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The total sulphur content in the mosses of Polish National Parks — changes within the last 10 years

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Abstract

The pollution of Polish National Parks with sulphur compounds was determined for 1975 and 1986 using the moss, *Pleurozium schreberi* as a bioindicator. The mean total sulphur content in the mosses of the parks ranged from 895 to 2116 $\mu g \cdot g^{-1}$ dry weight in 1975 and 1117 to 2410 $\mu g \cdot g^{-1}$ dry weight in 1986. Statistical differences were found in the concentration of sulphur in mosses between the particular parks, as well as among the peripheral and central park areas in 1975 while such differences were lacking in 1986. The total sulphur in mosses showed a tendency to increase over the 10-year period although there was no statistically significant difference between the concentrations of this element between the two studied periods. The level of total sulphur is significantly modified by atmospheric precipitation and does not therefore always accurately illustrate the degree of air pollution with SO_2. For this reason, mosses cannot be recognised as suitable indicators of pollution of the atmosphere with sulphur compounds.

Key words: *Pleurozium schreberi, air pollution with sulphur compounds, national parks*

INTRODUCTION

The pollution of Poland's atmosphere with sulphur dioxide (SO_2) is very high and constantly rising (The Statistical Yearbook [Rocznik Statystyczny] 1975-1986, Highton and Chadwick 1982). This is the result of both local emission and transboundary transport. The significant atmospheric SO_2 concentration results in an average of 8 tons of sulphur compounds per square kilometer reaching the surface of Poland's soil annually in wet and dry

deposition. These values reach 50 $t \cdot km^{-2}$ over 10% of Poland's surface (Kassenberg and Rolewicz 1985). Due to its chemical properties, sulphur dioxide has a detrimental effect on the environment (Siuta and Rejman-Czajkowska 1980).

Plants are used as test organisms for evaluating the degree and range of pollution. pH changes in bark (Grodzińska 1971, Grill et al. 1981), susceptibility of lichens (Bystrek 1987, Miszalski and Mydlarz 1987), accumulation of sulphur by pine needles (Molski et al. 1981) have been used as bioindicators for SO_2.

National parks are protected areas because of the unique valours of their ecosystems, but they are not, unfortunately protected from the effects of pollution (Grodzińska 1978, Grodzińska 1990). The commonness and annually increasing emission of sulphur dioxide into the atmosphere is a danger to the biocenoses of parks.

The objective of this study was to measure the concentration of total sulphur in the mosses *Pleurozium schreberi* and *Hylocomium splendens* collected in national parks in 1975 and 1986 and to determine on their basis the degree of danger to these parks over the last 10 years.

MATERIAL AND METHODS

Pleurozium schreberi (Brid.) Mitt. and *Hylocomium splendens* (Hedw) B. S. G., two common species of mosses in Poland, were collected in 12 national parks in the autumn of 1975 and again in 1986 in the same parks and in two parks established after 1975, the Gorczański and the Roztoczański National Parks (Table 1). Samples were taken in the central and peripheral park areas, 10 samples from each point (for a list and characteristics of each stand see Grodzińska 1978).

Unwashed, fresh plants were divided into green (younger) and brown (older) parts, then dried at a temperature of 85°C. Total sulphur was determined using the nephelometric method of Butters and Chanery. The samples from 1975 were analysed in the laboratory of the Department of Ecology of the Lund University (Grodzińska), while those from 1986 at the laboratory of the Department of Ecology of the Institute of Botany of the Polish Academy of Sciences in Kraków (Chrzanowska).

Statistical analysis was carried out using variance analysis and Duncan's multiple interval test.

The results are presented only for *Pleurozium schreberi* due to the insufficient number of samples of *Hylocomium splendens*.

Table 1

The total sulphur content ($\mu g\ g^{-1}$ d.w.) in the green (g) and brown (b) parts of *Pleurozium schreberi* collected from the central and peripheral areas of national parks in 1975 and 1986

Parks (abbreviation)	1975							1986						
	central			peripheral			$\bar{x}$	central			peripheral			$\bar{x}$
	g	b	$\bar{x}$	g	b	$\bar{x}$		g	b	$\bar{x}$	g	b	$\bar{x}$	
Słowiński (Sł)	1391	1375	1383	1712	1613	1662	1522	1500	767	1133	1493	710	1101	1117
Woliński (W)	1155	910	1037	1300	1527	1413	1225	1523	740	1131	2483	1797	2140	1635
Wielkopolski (Wi)	1620	1239	1429	2702	2407	2554	1922	2647	2333	2490	2153	2510	2331	2410
Kampinoski (Km)	1585	1125	1355	1360	1500	1430	1392	2070	2187	2128	2147	2043	2095	2112
Białowieski (Bł)	1903	2148	2025	1384	1843	1613	1819	2003	2070	2036	2322	1757	2039	2038
Świętokrzyski (S)	1452	1587	1519	2252	2072	2162	1840	1757	1337	1547	2167	2040	2103	1825
Ojcowski (O)	1722	2180	1951	–	–	–	1951	1840	1047	1443	–	–	–	1443
Karkonoski (K)	2632	1579	2105	2280	1974	2127	2116	–	–	–	–	–	–	–
Babiogórski (B)	953	1341	1147	1228	1776	1502	1324	–	–	–	1693	1090	1391	1391
Tatrzański (T)	963	1193	1078	1399	1370	1384	1231	–	–	–	1383	1823	1603	1603
Pieniński (P)	765	811	788	1144	1327	1237	1012	1647	1607	1627	1150	1437	1293	1460
Bieszczadzki (Bi)	840	950	895	–	–	–	895	1030	783	906	1667	1713	1690	1298
Gorczański (G)	–	–	–	–	–	–	–	–	–	–	1053	1507	1280	1280
Roztoczański (R)	–	–	–	–	–	–	–	1177	1623	1400	1587	1530	1558	1479
$\bar{x}$	1415	1370	1393	1676	1741	1708	1521	1719	1449	1584	1775	1663	1719	1662*

* Mean total sulphur concentration excluding the Gorczański and Roztoczański Parks egualled 1667 $\mu g \cdot g^{-1}$ d.w. in 1986.

RESULTS

THE TOTAL SULPHUR CONTENT IN *PLEUROZIUM SCHREBERI* IN 1975

The mean concentration of total sulphur in the samples obtained fom the central areas of parks was in the green parts of *Pleurozium schreberi* 1415 $\mu g \cdot g^{-1}$ and in the brown parts, 1370 $\mu g \cdot g^{-1}$. Samples of mosses from the peripheral parts of parks accumulated 1676 and 1741 $\mu g \cdot g^{-1}$ sulphur, respectively (Table 1). The difference in the level of total sulphur between the younger (green) and older (brown) parts of the mosses was not statistically significant (Table 2).

The mean total sulphur content in the green and brown parts of mosses from the central parts of parks was 1393 $\mu g \cdot g^{-1}$ (from 788 to 2105 $\mu g \cdot g^{-1}$), while in the peripheral parts, 1708 $\mu g \cdot g^{-1}$ (from 1237 to 2554 $\mu g \cdot g^{-1}$) (Table 1). The difference between the mean total sulphur content in mosses between the different park areas was statistically significant.

Table 2
Statistical analysis of total sulphur concentration in *Pleurozium schreberi* from national parks in two years under study

Year	Difference between			
	parts of moss	parts of park	parks	years
1975	1.31^{ns}c 0.04^{ns}p	9.04 c<p	4.17	2.02^{ns}
1985	8.13*c 0.76^{ns}p	2.85^{ns}	1.32^{ns}	

ns – $p>0.05$, * – $p<0.05$, c – central park area, p – peripheral park area

Statistically, the lowest total sulphur contents were found in *Pleurozium schreberi* from the Pieniński National Park (1012 $\mu g \cdot g^{-1}$), while the highest were found in the Karkonoski National Park (2116 $\mu g \cdot g^{-1}$) (Table 1). The difference in the sulphur concentrations was statistically significant, but only between these two parks.

THE TOTAL SULPHUR CONTENT IN *PLEUROZIUM SCHREBERI* IN 1986

The mean total sulphur content in samples from central park areas was an average of 1719 $\mu g \cdot g^{-1}$ in green parts and 1449 $\mu g \cdot g^{-1}$ in the brown parts of mosses. In the peripheral park areas, these values were 1775 and 1663 $\mu g \cdot g^{-1}$, respectively (Table 1). A statistically significant difference between the sulphur contents of younger and older parts of mosses was found only in the central areas of parks (Table 2).

The mean concentration of total sulphur in the green and brown parts of mosses in samples from the central park areas equalled 1584 $\mu g \cdot g^{-1}$ (from 906 to 2128 $\mu g \cdot g^{-1}$), while from the peripheral areas, 1719 $\mu g \cdot g^{-1}$ (from 1101 to 2331 $\mu g \cdot g^{-1}$) (Table 1). No statistical difference was found in the total sulphur content between the central and peripheral park areas (Table 2).

The lowest total sulphur content was found in mosses from the Słowiński National Park (1117 $\mu g \cdot g^{-1}$), the highest from the Wielkopolski National Park (2410 $\mu g \cdot g^{-1}$) (Table 1). The difference between the levels of total sulphur in the samples from these parks was, however, statistically insignificant (Table 2).

COMPARISON OF THE TOTAL SULPHUR CONTENT IN *PLEUROZIUM SCHREBERI* IN 1975 AND 1986

The mean total sulphur concentration in samples of mosses from 12 parks in 1975 was 1526 $\mu g \cdot g^{-1}$; in 1986 it equalled 1667 $\mu g \cdot g^{-1}$ (Table 1). The level of sulphur in plants from the individual parks was in 1986 higher or similar to that in 1975. Only in the case of the Słowiński and Ojcowski parks did it drop (Fig. 1). The difference in the total sulphur content of park mosses in 1975 and 1986 was statistically insignificant (Table 2). The lowest total sulphur level that was found in both periods under study in *Pleurozium schreberi* (the mean from green and brown parts) was 788 $\mu g \cdot g^{-1}$ (the central part of the Pieniński National Park in 1975)

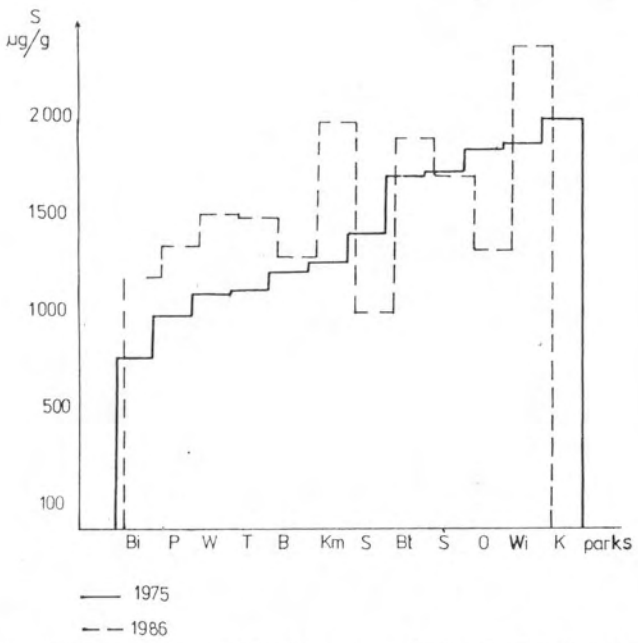

Fig. 1. Mean total sulphur levels ($\mu g \cdot g^{-1}$) in *Pleurozium schreberi* from national parks in 1975 and 1986. The names of the parks are given in Table 1

(Table 2). This value was taken as the background sulphur level for mosses from Polish parks and on its basis four groups of parks were distinguished (Fig. 2). "Clean" parks are those in which the concentration of total sulphur in mosses was at most about 1.5 that of the Pieniński National Park. Similarly, slightly polluted were those parks in which this concentration was 1.5-2.0 that of the Pieniński Park, moderately polluted – 2.0-2.5 times and heavily polluted – over 2.5 the concentration found in the mosses of the Pieniński National Park.

In 1975 the Pieniński and Bieszczadzki National Parks belonged to "clean" parks, the coastal parks along with the Kampinoski, Babiogórski and Tatrzański Parks represented the slightly polluted parks, the Wielkopolski and Białowieski were moderately polluted while only the Karkonoski Park was heavily polluted.

In 1986 only the Słowiński Park belonged to "clean" parks, the southern mountain parks along with Ojcowski and Roztoczański Parks were slightly polluted, the Woliński and Świętokrzyski Parks were moderately polluted while the parks of the central, lowland part of the country, that is, the Wielkopolski, Kampinoski and Białowieski Parks were strongly polluted.

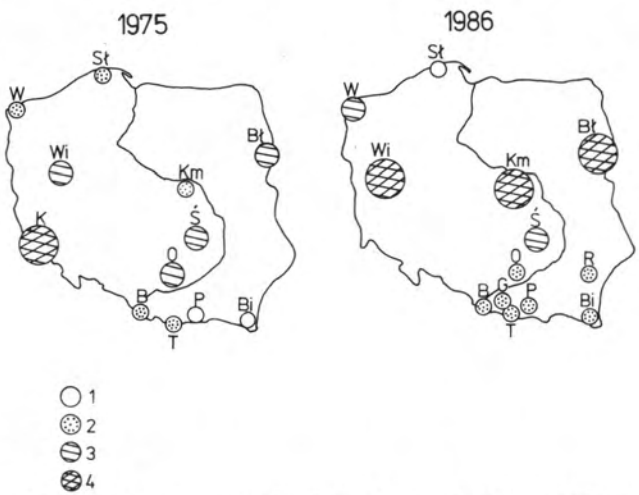

Fig. 2. Pollution of Polish national parks with sulphur dioxide in 1975 and 1986 based on the total sulphur content in mosses. The degrees of pollution were determined by comparing the total sulphur concentration in samples from the individual parks with the lowest sulphur concentration determined: 1 – clean parks, sulphur level up to 1.5. times greater than the lowest determined concentration; 2 – slightly polluted parks, sulphur concentration 1.5 to 2.0 times greater; 3 – moderately polluted parks, sulphur concentration 2.0 to 2.5 times greater; 4 – polluted parks, sulphur concentration over 2.5 times greater. The names of the parks are given in Table 1

DISCUSSION

Various biological materials are used to evaluate the pollution of the environment by sulphur compounds (Grodzińska 1983, Białobok et al. 1987). The most frequently used accumulator type bioindicators are pine

needles and tree bark (Grodzińska 1971, Molski et al. 1981, Karweta and Kawalec 1987), less frequently mosses (Gilbert 1968, Świeboda and Kalemba 1981, Borowiec and Zabłocki 1987).

Borowiec and Zabłocki (1987) determined the total sulphur content in several moss species, including *Pleurozium schreberi* and pine needles in the vicinity of the Police Chemical Works near Szczecin. They found elevated sulphur levels both in mosses and in pine needles and these results were in agreement with the zones in which the admissible levels of SO_2 were exceeded and with the zones in which the trees were damaged. For the mosses from these zones, the sulphur contents were 2.6-3.6 $g \cdot kg^{-1}$ and 2.4-2.7 $g \cdot kg^{-1}$, respectively, while from control areas the values equalled 1.4-2.5 $g \cdot kg^{-1}$. In our studies only samples from the most polluted parks reached total sulphur concentrations in the range of that in mosses from the zones in which tree damage occurs around the Police Chemical Plant. In the samples from the remaining parks, total sulphur levels near those from the control points around the Police Plant were found.

In comparison with the total sulphur concentration in mosses from an area experiencing very limited effects of industrial pollution such as southern Spitsbergen, samples of *Pleurozium schreberi* from all of the studied Polish parks contained significantly higher levels of total sulphur (Grodzińska 1987).

The emission of SO_2 in Poland rose between 1975 and 1986 from 2081 thousand tons per year to 2652 thousand tons per year (Statistical Yearbook 1975-1987 [Rocznik Statystyczny 1975-1987]). An increase in the level of accumulated sulphur in mosses was also observed in most of the parks over this period.

The national parks have been subjected these last few years to increased sulphur-containing air pollution. This is manifested by the lack of statistically significant differences between the sulphur contents in the mosses from the peripheral and central park areas. Such differences were found in the mid-1970's.

The amount of sulphur dioxide found over Polish territory is the sum of Poland's own SO_2 emissions from its industrial centres and the emissions reaching this country from abroad (Dovland 1987). Pollution from the Legnica-Głogów Industrial Basin reaches the Karkonoski National Park as does the pollution from the distant Czech Industrial Basin. The transboundary SO_2 pollution easily penetrates to the central lowland area of Poland. The SO_2 emitted from both eastern and western Germany is blown by westerly winds not only to the most western national parks of Poland (Wielkopolski National Park), but also to the more easterly Kampinoski and Białowieski National Parks. In addition, the increased sulphur pollution of the Wielkopolski and Kampinoski parks may have been caused by higher SO_2 emissions from the neighbouring urban agglomerations of Warsaw and Poznań.

In the first year of the study the coastal parks were only slightly polluted. Due to strong northerly winds and their significant distance from sources of pollution, the pressure of SO_2 on the Słowiański National Park did not increase over the last 10 years. The increasing sulphur emissions from the Szczecin region (Piech 1987) do, however, reach the Woliński National Park. This caused an increase in the total sulphur content in the mosses of that park.

In both of the studied periods, the mountain parks in southern and southeastern Poland belonged to the group of slightly polluted parks. The straight-line distance of these parks from industrial centres is not great. Because these areas are elevated significantly above sea level (especially the Tatrzański and Babiogórski Parks) they should be exposed to large fall-out of sulphur compounds which are carried by the north-west winds from the Kraków-Upper Silesian Industrial District. It seems that their degree of pollution as determined on the basis of accumulated total sulphur does not correspond to their actual condition. These parks are characterised by high annual precipitation levels, which may reduce the level of accumulated sulphur since it is easily washed out of moss cells (Gilbert 1968).

The Ojcowski National Park is situated in the most polluted area of the country which makes it puzzling that the samples of *Pleurozium schreberi* collected from that park contained relatively low levels of sulphur. On the other hand, mosses from the Białowieski National Park, considered to be in the area least endangered by industrial pollution, had high sulphur levels. The pollution profile of these parks obtained by Molski et al. (1981) studying pine needles differed from that presented in this paper and is in agreement with data on atmospheric SO_2 pollution. This points to the greater suitability of pine needles as a bioindicator of this type of pollution.

This study has shown that accumulation of sulphur by mosses is not a good indicator of atmospheric SO_2 pollution due to the strong modifying effects of weather conditions, especially precipitation.

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Zawartość siarki ogólnej w mchach polskich parków narodowych – zmiany w ciągu 10 lat

Streszczenie

Skażenie parków narodowych Polski związkami siarki w latach 1975 i 1986 określano przy użyciu mchu *Pleurozium schreberi* jako biowskaźnika. Średnie stężenie siatki ogólnej w mchach parków wahało się od 895 do 2116 $\mu g \cdot g^{-1}$s. m. w 1975 roku i od 1117 do 2410 $\mu g \cdot g^{-1}$s. m.

w 1986 roku. Stwierdzono różnice statystycznie istotne w stężeniu siarki w mchach między poszczególnymi parkami oraz między brzeżnymi i centralnymi częściami parków w 1975 roku i brak takich różnic w 1986 roku. Stężenie siarki ogólnej w mchach wykazywało tendencję wzrastającą w ciągu 10 lat, chociaż nie było różnic statystycznie istotnych w zawartości tego pierwiastka między dwoma okresami badań. Poziom siarki ogólnej w mchach jest silnie modyfikowany przez opady atmosferyczne i dlatego nie zawsze odzwierciedla właściwie stan skażenia powietrza SO_2. Z tego powodu mchy nie mogą być uznane za odpowiednie wskaźniki zanieczyszczenia atmosfery związkami siarki.