	4	42	1	10.8	2	2	*Acer pseudoplatanus*	X13	8	5	77	2	4.6	1	1	*Fraxinus excelsior*

Quad = quadrant of the basic grid; IAP n = number of species recorded by the "Index of Atmospheric Purity" method; IAP class = classes derived from the percentiles of the IAP values; VDI n = number of species recorded by the VDI method; LGW = Air Quality Value of the particular sampling site; LGK = Air Quality Class of the particular sampling site; VDI class = classes derived from the percentiles of the LGW values.

Q-values gained from literature and those calculated in this study sources differed significantly from each other (ANOVA, F-ratio 12.98; $P < 0.000$). Multiple range test for Q-values showed significant differences between all sources (Sauer, 2000; Frahm, 1998; and this study).

Table II shows the calculated Air Quality Classes derived from the IAP values, the Air Quality Values (LGW), the Air Quality Classes (LGK) and the Air Quality Classes derived from LGW for the comparison with IAP classes for the 52 investigated sites. Air Quality Classes (class width) are 9.69 for *Fraxinus excelsior* and 9.08 for *Acer* sp.. Percentil classes for the IAP classes derived from *F. excelsior* were: 25% 5; 50% 11.5; 75% 16.6; 99% 30.4, and for *Acer* sp. 25% 9.8; 50% 16.6; 75% 19.2; 99% 27.4. Percentil classes for the VDI method derived from LGW classes from *F. excelsior* were: 25% 32; 50% 39; 75% 62.3; 99% 84, and for *Acer* sp. 25% 18.2; 50% 25.8; 75% 47.0; 99% 69.4. According to VDI calculations three Air Quality Classes could be detected for each substrate category. The spatial distribution of these classes can be seen in Figure 1. Table I and Figure 2 give an overview on the distribution of the IAP-classes. Taking the topographical conditions into account an iso-gram was produced by interpolating the IAP-classes in Figure 3. A comparison between the transformed Air Quality Values in a four scaled system with the IAP-values, showed for the total area no significant differences ($Z = 0.8111$; $P = 0.417$). Nevertheless, this is hampered by the fact that only 13 of 52 sites (25%) showed the same classification. For seven sites the difference was even two or more classes.

3.2. Comparing biomonitoring and technical measurement data

In the investigated area, the distribution of the atmospheric pollutants is rather disperse. Concerning the pollutants measured, only half of the results of the technical measurement stations correlated significantly with each other. In Table III mean values of measurement data of SO_2, NO_2 and NO in comparison to VDI and IAP class values are given.

A significant correlation between IAP-classes and SO_2 for the years 1995 (0.773; $P = 0.009$), 1996 (0.633; $P = 0.005$), 1997 (0.825; $P = 0.003$) and for the sum of 1995–1999 (0.767; $P = 0.006$) could be detected. There was no significant correlation between SO_2 measurements compared to the VDI classes. NO, NO_2 and dust did not correlate with both, the IAP and the VDI classes.

4. Discussion

This study presents a first direct comparison between the IAP method and the adapted VDI methodology by using bryophytes. The results obtained varied markedly in several cases (Q-values of epiphytic species; classes of various pollution). The underlying causes can be attributed to the selection of different tree

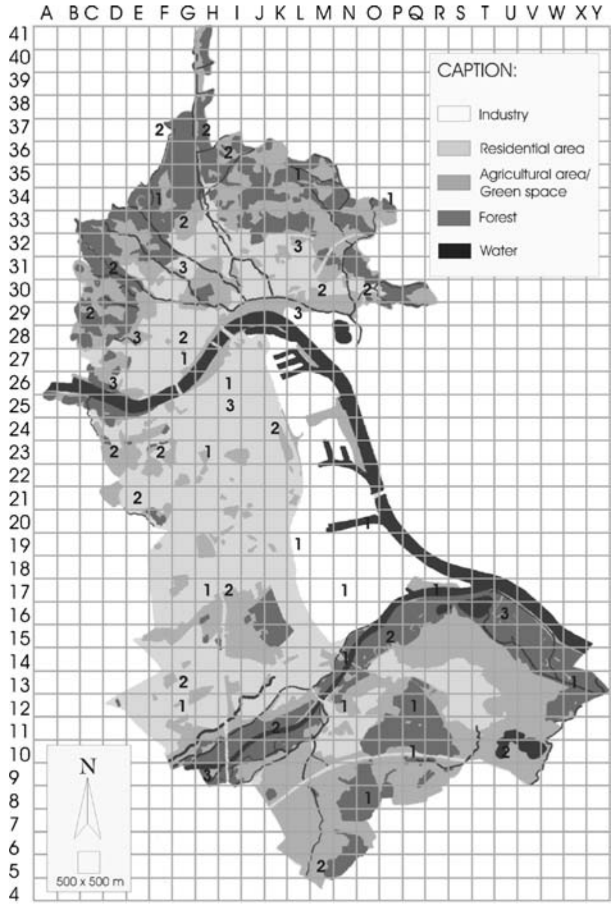

Figure 1. Air Quality Classes (LGK) of the investigated sites based on the VDI-method: '1', indicates heavy polluted area, '3', indicates low pollution.

species and the monitoring area per tree. Selecting different tree species, even within a very restricted area with comparable microclimatic conditions, had a major influence on the results, which is not surprising (e.g. Billings and Drew, 1938; Hohbohm, 1998). However, compared to previous studies (e.g. Dilg, 1998; VDI-Richtlinie, 1995) it can be concluded that the restriction to a single tree species or a group of two or three species should be the basis of comparable investigations. In contrast to the results obtained from literature (e.g. Dilg, 1998; VDI-Richtlinie, 1995) no significant difference between bryophyte species richness for *Acer pseudoplatanus* and *A. platanoides* was detected. Different species diversity for the IAP and the VDI method was based on a differing sampling size.

Large differences in the Q-values or comparable sensibility ratings were obtained compared to other authors (e.g. Frahm, 1998; Sauer, 2000; see Table I). A differing susceptibility to atmospheric pollutants is beside morphological and

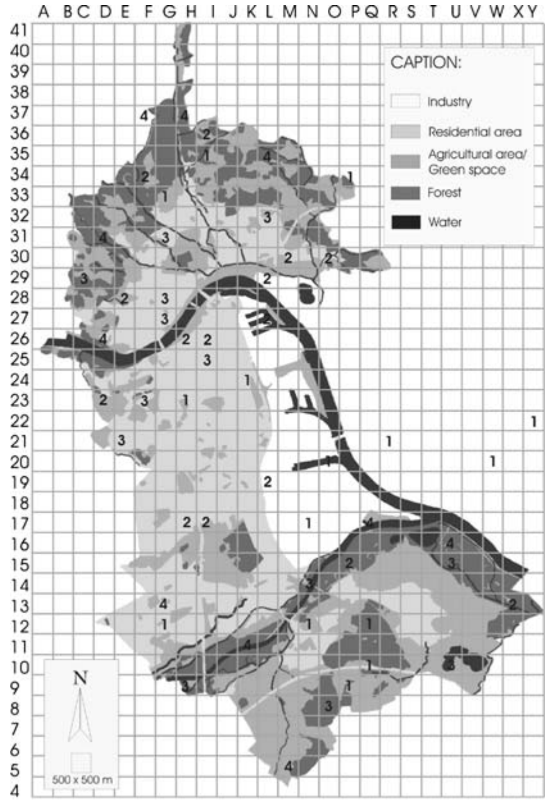

Figure 2. The air quality of Linz based on the IAP-values obtained from the investigated sites; Air Quality Classes: '1', heavy polluted area; to '4', area with low pollution.

physiological properties also a matter of the overall climate of an area and the geographic distribution of the bryophytes. Therefore, it is advised to do calculations regarding sensibility of species for each investigation separately. A sensitivity value obtained from one region should not be transferred to another or, at least be taken with caution. In addition, a restriction to selected species for overall monitoring programmes, as suggested in the upcoming VDI guidelines, must be seen critically.

Maps based on the results of the two tested biomonitoring methods show strong influences of the pollutant sources, as well as from the climatic conditions in the investigated area. Apart from industrial plants, motorways and roads, inversion weather situations add to the impact of air pollutants. Locations in the closer vicinity of emission sources are sometimes mirrored by lower values than those more far away. In the present study this was caused by topographic features, the predominant wind direction but also by contrasting wind flows between day and night (e.g. Mursch-Radlgruber *et al.*, 1999). The influence of local climate on sites situated along rivers should also be taken into account.

Figure 3. Isoline map of comparable air pollution areas taking the topographical conditions of Linz into account. The map derived from the interpolation of the IAP-classes: '1', heavy polluted area to '4', area with low pollution.

A comparison of results obtained by biomonitoring with those of technical measurements revealed poor correlations. This corresponds with results obtained by Gombert *et al.* (2004) for IAP values gained by lichen studies in France. In the present study, the only direct correlation between the two biomonitoring methods and atmospheric pollutants could be detected for IAP classes and SO_2. Low SO_2 concentrations of the years 1998 and 1999 which caused no acute damage of the bryophytes can be the reason why data from the years 1995–1997, but not from 1998 and 1999 correlated with the bryological data. SO_2-values of 1998 and 1999 followed were lower than those of the years before. A possible influence of current

TABLE III

Comparison of IAP and VDI classes with data of atmospheric pollutants obtained by technical measurements at the same sites; concentrations in mg/m^3. Measurement data cover the period from 1995 to 2000; location = location of the technical measurement equipment and the corresponding biomonitoring site (numbering according Figures 1 and 2).

Location	IAP	VDI	SO_2	NO	NO_2
K24	1	2	10.0	16.4	24.0
G28	3	2	6.3	24.6	29.4
H9	3	3	6.7	15.4	22.8
X13	2	3	5.2	16.2	22.0
N14	3	1	4.7	14.6	21.8
H23	1	1	8.7	20.0	30.5
H23	1	1	8.5	19.2	31.2
G28	3	2	5.2	32.0	31.4
I17	2	2	7.3	23.0	31.4
R21	1	1	6.7	7.2	19.2
D23	2	2	6.7	77.0	66.0

pollutants on the sensitive protonema would entail a temporal delay and thus, possible changes could only be observed in future investigations.

The results of this study confirmed that SO_2 had a detrimental influence on the distribution of bryophytes up to 1997. No data on NO_3 or NH_4 deposition were available for each station. These N-species have been emerged as important recent negative factors for bryophyte distribution (e.g. Pitcairn *et al.*, 1998; Turetsky, 2003). When comparing the IAP and the VDI method with the measured values of SO_2 concentrations it can be concluded that the IAP method should be preferred compared to the VDI method.

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