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The lichen *Parmelia physodes* (L.) Ach. as indicator for determination of the degree of atmospheric air pollution in the area contaminated by flourine and sulphur dioxide emission

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Abstract

On the area involved in the influence of conteminations emitted by the aluminium works and electric power plant, the degree of atmospheric air pollution was evaluated on the basis of the behaviour of healthy thallus of the lichen *Parmelia physodes*, analysis of fluorine and sulphur content in this thallus and in the bark substrate and the F and SO_2 concentrations in the air.

INTRODUCTION

Lichens are generally considered as a plant group particularly sensitive to air pollution. This property was noticed rather early at the mid of the 19th century. Nylander (1866) expressed at that time the opinion that the disappearance of lichens in Paris was largely dependent on the concentration of dust and smoke in the air. This observation has been stressed repeatedly in later lichenological studies.

The first experimental investigations concerning lichens were undertaken by Arnold in the period 1891—1901. They consisted in transfer of epiphytis lichens from country habitats to the city of Münich and observation of their gradual dying.

The lichen flora was elaborated in more detail as late as the 30-ies of this century in such cities as Oslo (Haugsja, 1930), Stockholm (Heg, 1934), Helsinki (Vaarna, 1934), Zurich (Vareschi, 1936) and somewhat later Cracow (Zurzycki, 1950). In these cities, notwithstanding the local climate, three zones were distinguished: the inner zone completely deprived of lichens and coinciding with the highest air pollution, the intermediate zone with few lichen species and the zone

of normal vegetation in the peripheral city districts. The above enumerated authors all stressed that one of the factors inhibiting lichen development in large cities is the increased content in the air of noxious gas components, particularly those containing sulphur.

Rydzak (1953) did not agree with this opinion. According to him, the occurrence of lichen is distinctly correlated with air temperature and moisture distribution in cities, while sulphur dioxide and other polluting gases are not a factor eliminating lichens from the flora of towns.

This controversial attitude of Rydzak (l.c.), as regards the causes of disappearance of lichens in town, prompted more intensive studies in this field. Brodo (1961), on the basis of Arnold's experiments (1891-1901), developed a method of epiphytic lichen transplantation from the bark of trees growing on areas not exposed to smoke, onto trees of the same or another species on sites with high air pollution. After 4 months of exposure he assayed the degree of damage to the lichen thallus and found it to diminish with the distance from the city.

The same method was applied by LeBlanc and Rao (1966), LeBlanc (1968), Schönbeck (1968, 1969). The latter author introduced certain modifications of the method consisting mainly in that the bark discs with the thallus of *Parmelia physodes* were not transplanted onto tree trunks, but placed on wooden plates and then exposed at certain points for 48 days. After this time the damage to the thallus showed a distinct dependence on the sulphur dioxide concentration in the air.

Within the framework of investigations on the influence of fluorine on the vegetation in the surroundings of the aluminium works "Skawina", the method of transplantation of the thallus of *Parmelia physodes* was also applied with only a few modifications concerning the technique of sampling described by Schönbeck (1969). The lichen was used for a biotest to evaluate the degree of atmospheric air pollution in the nearest surroundings of the aluminium works "Skawina" and electric power plant and on the area between the source of fluorine and sulphur compounds emission and the southern part of the city of Cracow. The results are reported in the present paper.

MATERIAL AND METHODS

Parmelia physodes (L.) Ach. (= *Hypogymnia physodes* (L.) Zopf.) was collected from two fir (*Abies alba* Mill.) trunks. The trees grew in a *Fagetum carpathicum* community at a distance of about 30 km south-east of the aluminium works "Skawina".

By means of a metal instrument devised by the authors (Fig. 1) bark discs 3.57 cm in diameter were cut out of the middle part of the fir trunks of age class III. Care was taken to chose samples with a uniform

degree of covering by the thallus. The discs thus obtained, about 4 mm thick comprised the subereous layer of dead cells and the suber-forming cambium. The discs were then placed on wooden plates with 10 "nests" cut out to fit the discs. In this way each plate contained 10 transplanted *Parmelia physodes* thalli each of a 10 cm^2 surface area (Fig. 2).

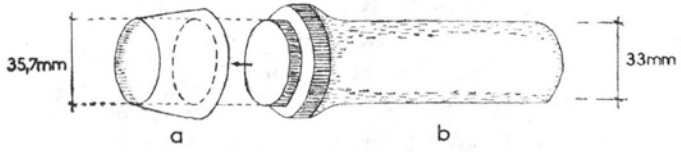

Fig. 1. Device for taking *Parmelia physodes* samples from the bark of trees: (a) the cutting part, (b) the handle

After taking photographs, the plates with transplanted *Parmelia physodes* were exposed on 19 sites at distances of 0.1 — 10 km from the aluminium works "Skawina" (Figs 3, 4, 5) and additionally at a control site where the lichen samples had been collected. The plates with the samples were placed at a height of about 3 m above ground on open areas exposed on the side of the smoke stacks.

After 30 days of exposure the degree of covering of the particular discs with the thallus was planimetrically determined, taking into account the thallus surface of natural colour and that with colour changed, that is passing from white through yellowish to brown. From the data obtained mean values were calculated for all discs on one plate and compared with the initial state.

In the exposed bark discs with the remaining lichen thallus fragments, the total fluorine content was determined by means of thorium nitrate and alizarin S (J ę c z a l i k, 1957) as well as total sulphur content according to the method of Bardsley and Lancaster (N o w o s i e l s k i, 1974).

The degree of air pollution on the investigated area by fluorine compounds and sulphur dioxide is shown on the basis of results for the second 6 months of the year 1975, obtained from the management of the aluminium works "Skawina". Fluorine and sulphur dioxide content in the air was determined by the contact method commonly used by the sanitary-epidemiological stations.

Data concerning the frequency and velocity of the winds from particular directions for the period of testing, that is from September 12 to October 12, 1976 were obtained from the Meteorological-hydrological Institute, Station at Balice airport.

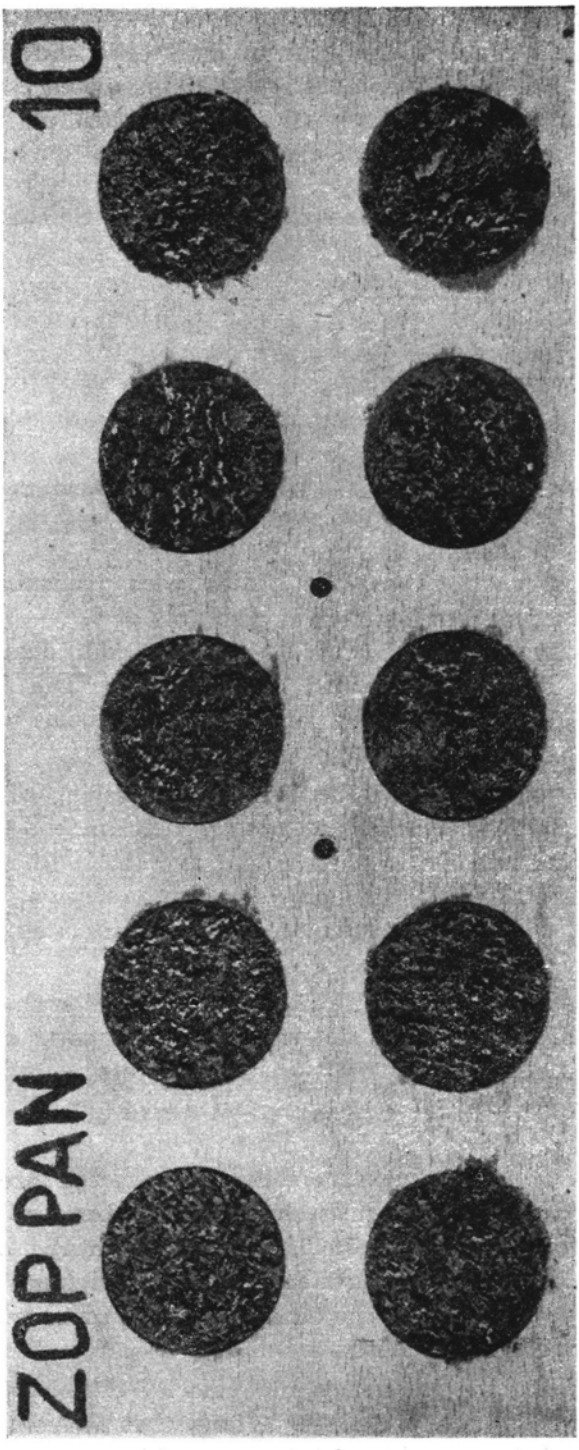

Fig. 2. Plate with transplanted *Parmelia physodes* thallus before exposure to pollution

RESULTS

1. Degree of damage to the *Parmelia physodes* thallus

The covering of the transplanted bark discs with *Parmelia physodes* before and after exposure is shown in Table 1. On sites 3 and 4, situated closest to the source of fluorine compounds emission, there remained no trace of living thallus after 30 days. Thallus of normal colour was preserved on the remaining sites in from 2.53 to 81.13 per cent, while on the control site, covering with healthy *Parmelia physodes* was 96.33 per cent. Moreover, on the latter site no changes in thallus colour, such as were observed on other sites and reaching from 1.42 to 91.53 per cent (site 4), were noted.

Table 1

Coverage of exposed bark samples with *Parmelia physodes*

Site	Distance from source of emission km	Situation	Bark coverage by lichen thallus					Diminution of thallus	
			before exposure			after exposure with			
			%	natural colour		changed colour			
				mm²	%	mm²	%	mm²	%
1	2.5	S	92.47	7380	79.81	477	5.16	1390	15.03
2	1.0	W	99.06	4572	46.15	5204	52.54	130	1.31
3	0.1	E	98.94	0	0	3054	30.87	6840	69.13
4	0.5	NNE	97.79	0	0	8035	91.53	744	8.47
5	1.5	E	98.94	3986	40.29	2826	28.56	3082	31.15
6	2.0	E	98.84	2505	79.74	6278	16.15	1101	4.11
7	3.5	NE	99.25	7914	25.34	1603	63.52	408	11.14
8	4.0	E	97.85	7729	78.99	387	3.95	1669	17.06
9	5.0	E	99.25	6792	68.43	141	1.42	2992	30.15
10	7.5	E	98.91	7189	72.68	497	5.03	2205	22.29
11	4.0	N	98.31	985	10.01	8673	88.23	173	1.76
12	4.0	NNE	96.67	884	9.14	7458	77.15	1325	13.71
13	5.5	NE	98.31	6112	62.17	396	4.03	3323	33.80
14	7.0	NE	97.59	5858	60.02	232	2.38	3669	37.60
15	7.5	NE	97.53	7912	81.13	301	3.08	1540	15.79
16	6.0	N	98.35	6178	62.82	1687	17.15	1970	20.03
17	6.0	N	95.60	242	2.53	7127	74.55	2191	22.92
18	8.0	NNE	97.22	734	7.55	7606	78.23	1382	14.22
19	10.0	NNE	98.25	2120	21.58	4408	44.86	3297	33.56
20	34.0	SE	99.70	9604	96.33	0	0	366	3.67

After the end of the experiment the decrease in the exposed lichen surface was 1.31 to 37.60 per cent and on site 3 it reached 69.13 per cent. On the latter site there only remained on bark discs fragments of dried brown thallus detached from the substrate, thus liable to be carried off by wind.

2. Fluorine and sulphur content in the exposed bark samples

The fluorine content in the bark with remains of lichen thallus varies from 4.4 ppm (control site) to 141.5 ppm (site 3). Beside these extreme values, in most of the samples F content varied within 6.3—18.5 ppm, only on sites 2, 4 and 5 it was 22.6 to 39.6 ppm (Fig. 3).

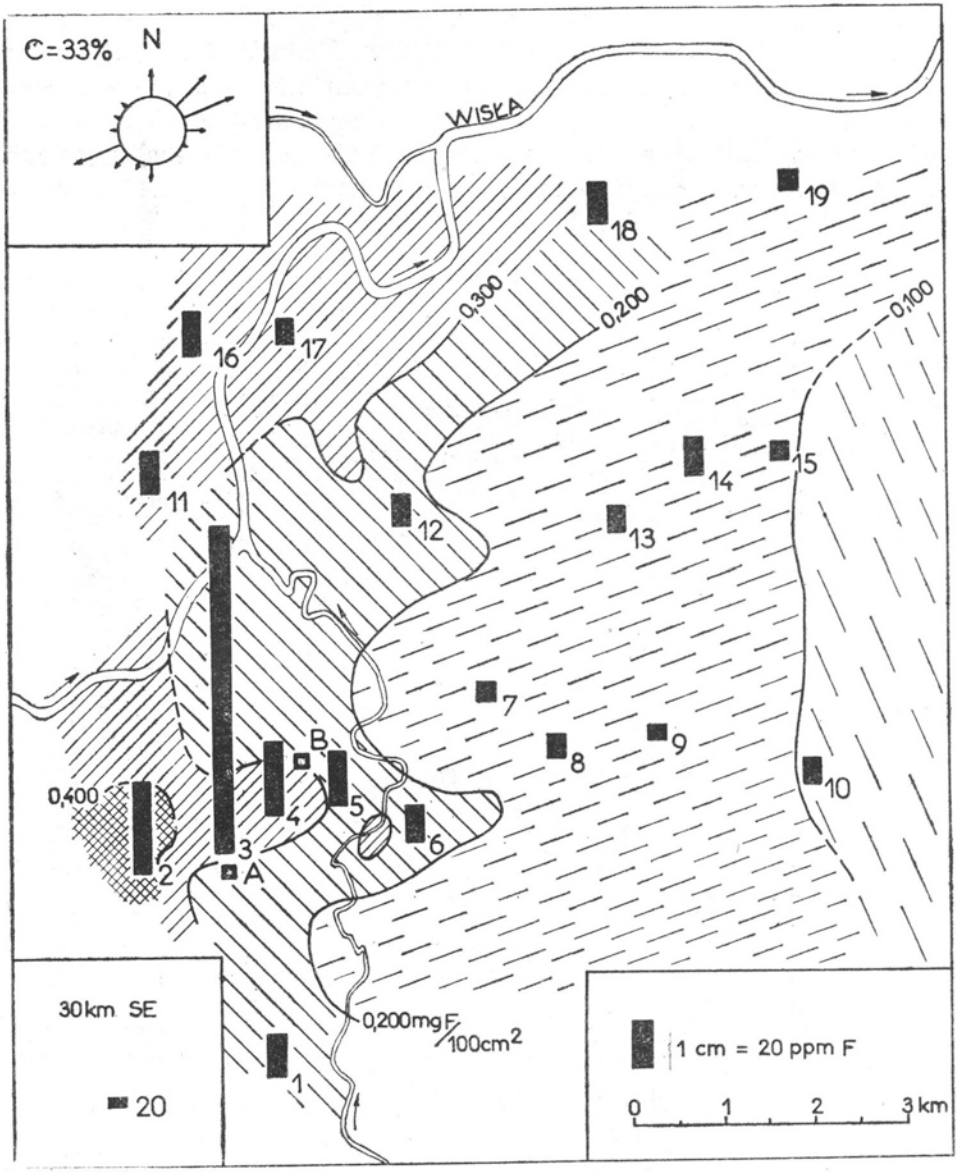

Fig. 3. Fluorine content in exposed samples (bark + lichen thallus) versus air pollution with fluorine in the given area. In left upper corner rose of winds for the period of exposure

1—20 sites of *Parmelia physodes* exposure, A — aluminium works „Skawina", B — electric power plant

A distinct negative relation is observed between fluorine content in the exposed bark discs and the remaining amount of healthy thallus. The correlation coefficient calculated for $n = 18$ reached a value of -0.4189, this indicating with a more than 90 per cent probability that fluorine exerts a noxious influence on the lichen thallus.

Total sulphur in the analysed bark samples occurs in amounts of 300 to 1440 ppm, in most samples it ranges from 500 to 940 ppm (Fig.

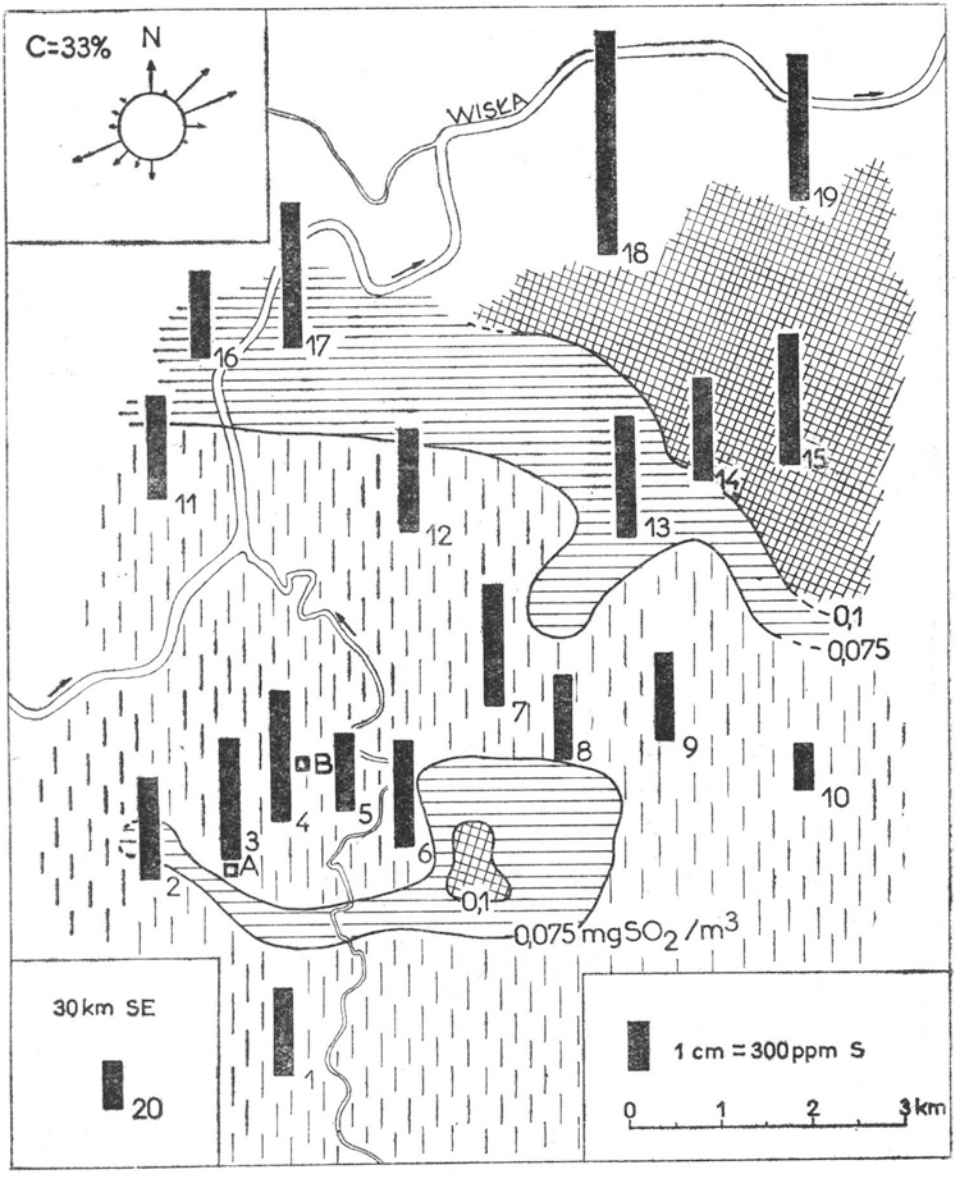

Fig. 4. Sulphur content in exposed samples (bark + lichen thallus) on the particular sites, and SO_2 concentration in the air. Legend as in fig. 3

Table 2

Frequency and velocity of winds from various direction recorded at Balice airport in the period Sept. 12 to Oct. 12, 1976

Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	C
Frequency of winds from various directions, %	7.5	1.1	10.8	12.9	5.4	1.1	—	—	4.3	2.1	4.3	10.8	2.1	2.1	2.1	—	33.4
Wind velocity m/sec	3.6	2.0	2.7	3.6	2.8	4	—	—	2.3	2	1	2.9	1.5	4	2	—	

4). A relatively high S content was found in samples exposed on sites 17, 18 and 19 lying north-east from the aluminium works "Skawina".

As in the case of fluorine, a significant negative correlation was observed between the sulphur content in bark samples and the amount of thallus with unchanged colour. The probability of the correlation of the latter two factors was still stronger, reaching a significance level $P_{0.05}$.

3. Fluorine and sulphur dioxide concentration in the air

In the period of exposure of *Parmelia physodes* (September—October, 1976) fluorine concentration in atmospheric air over the examined area varied from 0.08 to 0.38 mg/100 cm^{-2}/$month^{-1}$. On account of the lack of data from some measuring points, however, the degree of air pollution is presented in Fig. 3 on the basis of mean values for the second 6 months of 1975. It results from these data that fluorine concentration in the air was highest east and west of the source of gases emission. This high concentration also spread to the Vistula valley. On the other hand, mean sulphur dioxide concentration in the air in the same period amounted to 0.056 to 0.116 mg/m^{-3}/24 h^{-1}. Most affected by the influence of SO_2 proved to be the north-eastern part of the area under investigation, comprising a part of the city of Cracow (Fig. 4).

The distribution and concentration of fluorine and sulphur dioxide in the air are greatly influenced by winds, in the period investigated mostly north-eastern winds, with mean velocity of 3.6 m/sec, and in second place by south-western winds with a relatively high contribution of the Tatra foehn (Table 2).

4. Estimation of the degree of atmospheric air pollution on the investigated area

On the basis of the behaviour of healthy *Parmelia physodes* thallus, fluorine and sulphur content in the exposed bark samples and the F and SO_2 contents in the air, four zones were distinguished on the investigated area, with different atmospheric air quality. The distinguishing criteria are given in Table 3.

Zone I with higher air pollution with fluorine compounds comprises the nearest surroundings of the aluminium works "Skawina" (Fig. 5). Here the lichen thallus is completely destroyed before the lapse of 30 days of exposure. In bark samples from site 3, situated just outside the industrial premises, fluorine content was 141.5 ppm, and that of sulphur 840 ppm.

Table 3

Degree of preservation of uninjured *Parmelia physodes* thallus, fluorine and sulphur content in the exposed bark samples and F and SO_2 content in atmospheric air in the particular zones

Zone	I	II	III	IV
Uninjured thallus, %	0	<25	25—50	>50
Content in bark samples (ppm)				
F	<100	<20	<40	<20
S	840	>1000	<660	<780
Air contained				
F ($mg/100\ cm^{-2}/month^{-1}$)	>0.300	<0.300	<0.300	<0.200
SO_2 ($mg/m^{-3}/24\ h^{-1}$)	0.075	>0.1	0.075	<0.1

Zone II with SO_2 concentration in the air exceeding 0.1 $mg/^{-3}/24\ h^{-1}$ lies in the northern and north-eastern part of the area. After the period of exposure healthy thallus remained in only 2.3 to 21.6 per cent. The sulphur amount in the bark substrate was highest here, reaching 1440 ppm on 18 site. Fluorine content varied here from 10.8 to 18.3 ppm.

Zone III including sites 2, 5 and 6. The decisive criterion for distinguishing this zone was a higher coverage (25—46%) of the bark discs with *Parmelia physodes*, healthy thallus and a lower SO_2 concentration in the air as well as a lower sulphur content in the bark substrate than was noted in zone II.

Zone IV with a moderate air pollution, comprising the remaining part of the area examined and extending mainly on the southern and eastern side of the aluminium works. In this zone the thallus with unchanged colour was preserved in 60-81 per cent. Here, it is mainly sulphur dioxide, occurring in a concentration reaching 0.1 $mg/^{-3}/24\ h^{-1}$, that is noxious. Hence in some bark samples the content of sulphur was 780 ppm, whereas that of fluorine varied within 6.3 — 15.6 ppm.

DISCUSSION

Parmelia physodes grows on the bark of deciduous and coniferous trees, on old pieces of wood and thatched roofs, both on the lowland and in the mountains (Tobolewski, 1972). In spite of its wide spread, in recent years a successive disappearance of this lichen from previously occupied sites is observed as the concentration of noxious substance increases in the air (LeBlanc, 1968; Lundström, 1968; Rose, 1970). *Parmelia physodes*, namely, as shown by experimental investigations (Guderian, Schönbeck, 1971; Börtitz, Ranft, 1972; Ranft, Dässler, 1972), is a species sensitive to sulphur dioxide. Therefore, it is used more and more frequently in biological tests (Holub, Kontrišová, 1973, Kaleta, 1973; O'Hara, 1974). The area

on which the investigations were performed is under the influence of fluorine compounds emitted mainly by the aluminium works "Skawina" and sulphur dioxide from the electric power plant. Moreover, in the north-eastern part of the area the air is polluted by other industrial plants situated within the city of Cracow.

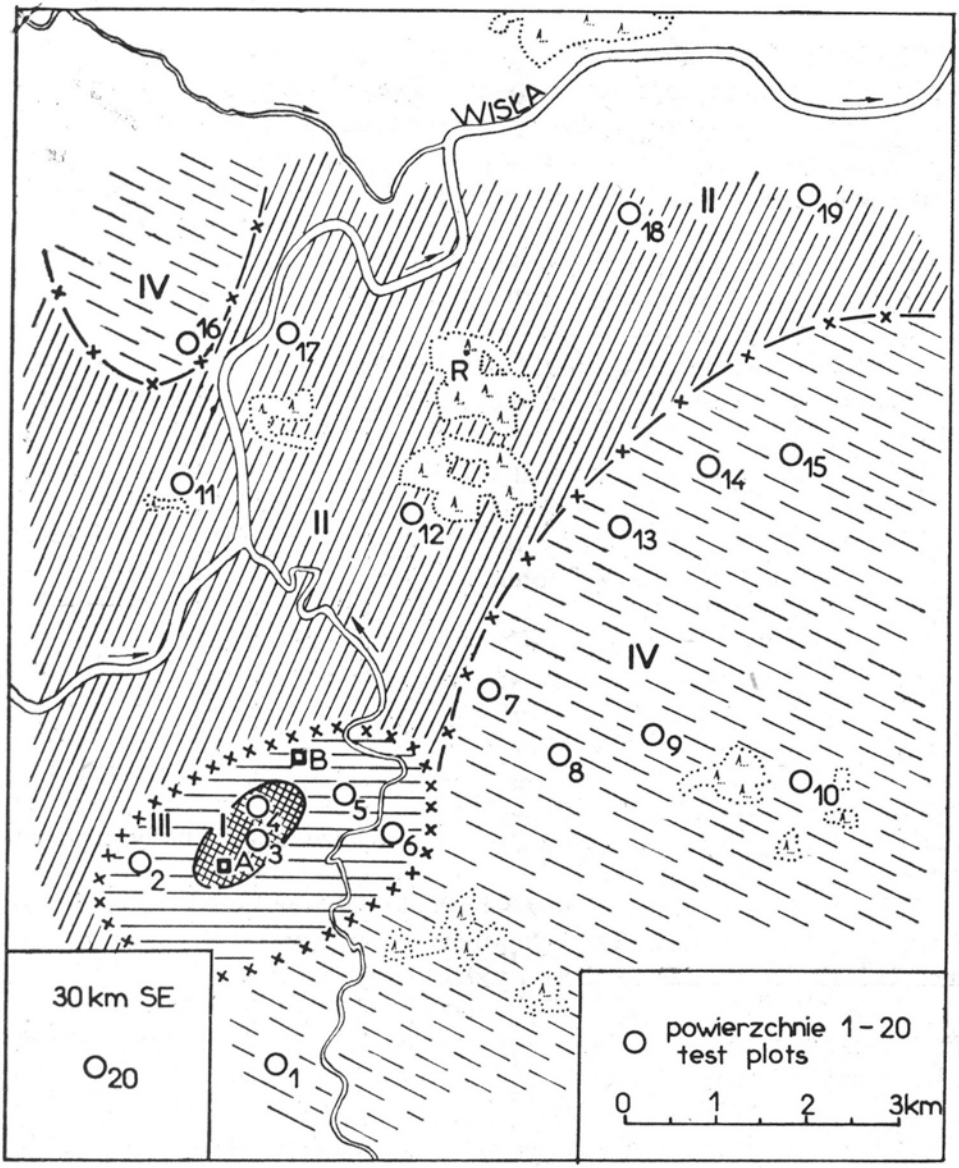

Fig. 5. Zones of various atmospheric air quality delineated on the basis of the result of investigations

1—20 — sites of *Parmelia physodes* exposure, I—IV — zones of atmospheric air quality, A — aluminium works „Skawina", B — electric power plant, R — floristic reservation „Skołczanka".

The spatial distribution of fluorine compounds in atmospheric air depends largely on the velocity and prevailing direction of the winds and on the terrain relief. Therefore, the highest fluorine concentrations occur in the close neighbourhood of the emission source and in the Vistula valley. On the other hand, the sulphur dioxide content in the air seems to be dependent on north-eastern winds which carry SO_2 from other areas.

The bark discs with *Parmelia physodes* were exposed to the joint action of both noxious substances. The degree of damage to the thallus is, therefore, mainly dependent on their concentrations in the atmospheric air. Other ecological factors, namely, such as temperature and moisture exerted but a slight influence on the transplanted *Parmelia physodes*. This is confirmed by the control result where the mean covering of the bark discs with healthy thallus was after 30 days of exposure 96.33 per cent.

The lichen thallus, as demonstrated by the experiment of Pearson and Skye (1965), may preserve its viability in dry but clean air for a period of 6 — 9 months. In city air polluted with sulphur dioxide, and hydrofluoride in the neighbourhood of the aluminium works the plants die within several weeks.

Both fluorine and sulphur dioxide are toxic for lichens even in very low concentrations. Under the experimental conditions, *Parmelia physodes* was injured by 0.002 ppm hydrofluoride and the lethal concentration of SO_2 for the lichen is below 0.018 ppm (Barkman, 1968). Thus the sensitivity of the lichen to these two gases is different.

Fluorine is an agent which plays no role in the physiological processes of plants. Therefore, it is deposited, and when its concentration becomes toxic to the given species it injures the cells. An external symptom of injury is necrosis. The dead part of the thallus shrinks and becomes detached from the substrate and falls off. In this way the surface covered by the lichen diminishes in size until finally nothing remains (LeBlanc et al., 1971).

Sulphur dioxide affects lichens both directly and indirectly in the form of sulphuric acid. The symptoms of injury to the thallus are morphologically similar to those produced by fluorine.

The direct influence of sulphur dioxide is usually of short duration, first because this gas is chemically not stable and is rapidly oxidized, and secondly because its toxic influence is manifested only when the thallus is fresh. Lichens in dry state, when metabolism ceases and gas exchange diminishes, are not damaged by sulphur dioxide (Wirth, Lange, 1974; Türk, Wirth, 1975).

The exceptional susceptibility of lichens to sulphur dioxide is explained by some authors (Barkman, Rose, Westhoff, 1968) by their specific structure based on the symbiosis of an alga with a fun-

gus. Under experimental conditions the isolated algal component on the lichen is more sensitive than the fungus. Therefore, air pollution acting on the lichen thallus causes above all physiological changes in the algal component, and in this way disturbs the delicate symbiotic equilibrium between the alga and the fungus, causing death of the whole organism.

The indirect influence of sulphur dioxide on lichens is the result of action of sulphuric acid. The high emission of sulphur compounds in towns and industrial districts produces a rise of H_2SO_4 content which, in turn, increases the acidity of the natural medium. Thus, acidophilicity, beside the presence of sulphur dioxide, is at present a common toxic factor exerting a destructive influence on lichen development (S k y e, 1968). Lichens, namely, in contrast to higher plants, are exposed to the direct action of acid precipitation since they absorb it with the whole surface of the thallus.

Complete destruction or considerable loses in thallus of *Parmelia physodes* after exposure to air pollution, due both to the influence of toxic and mechanical factors, made it impossible to determine fluorine and sulphur content in the lichen. Therefore, the bark discs were subjected to chemical analysis, notwithstanding the degree of their coverage with thallus. The results demonstrated wide differences in fluorine and sulphur content in the particular samples in dependence on the site of exposure. A significant correlation at a $P_{0.05}$ and $P_{0.10}$ level was found between the behaviour of thallus and the quantity of F and S in the bark substrate.

Although it is not possible by the method of transplantation of *Parmelia physodes* thallus, to distinguish the effect of fluorine and of SO_2, when they occur jointly in polluted air, however, on the basis of results of chemical analyses, it may be assumed that in zone I the agent mainly responsible for the damage to the thallus, is fluorine and in zone II it is sulphur dioxide. On the other hand, in zone III both gases had a noxious effect on *Parmelia physodes,* the influence of fluorine, on account of its high toxicity, beeing seemingly stronger. Air pollution in zone IV is lowest and allows the thallus to thrive in good health in 60 — 81 per cent. On some sites, however, a relatively high sulphur content was found in the bark samples, this allowing conclusions as to the toxicity of sulphur dioxide to the exposed samples. It is, therefore, to be expected that in the nearest future the limit of zone IV will shift further to the south-east in connection with the continuing increase of SO_2 emission.

CONCLUSION

The following conclusions may be drawn from the investigations performed:

1. The method of *Parmelia physodes* thallus transplantation may

be used as a biological test for determination of the degree of atmospheric air pollution on areas affected by industrial gas emission the year round. By this test the cumulated influence of this pollution on the plant organism in a given time period may be demonstrated.

2. Complete destruction of the lichen thallus occurring in the case of high concentrations of the toxic gases causes the thallus to dry up and its detachment from the substrate by wind. The absence of thallus on the bark discs diminishes in some degree the fluorine and sulphur contents in the given sample, although the gases are also accumulated mechanically. Therefore, the period of lichen exposure should be established in dependence on the kind of emission source and the expected concentration of the noxious substances in the air.

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Zastosowanie porostu Parmelia physodes (L.) Ach. jako wskaźnika do określenia stopnia zanieczyszczenia powietrza atmosferycznego w zasięgu oddziaływania emisji związków fluoru i dwutlenku siarki

Streszczenie

Do oceny stopnia zanieczyszczenia powietrza atmosferycznego przez dwutlenek siarki i związki fluoru zastosowano jako biotest porost epifityczny *Parmelia physodes* (L.) Ach.

Próby plechy porostu wraz z substratem korowym wycinano metalowym przyrządem (ryc. 1) z pni jodły pospolitej i transplantowano na drewniane tabliczki (ryc. 2). Następnie tabliczki te rozmieszczono na 20 stanowiskach (ryc. 3, 4 i 5) i eksponowano przez 30 dni.

Stopień zniszczenia plechy porostu na poszczególnych stanowiskach oceniano w porównaniu ze stanem wyjściowym utrwalonym na fotografii. Uzyskane wyniki przedstawiono w tabeli I.

Zawartość fluoru oraz siarki ogólnej w eksponowanych krążkach kory wykazywała duże zróżnicowanie (ryc. 3 i 4), w zależności od położenia danego stanowiska w stosunku do źródła emisji tych gazów.

Rozkład stężeń fluoru i dwutlenku siarki w powietrzu (ryc. 3 i 4) uzależniony był od przeważających kierunków wiatru, rzeźby terenu oraz, zwłaszcza w przypadku SO_2, nakładania się emisji innych zakładów przemysłowych.

W okresie przeprowadzonych badań najczęstsze były wiatry z sektora północno-wschodniego o dużej prędkości, a następnie z sektora południowo-zachodniego, przy znacznym udziale wiatrów halnych (tab. II).

Na podstawie zachowania zdrowej plechy porostu po ekspozycji, zawartość F i S w krążkach kory oraz stężenia F i SO_2 w powietrzu (tab. III) wykreślono strefy o różnej szkodliwości oddziaływania zanieczyszczonego powietrza na *Parmelia physodes* (ryc. 5).