CORRELATION BETWEEN ENVIRONMENTAL CONDITIONS AND THE DISTRIBUTION OF MOSSES EXPOSED TO URBAN AIR POLLUTANTS

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Abstract. Moss surveys have several advantages over conventional deposition monitoring based on precipitation, and allow the study of regional differences and temporal trends of airborne pollution. The purposes of this study were to: (i) describe the moss species growing in one of the largest industrial cities in Asia, (ii) document edaphic and atmospheric conditions at each site, (iii) collect materials and data for a program of regular moss monitoring, previously lacking in the Far East, (iv) uncover correlations among atmospheric and edaphic factors expected to influence moss growth. As a result, a total of fifteen moss species were recorded in twenty-five sites in Seoul, Korea, and most sites had four or five species. Each species' density was affected by soil parameters, but density of *Pogonatum nessii* and *Taxiphyllum taxirameum* was also affected by CO. In contrast, SO_2 was the only environmental variable that significantly affected the composition of moss communities. On the whole, species diversity rather than abundance of specific moss species might be a good indicator of atmospheric contamination in Seoul. This investigation will help fill the gap in knowledge of the interactions between environmental pollution and moss vegetation under field conditions.

Keywords: edaphic/atmospheric conditions, monitoring, moss, pollution

1. Introduction

Knowledge of the distribution of lichen species has been demonstrated to provide a useful bioindicator for environmental contamination. Under polluted condition, investigators have described decreases in thallus size and fertility, bleaching and convolution of the thallus, restriction of lichen occurrence to the base of vegetation, and mortality of sensitive species (Kauppi, 1983; Sigal and Nash, 1983). Due to excessive sensitivity to the pollutants, however, they were not suitable for urban environment.

Although the degree of sensitivity falls short of lichens, mosses could be used in more severe conditions. The Swedish scientists Rühling and Tyler (1970) pioneered the use of extensive regional surveys of mosses. Since their work, similar attempts have been tried in various parts of the world. These include studies in the North Eastern U.S.A. (Groet, 1976), New Zealand (Ward *et al.*, 1977), maritime provinces of Canada (Percy, 1983), and Nigeria (Onianwa *et al.*, 1986). In northern

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European countries, these surveys have been performed regularly (e.g. Rühling *et al*., 1987; Steinnes *et al*., 1992).

Moss surveys can uncover regional differences and temporal trends of airborne pollution. In addition these surveys have several advantages over conventional deposition monitoring based on precipitation monitoring. The sampling is simple, which allows a large number of sites to be included in the survey, and chemical analyses are much easier due to higher concentrations and strongly reduced contamination problems.

The abundance of mosses, and the diversity of moss communities are affected by both atmospheric and edaphic factors, even though mosses have a minimal internal transport system. Bottom turf layers likely act as a source of moisture at the beginning of dry events (Callaghan *et al*., 1978), and soluble compounds from the soil can be transported into the moss tissue during periods with extensive soil/water contact, such as rainy season and snowmelt (Ford *et al*., 1995). If this is true, it is likely that this upwardly moving water will contain chemicals derived from dissolved minerals. When *Rhytidiadelphus squarrosus* and *Hylocomium splendens* are grown under laboratory conditions with water and metals supplied only to the lower parts, pre-existing and added elements can be recovered from the extracellular and intracellular sites present in the new apically grown tissues (Brown and Brown, 1990; Brown and Sidhu, 1992; Sidhu, 1992). In fact, the total concentrations of pollutants in mosses cannot always be attributed to wet deposition, due to an unknown amount of input from other sources such as wind-blown soil dust and canopy leaching of soil-derived ions (Ross, 1990; Steinnes *et al*., 1992). Consequently, in studies of the relationship between moss community structure and pollutants, it is necessary to consider atmospheric and terrestrial variables.

The current investigation was conducted in Seoul, the Capital of South Korea to fill a gap in knowledge on the interactions between air pollution and moss vegetation under field conditions. For industrial and urban areas, the effects of air pollution on plant growth and the use of lower plants as bioindicators have attracted the attention of researchers in the last few decades. However, this area of research is complicated by the interaction of pollutants with many other environmental factors. Moreover, only a few studies can be found on this important subject in the Far East countries, one of the fastest developing regions in the world (Satake *et al*., 1987). Although official records indicate that the quantity and quality of pollutants discharged into atmosphere and land are improving (Choi, 1998), it would be reasonable to conclude that, in comparison to European and North American countries, environmental conditions of most Eastern countries are still poor, particularly in countries with lower overall levels of development in respect to energy consumption and emission reducing technologies.

The purpose of this paper is to:

(i) describe the moss species growing in one of the largest industrial cities in Asia;

(ii) document edaphic and atmospheric conditions at each site;
(iii) collect materials and data for a program of regular moss monitoring, previously lacking in the Far East;
(iv) uncover relationships between soil/atmospheric conditions and moss community structure.

The results of this study will guide future studies by screening species and measurement variables for their relationship with air/soil pollution.

2. Experimental

2.1. Study area

Various species of bryophytes are found in the Korean Peninsula (124°11′E–131°53′E, 33°06′N–43°01′N), but there are few published accounts of bryophyte distribution in this region. Large numbers of bryophytes occur in this small country because of its long north-south oriented topographic complexity, with 70% of the land dominated by hills and mountains, especially many high mountains with east-facing slopes. Relatively warm temperatures throughout the year (average 5–14 °C), abundant precipitation (up to 1500 mm annually), and invasion of North Eastern Chinese, Eastern Siberian, and Japanese floral elements, together with subtropical ones, also contribute to the high diversity. Seoul (127°00′E, 37°32′N) is located in west-central Korea; more than 20 sections constitute the city. The municipality covers an area of 605 km^2. In the west the city is bordered by the Yellow Sea, and in the east, north, and south by mountains. Prevailing wind direction is from the South and West in summer season, and from the North and East in winter season. Aside from the bordering mountain ranges, most of the area is flat. More than 20% of all Koreans live in Seoul and the population has expanded rapidly in the past 20 yr. More than 60% of the almost ten million people in Seoul live in the southern part of the city. The majority of pollutant emission sources, including point, area, or transport sources, are located in the southwestern part of the city. Industrial activity in the city is limited to manufacturing and light industry such as non-metallic mineral processing. Heavy metal emissions are predominantly from transport sources, and area sources, e.g. space heating.

2.2. Sampling

Moss communities were chosen that were close to 25 Ministry of Environment air pollution measurement facilities (Figure 1). They were within 50 m radius from the facilities. Mosses were sampled from randomly selected communities that had sufficient growth for sampling. The sampling sites are evenly distributed over the city. The study period was 24 July–12 August 2001, and there was no precipitation during this period.

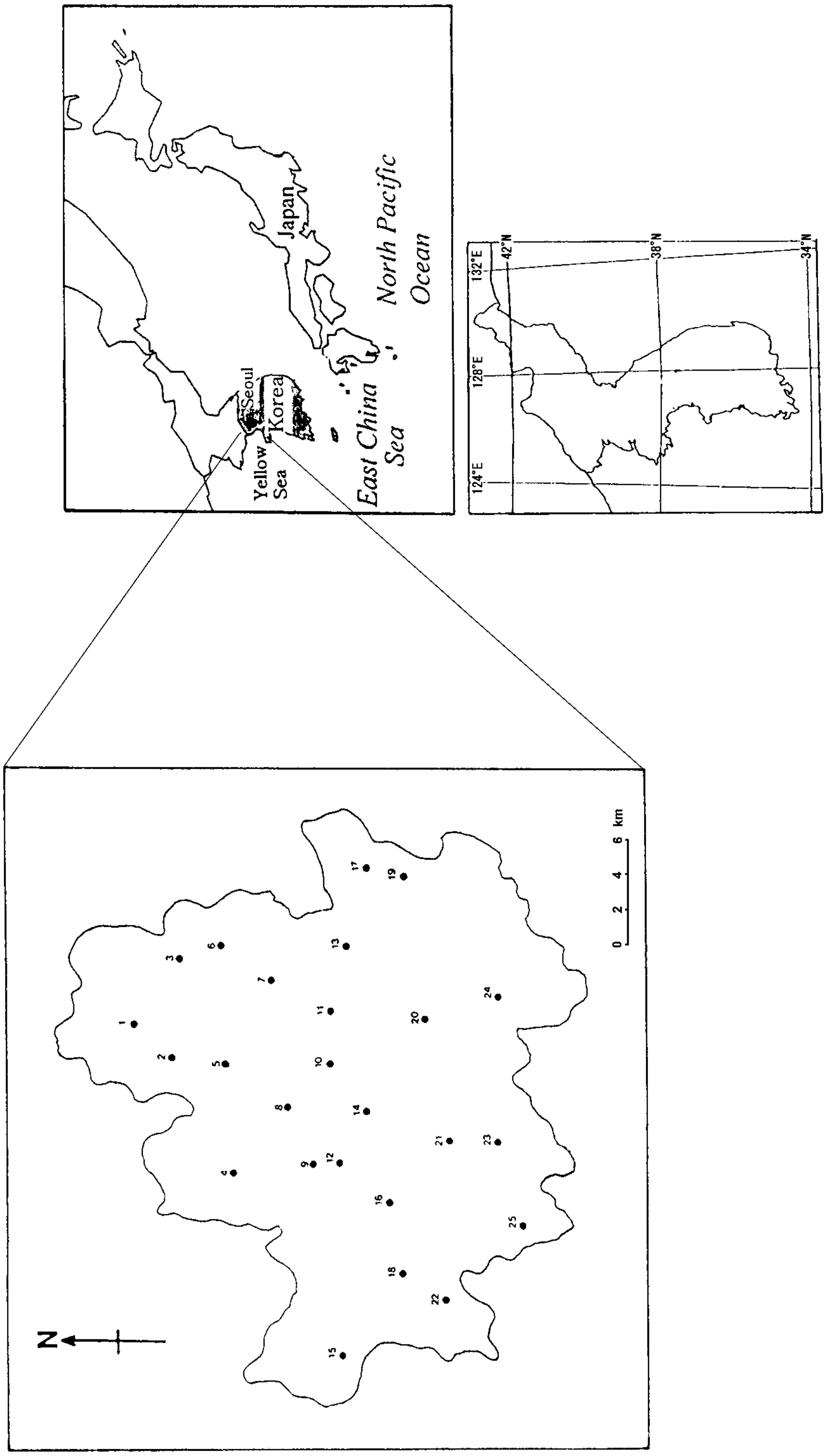

Figure 1. A map showing the sampling sites in Seoul.

Sampling procedures largely followed the recommendations given by Rühling *et al*. (1987), and moss samples were then identified (Choi, 1980). Sample sites were located in somewhat forested areas or small stands of trees, at least 40 m from any paved minor road or individual house, 70 m from any logging road or settlement, and 600 m from any highway or industrial operation, to avoid local contamination.

2.3. Environmental data collection

The Ministry of Environment provided atmospheric data for the study area. These included the levels of SO_2, NO_2, O_3, CO, total suspended particles (TSP), particulate matter (PM), and pH 5.6 below acid rain. To permit summarized evaluations and comparisons, yearly means were calculated from the monthly values of each factor; this produced arithmetic mean for each atmospheric element from June 2000 to May 2001.

Soil data for moss species (n = 5) in each area and water saturation deficiency index (WSD), which indicates the degree of exposure to pollutants through the water absorption capacity of the plants, for *Pogonatum nessii* were obtained with typical methods (Black *et al*., 1973; Jackson, 1967; Moore and Chapman, 1986; Bray and Kurtz, 1945). The basic data used in this study were density index, soil-pH, organic matter content, relative humidity of soil, soil-texture (sand-percentage/silt-percentage/clay-percentage), and the sum of all species' density found in each site. WSD was the ratio of the difference between 'infiltration weight (IW)' and 'fresh weight (FW)' of sampled moss to the difference between 'infiltration weight' and 'dry weight (DW)' of sampled moss, where IW was the weight of moss submerged in tap water for 12 hr under 500 W sodium lamp, and DW was the weight of infiltrated moss dried at 80 °C for 72 hr. Twenty g of soil was shaken vigorously with 100 mL of distilled water, and the solution was filtered with Whatman No. 44 to measure the soil-pH. The organic matter content was measured as 'loss on ignition', which is the difference between the weight of soil dried at 105 °C for 48 hr and the weight of soil furnaced in the electric oven at 600 °C for 4 hr. The soil humidity was the ratio of the difference between fresh weight and dry weight (105 °C, 48 hr) of soil to fresh weight of soil. To determine the soil-texture, 105 °C dried 40 g soil was mixed with 400 mL distilled water containing 1% sodium hexametaphosphate in 1000 mL cylinder and shaken vigorously. Distilled water was added up to 1000 mL and the hydrometer was released slowly to water surface. Sand percentage is calculated from (1-hydrometer measure after 40 s/dry soil weight) × 100, clay percentage is from (hydrometer measure after 120 m/dry soil weight) × 100, and silt percentage is from (100-sand percentage-silt percentage). Relationships among individual species densities (coverage per m^2) and environmental variables were analyzed separately.

TABLE I
Moss species found in Seoul

Species	No. of times they were found
Taxiphyllum taxirameum	16
Pogonatum nessii	15
Pogonatum inflexum	14
Polytrichum commune	11
Rhytidium tugosum	8
Hypnum erectiusculum	8
Ptychomitrum dentatum	5
Brachymenium exile	5
Rhodobryum reseum	4
Bryum argenteum	4
Myuroclada maximoviczii	3
Polytrichum alpinum	2
Plagiomnium rostratum	2
Ptychomitrium fauriei	1
Plagiomnium maximoviczii	1

2.4. Statistical analysis

The SAS statistical package was used for correlation analysis of soil, atmospheric, and moss variables. The relationship between environmental variables and each species density was explored through stepwise regression models (SPSS) with an entrance criterion of $p < 0.05$ (partial correlation). Interaction and higher-order terms in the models were assessed through their effect on R^2 and residual error. Moss community composition was analyzed using detrended correspondence analysis (DCA) of species density, using the PC-ORD software package. The relationship between DCA axis scores and environmental variables was then analyzed by Pearson Correlation, and confirmed using Spearman's Rank Correlation.

3. Results

3.1. Species found in Seoul

Fifteen species were recorded in twenty-five sites in Seoul (Table I). Frequently observed species were *Taxiphyllum taxirameum* (found in 16 sites), *Pogonatum nessii* (in 15 sites), *Pogonatum inflexum* (in 14 sites), and *Polytrichum commune* (in 11 sites). On the other hand, *Ptychomitrium fauriei*, *Polytrichum alpinum*, *Plagiomnium rostratum*, and *Plagiomnium maximoviczii* were rare species (found in only 1 or 2 sites). Most sites had 3 to 8 species in them. The highest diversity was shown at site Chongno (site 10, Figure 1) with 6 species, and the lowest at site Kuro (site 21, Figure 1) with 1 species.

3.2. Atmospheric and terrestrial parameters

Table IIa includes the Pearson correlation coefficients among atmospheric parameters, sums of all species' density found in each site (SDS), and water saturation deficiencies (WSD). There were significant positive correlations between atmospheric SO_2 and water saturation deficiency, CO and acid rain, and between acid rain and SDS. Particulate matter (PM) correlated negatively with SO_2 level. Pearson correlation coefficients were also calculated among terrestrial parameters and moss density (Table IIb). Soil organic matter and moss densities were positively correlated, and organic matter and sand content were negatively correlated. Correlation coefficients within atmospheric parameters, terrestrial parameters, and SDS at each site are presented in Table IIc. Soil-pH was negatively correlated with SO_2 level, but positively correlated with total suspended particles.

3.3. Environment-species relationships

The stepwise multiple regression procedure produced significant ($p < 0.05$) models for each species' density (Table III). Carbon monoxide contributed to the models for *T. taxirameum* and *P. nessii*, but atmospheric parameters did not fulfill the entrance criteria for the remaining species. Terrestrial parameters were included in all species models. Soil organic matter (SOR) was a significant parameter in models for *T. taxirameum*, *P. nessii*, *H. erectiusculum*, and *P. commune*. The model for WSD of *P. nessii* included only SO_2. When total density was modeled, sand (SAP) was the only significant parameter. However, when the entrance criterion was loosened to $p < 0.1$, soil organic matter (SOR), sand (SAP), and carbon monoxide were then included in the model, and the R^2 increased from 0.41 to 0.53.

3.4. Moss community analysis

Detrended correspondence analysis (DCA) successfully separated the sites, based on moss community composition (Figure 2). Sites with low species diversity (two or less species) were found at extremities of the 'cloud' of sites. Site scores along the first axis of the DCA were significantly correlated with SO_2 (r = 0.44); none of the other environmental variables were significantly correlated with any of the first three DCA axes. This pattern was confirmed using Spearman's Rank Correlation analysis (Table IV). In general, atmospheric variables were more highly correlated than soil variables with DCA axes.

TABLE II

Correlation analysis among environmental factors (only the data significant at $p < 0.05$ shown)

(a) Pearson correlation coefficients among atmospheric parameters, sum of all species' densities, and water saturation deficiency

	SO_2	NO_2	TSP	PM	O_3	CO	AR	SDS	WSD
SO_2									
NO_2									
TSP									
PM	–0.56196								
O_3		–0.40486		–0.46009					
CO									
AR						0.93449			
SDS							0.62184		
WSD	0.92913								

(b) Pearson correlation coefficients among terrestrial parameters and species' coverages

	DS	SPH	SRH	SOR	SAP	SIP	CLP
DS							
SPH							
SRH							
SOR	0.52458	0.24467					
SAP	–0.49516			–0.61376			
SIP							
CLP	0.4341		0.21273	0.50953			

(c) Pearson correlation coefficients among atmospheric parameters, terrestrial parameters, and moss densities

	SO_2	NO_2	TSP	PM	O_3	CO	AR	SDS
DS				0.35589				
SPH	–0.59611		0.51958	0.33762				
SRH								
SOR								0.32735
SAP								–0.34691
SIP								
CLP							0.33945	

AR: acid rain; DS: moss density (coverage of moss per m^2); SDS: sums of all species' DS found in each site; TSP: total suspended particles; PM: particulate matters; WSD: waster saturation deficiency; COV: coverage of moss; SPH: soil-pH; SRH: soil relative humidity; SOR: soil organic matter; SAP: soil sand-percentages; SIP: soil silt-percentages; CLP: soil clay-percentages.

TABLE III

Parameter estimates and coefficients of determination (R^2) for soil and atmospheric variables in multiple regression models of species density, total density at each site, and water saturation index (*Pogonatum nessii*). All coefficients are $\times 10^{-3}$. The entrance criterion for each variable was $p < 0.05$ (partial correlation)

Dependent variable	SOR	SAP	SPH	CLP	SRH	CO	SO_2	INT	R^2	
T. taxirameum	(16)[a]	1.34		–1.19		–0.075	0.46		4.84	0.85
P. nessii	(15)	1.03					0.78		–5.41	0.85
P. inflexum	(14)		–0.24						19.1	0.53
H. erectiusculum	(8)	0.84							–3.15	0.63
P. commune	(13)	1.18							–5.23	0.32
P. dentatum	(9)				–0.14				–0.81	0.59
Total density	(25)		–0.89						69.9	0.41
Total density	(25)[b]	2.82	–0.38				2.84		14.3	0.53
WSD[c]								735	10.6	0.81

[a] Number of samples.
[b] p (enter) < 0.1.
[c] Coefficients are $\times$ 1.

TABLE IV

Correlations among atmospheric variables, soil variables and plot scores (n = 28) derived from detrended correspondance analysis of moss community composition

Variable	Axis 1	Axis 2	Axis 3
SO_2	0.468*	–0.202	–0.008
NO_2	–0.286	0.291	–0.051
PM[a]	–0.053	0.387	0.120
O_3	0.178	0.169	–0.313
CO	0.200	–0.037	0.031
SPH	–0.218	0.166	–0.008
SRH	–0.286	–0.081	0.127
SOR	–0.210	–0.057	–0.084
SAP	0.009	–0.073	0.055
CLP	0.088	–0.017	–0.035

* $p < 0.05$.
[a] n = 21.
PM: particulate matter; SPH: soil pH; SRH: soil relative humidity; SOR: soil organic matter; SAP: soil sand-percentage; CLP: soil clay-percentage.

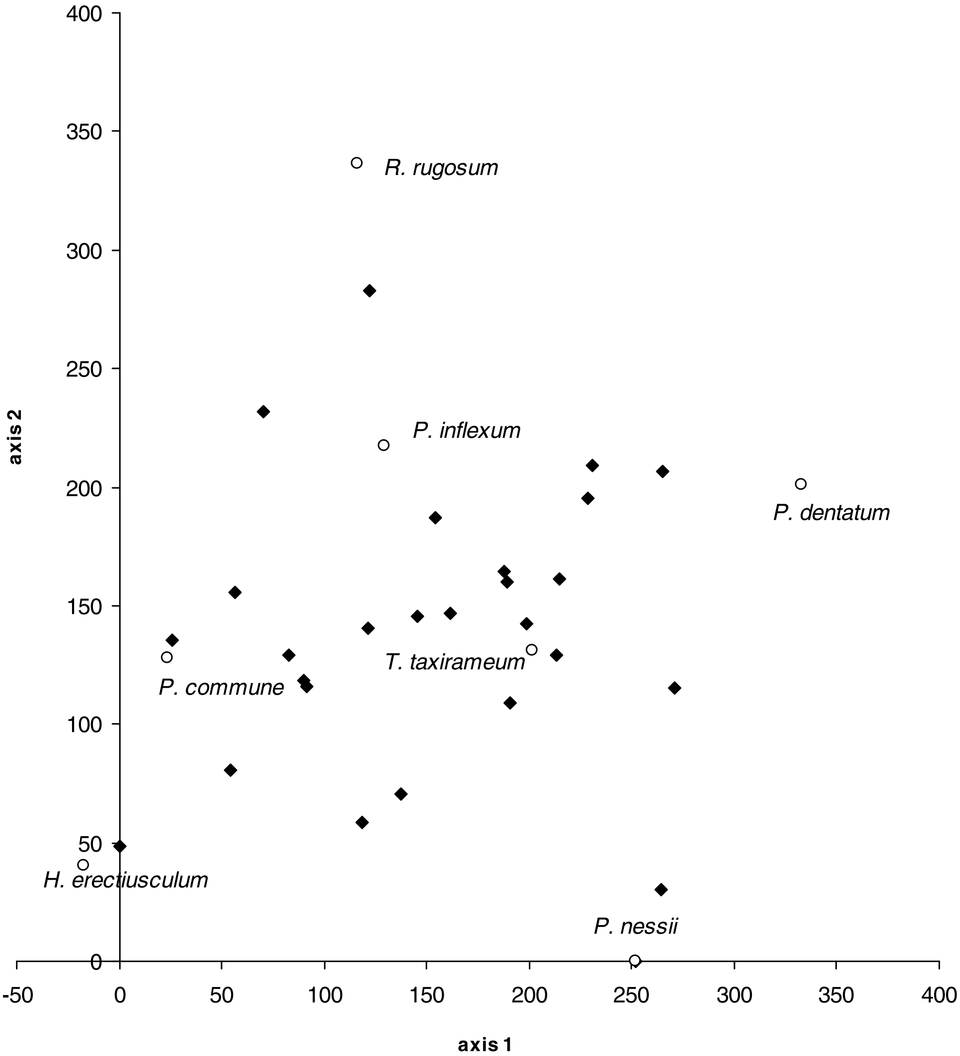

Figure 2. Axis scores from DCA of moss communities at each site. Species scores are labeled with the appropriate species name. Filled diamonds: site scores. Open circles: species scores.

4. Discussion

4.1. Species found in Seoul

As expected, ubiquitous species in Far-East Asia such as *Pogonatum nessii* and *Pogonatum inflexum* were found frequently. Those known to inhabit hills or clean river sides, such as *Ptychomitrium fauriei, Polytrichum alpinum, Plagiomnium rostratum*, and *Plagiomnium maximoviczii*, were less commonly observed.

Although Seoul is a fast developing city, its environmental conditions have improved in recent years (Choi, 1998). A diverse group of mosses were found in most parts of Seoul. However, the sites with large-scale industrial complexes in the same administrative district, such as Kuro (site 21, Figure 1) and Kumchun, (site 23, Figure 1) had fewer species.

The distribution of *Bryum argenteum* and *Brachymenium exile* appeared to be strongly influenced by soil pH. *Bryum argenteum* is one of the most frequently observed species in the world. It grew in soil that had the highest pH (average 6.15), and the pH range of its distribution was very narrow (6.0–6.2), indicating that *Bryum argenteum* prefers less acidic soil. The opposite case was *Brachymenium exile*, which grew on the soil that had the lowest pH value (average 5.06). *Rhytidium rugosum* and *Myuroclada maximoviczii* distribution favoured sites with higher relative soil humidity (average 62.13%). *Pogonatum nessii* existed in a humidity range three times as broad as that of *Myuroclad maximoviczii*. As for the organic matter content, *Bryum argenteum* could not be found in sites with low organic matter content. In contrast, the species distribution, and species diversity did not appear to be strongly affected by variation in atmospheric parameters. It is clear, however, that *Ptychomitrum dentatum* tolerates high levels of SO_2 (up to average 0.0098 ppm). This was confirmed by the DCA analysis (Figure 2); SO_2 was correlated to DCA axis 1, and sites at the extreme positive end of axis 1 were colonized by *Ptychomitrum dentatum* or *Pogonatum nessii*. Sites with populations of *Hypnum erectiusculumin* or *Polytrichum commune* were found at the negative end of DCA axis one, and thus at lower concentrations of SO_2 (average 0.0067 ppm).

4.2. Atmospheric and Terrestrial Parameters

The analyses in Table IIb gave expected results. Although the degree of correlation was not high, moss density would be expected to be linked to soil organic matter content. To further study moss preference for specific soil conditions, we also obtained soil-pH, relative humidity of soil, and organic matter content of soil in areas 5 m from the margin of healthy populations of certain species. These included species that occurred at least 8 times during the survey: *Ptychomitrum dentatum, Taxiphyllum taxirameum, Pogonatum nessii, Polytrichum commune, Rhytidium rugosum, Pogonatum inflexum*, and *Hypnum erectiusculumin*.

Comparison of soil from areas with and without thriving moss populations identified *Ptychomitrum dentatum, Taxiphyllum taxirameum*, and *Pogonatum inflexum* as having some preference for increased soil relative humidity and organic matter content, although assessment of the significance of this preference requires further study. It is also possible that these species were able to secure more water and nutrients from surroundings than other species. However, whether they flourished on the land suitable for them or they changed the characteristics of soil is unclear without further experimentation.

Because the leaf membranes of the plants cannot function properly with prolonged exposure to external pollutants, the plants cannot fully absorb water. This leads to a higher level of WSD. Again in this study atmospheric SO_2 and WSD showed a very high correlation (coefficient 0.93). Rain acidity and CO level also had a highly positive relationship. This may indicate that CO is one of the major components of acid rain (Table IIa). From the analysis of atmospheric and terrestrial parameters (Table IIc), soil-pH correlated negatively with SO_2 level, and positively with total suspended particle (TSP). Although the correlation coefficient was relatively low, it is appropriate to predict that SO_2 is a considerable cause of soil-acidification.

When each species was analyzed separately by multiple regression, models of the density *P. nessii* and *T. taxirameum* included both terrestrial and atmospheric parameters; these models accounted for more than 80% of the variation in species density. Carbon monoxide was the only atmospheric parameter incorporated into these models, indicating the potential importance of either acid rain or automobile exhaust to control of moss distribution. The other mosses were influenced predominantly by soil variables; each species responded to specific combinations of soil variables.

More and more, our environment is affected not only by the traditional air pollutants, SOx, ozone and NOx, but by a steadily growing, almost incalculable number of other chemical substances, such as heavy metals, polycyclic aromatic or halogenated organic compounds (Fränzle, 1993; Oehlmann *et al*., 1996). Mosses may be very suitable for detection of these new kinds of pollutants. Their potential use as indicators in the Far-East region requires further research.

5. Conclusions

In Seoul, 15 moss species were found in 25 sites. Most sites had four or five species, and *Taxiphyllum taxirameum, Pogonatum nessii*, and *Pogonatum inflexum* were frequently observed. Although density of *Pogonatum nessii* and *Taxiphyllum taxirameum* might be affected by CO, species' densities were largely affected by soil parameters. SO_2 was the only environmental variable that significantly affected the composition of moss communities. More generally, species diversity might be a good indicator of atmospheric pollution rather than abundance of specific moss species in Seoul.

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