ZAKŁAD OCHRONY PRZYRODY I ZASOBÓW NATURALNYCH POLSKIEJ AKADEMII NAUK

1987 STUDIA NATURAE — SERIA A NR 31

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Degradation of pine forest *Vaccinio myrtilli-Pinetum* vegetation under the influence of zinc and lead smelter

Przekształcenia roślinności boru sosnowego *Vaccinio myrtilli-Pinetum* w zasięgu oddziaływania huty cynku i ołowiu w Bukownie koło Olkusza

Abstract

This paper describes the effect of the „Bolesław" mining and metallurgic complex in Bukowno near Olkusz on the vegetation of the fresh coniferous forest association *Vaccinio myrtilli-Pinetum*. The increase in concentration of zinc, lead and cadmium in selected plant species under the influence of industrial emission, and the dependence of this increase upon the magnitude of dust fall and site conditions, are analized. The extent of accumulation of heavy metals in plants was assumed to be an indicator of the degree of pressure exerted by the industrial complex. The degradation of fresh coniferous forest was increasing along with an increase in this pressure. The species composition of the association, and the quantitative relations among species representing various site types underwent considerable changes. In patches extremely degraded, the plant species characteristic of poor sandy grass-lands gained predominance over forest plants.

I. Introduction and objective of the study

For ages the activity of man was a cause of changes in vegetation cover of Poland, resulting in replacing over large areas a natural vegetation with crops and seminatural plant communities. Such direction of changes was forced by an agricultural character of the economy, and it persisted in Poland almost to the end of XIX-th century. A rapid, and to a great extent uncontrolled with respect to side effects, development of industry in the last several score years caused threat to vegetation cover on previously unknown scale as to the degree

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of damage and area involved. The increasing urbanization of the country, as well as a spontaneous development of motorization connected with crowding and extension of road network also participated in vegetation degradation over large areas.

The threat to plants concerns various organizational levels, beginning with disturbances in physiological processes, changes in chemical composition of tissues and external injuries, through disapearance of certain plant species in some localities and extinction of susceptible species, and ending with degradation and extinction of whole plant communities as it occurs in most affected areas.

It is attempted in this paper to present some of the problems connected with the influence of zinc and lead smelter on vegetation. The smelter is located in Bukowno near Olkusz, in the Silesia-Kraków Industrial District. The vegetation in this area remains under the effect of various unfavourable factors, such as fallout of the industrial dusts containing toxic components, immision of urban dust, pollution of air with automobile exhausts and gaseous toxic substances of industrial and urban origin, drying up of soils, increased penetration of people and live-stock, various economic activities, and many other factors of lesser importance.

The air pollution and drying up of sites, due to a general water deficit, are undoubtedly the most serious problems. The air pollution with gases and dusts not only directly injures the plants and disturbs the basic metabolic processes, physically and biochemically, but also indirectly degrades the vegetation cover through unfavourable changes in soil and meso- and microclimate. Out of various components of emissions, the substances toxic to plants, such as sulphur dioxide, carbon monoxide, nitric oxides and heavy metals, mainly lead, zinc and cadmium, are most active.

In the area of influence of „Bolesław" smelter many studies recording its destructive effect on natural environment have already been completed. They concerned the abiotic environment and selected components of plant and animal world (Dorling msc., Kaźmierczakowa 1975, Kaźmierczakowa, Rams 1974, Makomaska msc., Pasternak 1973, 1974, Rybicki 1968, Sawicka-Kapusta 1977, Świeboda 1977, 1978, 1980, Wąchalewski et al. 1975, 1978).

The studies presented in this paper concerned the forest communities. Out of many effects of air pollution on structure and function of a forest ecosystem the following two have been selected: accumulation of heavy metals, which are the main components of dust emissions of the smelter concerned, in selected plant species, and qualitative and quantitative changes in floristic composition occurring in the fresh coniferous forest type upon the activity of the smelter. The degree of contamination of plants with haevy metals was used as an index of intensity of emission's effect. In order to compare the degree of contamination of forest plants with those of other site types, selected plant species growing on sandy waste lands were also analized. The analyses of plants from the ex-

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perimental plots served to determine the speed of the process of contamination of plants and soil.

I would like to thank Dr. H. Piękoś-Mirkowa for the identification and the verification of identification of some vascular plant species, Dr. R. Ochyra for the identification of mosses and lichens, Dr. E. Kotejowa, assistant professor, for helpful discussion, and Dr. Z. Poznańska for help in field work.

II. Detailed location and scope of the investigations

The pine forests from vicinity of Bukowno situated on the boundary of Kraków-Częstochowa Upland and Silesian Upland were the object of this study. Once, they dominated over this area, and today they are still quite frequent. Analized forest patches constituted fragments of *Vaccinio myrtilli-Pinetum* association, which have been deformed to a various degree due to many unfavourable facts connected with man's activity.

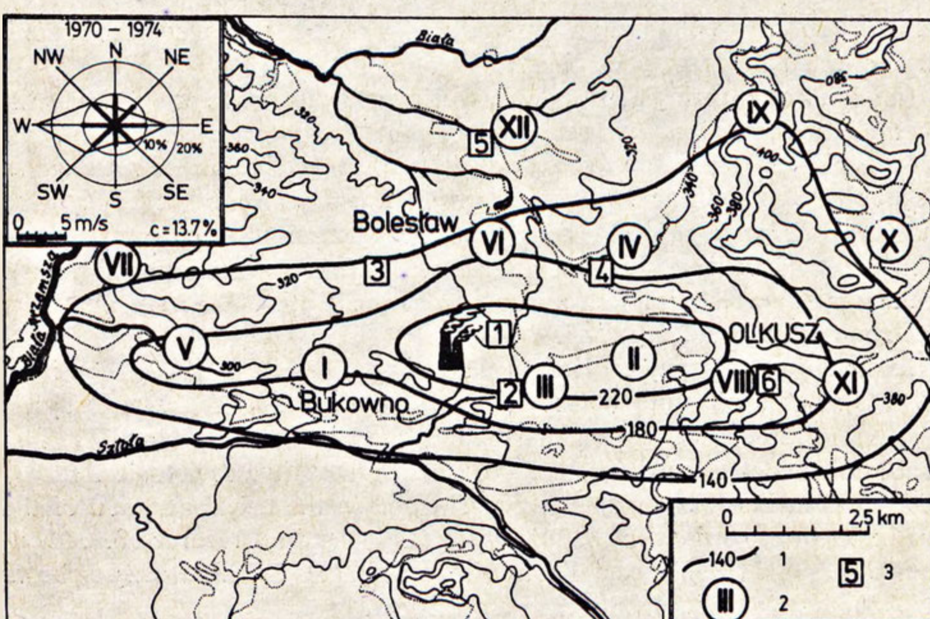

Fig. 1. Location of study areas and experimental plots: 1 — main emission source, 2 — approximate total dustfall, 3 — study areas, 4 — experimental plots. In the left upper corner — wind rose, c — calm

Ryc. 1. Lokalizacja powierzchni badawczych i poletek doświadczalnych w terenie badań: 1 — główne źródło emisji, 2 — przybliżony ogólny opad pyłu, 3 — powierzchnie badawcze, 4 — poletka doświadczalne. W lewym górnym rogu — róża wiatrów, c — cisza

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There were 12 areas situated in a distance of 1.25 to 8.5 km from the „Bolesław" smelter, a main source of emission toxic to plants in this area, selected for this study (fig. 1). Their location was adjusted to the distribution of dustfall measuring stations operating during the period 1969—71. The control data concerning the concentration of heavy metals in plants were obtained from two control areas, of which the I-st was situated approximately 20 km away in north-eastern direction, on the boundary of the Silesia-Kraków Industrial District, and the II-nd approximately 60 km away in the same direction, on Jędrzejów Plateau. This region belongs to the least polluted areas in Southern Poland.

Each of the area, mentioned above, comprised a patch of pine forest and also a sandy treeless site, a waste land. The latter ones constituted fragments of sandy grassland of the order *Corynephoretalia*, open sands without vegetation, or sandy fallows.

The following herbaceous plant species were collected in forest sites (total number of collected samples is given in brackets; not all of the species occurred in each area): *Deschampsia flexuosa* (L.) Trin. (41), *Vaccinium vitis-idaea* L. (35) and its fruits (4), *Vaccinium myrtillus* L. (33), *Arabis arenosa* (L.) Scop. (24), *Thymus serpyllum* L. (13), and *Viola tricolor* L. (7). The species collected in sandy waste were as follows: *Arabis arenosa* (21), *Thymus serpyllum* (14), and *Viola tricolor* (9). Simultaneously, samples of soil from plants' root zone were collected in both types of site.

In addition, in spring of 1972, six experimental plots were established with soil brought from a sandy waste land of the I-st control area. The control plot was also established in the I-st control area. These plots were rectangular in shape 1 × 3 m, and the depth of soil brought to them was 30 cm. They were planted with *Thymus serpyllum* seedlings collected from place of average dustfall. These plants were dug out after three growing seasons (2 1/2 years). At the same time soil samples were collected from depth of 0—3 cm, and from root zone of *Thymus serpyllum*.

In pine forests the phytosociological survay was conducted, which consisted of 2 or 3 records taken in places from which plants were collected for analyses. In order to evaluate changes which had taken place in *Vaccinio myrtilli-Pinetum* association under intense effect of the smelter, the phytosociological survey records taken in Góra Chełm reserve, situated in the neighbourhood of the area under investigations, by S. Michalik (1981), and the records of A. Medwecka-Kornaś (1952) in the Kraków's Jura (part of Kraków-Częstochowa Upland) completed in 1948—49, were utilized.

The field studies were conducted in 1970—74, and supplementary field observations were continued till 1977. Plants and soil from forests and sandy waste lands were collected during a growing season of 1972. *Thymus serpyllum* and soil from experimental plots, established in spring of 1972, were collected in the autumn of 1974.

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III. Characteristics of selected environmental elements in the study area

Soils. The land tract under investigations comprised by and large the area covered with sands of glacial origin. They form a layer, several dozen meters deep in some places, situated over old Triassic formation such as Muschelkalk and dolomites. Sometimes limestones and dolomites come to the surface, or they are covered with a thin layer of sand only (Lancewicz, Kondracki 1964).

Slightly loamy podzolic soils prevail in this area. There are loose shifting sands in some places. Small areas are occupied by carbonate rendzinas, developed in places where limestone rocks come to the surface from under the sand layer. Slightly larger areas are occupied by brown podzolic soils formed from loamy sands (Strzemski 1954, Mapa gleb Polski, 1961).

The forests mainly survived on poor podzolic soils. This soil type was represented in all study areas.

Water relations. These sites, poorly supplied with nutrients, were also deficient in water. Ground water table was at the depth of several or sometime of several dozen meters. The water relations are getting worse all the time in connection with zinc and lead ore exploitation of long tradition. Drying up of this area have distinctly intensified during the last several years due to the establishment of new, and expansion of old mines. Changes in water relations caused by industrial activities covered a considerable percentage of investigated area. In 1968, drainage crater of the mine, 3—4 km wide, in shape of elongated ellipse constricted in the middle, stretched over 15 km from east to west (Rybicki 1968). It may be supposed that area drained by the mine had increased during the subsequent years.

Climate. The study area is situated within Silesia-Kraków climatic region belonging to climates of Central Uplands (Romer 1949). The climate of this region has some continental traits, such as high mean annual amplitude of air temperature, quite high amount of precipitation during the summer, and relatively high number of frosty days during the year.

Long term average total annual precipitation is 726 mm (data from Olkusz station). The maximum precipitation is in July (113 mm), and minimum in February (38 mm). During so called main season of plant development, comprising the period from May to July, the precipitation amounts to 35% of annual total, while the summer half of the year covers 2/3 of total annual precipitation (Gumiński 1950). The value of this precipitation distribution, favourable for plants, is lowered however by the fact that considerable quantity of precipitatin falls in form of torrential rains (Schmuck 1959), which at very pervious substratum brings only temporary improvement of water relations in soil. This is also confirmed in a relatively low air humidity in Silesia-Kraków climatic region, calculated from the difference between precipitation and evaporation (Schmuck 1959).

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Mean annual temperature in the study area is 7.1°C. July is a warmest month (mean temperature 17.6°), and February a coldest one (—3.0°). The growing season lasts for 207 days, 4 April to 30 October, on the average. The late spring frosts usually occur on 7 May, but they may take place as late as 2 June (Gumiński 1950). The average number of frosty days is 40 to 50 annually (Milata 1953).

The wind is one of climatic factors which strongly effect the distribution of air pollutants, and this is why the wind conditions in the area under investigations should be discussed in detail. The data on direction and mean wind velocity during 1970—74 showed that westerly winds prevailed, since 24% of all winds were blowing from the west, and the winds from SW, W and NW jointly amounted to over 47% (fig. 1). The easterly winds were also quite frequent — about 15% on the average. Calms were rare, and they comprised about 14% of all measurements.

The westerlies were not only most frequent winds but they also had highest velocity. The winds from the west were blowing with mean velocity of 3.38 m/sec., from north-west 3.16, from south-west 3.03, and from the east 3.11 m/sec.

Air pollution. A toxic air pollution is undoubtadly a strongest factor affecting the vegetation in the investigated area, situated in a direct neighbourhood of large mining and metallurgic complex.

In spite of the fact, that air pollutants originated from various sources, the principal role was played by the emission of the smelter itself, as to the amount and content of heavy metals. According to data published by Ząbczyński (1970) the „Bolesław" complex emitted approximatelly 12 000 tons of dust and gases annually during the years preceding this study. The composition of emission in that period is shown in table I. In the later period the emission was considerably reduced thanks to the installation of highly efficient filters (comp. Wąchalewski et al. 1975).

Approximate, general picture of the imission in this area is shown in fig. 1. Central position is occupied by the industrial complex, around which the dustfall reaches 250 tons per square kilometer annually. Urban and industrial emission of the town of Olkusz contributes somewhat to the total dustfall (comp. study area IX in fig. 1). It seems that dustfall originating from all other sources, with an exception of Olkusz, makes a more or less uniform background distinctly overlapped by high industrial emission of the „Bolesław" complex.

Distribution of pollutants depends on wind conditions. The dustfall along main wind directions, western and eastern, was as much as 150 t/km^2/ year 6 kilometers away from the main source. A distinct effect of emission of the complex along these directions is still visible as far as 8 km away from the source, while the range of this influence is much smaller in northern and southern direction. Further away, e. g. in the I-st control area, situated 20 km from the smelter, the annual dustfall was 92 t/km^2. Similar emission exists

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TABLE I

Emission of dusts and gases from „Bolesław" Mining and Metallurgic Complex (according to Ząbczyński 1970)
Emisja pyłów i gazów z Kombinatu Górniczo-Hutniczego „Bolesław" (wg Ząbczyńskiego 1970)

Substance Substancja	t/year t/rok
Non-toxic dust Pył nietoksyczny	1 755
Zinc Cynk	1 260
Lead Ołów	329
Cadmium Kádm	13,7
Sulphur dioxide Dwutlenek siarki	8 860
Sulphuric acid Kwas siarkowy	53,8
Arsenous hydride Arsenowodór	0,945
Total Razem	12 072,445

TABLE II

Percentage of selected chemical elements in dustfall from the vicinity of „Bolesław" Mining and Metallurgic Complex (according to Dorling msc.)
Udział procentowy wybranych pierwiastków w imisji w okolicy Kombinatu Górniczo-Hutniczego „Bolesław" (wg Dorling, msc.)

	Ca	Mg	Fe	Na	K	Zn	Pb	Cd	Cu	Co
Soluble part Część rozpuszczalna	9,3	1,05	0,08	0,81	1,50	10,5	0,60	0,11	0,042	0,0005
Insoluble part Część nierozpuszczalna	2,4	0,15	1,85	0,45	2,25	2,6	0,82	0,05	0,037	0,0002

in large areas located at the edge of Silesian Industrial District (Skawina, Wąchalewski 1965).

The chemical composition of complex's dust was analized by Dorling (msc.). The dust collected at a distance of 1 km south of the complex contained 53% of soluble and 47% of insoluble components (table II). The insoluble

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part consisted mostly of very fine dust in which diameter of 80% of grains was under 4 μm. Oxides of silicon, zinc, iron and aluminum, and calcium sulphate and zinc sulphide dominated in this part. The soluble part contained mainly hydrated sulphates of calcium, zinc and magnesium.

During an analysis of the potentially toxic heavy metals present in the emission the attention should be payed to a large quantity of zinc compounds which are easily transferred to water solution. Also the concentrations of lead and cadmium were relatively high, and over 40% of lead and about 70% of cadmium present in imission formed water soluble compounds.

Soil pollution. Long term fallout of many various chemical compounds within the study area resulted in a serious soil modification. Poor sandy soils are very susceptible to changes and are easily altered. According to detailed studies of Warda (msc.) in poor sandy soils a considerable percentage (nearly 35%) of lead remains in assimilable form.

Due to fallout of large quantity of base-forming compounds, including metal oxides, a considerable soil alkalization took place in the area under investigations. Soils of fresh coniferous forest which normally are strongly acid, show here increased reaction sometime even above $pH_{H_2O} = 7$ (Wąchalewski et al. 1975, comp. also chapter 5 of this paper). Changes in soil reaction indicate unsettled balance of soil biochemical processes. Also a set-back in humification and mineralization of organic matter has been observed here, similarly as in other areas remaining under influence of high imission of toxic industrial dusts (Hajduk 1961, Skawina 1967, Kaleta 1969).

As it has been reported many times, the fallout of large quantity of industrial dust results in accumulation in soil of some chemical elements present in the imission. This particularly concerns the heavy metals which most frequently accumulate in topsoil (Skawina, Wąchalewski 1965, Skawina 1967, Greszta, Godzik 1969, Sapek, Skłodowski 1976, Skłodowski, Sapek 1977, Warda 1976, Marczak, Biedroń 1976, 1978 and many others). The studies of Wąchalewski et al. (1975, 1978), as well as Kowalkowski and Szczubiałka (1981) showed, that total content of zinc, lead and cadmium in forest soils near the „Bolesław" complex is very high, many times higher than normal content in unpolluted soils. Compounds of these metals accumulated mainly in forest litter and topsoil.

IV. Methods

Plant samples collected for chemical analyses consisted of several or several dozen specimens of a given species. The plants were washed under strong current of tap water, rinced twice in distilled water, and then divided into overground portions and root systems. In case of *Vaccinium vitis-idaea* the fruits were also separated. The plant material was partly dried, homogenized and further dried in 105°C to obtain a constant weight. Then, 1 g samples

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were burned in 500°C. Ash was dissolved in 20% HCl under increased temperature. After filtration a redistilled water was added to solution to obtain 100 ml of liquid. The concentration of lead and zinc in a solution was determined utilizing „Spekol" calorimeter of Zeiss production. The plant samples collected in sample plots were analized in Varian Techtron spectrophotometer Model 1000.

Assimilable and total content of investigated metals in soil was also determined using spectrophotometer mentioned above. A soil sample of 1 g was burned in Kieldahl burner in 60% $HClO_4$. The sample was heated to decolourization, and after cooling, 10 ml of redistilled water was added. Then it was heated again to the boiling point. The hot solution was filtrated to 50 ml flasks and supplemented with redistilled water. The content of assimilable metals in soil was determined using 0.05 M solution of EDTA salt. Suspension of 20 g of soil in 50 ml of solution was shaken for 1 hour and then filtrated. The determination was made directly in a filtrate.

The remaining soil analyses were accomplished using standard methods. The phytosociological survey was completed according to Braun-Blanquet method commonly used in Poland (Pawłowski 1972). The names of vascular plants are given according to the identification key „Rośliny polskie" (Szafer, Kulczyński, Pawłowski 1967), those of mosses according to the identification keys „Mchy" v. I and II (Szafran 1957—61). The rank of species in the phytosociological system is given after Matuszkiewicz (1981).

V. Results

1. Accumulation of lead and zinc in plants and its dependence on environmental conditions

The analyses showed a very high accumulation of these two components of emission of „Bolesław" industrial complex in plant tissues. The size of accumulation was dependent on imission of dusts. However, at the same total dustfall there were distinct differences in lead and zinc concentration depending on plant species, portion of a plant, and also site conditions (comp. table III). In most cases the extent of these differences was increasing with increasing degree of environmental pollution.

The maximum, minimum and average concentration of lead and zinc in plants collected within the radius up to 8.5 km from the smelter were compared with concentration of these metals in plants collected in two control areas, I-st app. 20 km, and II-nd app. 60 km north east of the emission source (table III). The mean lead concentration in plants near the smelter was from eight to thirty times higher, depending on species, portion of plant and environment, than in plants from the II-nd (further away) control area. The maxi-

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TABLE III

Lead and zinc content in plants (ppm dry mass) collected around the industrial „Bolesław" complex and in control plots

Zawartość ołowiu i cynku w roślinach (ppm s. m.) zebranych wokół kombinatu „Bolesław" i na powierzchniach kontrolnych

Species Gatunek	Environment Środowisko	Plant's portion Część rośliny	Pb content Zawartość Pb					Zn content Zawartość Zn				
			1,25—8,5 km from Complex 1,25—8,5 km od Kombinatu			20 km	60 km	1,25—8,5 km from Complex 1,25—8,5 km od Kombinatu			20 km	60 km
			highest najwyższa	lowest najniższa	mean średnia	mean średnia	mean średnia	highest najwyższa	lowest najniższa	mean średnia	mean średnia	mean średnia
Arabis arenosa	pine forest bór sosnowy	above-ground nadziemna	291	51	142	—	—	3800	800	1671	—	—
		underground podziemna	940	153	440	—	—	3100	500	1444	—	—
	sandy waste land nieużytek piaszczysty	above-ground nadziemna	210	76	139	—	—	3275	520	1240	—	—
		underground podziemna	695	113	269	—	—	1870	340	927	—	—

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	pine forest bór sosnowy	above-ground nadziemna	259	67	139	—	11	1530	560	918	—	510
		underground podziemna	1100	304	522	—	88	2000	560	1082	—	440
Viola tricolor	sandy waste land nieużytek piaszczysty	above-ground nadziemna	178	59	110	38	—	2040	520	920	560	—
		underground podziemna	610	234	405	240	—	1800	440	948	380	—
	pine forest bór sosnowy	above-ground nadziemna	420	100	218	50	—	2245	464	1021	488	—
		underground podziemna	950	165	380	112	—	1710	473	1151	276	—
Thymus serpyllum	sandy waste land nieużytek piaszczysty	above-ground nadziemna	370	107	168	122	22	1350	314	652	520	52
		underground podziemna	537	32	222	122	12	2090	308	920	432	30
Vaccinium vitis-idaea	pine forest bór sosnowy	fruits owoce	17	7	13	—	—	73	20	38	—	—
		above-ground nadziemna	294	32	105	34	—	680	130	314	134	—
		underground podziemna	832	50	250	41	—	1380	160	585	135	—
Deschampsia flexuosa	pine forest bór sosnowy	above-ground nadziemna	326	39	118	30	5	940	122	405	174	104
		underground podziemna	365	38	159	47	19	1400	295	678	323	160
Vaccinium myrtillus	pine forest bór sosnowy	above-ground nadziemna	235	20	96	44	10	830	122	389	258	26
		uderground podziemna	620	12	117	37	12	610	70	288	143	26

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TABLE IV

Coefficient of linear correlation between emission size (up to 20 km from source) and lead concentration in plants, and between emission size and zinc concentration in plants

Wartość współczynnika korelacji prostoliniowej między wielkością imisji (do 20 km od źródła emisji) a zawartością ołowiu w roślinach oraz między wielkością imisji a zawartością cynku w roślinach

Species Gatunek	Environment Środowisko	Plant's portion Część rośliny	Number of samples Liczba prób	Coefficient of correlation r Współczynnik korelacji r	
				Pb/total dustfall Pb/ogólny opad pyłu	Zn/total dustfall Zn/ogólny opad pyłu
Arabis arenosa	pine forest bór sosnowy	above-ground nadziemna	24	0,669***	0,641***
		underground podziemna	24	0,572**	0,658***
	sandy waste land nieużytek piaszczysty	above-ground nadziemna	21	0,444*	0,743***
		underground podziemna	21	—0,119	0,606**
Viola tricolor	pine forest bór sosnowy	above-ground nadziemna	5	0,951*	0,874
		underground podziemna	5	0,950*	0,902*
	sandy waste land nieużytek piaszczysty	above-ground nadziemna	9	0,771*	0,676*
		underground podziemna	9	0,563	0,758*
Thymus serpyllum	pine forest bór sosnowy	above-ground nadziemna	13	0,500	0,472
		underground podziemna	13	0,439	0,550
	sandy waste land nieużytek piaszczysty	above-ground nadziemna	13	0,730**	0,516
		underground podziemna	13	0,327	0,172
Vaccinium vitis-idaea	pine forest bór sosnowy	above-ground nadziemna	35	0,702***	0,803***
		underground podziemna	35	0,787***	0,853***
Deschampsia flexuosa	pine forest bór sosnowy	above-ground nadziemna	38	0,595***	0,630***
		underground podziemna	38	0,586***	0,675***
Vaccinium myrtillus	pine forest bór sosnowy	above-ground nadziemna	30	0,578***	0,596***
		underground podziemna	30	0,508**	0,726***

* p>0.05,
** p>0.01,
*** p>0.001

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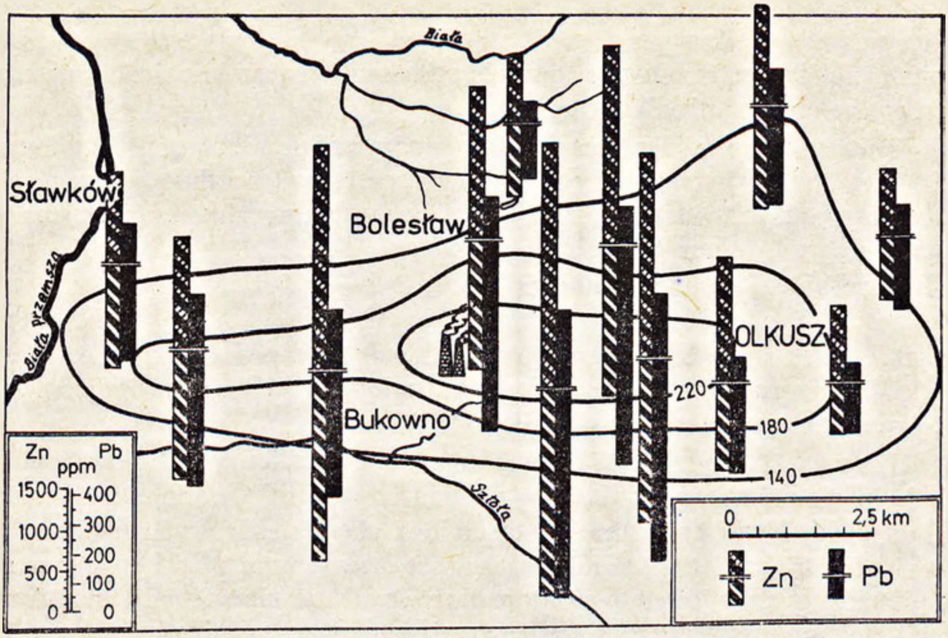

Fig. 2. Mean lead and zinc concentration in *Arabis arenosa* growing in pine forests: 1 — lead content in above-ground parts of plants, 2 — lead content in underground parts of plants, 3 — zinc content in above-ground parts of plants, 4 — zinc content in underground parts of plants

Ryc. 2. Średnia zawartość ołowiu i cynku w *Arabis arenosa* rosnącej w borach sosnowych: 1 — zawartość ołowiu w nadziemnych częściach roślin, 2 — zawartość ołowiu w podziemnych częściach roślin, 3 — zawartość cynku w nadziemnych częściach roślin, 4 — zawartość cynku w podziemnych częściach roślin

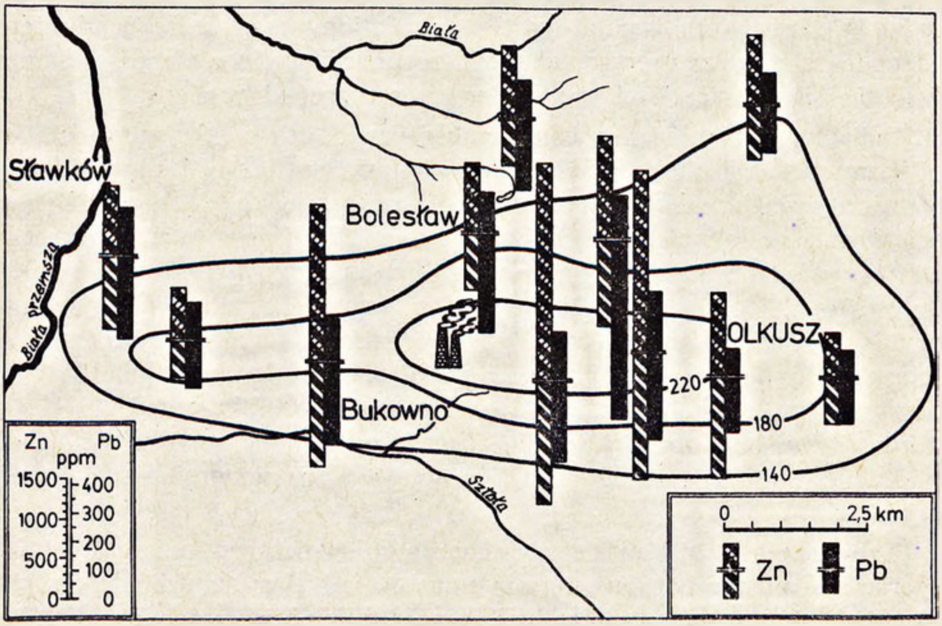

Fig. 3. Mean lead and zinc concentration in *Arabis arenosa* growing on sandy waste lands. Explanations as in. fig. 2

Ryc. 3. Średnia zawartość ołowiu i cynku w *Arabis arenosa* rosnącej na piaszczystych nieużytkach. Objaśnienia jak na rycinie 2

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mum values were from twelve to seventy times higher than in a similar material from the area relativelly clean.

The analogous differences in zinc concentration were somewhat lower. Its concentration in plants near the smelter was from two to thirty times higher than in plants in the II-nd control area. The maximum values near the smelter were higher by three to seventy times.

Lead and zinc concentration in plants from the I-st control area situated at the edge of Silesia-Kraków Industrial District was constantly higher than content of each of these two metals in plants collected in a relatively unpolluted area. The differences in concentration of each metal varied from two to over ten times (comp. table III).

Location of the study in an area where one emission source plays a chief role in air pollution permitted to show a quantitative relationship between total dustfall and concentration of emitted chemical elements in plants. It was a linear correlation, significant in most cases (comp. tab. IV). This correlation was overshadowed to a certain degree by the results of analyses of plants collected in areas near Olkusz, where emission size was distinctly increased by local urban and industrial sources (comp. fig. 1), so sometime the relationship between the distance from the industrial complex and heavy metal content in plants turned out to be more clear (comp. chapter 5 b).

Out of 36 cases of correlation between emission size and heavy metal content in plants, in 26 cases this correlation was statistically significant (table IV). It is worth to point out that correlation was more frequently significant in relation to overground plant portions than in underground ones. Also the significance level was higher for overground portions.

Individual plant species considerably varied as to the accumulation of heavy metals in their tissues. Very high concentration of lead and zinc in plant's dry weight was discovered in *Arabis arenosa*, *Viola tricolor* and *Thymus serpyllum*. The lower concentration was found in *Vaccinium vitis-idaea* and *Deschampsia flexuosa*, while the concentration in *Vaccinium myrtillus* was the lowest (fig. 2—6, table III). As far as zinc is concerned, the highest amount of this element was accumulated by *Arabis arenosa*. Its maximum content in shoots of this plant was 3800 ppm, i.e. nearly 0.4% of dry weight, at 3100 ppm of zinc in roots. The highest concentration of lead was discovered in roots of *Viola tricolor*, 1100 ppm dry weight. While in overground portions the highest lead concentration was present in *Thymus serpyllum* amounting to 420 ppm dry weight.

The differences in lead and zinc concentration between underground and overground plant's portions were in some cases higher than differences between individual species. Lead and zinc concentration in overground and underground portions of investigated plant species was analized in detail, while the results referring to the concentration of these metals in fruits of *Vaccinium vitis-idaea* should be taken as an example (fig. 7).

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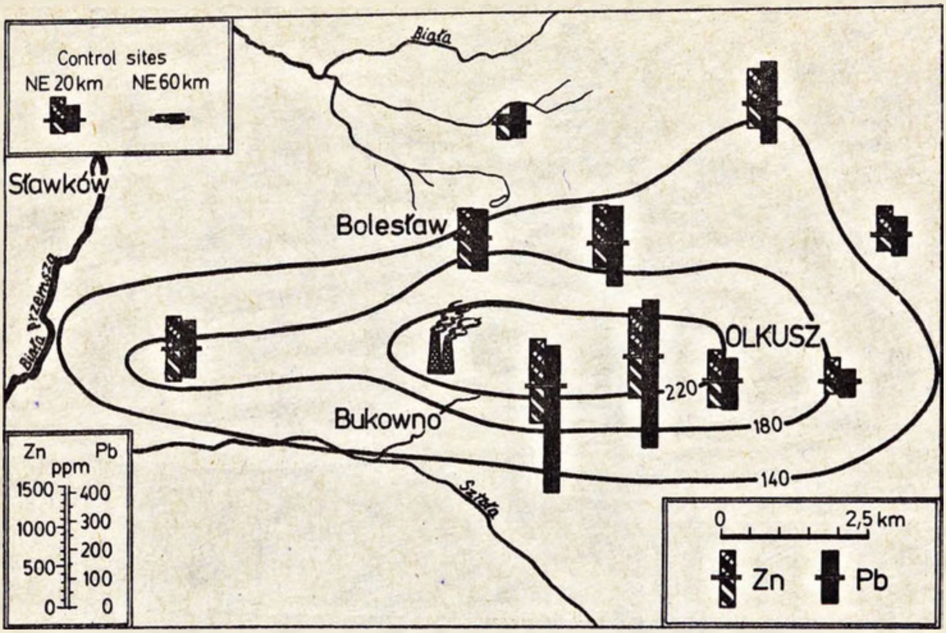

Fig.4. Mean lead and zinc concentration in *Vaccinium vitis-idaea* growing in pine forests. Explanations as in. fig. 2

Ryc. 4. Średnia zawartość ołowiu i cynku w *Vaccinium vitis-idaea* rosnącej w borach sosnowych. Objaśnienia jak na rycinie 2

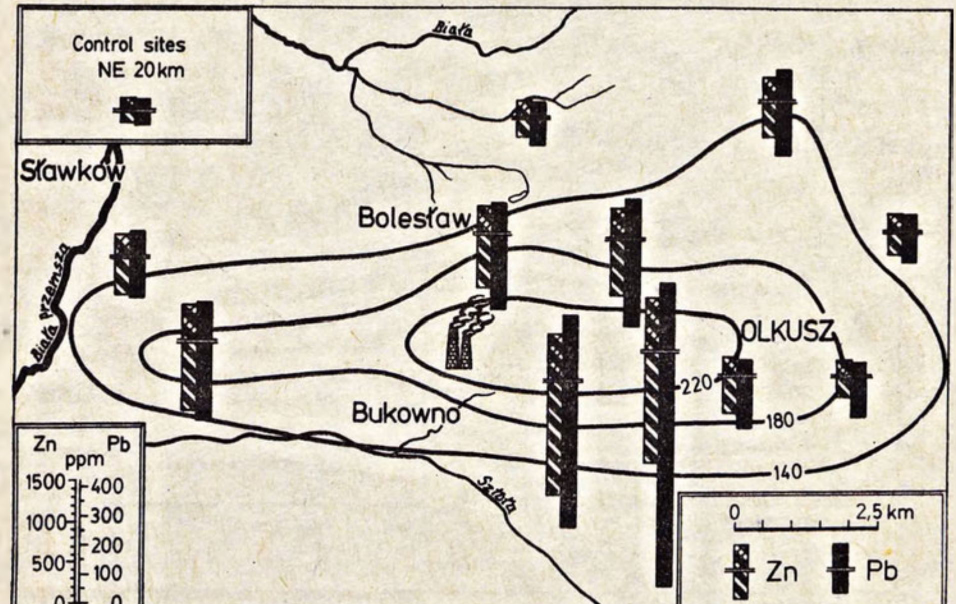

Fig. 5. Mean lead and zinc concentration in *Deschampsia flexuosa* growing in pine forests. Explanations as in fig. 2

Ryc. 5. Średnia zawartość ołowiu i cynku w *Deschampsia flexuosa* rosnącej w borach sosnowych. Objaśnienia jak na rycinie 2

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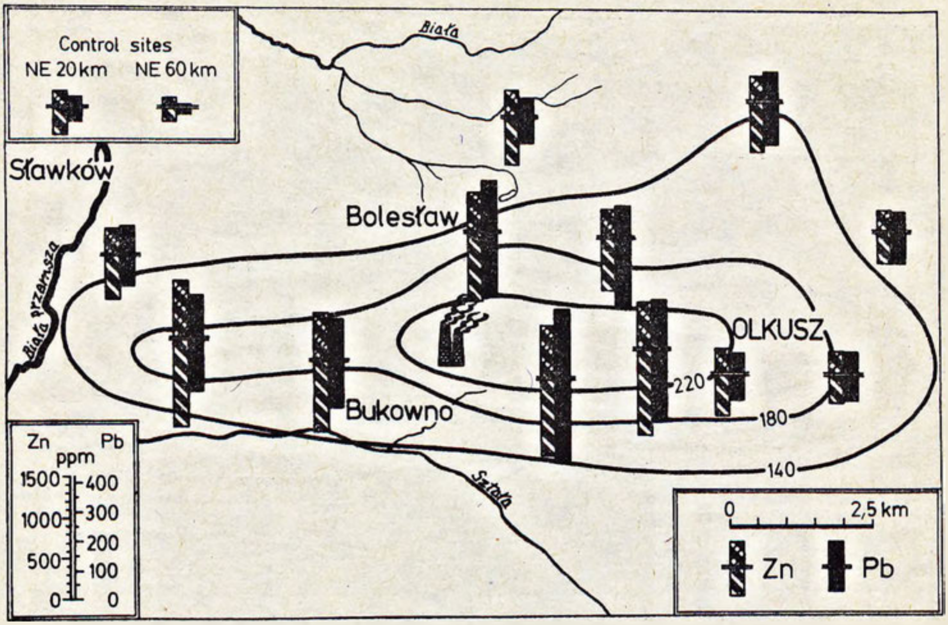

Fig. 6. Mean lead and zinc concentration in *Vaccinium myrtillus* growing in pine forests. Explanations as in fig. 2

Ryc. 6. Średnia zawartość ołowiu i cynku w *Vaccinium myrtillus* rosnącej w borach sosnowych. Objaśnienia jak na rycinie 2

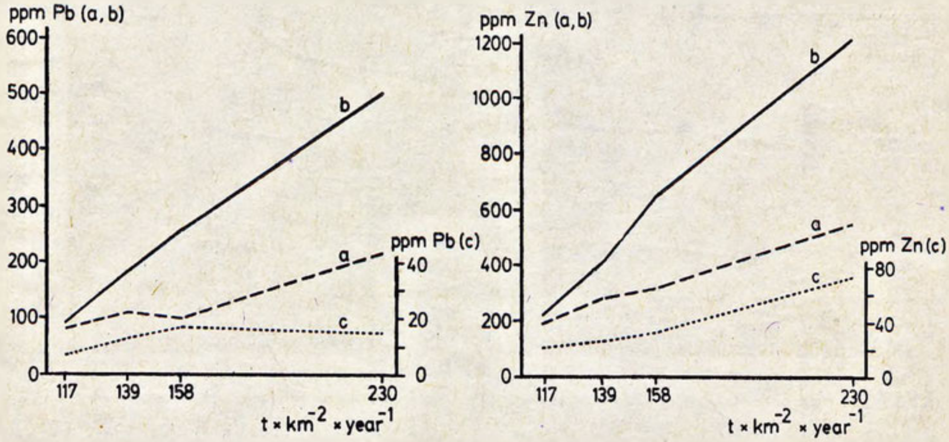

Fig. 7. Increase in lead and zinc concentration in above-ground parts (curve a), underground parts (curve b), and fruits (curve c) of *Vaccinium vitis-idaea* with increasing dustfall

Ryc. 7. Wzrost zawartości ołowiu i cynku w częściach nadziemnych (krzywa a), częściach podziemnych (krzywa b) i owocach (krzywa c) *Vaccinium vitis-idaea* wraz ze wzrostem wielkości imisji

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TABLE V

Content of organic matter and storage of lead and zinc in total and assimilable form in the soil from root systems of selected plant species growing under different total dustfall

Zawartość materii organicznej oraz nagromadzenie ołowiu i cynku w formie ogólnej i przyswajalnej w glebie z systemów korzeniowych wybranych gatunków roślin rosnących przy różnym ogólnym opadzie pyłu

Plant species Gatunek rośliny	Environment Środowisko	Total dustfall t/km²/year Ogólny opad pyłu t/km²/rok	Organic matter content Zawartość materii organicznej %	Pb ppm		Zn ppm	
				assimilable przyswajalny	total ogólny	assimilable przyswajalny	total ogólny
		92	3,17	83,3	184,2	105,8	150,0
Vaccinium	pine	117	4,64	129,2	284,6	141,7	275,0
vitis-idaea	forest	126	2,33	112,5	256,8	120,7	227,3
		137	3,23	154,0	312,8	415,8	708,3
	bór	139	2,03	112,5	234,3	128,3	183,3
	sosnowy	143	1,42	142,0	223,0	125,8	300,0
		146	2,61	113,0	201,0	113,7	175,0
		158	17,43	566,7	1418.0	1779,7	4083,3
		202	1,87	95,8	172,6	105,0	187,3
		211	1,84	81,2	178,8	175,8	241,7
		230	3,10	220,8	390,7	500,0	866,7
		248	6,78*	475,0*	753,5*	485,0*	937,5*
		117	5,08	168,5	266,0	245,0	525,0
	pine	126	4,49	306,2	1038,2	317,5	1350,0
	forest	137	9,40	350,0	716,8	1002,5	2650,0
	bór	139	3,68	331,2	435,5	400,0	762,5
	sosnowy	143	3,01	419,0	619,8	652,5	2050,0
		146	9,77	294,2	415,5	349,2	662,5
		158	13,54	1025,0	2613,0	2267,6	6550,0
Arabis		176	3,24	300,0	418,5	960,0	2037,5
arenosa		202	3,72	187,5	385,2	198,8	368,8
		211	3,04	344,8	636,5	735,0	1500,0
		230	4,86	625,0	1155,8	935,0	1750,0
		248	5,68	506,2	1139,0	1062,5	1950,0
	sandy	117	2,44	168,5	366,0	298,8	662,5
	waste	137	0,93*	100,0*	198,0*	125,0*	425,0*
	land	139	1,50	130,8	234,2	275,0	463,8
	nieużytek	143	4,90	675,0	885,2	840,0	1602,5
	piaszczy-	146	3,70	168,8	318,2	183,7	437,5
	sty	158	1,46	412,5	636,2	605,0	1812,5
		176	1,72	229,8	382,0	767,5	1752,5
		202	7,18	306,2	566,2	690,0	1600,0
		211	0,94	131,2	184,2	166,8	350,0
		230	6,27	737,5	1072,0	1540,2	2001,0
		248	1,32	112,5	184,2	162,5	287,5

Vaccinium vitis-idaea: mean value from two samples is marked with a star, the remaining values are the means from three samples;

Arabis arenosa: value from one sample is marked with a star, the remaining values are the means from two samples.

Vaccinium vitis-idaea: gwiazdką oznaczono wartość średnią z dwóch prób, pozostałe wartości stanowią średnią z trzech prób;

Arabis arenosa: gwiazdką oznaczono wartość z jednej próby, pozostałe wartości stanowią średnią z dwóch prób.

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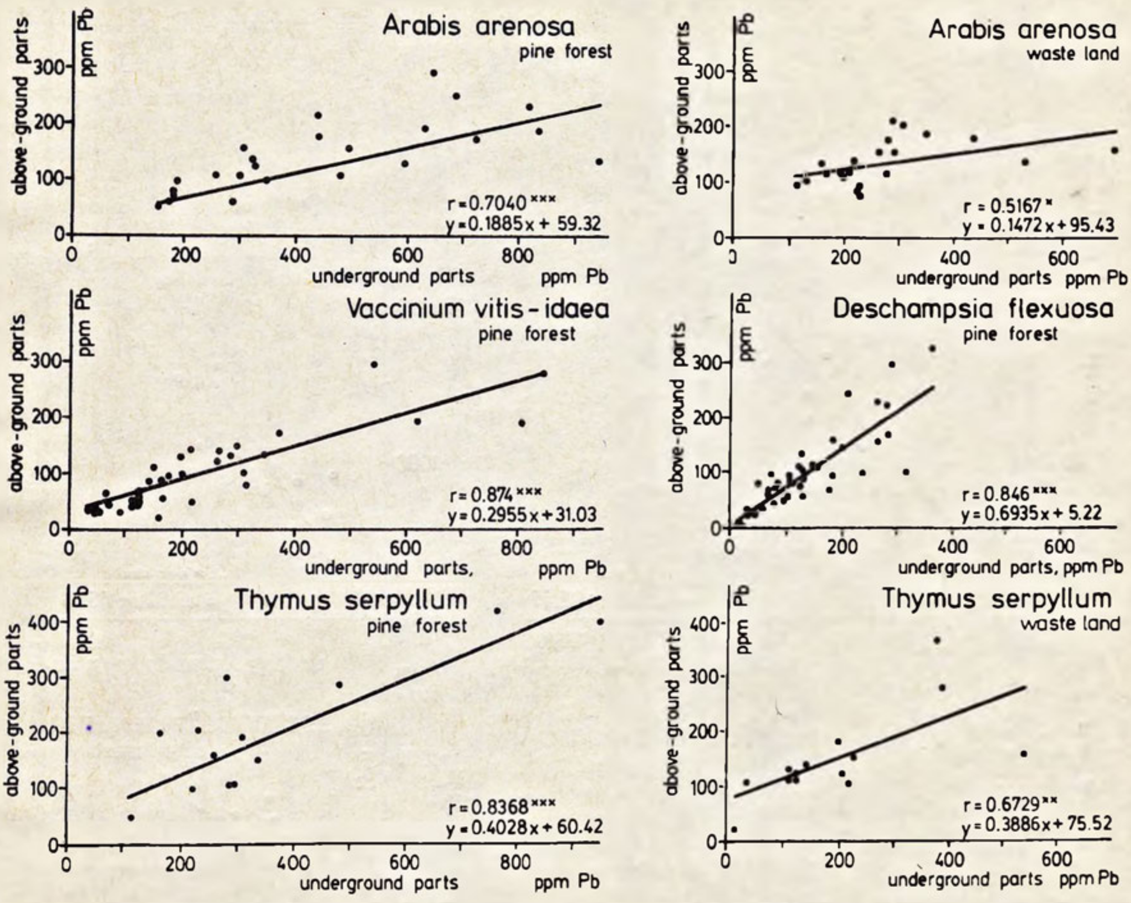

Fig. 8. Relationship between lead concentration in above-ground parts and its concentration in underground parts of selected plant species. Designation of confidence level: x — p > 0.05, xx — p > 0.01, xxx — p > p.001

Ryc. 8. Związek między zawartością ołowiu w częściach nadziemnych a zawartością tego pierwiastka w częściach podziemnych wybranych gatunków roślin. Oznaczenie poziomu ufności: x—p > 0.05, xx—p > 0,01, xxx—p > 0,001

As regards to a place of highest concentration in a plant, the metals concerned behaved differently. Lead, as a rule, occurred in higher concentration in undergroud portions (comp. fig. 7), while concentration of zinc was higher in overground portions in some species, e. g. *Arabis arenosa*, and in underground portions of other species, e. g. *Vaccinium vitis-idaea* and *Deschampsia flexuosa* (figs. 7 and 9). Only in the II-nd control area concentration of zinc was a proper one i.e. higher in overground portions.

Under high content of heavy metals in soil and in a dustfall, a not accidental relationship between metal's concentration in an under- and an overground portion of a plant becomes established. There was a significant positive linear correlation between these values in plants analized (figs. 8 and 9).

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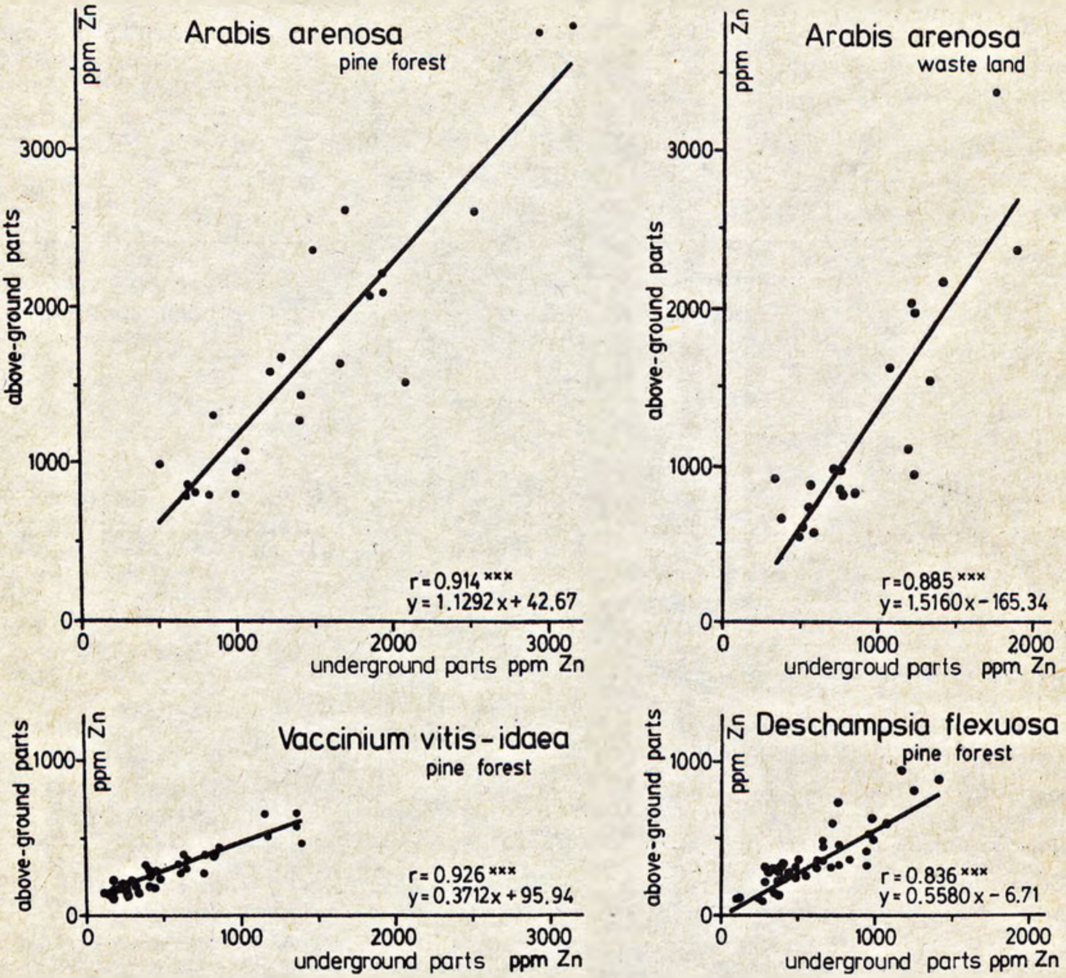

Fig. 9. Relationship between zinc concentration in above-ground parts and its concentration in underground parts of selected plant species. Designation of confidence level as in fig. 8

Ryc. 9. Związek między zawartością cynku w częściach nadziemnych a zawartością tego pierwiastka w częściach podziemnych wybranych gatunków roślin. Oznaczenie poziomu ufności jak na rycinie 8

The data in figures 2 and 3, and table III show a distinct effect of environment on lead and zinc concentration in plants. In a same area, i.e. at a same total dustfall, plants from forest had considerably higher lead and zinc concentration than plants growing on open sandy waste land. In order to explain the reasons of these differences the soil from root systems of investigated plant species was analized. In spite of the fact that podzolic soils formed from poor sands occur in the study area, their reaction is close to neutral. The reason for a distinct increase in pH is undoubtedly connected with a fallout of base-forming dusts (comp. table II). The soil pH_{H_2O} was increasing along with in-

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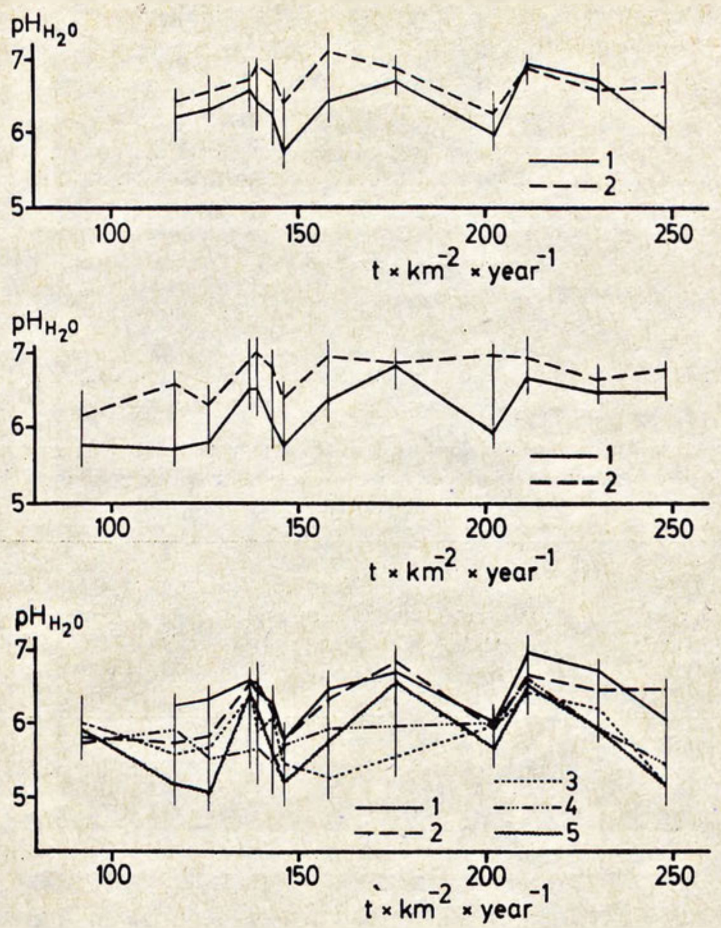

Fig. 10. Reaction of soil (pH_{H_2O}) from root systems of plants in study areas within the range of high dustfall and in the control plots. A — reaction of soil from under *Arabis arenosa*: 1 — growing in pine forests, 2 — growing on sandy waste lands; B — reaction of soil from under *Thymus serpyllum*: 1 — growing in pine forest, 2 — growing on sandy waste lands; C — reaction of soil from under the following plants species growing in pine forests: 1 — *Arabis arenosa*, 2 — *Thymus serpyllum*, 3 — *Vaccinium myrtillus*, 4 — *Vaccinium vitis-idaea*, 5 — *Deschampsia flexuosa*

Ryc. 10. Odczyn gleby (pH_{H_2O}) z systemów korzeniowych roślin na powierzchniach badawczych w zasięgu wysokiej imisji i na powierzchniach kontrolnych. A — odczyn gleby spod *Arabis arenosa*: 1 — rosnącej w borze sosnowym, 2 — rosnącej na piaszczystym nieużytku; B — odczyn gleby spod *Thymus serpyllum*: 1 — rosnącej w borze sosnowym, 2 — rosnącej na piaszczystym nieużytku; C — odczyn gleby spod następujących gatunków roślin z borów sosnowych: 1 — *Arabis arenosa*, 2 — *Thymus serpyllum*, 3 — *Vaccinium myrtillus*, 4 — *Vaccinium vitis-idaea*, 5 — *Deschampsia flexuosa*

creasing dustfall, although in some areas the soil reaction was more acid than size of imission would suggest (fig. 10). This fact could be explained to a certain degree by heterogeneous character of dustfall and variations in areas selected for this study. Alkalescent action of dusts was accompanied with acidifying action of sulphur dioxide, thus the existing conditions were the results of action of various processes frequently of opposite character.

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The soil reaction in waste lands was slightly higher than in forests, as it has been shown in fig. 10 a and b. On the other hand the soil reaction in pine forest varied with the depth. The highest pH_{H_2O} was recorded in topsoil i. e. in root zone of *Arabis arenosa* and *Thymus serpyllum*, where it varied from 6.1 to 7.1. The soil from root systems of plants rooting deeper, in accumulation layer or in a tranzition to illuvial layer, was slightly more acid. A relatively lowest reaction was recorded for soil from the root system of *Deschampsia flexuosa* i.e. 5.1 to 6.6 pH_{H_2O} (fig. 10 c).

TABLE VI

Coefficient of multiple correlation $_cR$ between total dustfall, organic matter content and total content of each studied metal in the soil from root systems of plants

Wartość współczynnika korelacji wielokrotnej $_cR$ między ogólnym opadem pyłu, zawartością materii organicznej a ogólną zawartością każdego z badanych metali w glebie z systemów korzeniowych roślin

Species Gatunek	Environment Środowisko	Number of samples Liczba prób	Pb	Zn
Arabis arenosa	pine forest bór sosnowy	24	0,674**	0,638**
	sandy waste land nieużytek piaszczysty	21	0,606*	0,466
Vaccinium vitis-idaea	pine forest bór sosnowy	35	0,969**	0,941**

* p> 0,05,
** p> 0,01

The data in table V show that lead and zinc content in soil depended to a great degree on dustfall and on organic matter content. The content of both these metals in forest soil was higher than in soil of waste lands at the same depth. On the other hand the lead and zinc content in deeper soil layers was lower than in topsoil (table V). Thus, in forest area where dustfall was 158 $t/km^2/$ year, there were 566.7 ppm of Pb-EDTA in soil from under *Vaccinium vitis-idaea* having roots in A_1 layer, and 1025.0 ppm of Pb-EDTA in soil from under *Arabis arenosa* rooting in transition zone between layer A_0 and A_1. These values for zinc were 1779.7 and 2267.5 ppm Zn-EDTA respectively. A similar distribution was present in all forest areas (table V). The differences

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in metal accumulation in soil samples collected from root zone of *Arabis* in pine forests and in waste lands were, on the other hand, not constant, although by and large the higher accumulation of lead as well as zinc was present in forest soils. Taking factors affecting the size of metal accumulation in soil into consideration, the multiple correlation between this value, the total dustfall and organic matter content in soil was computed. This correlation was high, and in five cases out of six analized turned out to be statistically significant (table VI). Interpretation of cR coefficient permits to conclude that in

TABLE VII

Coefficient of linear correlation *r* between total content of each studied metal and the content of their assimilable form in soil from root systems of plants

Wartość współczynnika korelacji prostoliniowej *r* między ogólną zawartością każdego z badanych metali a zawartością ich form przyswajalnych w glebie z systemów korzeniowych roślin

Species Gatunek	Environment Środowisko	Pb total/Pb-EDTA Pb ogólny/Pb-EDTA	Zn total/Zn-EDTA Zn ogólny/Zn-EDTA
Arabis arenosa	pine forest bór sosnowy	0,8989*	0,9628*
	sandy waste land nieużytek piaszczysty	0,9628*	0,8812*
Vaccinium vitis-idaea	pine forest bór sosnowy	0,9259*	0,8588*

* p>0,001

forest soil from root zone of *Vaccinium vitis-idaea* the total lead content was in 93% determined by total dustfall and organic matter content. In case of zinc it was 88%. This percentage was much lower for topsoil in rooting zone of *Arabis arenosa*. It was 45% for lead and 40% for zinc. On the other hand lead and zinc content in soil from waste lands, from root zone of *A. arenosa*, was more strongly determined by other factors than those analized. The latter ones determined Pb content in 37%, and Zn content only in 22%.

A significant correlation between soil organic content and lead and zinc accumulation in soil explains to a great extent the difference in metal accumulation in upper and lower layers of forest soil, and the difference observed between forest and waste land soil at the same dustfall level. The soils of waste lands were not uniform, and they varied with respect to organic matter content. In some cases the percentage of organic matter in soil samples from under *Arabis* was higher in a waste land than in forest soil (comp. table V).

There was also a distinct correlation between total content of each metal in soil and its content in form soluble in EDTA (table V). The coefficients of linear correlation between these two values are shown in table VII.

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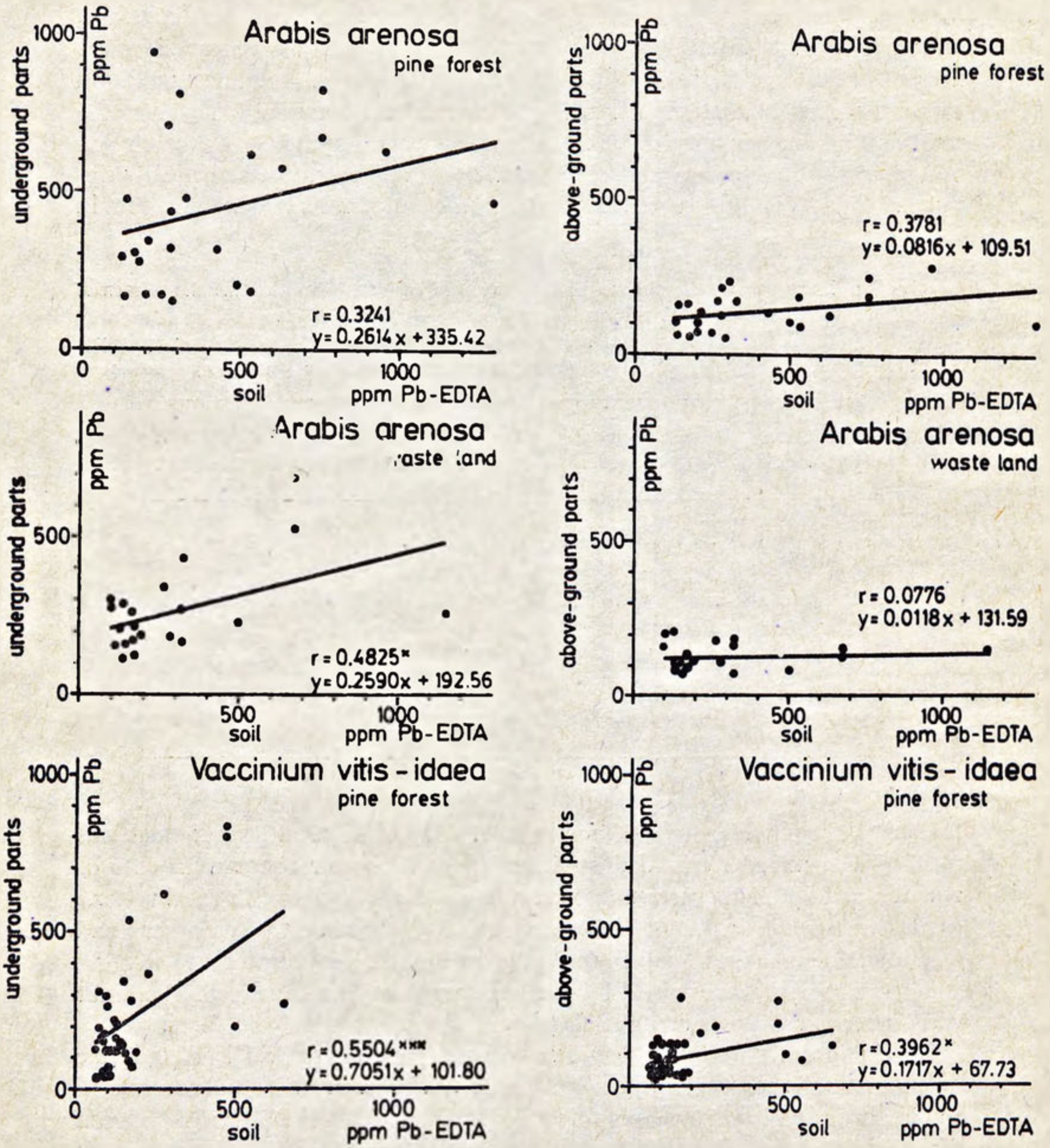

Fig. 11. Relationship between assimilable lead content in soil from root systems and its concentration in above-and underground parts of plants growing in two different environments. Designation of confidence level as in fig. 8

Ryc. 11. Związek między zawartością przyswajalnego ołowiu w glebie z systemów korzeniowych a zawartością tego pierwiastka w nadziemnych i podziemnych częściach roślin z różnych środowisk. Oznaczenie poziomu ufności jak na rycinie 8

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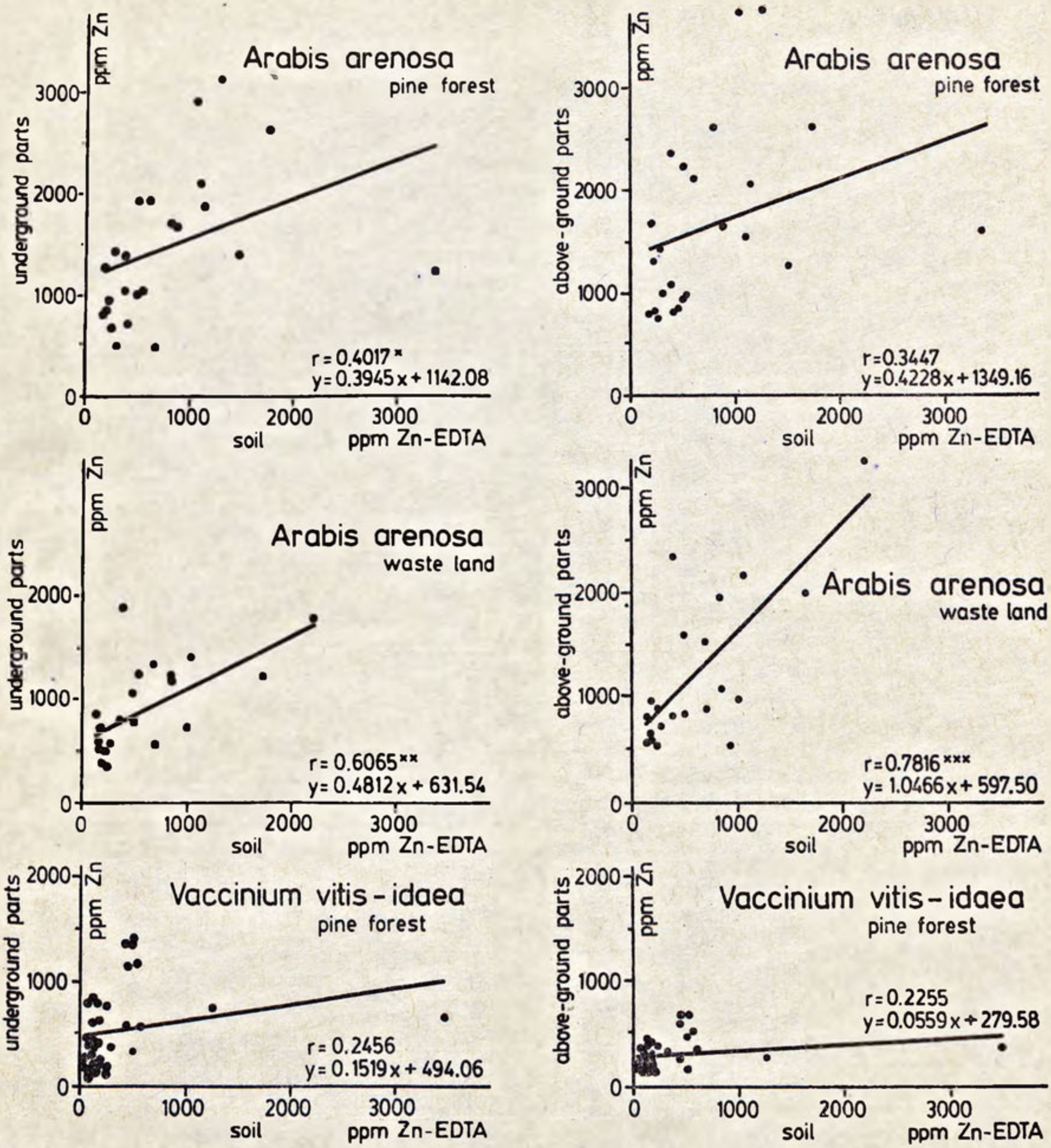

Fig. 12. Relationship between assimilable zinc content in soil from root systems and its concentration in above-and underground parts of plants growing in two different environments. Designation of confidence level as in fig. 8

Ryc. 12. Związek między zawartością przyswajalnego cynku w glebie z systemów korzeniowych a zawartością tego pierwiastka w nadziemnych i podziemnych częściach roślin z różnych środowisk. Oznaczenie poziomu ufności jak na rycinie 8

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TABLE VIII

Chemical properties of soil brought to experimental plots
Właściwości chemiczne gleby nawiezionej na poletka doświadczalne

Organic matter Substancja organiczna %	C %	N %	C/N	Hydrolytic acidity me/100 g of soil Kwasowość hydrolityczna me/100 g gleby	Sum of exchangable basis me/100 g of soil Suma zasad wymiennych me/100 g gleby	Degree of saturation with basic cations Stopień nasycenia kationami o charakterze zasadowym %	Na_2O mg/100 g of soil Na_2O mg/100 g gleby	K_2O mg/100 g of soil K_2O mg/100 g gleby	P_2O_5 mg/100 g of soil P_2O_5 mg/100 g gleby	CaO mg/100 g of soil CaO mg/100 g gleby	MgO mg/100 g of soil MgO mg/100 g gleby	pH		Pb-EDTA ppm	Cd-EDTA ppm
												H_2O	KCl		
1,39	0,81	0,07	12	2,60	6,30	68,48	1,4	3,2	6,7	164	10,0	6.30	5,90	16,50	1.05

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The relationship between the content of assimilable form of metals in soil from the root systems and their concentration in overground and underground portions of selected plant species is shown in figures 11 and 12. In case of lead a distinct positive linear correlation existed between its content in soil and its concentration in underground portions of plants. In overground portions of plants the lead accumulated in smaller quantities and largely independently of its content in soil (comp. fig. 11). The lead concentration in underground plant parts was similar or even higher than the content of its assimilable form in soil.

The relationship between zinc accumulation in soil and its concentration in plants was weak in relation to overground as well as to underground plant portions (fig. 12). Only in case of *Arabis arenosa* from waste lands it was statistically significant. and in overground portions zinc concentration was higher than content of its assimilable form in soil.

2. Accumulation of lead and cadmium in plants and soil on experimental plots

There were six experimental plots established in the study area (fig. 1), and one control plot established in the I-st control area, app. 20 km away from the smelter. The soil which was brough to the experimental plots also originated from the I-st control area.

The soil brought to experimental plots was classified as light loamy sand, rich in nutrients, with pH close to neutral (table VIII). The content of assimilable forms of lead and cadmium was initially as follows: 16.5 ppm Pb-EDTA and 1.5 ppm Cd-EDTA.

After three growing seasons, the lead and cadmium concentration at *Thymus serpyllum* planted in the plots at the beginning of the experiment, was analized.

The concentration of assimilable forms of lead and cadmium was determined in soil samples collected in top, 0—3 cm, layer, and from root systems of *Thymus serpyllum*. Also pH of these samples was measured.

During the exposure to activity of falling dusts containing toxic metals the soil in plots became strongly polluted with lead and cadmium. Also the concentration of these metals in overground and underground plant parts had drastically increased, which was evaluated by comparing its value with concentration in plants from the control plot. The amount of assimilable lead in topsoil of control plot had doubled, while the amount of this element in the plot situated in zone of highest dustfall, 0.7 km away from the emitter, had increased 7-fold (fig. 13). Thus, after two and a half years of exposure the soil in control plot contained 30.0 ppm Pb-EDTA in surface layer, and 21.0 ppm in deeper layer, while the initial value was 16.5 ppm. The maximum content of assimilable lead was 119.2 ppm in surface layer, and 85.0 ppm in deeper layer.

The increase in Cd-EDTA content in the control plot was very little.

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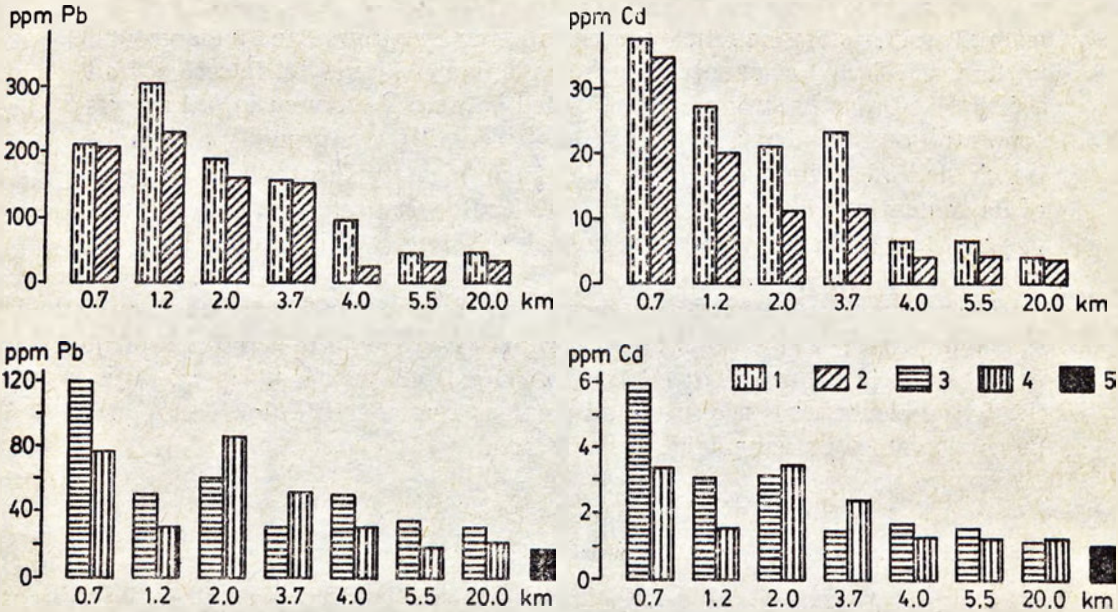

Fig. 13. Lead and cadmium content in plants and soil from experimental plots after three growing seasons: 1 — overground parts of *Thymus serpyllum*, 2 — underground parts of *Thymus serpyllum*, 3 — soil from 0—3 cm, 4 — soil from root system of *Thymus serpyllum*, 5 — soil brought to the plots

Ryc. 13. Zawartość olowiu i kadmu w roślinach i glebie z poletek doświadczalnych po trzech sezonach wegetacyjnych: 1 — części nadziemne *Thymus serpyllum*, 2 — części podziemne *Thymus serpyllum*, 3 — gleba z warstwy 0—3 cm, 4 — gleba z systemu korzeniowego *Thymus serpyllum*, 5 — gleba nawieziona na poletka

At the end of experiment it was 1.12 ppm in surface layer and 1.25 ppm in deeper layer, while the initial value was 1.05 ppm. In the plot most strongly contaminated the cadmium content reached 5.95 ppm Cd-EDTA in a surface layer, and 3.55 ppm in a deeper layer (table IX).

The plants in experimental plots accumulated large amounts of toxic metals during three growing seasons, and the concentrations in overground portions were higher than in undrground ones (fig. 13). Therefore, as far as lead was concerned, this was opposite situation to one observed in waste lands and pine forests where, as a rule, the concentration of this element was higher in underground parts of *Thymus serpyllum* (comp. fig. 8). The maximum increase in lead concentration was over 6-fold, as compared with plants in control plot, in overground as well as in underground portions. Plants of thyme from plots near the smelter reached as much as 304.8 ppm of lead in overground parts, and 227.9 ppm in underground portions, as compared with 48.4 and 34.8 ppm in plants of the control plot respectively (table IX).

Even greater differences were found in cadmium concentration in plants, where in an extreme case its value in overground as well as underground parts was 9.4 times greater than in the control plot (fig. 13). The maximum cadmium concentration in thyme was 37.73 ppm in overground, and 34.88 in under-

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TABLE IX

Lead and cadmium in *Thymus serpyllum* and in soil, and soil reaction in experimental plots after three growing seasons

Zawartość ołowiu i kadmu w macierzance piaskowej *Thymus serpyllum* i w glebie oraz odczyn gleby na poletkach doświadczalnych po trzech sezonach wegetacyjnych

Plot No* Numer poletka*	Distance from smelter Odległość od huty km	Direction Kierunek	Total dust-fall t/km²/year Ogólny opad pyłu t/km²/rok	Content of Pb-EDTA in soil Zawartość Pb-EDTA w glebie ppm		Pb concentration in plant ppm d.m. Zawartość Pb w roślinie ppm s.m.		Content Cd-EDTA in soil Zawartość Cd-EDTA w glebie ppm		Cd concentration in plant ppm d.m. Zawartość kadmu w roślinie ppm s.m.		Soil reaction Odczyn gleby			
												pH H_2O		pH $_{KCl}$	
				in layer w warstwie 0—3 cm	from root system of plants z systemu korzeniowego rośliny	in overground portions w częściach nadziemnych	in underground portions w częściach podziemnych	in layer w warstwie 0—3 cm	from root system of plants z systemu korzeniowego rośliny	in overground portions w częściach nadziemnych	in underground portions w częściach podziemnych	in layer w warstwie 0—3 cm	from root system of plants z systemu korzeniowego roślin	in layer w warstwie 0—3 cm	from root system of plants z systemu korzeniowego roślin
Soil brought to plots Gleba nawieziona na poletka				16,5				1,05				6,30		5,90	
1	0,7	NW	250	119,2	76,0	209,6	207,1	5,95	3,35	37,73	34,88	7,05	7,00	6,65	6,50
2	1,2	ES	230	50,0	25,0	304,8	227,9	3,05	1,55	27,10	19,94	6,50	6,50	5,90	5,85
3	2,0	NW	136	60,0	85,0	187,0	160,0	3,12	3,45	20,78	11,25	6,70	6,95	6,40	6,60
4	3,7	NE	143	30,0	51,0	157,1	153,2	1,48	2,40	23,29	11,53	6,75	6,70	6,00	6,10
5	4,0	N	117	50,0	30,0	96,6	25,0	1,67	1,30	6,61	4,10	6,50	6,50	6,20	5,90
6	5,5	E	202**	34,2	18,8	46,4	33,1	1,55	1,25	6,61	4,30	6,60	6,60	5,95	5,90
7	20,0	NE	92	30,0	21,0	48,4	34,8	1,12	1,25	4,03	3,70	6,70	6,60	6,15	6,10

* Numeracja poletek jak na rycinie 1.

** Imisja podwyższona przez miejskie i fabryczne pyły Olkusza.

* Plot numbering as in fig. 1.

** Imission increased by urban and industrial dusts of Olkusz.

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ground portions, while the respective values in the control plot were 4.03 and 3.70 ppm (table IX).

The degree of pollution of plants and soil in the experimental plots was dependent on size of imission. But, since one of the plots, no. 6, was situated near Olkusz (comp. fig. 1), where only part of the dust originated from the smelter, the relationship between size of accumulation of toxic metals in plots and their distance from the complex turned out to be more distinct (comp. fig. 13).

Much lower, than suggested by dustfall and distance from the emitter, content of assimilable form of lead in soil of plot no. 2, may be connected with certain acidification, better detectable when soil reaction was determined with 1 n KCl than with water extract (comp. table IX). The reaction of soil in plot

TABLE X

Comparison between lead concentration (ppm d.m.) in *Thymus serpyllum* collected in study plots and that collected from sandy waste land situated in the direct neighbourhood of plots

Porównanie zawartości ołowiu (ppm s.m.) w *Thymus serpyllum* zebranej z poletek doświadczalnych oraz z piaszczystych nieużytków w bezpośrednim sąsiedztwie poletek

Plot No.* Nr poletka*	Plants from plots Rośliny z poletek		Plants from waste lands Rośliny z nieużytków	
	overground portions części nadziemne	underground portions części podziemne	overground portions części nadziemne	underground portions części podziemne
2	304,8	227,9	370,0	375,0
4	157,1	153,2	155,0	225,0
5	96,6	25,0	107,0	218,0
6	46,4	33,1	140,0	140,0
7	48,4	34,8	122,0	122,0

* Plot numbers as in fig. 1.

* Numery poletek jak na rycinie 1.

no. 2 was 5.90 pH_{KCl} in surface layer, and 5.85 pH_{KCl} in deeper layer. Lower soil pH helps the transformation of lead into more soluble forms and makes leaching possible in a greater extent than at high pH. On the other hand, plants in this plot accumulated decidedly highest amount of lead. After 2.5 year exposure the soil reaction in surface layer of all other plots was raised, and its maximum value was 6.65 pH_{KCl}, while the initial value was 5.90 pH_{KCl} (table IX).

The 2.5 year exposure resulted in drastic increase in content of toxic haevy metals, lead and cadmium, in plants as well as in soil. In comparison with control plot data, the increase in metal concentration in plants was considerably

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higher than increase in content of assimilable forms of these elements in the soil from their root systems, and also in the soil surface layer.

There were distinct differences with respect to lead concentration between *Thymus serpyllum* plants from the experimental plots and plants of the same species collected in nearby waste lands subjected to the same dustfall. These differences mainly concerned underground plant portions, and only in area least polluted also the aerial parts. For example the plants collected in waste lands situated in a neighbourhood of plot no. 2 contained 370.0 ppm Pb in aboveground parts, and 375.0 ppm Pb in underground portions, while these values for the plot were 304.8 and 227.9 ppm respectively. Similarly, the plants from the neighbourhood of plot no. 4 contained 155.0 and 225.0 ppm Pb, while the plants from this plot — 155.1 and 153.2 ppm. On the other hand, the plants from waste land in a neighbourhood of the control plot contained 122.0 ppm Pb in underground as well as overground portions, while the plants in the plot contained 48.4 and 34.8 ppm of this metal respectively (table X).

The accumulation of lead in plant shoots from plots situated in an area strongly polluted was after three growing seasons similar to the concentration of this metal in plants from waste lands, while the underground parts of plants grown in the plots accumulated much less lead than plants in waste lands. On the other hand, in zone of lesser imission the shoots as well as underground plant portions in the plots had not reached as yet the lead pollution level characteristic to plants from waste lands, where toxic imission components had accumulated in soil and permanent plant parts over many years.

3. Changes in the floristic composition of a pine forest *Vaccinio myrtilli-Pinetum* within the range of influence of the smelter

The pine forests in vicinity of Olkusz and Bukowno, well preserved in the past (comp. Medwecka-Kornaś 1952), have been strongly damaged during the last several dozen years, mainly due to increasing pressure of industry. The expansion of old industrial establishments caused such a strong degradation of environment, that forest have disapeared in many areas, and those that survived have been strongly damaged. In the area covered by this study, i. e. up to 8 km from the smelter, various stages of pine forest dying may be observed. In the closest neighbourhood of the complex the remnants of pine forest are extremely damaged, while at further distance from the smelter a forest condition is slightly better, although also in this area there are considerable changes in appearance and species composition of forest stands.

In order to grasp the relationship between the pressure exercised by the smelter and the degree of degradation of the pine forest, the author analized the phytosociological records done on the study areas arranging them according to the heavy metal accumulation in the herbaceous plants. The amount o metal concentration was accepted as an indicator of that pressure (table XI)

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Because of the different degree of damage of the community, including forest stands as well as herbaceous vegetation, 34 records presented here form a heterogenous material. According to the criteria used by foresters (Kamieniecki 1972) concerning the degree of stand degradation, the patches extremely damaged should be included in class III, while relatively many patches were classed as transitional between class III and II, and the remaining ones, relatively best preserved, were included in class II because of health conditions of pine. For comparison the data of S. Michalik (1981), originating from Góra Chełm reserve, situated in direct neighbourhood of the study area, app. 8 km

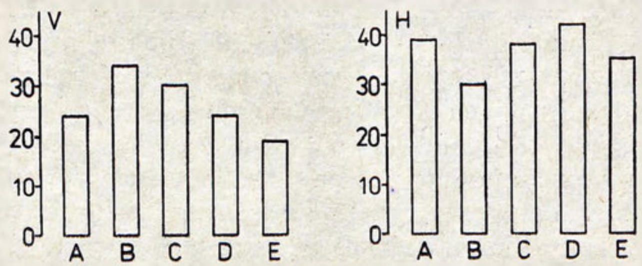

Fig. 14. Mean number of species in a phytosociological record v and the value of Pfeiffer's index H in patches of fresh coniferous forest *Vaccinio myrtilli-Pinetum*. Surroundings of Bukowno: A — patches extremely damaged (records 1—8 in table XI), B — patches strongly damaged (records 9—25), C — patches little damaged (records 26—34), D — records from publication of S. Michalik (1981) completed in relativelly well preserved patches of fresh coniferous forest in Góra Chełm reserve, E — records from publication of A. Medwecka-Kornaś (1952) completed in patches of the same association in Kraków's Jura in 1948—1949

Ryc. 14. Średnia liczba gatunków w zdjęciu v i wartość wskaźnika Pfeiffera H w płatach boru świeżego *Vaccinio myrtilli-Pinetum*. Okolice Bukowna: A — płaty skrajnie zniszczone (zdjęcia 1—8 w tab. XI), B — płaty silnie zniszczone (zdjęcia 9—25), C — płaty słabo zniszczone (zdjęcia 26—34), D — zdjęcia z pracy S. Michalika (1981) wykonane w stosunkowo dobrze zachowanych płatach boru świeżego w rezerwacie Góra Chełm. E — zdjęcia z pracy A. Medweckiej-Kornaś (1952) wykonane w płatach boru świeżego na Jurze Krakowskiej w latach 1948—1949

north east from the smelter, were utilized. The community of fresh coniferous forest, analized in 1974, was relatively well preserved, but nevertheless, because of high susceptibility of pine to industrial air pollution, this stand should be classified as degradation class I. The effect of industrial emission was even smaller in case of pine stands in Kraków's Jura in 1948—49. Their condition was described by A. Medwecka-Kornaś in 1952. Her investigations also included the area of this present study.

The number of species occurring in individual phytosociological records may be used as homogeneity index of entire group of records (Scamoni 1967). This index, computed for all records listed in table XI jointly, has a very low value of 22. For comparison the homogeneity index was computed for 17 records from Góra Chełm reserve published by S. Michalik (1981), and 8 records published by A. Medwecka-Kornaś (1952). Its value was 42 and 35 respectively (comp. fig. 14).

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In order to distinguish groups of homogenous records, the material presented in table XI was divided into three groups, corresponding to III, III/II and II stand degradation class. The first group comprised records 1—8, the second 9—25, and the third 26—34. The homogeneity index computed for each group was 39, 30 and 38 respectively. Thus, the homogeneity of individual groups turned out to be higher than that of all records jointly, and it was close to values recorded by other authors in less degraded patches of fresh coniferous forest. The least homogenous was transitional group III/II, and the patches representing it had the highest average number of species per single record (comp. fig. 14).

For analysis of effect of the smelter on qualitative composition of fresh coniferous forest, the taxonomic value and group abundance of species of various site requirements (according to equations given by Pawłowski, 1972; for sign + the value of 0.25 was assumed) were determined in individual groups of phytosociological records from vicinity of Bukowno, and for comparison in records from Góra Chełm reserve and Krakow's Jura. The species characteristic for the following classes of plant communities were distinguished: coniferous and mixed coniferous forests connected with poor soils (*Vaccinio-Piceetea*), cutovers (*Epilobietea angustifolii*), poor grasslands with heather (*Nardo-Callunetea*), xerothermic grasslands and thermophilous communities (*Festuco-Brometea* and *Trifolio-Geranietea* jointly), sandy grasslands (*Sedo-Scleranthetea*), and meadows (*Molinio-Arrhenatheretea*).

In patches most severely damaged (records 1—8 in table XI) pines were strongly injured, and considerable number of trees were dead. Some of the pines had characteristic shape. The crown of a tree was dead, while lowest branches were lowered to ground level at the ends, and then raised, forming branching resembling young trees. Such a modification of the pines caused by industrial air pollution was already described by Wolak (1970).

Because of the large number of dead shoots and scanty foliage on the live ones, there was much light in the forest. Pine crown density was 20—70% (av. 42%). The understory composed mainly of pine saplings with little admixture of *Betula verrucosa* was irregularly developed. Sometime it was not present at all, and its crown density was 20%, on the average (max. 40%). Some pines were planted e. g. in record 3 (table XI).

Herbaceous plant cover formed mosaic pattern with patches of open ground, covering 5—40% of surface area. Mosses were scarce, and they covered 5—20% of surface area accompanying herbaceous plants. In shaded places the vegetation of forest floor retained character of forest floor vegetation, while in more open places photophilous plants dominated.

Out of tree and shrub species characteristic of the class *Vaccinio-Piceetea* beside Scotch pine, only seedlings of *Juniperus communis* were found. Some species of lower vegetation were present, such as *Pirola secunda*, *Chimaphila umbellata*, *Vaccinium myrtillus* and *V. vitis-idaea*. They were quite frequent (III and IV degree of constancy) but of small abundance, usually single spe-

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cimens in a patch. Many individual plants of various species were injured. They were accompanied by species characteristic of the class *Nardo-Callunetea*, frequently *Luzula multiflora*, rarely *Calluna vulgaris*, and sporadically *Genista pilosa*. Out of cutover species *Calamagrostis epigejos* was present here. Classes *Festuco-Brometea* and *Trifolio-Geranietea* were represented by as many as nine species. The following were more frequent: *Helianthemum ovatum*, *Dianthus carthusianorum*, *Euphorbia cyparisias*, and *Potentilla arenaria*. The remaining species occurred sporadically.

Principal plants of herbaceous cover in extremely degraded patches of fresh coniferous forest represented species characteristic of sandy grasslands (*Sedo-Scleranthetea*). They were favoured by sandy substratum and little shading. The following three were constant components: *Festuca ovina* and *Thymus serpyllum* — very abundant and resistant to extreme conditions, and *Rumex acetosella* of little abundance. Out of mosses, one species was quite frequent i. e. *Bryum caespiticium*. The following species were less frequent: *Corynephorus canescens*, *Hieracium pilosella*, *Koeleria glauca*, *Scleranthus perennis*, *Armeria elongata*, and moss *Ceratodon purpureus*.

Of the meadow plants, 12 species were present, however, only two reached higher degress of constancy, i.e. *Cerastium vulgatum* and *Leontodon hastilis*, and no species reached higher abundance degrees. Out of the remaining species, not members of groups distinguished, *Betula verrucosa*, mentioned above, and *Salix rosmarinifolia* were present. *Arabis arenosa*, very resistant to pollution, *Deschampsia flexuosa* and moss *Brachythecium velutinum* were constant components of herbaceous layer. These species were quite abundant in some patches. The following were also quite frequent: *Agrostis vulgaris*, *Epipactis atropurpurea*, *Silene inflata*, and moss *Pohlia nutans*. The remaining 11 species were rare or sporadic, and of little abundance.

The average number of species in a single phytosociological record in patches extremely degraded was 24. It was identical with number given by Michalik (l. c) for Góra Chełm reserve (fig. 14), and the number of species in individual constancy degrees was also similar (fig. 15), but the composition of species was different. With increasing pressure exerted by the smelter the species characteristic for fresh coniferous forest were disapearing, and their place was taken by species foreign for this association. The figure 16 shows the mean numbers of species of community classes, mentioned above, present in a single phytosociological record, on the basis of taxonomic value of individual groups and their group abundance. In patches extremely degraded, where plants contained greatest amounts of lead and zinc, and alkaline action of dustfall caused increase in soil reaction almost to value of $pH_{H_2O} = 6.5$ in surface layer, the plants characteristic to coniferous forests comprised only about 22% of the total number of species, and covered app. 27% of surface area occupied by herbaceous vegetation. The cutover species and those typical for poor, acid grasslands were not frequent. On the other hand the species characteristic to sandy grasslands made a strongest group composed of 27%

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Table XI

Degraded fresh coniferous forest Vaccinio myrtilli-Pinetum within the range of influence of zinc and lead smelter in Bukowno

Zdegradowany bór świeży Vaccinio myrtilli-Pinetum w strefie oddziaływania huty cynku i ołowiu w Bukownie

Number of record - numer zdjęcia		1	2	3	4	5	6	7	8	Constancy	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Constancy	26	27	28	29	30	31	32	33	34	Constancy
Date - data		31.7 1973	31.7 1973	30.7 1973	30.7 1973	30.7 1973	30.7 1973	30.7 1973	30.7 1973		31.7 1973	16.9 1974	16.9 1974	17.7 1973	17.7 1973	26.7 1973	19.8 1970	19.8 1970	19.8 1970	17.7 1973	17.7 1973	17.7 1973	31.7 1973	31.7 1973	26.7 1973	26.7 1973	26.7 1973		27.7 1973	27.7 1973	27.7 1973	26.7 1973	26.7 1973	26.7 1973	27.8 1971	30.7 1973	30.7 1973	
Locality and number of area - miejscowość i numer powierzchni		Bukowno I			Las pod Olkuszem II			Starczynów III				Olkusz Stary IV			Przymiarki V			"Osadniki" VI			Bukowno-Dziurka VII			Olkusz VIII		Pomorskie Skały IX				Skalskie X			Olkusz-Racotówka XI			Karna XII		
Exposure - ekspozycja		W	-	-	-	-	-	N	W		W	W	S	-	S	S	ES	SW	N	NW	N	NW	S	SW	N	W	NW		-	N	N	-	W	SW	S	-	-	
Gradient - nachylenie		2	-	-	-	-	-	2	2		5	1	2	-	3	2	5	3	3	5	2	1	5	5	3	2	2		-	-	3	-	3	2	10	-	-	
Height of trees - wysokość drzew (m)		15-18	8	18	10-18	10-15	18-20	5-7	18		5-10	7	10	12	8	10	10-12	15-18	20	14	10	8	30/5	30/10	15	10	15		18	15	18	4	8	8	12	9	12	
Diameter breast height - pierśnica (cm)		25-30	7-15	5-40	10-50	10-30	10-20	5-20	10-20		3-15	3-15	5-15	20-30	10-30	10-30	20-40	20	20-40	5-40	15	10	30	30/10-20	15-40	5-15	10-20		25	20	25	2-8	4-15	3-15	10-30	10	12	
Canopy cover - zwarcie warstwy drzew (%)		35	70	30	20	30	50	60	40		60	80	70	70	70	65	40	35	35	70	85	95	5	5/80	60	60	50		60	65	60	95	90	95	70	80	80	
Shrub cover - zwarcie warstwy krzewów (%)		5	5	30c.	40	20	35	-	30		3	3	3	3	5	10	40c.	1	1	5	2	2	60(A_1/B)	3	5	3	2		5	1	5	-	-	-	3	-	1	
Herbaceous plants cover - zwarcie warstwy zielnej (%)		90	90	60	70	70	95	80	90		90	85	75	90	60	60	90	95	100	80	80	70	80	95	90	80	90		95	95	100	60	70	80	90	70	90	
Bryophytes and lichens cover - zwarcie warstwy mszaków i porostów (%)		5	5	20	15	10	10	5	5		25	15	10	5	10	30	1	3	50	20	10	5	3	10	2	5	5		50	40	20	3	60	5	40	50	80	
Distance from emission source - odległość od źródła emisji (km)		1.25			3.40			1.25				3.68			2.50			1.93			5.82				5.55		6.75				7.90			7.75			4.08		
Direction - kierunek		WSW			E			ESE				NE			W			NNE			WNW				ESE		WN				ENE			ESE			NNE		
Dustfall (t/km^2/year) - opad pyłu (t/km^2/rok)		176			248			230				143			211			158			137				201		139				126			146			117		
Mean Pb (ppm) concentration in plants: Średnie stężenie Pb (ppm) w roślinach: - in above-ground parts - w częściach nadziemnych		193			219			213				148			131			134			114				69		123				76			55			62		
- in underground parts - w częściach podziemnych		293			544			393				396			238			326			190				164		183				135			101			130		
Mean Zn (ppm) concentration in plants: Średnie stężenie Zn (ppm) w roślinach: - in above-ground parts - w częściach nadziemnych		1829			1246			1100				1164			745			796			685				612		595				462			420			459		
- in underground parts - w częściach podziemnych		1543			1448			1231				1123			1073			957			928				648		648				[illegible]			342			507		
Area - powierzchnia (m^2)		400	400	400	400	400	400	400	400		400	400	400	400	[illegible]	[illegible]	200	150	150	400	400	400	400	400	400	400	400		400	400	400	400	400	400	400	400	400	
Vaccinio-Piceetea:																																						
Trees and shrubs:																																						
Pinus silvestris	a	3.2°	4.3°	2.1°	2.1°	2.1°	3.2°	3.2°	3.2°	V } V	4.4°	5.5°	4.4°	4.4°	4.4°	5.4°	4.3°	3.2°	3.2°	4.3°	4.4	5.5	+	5.4	4.4°	4.4°	3.3°	V } V	4.2	4.2	4.2	5.5	5.5	5.5	4.4	5.4	4.3	V } V
"	b	+°	.	3.1°	3.3°	3.2°	3.2°	3.3°	.	IV	+°	+°	+°	.	.	+	3.3	+	+°	+°	.	.	3.3	1.2	1.1	+°	+	IV	+	.	+	+	.	.	+	.	+	III
"	c	+	+	+	+	+	.	.	+	IV	.	.	+	+	.	+	+	+	.	+°	+	+	.	.	+	+°	+	IV	+	+	+	.	.	.	.	.	.	III
Juniperus communis	b	.	.	.	+	.	+	.	+	- } II	+°	.	.	+	+	+	+	+°	+	+	+	+	.	.	.	+°	1.1	IV } V	+	+	+	.	.	+°	.	.	.	II } III
"	c	.	.	.	.	.	.	.	+	II	+	+	+	+	.	1.1	+	.	+	+	+	+	.	.	+	+	+	IV	+	+	+	.	.	.	.	.	.	III
Betula pubescens	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	III	.	.	.	.	.	.	.	.	.	I
"	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	I } II
Picea excelsa	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	+	.	.	I
"	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	+	.	I
Herbaceous plants:																																						
Pirola secunda		.	.	+.2°	+.2°	+.2	+	+	2.2	IV	+	+	1.2	.	+.2	+.2	.	.	1.2	+.2	+.2	1.2	+.2	1.2	+	1.2	+.2	V	1.1	+	1.2	+.2	2.2	2.2	+.2	.	+	V
Chimaphila umbellata		.	.	.	+.2°	.	+	+	+°	III	+.2	+	1.2	+.2	+	+.2	+	+	+	.	1.2	+.2	+	+.2	+	1.2	.	V	.	.	.	.	+	.	+	.	+	III
Vaccinium myrtillus		+.2°	.	.	+°	.	+	+°	+	III	.	.	1.2	.	.	.	+°	1.2	1.2	.	.	.	+.2	+°	.	.	1.2	III	+	2.2	2.2	+.2	1.1	+	2.2	1.1	+	V
Vaccinium vitis-idaea		.	.	.	+.2°	.	1.2°	+	+	III	.	1.2	+.2°	.	.	.	+.2°	1.2	.	.	.	.	+.2	+.2	.	.	2.3	III	2.3	.	2.1	.	.	.	4.4	2.3	4.3	III
Monotropa hypopitys		.	.	.	.	.	.	.	.	-	.	.	.	.	+.2	+.2	.	.	.	.	+.2	.	.	+.2	.	.	.	III	.	.	.	.	.	.	.	+	.	II
Pirola chlorantha		.	.	.	.	.	.	.	.	-	.	+	.	.	.	+.2	.	.	.	.	.	.	.	.	.	+.2	+.2	II	+	+	.	.	+.2	.	.	+	.	III
Pirola minor		.	.	.	.	.	.	.	.	-	+	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	+.2	II	.	.	.	.	.	.	.	.	.	-
Pirola uniflora		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	I	.	.	.	+.2	.	+	.	.	.	II
Melampyrum pratense		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	1.1	.	II
Trientalis europaea		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	+	.	.	1.1	.	II
Lycopodium complanatum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	+.2	.	.	.	.	.	.	.	.	I
Bryophytes and lichens:																																						
Cladonia silvatica		.	.	.	.	.	.	.	.	-	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Nardo-Callunetea:																																						
Herbaceous plants:																																						
Luzula multiflora		.	+	1.1	1.1	+	+	2.1	1.1	V	1.1	1.2	1.2	+	+	+	+	+	+	.	1.2	+.2	.	+.2	+	1.2	.	V	+	.	.	+	.	+	.	.	.	III
Calluna vulgaris		+	.	.	.	+.2	+°	.	.	II	.	.	.	.	.	+	.	4.4	4.4	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	4.3	3.3	4.4	II
Genista germanica		.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Luzula campestris		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Polygala vulgaris		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Potentilla erecta		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.2	I	.	.	.	.	.	.	.	.	+.2	II
Lycopodium clavatum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	+.2	.	.	.	I
Epilobietea angustifolii:																																						
Trees and shrubs:																																						
Salix caprea	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	1.1	.	.	.	+	+	+	+	+	.	+	+	III } III	+	.	+	.	.	.	.	.	.	II } III
"	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	II	+	+	+	.	.	.	.	.	.	II
Sambucus nigra	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Herbaceous plants:																																						
Calamagrostis epigeios		+	.	.	+	.	.	.	.	II	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	.	.	I	.	.	.	.	.	.	.	+.2	.	I
Chamaenerion angustifolium		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	II	.	.	.	.	+	.	.	+	.	III
Fragaria vesca		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	1.2	+.2	.	+.2	.	.	.	II	.	.	.	.	.	.	.	.	.	I
Festuco-Brometea, Trifolio-Geranietea:																																						
Herbaceous plants:																																						
Helianthemum ovatum		1.2	+.2	.	.	.	+	+	+	IV	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	II	.	.	+	.	.	.	.	.	.	II
Dianthus carthusianorum		+	.	.	.	.	.	.	+	IV	.	.	.	.	.	.	1.2	.	+.2	.	+.2	.	1.2	.	.	.	.	III	.	.	+	.	.	+.2	.	.	.	II
Euphorbia cyparissias		+	.	.	.	.	.	.	.	II	.	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	.	II	.	.	.	.	.	.	.	.	.	I
Potentilla arenaria		1.2	.	.	.	.	.	.	+	III	.	.	.	1.2	1.2	1.1	.	.	.	.	.	.	.	.	.	.	.	III	.	.	.	.	.	.	.	.	.	-
Centaurea scabiosa		.	.	.	.	.	.	.	+	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	-
Coronilla varia		.	.	.	.	.	.	.	+	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	-
Medicago falcata		.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Thalictrum minus		.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Trifolium medium		.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	-
Arabis hirsuta		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Astragalus glycyphyllos		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Plantago media		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Scabiosa ochroleuca		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Silene nutans		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	I
Sedo-Scleranthetea:																																						
Herbaceous plants:																																						
Festuca ovina		4.4	5.5	3.3	2.2	3.3	4.4	4.3	4.4	V	5.5	5.5	3.3	4.4	3.3	3.3	2.2	1.2	1.2	4.4	4.4	3.3	3.3	4.4	5.5	4.4	3.3	V	5.5	3.3	4.4	2.2	2.2	2.2	2.2	1.1	3.2	V
Rumex acetosella		+	1.1	+.2	+.2	+	+	1.1	+	V	+.2	+.2	+	+	+	+	+	+°	.	+	+	.	1.1	+	+	+	+	V	+	+	+	+	+.2	+.2	+	+	.	V
Thymus serpyllum		3.3	1.2	+.2	+	.	+.2	3.2	+	V	1.2	+	.	1.2	2.2	1.2	.	2.2	+.2	1.2	2.2	+.2	3.2	2.2	2.2	1.2	+	V	1.2	.	+	+	.	.	.	.	.	II
Corynephorus canescens		.	.	+	.	+	.	1.1	.	II	.	+.2	.	+	+	.	.	.	.	.	.	.	+	.	.	.	.	II	+	.	.	+	.	.	.	.	.	-
Hieracium pilosella		+	+	+	.	.	+	.	.	II	+	.	.	+	+	.	.	.	.	+	+	1.2	+.2	+.2	+	.	+	IV	1.2	+	.	1.2	+	1.2	+.2	1.1	1.1	V
Koeleria glauca		.	.	+	+	+	.	.	.	II	+.2	+.2	+.2	.	.	.	+.2	.	.	.	.	.	1.2	.	.	.	.	II	+	.	.	.	.	.	.	.	.	I
Scleranthus perennis		.	+	.	.	.	.	+	.	II	.	.	.	.	.	.	.	.	.	.	.	.	1.2	.	.	.	.	II	.	.	.	.	.	.	.	.	.	-
Armeria elongata		.	.	.	.	.	.	+	.	I	+.2	.	.	.	.	.	+°	+	+	+	.	.	+.2	.	+	+	.	III	.	.	.	.	.	.	.	.	.	-
Gypsophila fastigiata		.	.	.	.	.	.	.	.	-	+.2	+	+	.	.	.	.	.	.	+	.	+	1.2	+	.	.	.	II	.	.	.	.	.	.	.	.	.	-
Jasione montana		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	I	.	.	.	+	.	.	.	.	.	I
Sedum acre		.	.	.	.	.	.	.	.	-	.	.	.	.	+.2	.	.	.	.	+.2	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Silene otites		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	I	.	.	.	.	.	.	.	.	.	-
Bryophytes and lichens:																																						
Bryum caespiticium		+	.	+	1.2	+	.	.	.	III	.	.	+.2	.	2.2	.	.	.	.	+	+.2	.	+	.	.	.	.	II	.	.	.	.	.	.	.	.	.	-
Ceratodon purpureus		.	.	1.2	1.2	1.2	.	.	.	II	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	+	.	.	I
Brachythecium albicans		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Rhacomitrium canescens		.	.	.	.	.	.	.	.	-	.	.	.	.	.	1.2	.	.	.	.	.	+.2	.	1.2	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Molinio-Arrhenatheretea:																																						
Herbaceous plants:																																						
Cerastium vulgatum		+	+	.	.	.	1.2	.	+	III	.	.	+	+	+	+	+	+	+	1.1	+.2	+	1.1	1.2	.	.	+	III	+.2	+	+	+	+	+.2	+	+	+	V
Leontodon hastilis		+	1.1	.	.	.	+	.	1.2	III	+	.	.	1.2	1.1	1.1	.	.	.	2.2	1.1	+	+	.	.	.	+	IV	+	.	+	+	1.1	.	.	+	.	III
Anthyllis vulneraria		+	.	.	.	.	+	.	1.1	II	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	I	.	.	.	.	.	.	.	.	.	-
Leontodon hispidus		+	.	.	.	+	.	.	.	II	.	.	.	.	.	.	.	.	+	.	.	.	1.1	+	.	.	.	II	.	.	.	.	.	.	.	.	.	-
Lotus corniculatus		+	.	.	.	.	+.2	.	.	II	.	.	+	+.2	+.2	+.2	.	.	.	.	.	.	+	+	.	.	+	II	+	+°	+	.	+	+	+.2	1.1	+	IV
Plantago lanceolata		+	+	.	.	.	+	.	.	II	.	.	.	.	+	.	.	.	.	1.1	+	+	+	+	.	.	.	II	+	.	.	+	.	.	.	.	.	I
Rumex thyrsiflorus		+	.	.	+.2	.	.	.	.	II	+	.	.	.	.	.	+	.	.	.	.	+	+	.	.	.	.	II	.	.	.	.	.	+	.	+	+	III
Achillea millefolium		+.2	.	.	.	.	.	.	.	I	.	.	.	+	.	.	.	.	.	.	+	+	.	+	+	.	.	II	.	.	.	.	.	.	.	.	.	-
Knautia arvensis		.	.	.	.	.	.	.	+	I	.	.	.	.	.	.	.	.	.	.	+	+	+	+	.	.	.	II	.	.	.	.	.	+	.	+	+	II
Ranunculus acer		+	.	.	.	.	.	.	.	I	.	.	.	+	.	.	.	.	.	.	.	+	.	+	+	.	.	I	.	.	.	.	.	.	.	.	.	-
Taraxacum officinale		.	.	.	.	.	+	.	.	I	.	.	.	.	.	.	.	.	.	+	.	+	.	+	.	.	.	II	.	.	.	.	.	+	.	+	+	II
Trifolium pratense		+	.	.	.	.	.	.	.	I	.	.	.	+	.	.	.	.	.	1.2	+.2	+	+	+.2	.	.	.	I	.	.	+	.	.	.	.	+	+	II
Trifolium repens		.	.	.	.	.	.	.	.	-	.	.	.	+.2	1.2	+.2	.	.	.	.	+.2	+	+	+.2	+	.	.	II	.	.	.	.	.	.	.	.	.	-
Alectorolophus glaber		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	2.2	+.2	+	.	.	.	.	.	III	+.2	.	+	.	.	.	.	.	+	II
Centaurea jacea		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Daucus carota		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Lathyrus pratensis		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Leontodon autumnalis		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Trifolium dubium		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	+.2	.	.	I
Vicia cracca		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Festuca pratensis		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	-	.	.	.	.	.	.	.	.	+	I
Others:																																						
Trees and shrubs:																																						
Betula verrucosa	a	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	+	.	.	.	.	.	I
"	b	1.1	.	2.1	.	.	+	.	.	II } IV	.	.	+	.	.	.	.	.	.	+	1.1	+	2.2	+	.	.	.	II } III	.	.	.	.	.	.	+	.	.	I } II
"	c	+	+	+	.	.	.	.	+	III	.	.	.	.	+	.	.	.	.	.	+	.	+	+	.	.	+	II	.	.	.	.	.	.	.	.	.	-
Quercus robur	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	+	.	.	.	.	.	1.1	.	.	.	.	I } III	.	.	.	.	.	.	+	.	.	I } III
"	c	.	.	.	.	.	.	.	.	-	+	+	+	.	.	.	.	.	.	+	.	.	+	.	+	+	+	III	.	.	+	.	.	.	.	.	+	II
Padus avium	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	- } II	.	.	.	.	.	.	.	.	+	I } II
"	c	.	.	.	.	.	.	.	.	-	.	.	.	+	+	+	.	.	.	.	.	+	.	.	+	.	+	II	.	.	.	.	.	.	.	.	.	I
Populus tremula	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	II } II	+	.	+	+	.	.	+	.	+	III } III
"	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	I
Sorbus aucuparia	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	+	+	.	.	.	.	1.2	+	.	.	.	I } II	.	+	.	.	.	+	+	+	.	I } III
"	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	.	+	.	+	.	.	.	II	.	.	+	.	.	.	+	.	.	III
Frangula alnus	b	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	- } I	.	.	.	.	.	.	.	.	.	- } I
"	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	I	.	.	.	.	.	.	+	.	.	I
Salix rosmarinifolia	b/c	+	.	+	+	+	.	.	.	III	.	.	.	+	+	.	.	.	.	.	.	.	+	.	.	.	+	II	.	.	.	.	.	.	.	.	.	I
Corylus avellana	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Crataegus sp.juv.	c	.	.	.	.	.	.	.	.	-	.	.	.	.	+	.	.	.	.	+°	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Rhamnus cathartica	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Pirus communis	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Rosa sp.juv.	c	.	.	.	.	.	.	.	.	-	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Tilia cordata	c	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Herbaceous plants:																																						
Arabis arenosa		1.2	2.2	3.2	+	2.1	1.1	1.1	1.1	V	+	+	+	+	1.1	1.1	1.1	.	+	+	1.1	+	2.1	1.1	1.1	+	1.1	V	+	+	1.1	1.1	.	+	+	+	.	IV
Deschampsia flexuosa		+.2	+.2	2.2	3.3	3.3	1.2	.	1.1	V	+.2	1.2	2.2	.	.	.	4.5	2.2	3.3	.	+.2	+.2	1.2	+.2	.	1.2	1.2	IV	2.2	3.3	2.2	3.3	2.2	4.4	3.3	2.2	2.2	V
Agrostis vulgaris		1.2	1.2	.	.	.	+.2	1.2	.	III	.	+	+	.	+	1.2	.	1.2	+	.	.	.	.	.	+	.	.	II	1.2	+.2	+	.	+.2	.	+	+.2	1.2	IV
Epipactis atro-purpurea		.	.	+	.	.	+.2	.	+	III	+	.	+	+	+	1.1	.	.	.	.	1.1	1.1	+	+	.	+	.	IV	.	.	.	.	+	+	.	.	.	II
Silene inflata		1.1	+.2	.	.	.	+	+	+	III	+.2	+	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	II	.	.	.	.	.	.	.	.	.	-
Carex ericetorum		.	.	+.2	.	.	.	.	+.2	II	.	.	.	.	+	.	.	+.2	.	.	.	.	+.2	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Cytisus ratisbonensis		.	.	.	.	.	+.2	.	+	II	.	.	.	.	.	.	.	.	1.2	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Pimpinella saxifraga		.	.	.	.	.	+	.	+	II	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	-
Campanula polymorpha		+	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+.2	.	+	II	.	.	.	.	.	.	.	.	.	-
Carex hirta		+.2	.	.	.	.	.	.	.	I	.	.	.	+.2	.	.	.	.	.	.	.	.	+.2	1.2	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Carlina acaulis		.	.	.	.	.	+°	.	.	I	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	-
Euphrasia stricta		1.1	.	.	.	.	.	.	.	I	1.2	+	+	.	.	+	.	.	.	1.1	+	+	+.2	.	.	.	+	III	.	.	.	.	.	.	.	.	.	-
Hypochoeris radicata		+	.	.	.	.	.	.	.	I	.	.	.	.	.	+	.	.	.	+	+	+	+	.	.	+	.	III	.	.	.	+	+	+	+	.	+	III
Poa pratensis		+	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	+	+.2	.	+	+	+	.	.	II	.	+.2	.	+.2	+.2	.	+	+	+	IV
Viola tricolor		.	.	.	.	.	.	+	.	I	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Linum catharticum		.	.	.	.	.	.	.	.	-	.	.	.	+	.	+	.	.	.	+	+	.	.	+	.	.	.	III	.	.	.	.	.	.	.	.	.	-
Epipactis latifolia		.	.	.	.	.	.	.	.	-	+	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	II	.	.	.	.	.	.	.	.	.	-
Erigeron acer		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	+	.	II	.	.	.	.	.	.	+	.	.	I
Hieracium Lachenalii		.	.	.	.	.	.	.	.	-	.	.	.	.	.	+	.	.	.	+	.	.	.	+	.	.	+	II	+	.	+	+	+	.	.	.	.	III
Agrostis alba		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Anthoxanthum odoratum		.	.	.	.	.	.	.	.	-	+	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	I	.	+.2	.	.	.	.	1.1	.	.	II
Convolvulus arvensis		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	I	.	.	.	.	+.2	.	.	.	.	I
Cytisus ruthenicus		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Epilobium collinum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	I	.	.	.	.	.	.	.	+	.	I
Equisetum arvense		.	.	.	.	.	.	.	.	-	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Galeopsis sp.juv.		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	I	.	.	.	.	+	.	.	.	.	I
Galium mollugo		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	+	.	.	.	.	.	+.2	.	.	.	I	+.2	+.2	+	.	.	.	.	.	.	II
Geranium columbinum		.	.	.	.	.	.	.	.	-	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Hypericum perforatum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Melandrium album		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	I	.	.	+	.	.	.	+	.	.	II
Microstylis monophyllos		.	.	.	.	.	.	.	.	-	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Mycelis muralis		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	I	.	.	.	.	.	.	.	+	.	I
Plantago maior		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Prunella vulgaris		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Rubus plicatus		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	I	.	.	.	.	.	.	+	+	.	II
Trifolium campestre		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Tussilago farfara		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	.	.	.	.	+	.	.	.	I
Veronica chamaedrys		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	I	+	.	+	.	.	.	+	.	.	II
Viola canina		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Luzula pilosa		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	1.1	2.1	1.1	.	.	+.2	+	1.1	+	IV
Veronica officinalis		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	+.2	.	+	.	.	.	+	.	+	III
Hieracium sp.		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	+	.	+.2	.	II
Dryopteris filix-mas		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	+°	.	.	.	I
Galium vernum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	+.2	.	.	.	.	.	.	.	.	I
Lolium perenne		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	+	.	.	I
Medicago lupulina		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	+	.	.	.	.	.	.	I
Ranunculus polyanthemos		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	+	.	.	.	.	.	.	.	.	I
Rubus sp.juv.		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	+	.	.	.	.	.	.	.	I
Stellaria media		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	+.2	.	.	.	.	I
Bryophytes and lichens:																																						
Brachythecium velutinum		.	1.2	2.2	2.2	2.2	1.2	1.2	1.2	V	2.2	2.2	1.2	+	.	.	+	+	+	.	.	+	+	+	1.2	1.2	+.2	IV	+	.	.	+.2	.	.	.	.	.	II
Pohlia nutans		1.2	.	.	.	.	+	+.2	+	III	.	.	.	+	.	.	.	.	.	.	+.2	.	+	.	.	.	.	I	.	+.2	.	.	+.2	.	.	.	.	II
Bryum capillare		.	.	.	.	.	+	+.2	+	II	.	.	.	+.2	.	3.3	+	.	.	+	.	1.2	.	.	.	.	.	II	.	.	.	.	.	.	+	.	.	I
Lophozia barbata		.	.	.	.	.	.	.	.	-	.	.	.	.	+	.	.	.	.	.	+	+	.	.	.	.	+.2	II	.	.	.	.	.	.	.	.	.	-
Pleurozium schreberi		.	.	.	.	.	.	.	.	-	.	.	+.2	.	.	.	.	+.2	4.4	.	.2	.	.	.	.	.	.	II	3.3	4.3	2.2	+.2	3.2	3.3	3.3	3.3	4.5	V
Brachythecium rutabulum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	.	1.2	.	II	1.2	.	.	.	2.2	+.2	+.2	.	.	III
Bryum argenteum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Bryum inclinatum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+.2	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Calliergon cuspidatum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	2.2	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Cladonia sp.		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Mnium cuspidatum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	I	.	+	.	.	.	.	.	.	.	I
Thuidium delicatulum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	2.2	1.2	1.2	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Tortella tortuosa		.	.	.	.	.	.	.	.	-	.	.	+.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	I	.	.	.	.	.	.	.	.	.	-
Hylocomium splendens		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	+	.	+	II
Brachythecium salebrosum		.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-	.	.	.	.	.	.	+	.	.	I

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of all the species, and they occupied 28% of surface area; which was as much as occupied by forest species. With respect to number of species, quite numerous were plants characteristic to xerothermic grasslands and thermophilous communities, 5% together, and plants characteristic to meadows — 8%, but they occupied very small area (comp. fig. 16).

The phytosociological records from No. 9 to No. 25 in table XI show patches transitional between III and II stand degradation class. The pine trees were also strongly damaged here, and forms with prostrated branches were still present. *Betula verrucosa* sporadically occurred in stands. Seedlings and saplings of pine and birch were quite numerous. Crown density of tress varied

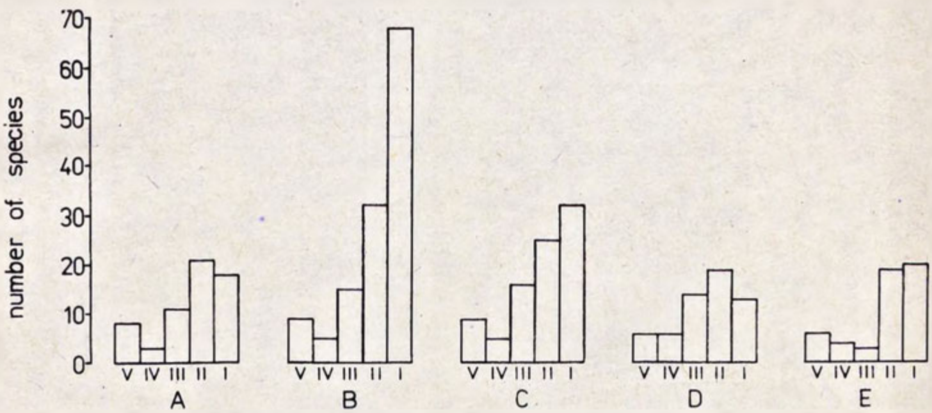

Fig. 15. Number of species in individual constancy classes (V—I) in patches of fresh coniferous forest *Vaccinio myrtilli-Pinetum*. A—E as in fig. 14

Ryc. 15. Udział gatunków w poszczególnych klasach stałości (V—I) w płatach boru świeżego *Vaccinio myrtilli-Pinetum*. hA—E jak na rycinie 14

from 35% to 95%, average 65%. Canopy density of shrub layer was little usually from 1% to 10%. It was formed by up-growth of pine, sometime with considerable admixture of *Betula verrucosa*, *Quercus robur*, *Sorbus aucuparia*, *Salix caprea*, and *Juniperus communis*. Sporadically *Frangula alnus* was present. Only in patches with underplanted pine the canopy density of layer *b* was high (comp. record 15 in table XI).

It most patches herbaceous vegetation had also mosaic arrangement. It covered from 60% to 100% of surface area, average 83%. Mosses were still scarce here, covering from 1% to 10% of surface area of a patch, exceptionally 50% (comp. fig. 16 I).

Of the species characteristic to the class *Vaccinio-Piceetea*, besid: most resistant ones, which were present in extremely degraded forest patches, also few other species had survived here, such as *Monotropa hypopitys*, *Pirola chlorantha*, *P. minor*, *P. uniflora*, and also lichen *Cladonia silvatica*.

The group of species characteristic to poor grasslands of the class *Nardo-Callunetea* was also enlarged. Beside common *Luzula multiflora*, and sporadic

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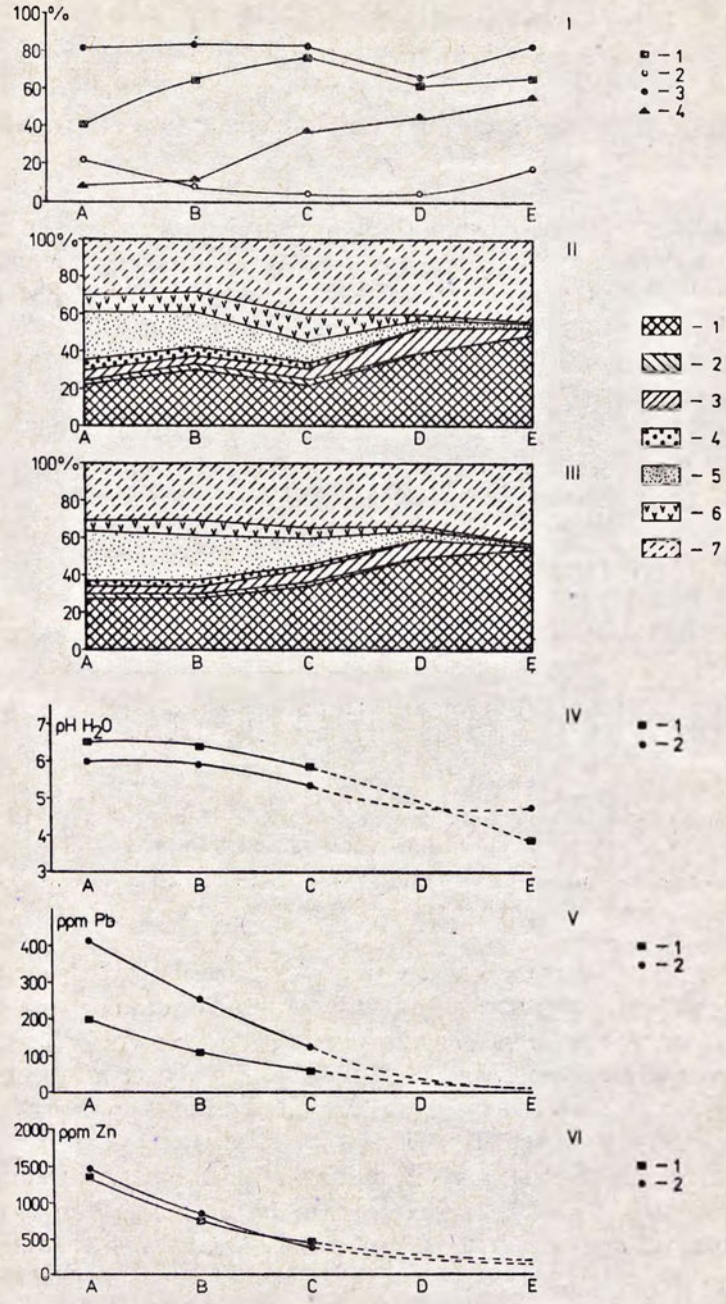

Fig. 16. Floristic composition and structure of patches of fresh coniferous forest *Vaccinio myrtill-Pinetum* in connection with soil reaction and heavy metal concentration in plants of herbaceous layer. I — density of individual layers of community: 1 — trees, 2 — shrubs, 3 — herbaceous plants, 4 — mosses; II — taxonomic value of species groups characteristic for classes: 1 — *Vaccinio-Piceetea*, 2 — *Epilobietea angustifolii*, 3 — *Nardo-Callunetea*, 4 — *Trifolio-Geranietea* and *Festuco-Brometea*, 5 — *Sedo-Scleranthetea*, 6 — *Molinio-Arrhenatheretea*, 7 — remaining species; III —

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but abundant *Calluna vulgaris*, also *Luzula campestris*, *Polygala vulgaris*, and *Potentilla erecta* were also present sometime.

Of cutover species *Salix caprea* was quite frequent, *Chamenerion angustifolium* and *Fragaria vesca* less frequent, and *Sambucus nigra* (seedlings) and *Calamagrostis epigejos* were sporadic.

Out of ten thermophilous species the following were more frequent: *Dianthus carthusianorum*, *Potentilla arenaria*, *Helianthemum ovatum* and *Euphorbia cyparisias*.

Still the species from the class *Sedo-Scleranthetea* dominated in herbaceous layer. The following were constant components: *Festuca ovina* attaining III—V abundance degree in most patches, *Rumex acetosella*, and *Thymus serpyllum*. *Hieracium pilosella* and *Armeria elongata* were less frequent. The remaining species of herbaceous plants and mosses were rare and not numerous (comp. table XI).

The meadow plants were abundant in this group of patches. As many as 20 species from the class *Molinio-Arrhenatheretea* were present here. Some of them attained higher constancy degrees, i.e. *Leontodon hastilis*, *Cerastium vulgatum*, and *Trifolium repens*. The meadow species occurred singly or in small numbers. Only *Leontodon hastilis* and *Alectorolophus glaber* attained second degree of abundance in one of the patches.

Out of the reamining species the seedligs of many shrubs were more frequent than in other groups of phytosociological records (comp. table XI). Out of herbaceous plants *Arabis arenosa* was a constant components of herbaceous layer, and *Deschampsia flexuosa* was very frequent and sometimes very abundant. *Euphrasia stricta*, *Hypochoeris radicata*, *Linum catharticum*, and moss *Brachythecium velutinum* were present in half of the total number of records in this group. The remaining 31 species of vascular plants and 12 species of mosses were not frequent or sporadic.

This group of records was characterized with the highest average number of species, i.e. 34, and the lowest homogeneity, as compared with remaining groups (comp. fig. 14). This was caused by presence of large number of sporadic and not frequent species (fig. 15).

←

group abundance of distinguished groups of species; IV — soil reaction (pH_{H_2O}): 1 — at depth of 0—5 cm, 2 — at depth of 15—20 cm; V — lead concentration in plants of herbaceous layer: 1 — in above-groun parts, 2 — in underground parts; VI — zinc concentration in plants of herbaceous layer: 1 — in above-ground parts, 2 — in underground parts. A — E as in fig. 14

Ryc. 16. Zmiany składu florystycznego i struktury płatów boru świeżego *Vaccinio myrtilli-Pinetum* w powiązaniu z odczynem gleby i zawartością metali ciężkich w roślinach runa. I — zwarcie poszczególnych warstw zbiorowiska: 1 — warstwa drzew, 2 — krzewów, 3 — roślin zielnych, 4 — mchów. II — wartość systematyczna grup gatunków charakterystycznych dla klas: 1 — *Vaccinio-Piceetea*, 2 — *Epilobietea angustifolii*, 3 — *Nardo-Callunetea*, 4 — *Trifolio-Geranietea* i *Festuco-Brometea*, 5 — *Sedo-Scleranthetea*, 6 — *Molinio-Arrhenatheretea*; 7 — pozostałe gatunki. III — ilościowość zbiorowa wyróżnionych grup gatunków. IV — odczyn gleby (pH_{H_2O}): 1 — na głębokości 0—5 cm, 2 — na głębokości 15—20 cm V — zawartość ołowiu w roślinach runa: 1 — w częściach nadziemnych, 2 — w częściach podziemnych. VI — zawartość cynku w roślinach runa: 1 — w częściach nadziemnych, 2 — w częściach podziemnych. A—E — jak na rycinie 14

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Figure 16 shows that stand crown density in this group was considerably higher than in group of patches extremely degraded, while canopy density of herbaceous layer had only slightly increased. On the other hand, the canopy density of shrub layer had decreased (fig. 16 I). There was a little increase, as compared with extremely damaged patches, in taxonomic value of the species characteristic of the class *Vaccinio-Piceetea*, and also *Molinio-Arrhenatheretea*, at simultaneous slight limitation of the species from the class *Sedo-Scleranthetea*. There were no changes as regards the remaining groups of species. The group abundance of the species characteristic of the community classes discussed remained almost the same (comp. fig. 16 II and III).

The lesser pressure of air pollution in this group of fresh coniferous forest patches was indicated by somewhat lower soil reaction, in surface as well as in deeper layer, and concentration of lead and zinc in plant tissues reduced by half as compared with patches extremely damaged (fig. 16 IV—VI).

Relatively best preserved patches of fresh coniferous forest in vicinity of the smelter are represented by the phytosociological records No. 26 to No. 34 in table XI. These forests were classified as II stand degradation class, because of evidently high degree of damage to pine trees. The stands were mainly composed of pine with little admixture of birch, and their crown density varied from 60% to 95%, av. 77%. Understory consisted of same species as in a previous group of patches, but also spruce has appeared here. Its crown density was very low, amounting to less than 2% on the average. The forest floor was almost completely covered by herbaceous plants and mosses. The canopy density of herbaceous layer was from 60% to 100%, av. 83%. The moss cover was relatively high, up to 80%, at average value of 39% (comp. fig. 16 I), although in some patches it was only 3% to 5%.

The herbaceous layer was enriched with the following species characteristic of the class *Vaccinio-Piceetea: Melampyrum pratense*, *Trientalis europaea*, and *Lycopodium complanatum*. On the other hand, there were no *Pirola minor* and *Cladonia silvatica*, which were present in patches more strongly damaged. Of the species characteristic of the class *Nardo-Callunetea*, *Lycopodium clavatum* has appeared, while there were no *Luzula campestris* and *Polygala vulgaris*. The reason for these and other changes was undoubtedly increased shading of forest floor. The group of cutover species from the class *Epilobietea angustifolii* was still present, with an exception of *Sambucus nigra*. Strong retreat was noticed in group of thermophilous species, and only *Helianthemum ovatum* and *Dianthus carthusianorum* occurred rarely, and *Euphorbia cyparisias* and *Silene nutans* sporadically. Also the numbers and frequency of sandy plants were considerably reduced. The following species were constant components of herbaceous cover in this group of phytosociological records: *Festuca ovina*, sometime very abundant in well lighted patches, *Rumex acetosella*, and *Hieracium pilosella*. Rare was *Thymus serpyllum*, and sporadic — *Koeleria glauca*, *Sedum acre*, and *Ceratodon purpureus*. The meadow plants were still present in herbaceous layer. A total of 12 species, occurring singly or in small numbers,

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were recorded. *Cerastium vulgatum*, *Leontodon hastilis*, *L. hispidus*, and *Plantago lanceolata* were the more frequent ones.

Also quite frequent were seedlings and saplings of trees and some shrubs, with *Quercus robur*, *Populus tremula*, and *Sorbus aucuparia* occurring more frequently. Of herbaceous plants and mosses the following were constant or very frequent species: *Deschampsia flexuosa* and *Pleurozium schreberi*, both very abundant, and *Arabis arenosa*, *Agrostis vulgaris*, *Poa pratensis*, and *Luzula pilosa*. *Hypochoeris radicata*, *Hieracium lachenalii*, *Veronica officinalis*, and *Brachythecium rutabulum* were frequent.

There were 30 plant species in a single photosociological record in this group of fresh coniferous forest patches, i.e. a little less than in a previous group. There was a distinct reduction in number of sporadic species (fig. 15). At the same time the homogeneity of this group had increased (fig. 14).

The crown density of tree layer had increased, and canopy density of understory had somewhat decreased, while that of herbaceous layer remained the same. On the other hand, moss cover per single record had increased many times (fig. 16 I).

The percentage of species representing various ecological groups, expressed as taxonomic value showed slight drop in number of species characteristic of coniferous forests, but their group abundance markedly increased (fig. 16 II and III). The elimination of species foreign to fresh coniferous forest site i.e. sandy, meadow and thermophilous species, in favour of species characteristic of the class *Vaccinio-Piceetea*, may be seen in diagram III in fig. 16.

A further decrease in pollution pressure was observed in this group of fresh coniferous forest patches, which was reflected in lower soil reaction (fig. 16 IV), and considerably lower lead and zinc concentration in tissues of herbaceous plant species (fig. 16 V and VI). Only in these patches existed proper distribution of zinc in plants, i.e. there was more of it in aerial than in underground parts.

VI. Discussion

The results presented in this paper were obtained under specific conditions of the environment subjected to strong pressure of industrial air pollution. The samples for the analyses were collected from carefully chosen areas, and the analysis of results showed, that the application of phytosociological classification was in this respect highly advisable. Since the plant community is a good indicator of a habitat, the collection of samples in a same association eliminates, to a high degree, the variability resulting from changing site conditions, and aids demonstration of pollution effects. For this reason a more distinct correlation between size of the dustfall and the contamination of plants and soil with heavy metals was detected in coniferous forests representing a single plant association, although degraded to a various degree, than in sandy waste lands of various character and origin. All of the results obtained

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in this study have been analized here, without discarding those that departed from others due to local disturbances (e. g. additional emission sources). The intention of this study was to verify how far the expected relations may be found in field conditions.

It have been reported many times that plants growing within the range of imission containing heavy metals accumulate in their tissues large quantities of these elements. Under such conditions the metal concentration exceeds many times a normal level in aboveground as well as in underground plant portions. Assuming concentration of lead in plant tissues of 3—10 ppm to be normal (Zimdahl and Arvic, acc. to Peterson 1979, Kabata-Pendias, Pendias 1979), the concentration stated in vicinity of ,,Bolesław'' smelter of several hundred ppm indicates a very high degree of environmental contamination in this region. Similar excess was discovered in case of zinc, since it's concentration in plants was as much as 4000 ppm, while the normal one was assumed to be 15—80 ppm (Kabata-Pendias, Pendias 1979). The cadmium concentration in plants exposed to toxic dusts was as much as 38 ppm, while its normal concentration is 1 ppm (Kabata-Pendias, Pendias l. c.). High concentration of cadmium is particularly toxic to living organisms.

Many other authors have reported similar contamination of plants with heavy metals in vicinity of non-ferrous metal smelters, especially zinc and lead. The initial data concerning the region of „Bolesław" smelter have been reported by the author of this paper in 1975. Similar values may be found in papers of Kaźmierczakowa and Rams (1974), Świeboda (1977, 1980), and Wąchalewski et al. (1978). Also around other smelters of non-ferrous metals, in Poland as well as in other countries, similar or even higher degree of contamination of plants with heavy metals was found (Zimdahl 1976, Peterson 1978, Kabata-Pendias, Pendias 1979, Jastrow and Koeppe 1980, together with references).

Most of the authors indicated a correlation between the distance from emission source and heavy metal concentration in plants and soil. However, the size of imission depends not only on the distance from emission source, but also on many other factors, such as for example, diversified dust particle size, direction and strength of wind, topography. In this study the attempt was made to demonstrate the correlation between size of dustfall and concentration of heavy metals in plants and soil. In many cases it was possible to ascertain a significant correlations, in spite the fact that in the study area, there were additional emission sources e.g. urban emission of Olkusz, and also a high background of dustfall (com. fig. 1).

As far as relation dustfall—plant is concerned, there was a more distinct connection between amount of dustfall and heavy metal concentration in aerial parts of plants. While there was only indirect correlation between dustfall and metal concentration in underground plant parts. We deal here with the following correlations: „dustfall size — metal content in soil" and „metal content in soil — metal concentration in underground plant parts". As far as

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relation soil — plant is concerned, the correlation between content of assimilable Pb and Zn in soil and concentration of these elements in underground plant parts was more distinct than correlation between Pb and Zn in soil and Pb and Zn in overground portions of plants (comp. fig. 11 and 12). Similar results were also obtained by Jones, Jarvis and Cowling (1973).

Many laboratory and greenhouse studies showed, that various plant species, and even different varieties of a same species, growing in the environment polluted with heavy metals accumulate various quantities of these elements in their tissues (John and Van Laerhoven 1976). Also the plant species analized in this study and collected in the same locality varied with respect to Pb and Zn concentration. These difference resulted not only from different absorption of these metals by different species, but to a certain degree also from different depth of root development. The metal content in soil was decreasing with increase in depth.

There are large differences in concentration of heavy metals in different plant organs. In this study mainly aerial and underground portions were analized, and only few results concerned fruits. Usually, a higher concentration was observed in underground plant parts. The experiments with *Thymus serpyllum* planted in plots with clean soil seems to show that distribution of heavy metals in a given plant species depends, at least to a certain degree, on a main source of inflow of these elements, such as polluted air or soil. The fact that at excessive concentration of heavy metals in plant tissues there is no equalization of this concentration in a plant, indicates that there exist physiological barriers regulating, to a certain degree, transport of heavy metals in plants (Motto et al. 1970, Jones, Clement and Hopper 1973, Malone et al. 1974).

Comparison between concentration of haevy metals in plants collected in a forest and concentration in plants collected in treeless sandy sites showed that forest does not protect plants against air pollution. On the contrary, as a same dustfall, forest plants were considerably more subjected to harmful action of toxic emission components than plants in treeless site. It was mainly because dust accumulates on and under tree crowns (Hajdúk 1974), and the content of heavy metals in the forest soil is high. Also Little and Martin (1972) in vicinity of a smelter stated higher pollution of soil with zinc, lead and cadmium in forests than in meadows. It has been proved many times, that haevy metals are subjected to strong sorption by humus substances. This is why large accumulation of these elements has been observed in surface soil layers, mainly in the litter and organic horizons (Vetter et al. 1974, Wąchalewski et al. 1975, 1978, Turski and Baran 1976, Marczak and Biedroń 1978, Kowalkowski and Szczubiałka 1981). Accumulation of heavy metals in soil is connected, to a large degree, with soil type (Warda msc., Turski and Baran 1976). The present study, limited to a single soil type, i. e. podzolic soil, showed that imission's size was a main factor controlling content of Pb and Zn in soil. The organic matter was a second factor determ-

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ining the retention of these elements in soil. The multiple correlation showed that these two factors primarily determine Pb and Zn content in horizon A_1 of forest soil. In the transition zone between horizon A_0 and A_1, i.e. in root zone of *Arabis arenosa* this correlation was weaker. However, it should be pointed out, that not whole organic matter plays a significant role in the process of accumulation of heavy metals in soil, but only a soil humus, especially humic acids. Stevenson (1976) wrote as follows: „It is probably that humic substances are the final sink for heavy metals in many soils and sediments".

Increased assimilation of heavy metals by plants growing in a forest may be also connected with somewhat lower pH of forest soil as compared with sandy waste land soils. Also some factors of forest microclimate, such as higher air and soil humidity, longer retention of dew on leaves, may favour greate assimilation of these elements by plants.

Pollution of plants in the experimental plots indicated that their contaminatr ion with heavy metals took place very quickly, since after two years it reache-d almost the same level as the one resulting from long term emission. This confirms the observations of other authors who conducted studies directly after initiating work in industrial establishments, or lysimetric studies with soil and plants exposed to industrial emissions (Warda msc., 1976, Karweta 1976, Roszyk E. and Roszyk S. 1976).

Most of the studies conducted around industrial establishments were limited to the area located in a radius of 5 to 10 km from emission source. However effect of emission on natural environment may be detected in much greater distance, e. g. Buchauer (after Peterson 1978) and Strojan (1978) found increased content of heavy metals in forest litter and soil in a distance as great as 40 km from emission source. In the present study plants and soil from so called I-st control area, situated 20km away from the smelter, were characterized with distinctly increased concentration of heavy metals analized. Also values obtained in the II-nd control area, located 60 km away from the smelter in a region without developed industry, were frequently higher than those assumed to be normal. This was true particularly in case of lead (comp. table III). This fact is certainly connected with carrying gasses and small dust particles over long distances, which results in air pollution over vast aerias of Europe, and is evident in Southern Poland (Ottar 1977).

In analysis of changes in coniferous forest *Vaccinio myrtilli-Pinetum* upon effect of the smelter, it was assumed after Faliński (1966) and Olaczek (1972), that a numerical ratio between species of individual syngenetic groups was an index of the degree of degeneration of association. As degree of degeneration increases, number of species characteristic of a given association and of the higher units decreases, and number of species from other communities increases. Similarly the percentage of area occupied by individual groups of species behaves. In vicinity of the „Bolesław" smelter three phases of degradation of fresh coniferous forest were distinguished, which were compared

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with patches of the same community, well preserved (Michalik 1981), and assumed to be exemplary (Medwecka-Kornaś 1952), (comp. fig. 16).

The changes in floristic composition of fresh coniferous forest consisted of penetration of photophilous non-forest species from several other plant community classes. It was caused by simultaneous action of many factors, of which air and soil pollution with heavy metals, air pollution with SO_2, increased soil pH, and drying up of sites, were the most important ones. These factors overlapped one another, and in the field only the resultant of their action was observed. Because of high toxicity of heavy metals it seems that they were a main cause of damages to vegetation cover observed here, however strong action of sulphur dioxide should not be neglected. A strong degradation of *Vaccinio myrtilli-Pinetum* association resulted, to a large degree, from high susceptibility of Scotch pine to industrial air pollution, especially to SO_2. Thinning of crowns, checking of growth, and finally dying, led to opening of stands to more light, which in turn resulted in disappearing of shade loving herbaceous species. Along with that, the accumulation of toxic emission components in soil, increase in soil pH, and increase in air pollution had been taking place. Also dryness of substratum was increasing since draining of the area was stimulated by industry. As a result of these changes new species came in, foreign to fresh coniferous forest community, and character of herbaceous layer has changed completely.

When analizing the occurrence of species characteristic of the class *Vaccinio-Piceetea* and the aliance *Dicrano-Pinion* to which the association *Vaccinio myrtilli-Pinetum* belongs, it may be noticed that out of 15 species, occurring in investigated area, six survived in extremely degraded patches at maximum degree of plant and soil contamination with heavy metals, and considerably increased soil reaction. They were as follows: *Pinus silvestris*, *Juniperus communis*, *Pirola secunda*, *Chimaphila umbellata*, *Vacinium myrtillus*, and *V. vitis-idaea*. Similarly as pine, the other species were frequently injured, had lowered vitality, and did not flower, nor produced fruits. With decreasing pressure of the smelter further species were appearing, characteristic of coniferous forests, i. e. *Monotropa hypopitys*, *Pirola chlorantha*, *P. minor*, *P. uniflora*, and *Cladonia silvatica*. Only in best preserved patches of fresh coniferous forest the following species were growing: *Melampyrum pratense*, *Trientalis europaea*, and *Lycopodium complanatum*. In well preserved patches (Michalik 1981) and recognized as model ones (Medwecka-Kornaś 1952), the group abundance as well as taxonomic value of species characteristic of the class *Vaccinio-Piceetea* increased even more, and they dominated in a community (comp. fig. 16 II and III).

The opposite behaviour was observed in case of photophilous species connected with sandy grasslands, and thermophilous and meadow species. They dominated over forest species in patches extremely damaged. Gradually they were disappearing from communities, to disappear almost completely in model patches (comp. table XI and fig. 16). It may be worth to point out, that some communities of the order *Festuco-Sedetalia*, belonging to the class

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Sedo-Scleranthetea enter the composition of dynamic group of pine forest communities and may form final phases of the process of their degradation (Matuszkiewicz 1981). A similar course of that process was described in the vicinity of other industrial works (cf. Hajdúk 1961).

The mosses turned out to be a good indicator of the degree of degradation of fresh coniferous forest. Their abundance was decreasing rapidly with increasing emission (comp. fig. 16 I). Similar observations were made by Folkeson and Kvillner (1983) around the smelter in Gusum in Southern Sweden, emitting mainly Cu and Zn. They found that many moss species, typical of coniferous forests, such as *Pleurozium schreberi*, *Hylocomium splendens*, *Ptilium crista-castrensis*, and *Dicranum undulatum* (*D. polysetum*) are particularly susceptible to pollution of environment with heavy metals. Also Lux (1964) noticed susceptibility of *Pleurozium schreberi* to industrial emissions. In vicinity of Bukowno none of these species was present in patches of extremely degraded forest. *Pleurozium schreberi* appeared in patches transitional between III and II degradation degree, while in forests relatively well preserved it was a constant and abundant species (comp. table XI). Also *Hylocomium splendens* grew only in that latter group of patches. *Ptilium cristacastrensis* and *Dicranum undulatum* was present no sooner than in patches of fresh coniferous forest belonging to I-st degradation class and in model patches (comp. Michalik l. c. and Medwecka-Kornaś l.c.). In Bukowno, as in Gusum, *Pohlia nutans* turned out to be a resistant species growing quite frequently in extremely damaged patches.

The changes in floristic composition of forests in vicinity of the „Bolesław" smelter may be compared with those described by Lux (1964) in pine forests being under pressure of industrial air pollution in Dübener Heide. According to his observations more and more non-forest photophilous species were entering along with increasing degree of damage to the community. Also the number of species in a community was gradually increasing. This author did not observe second reduction in number of species in patches most strongly damaged. It seems that degree of forest damage there had not reached such intensity as near the „Bolesław" smelter. On the other hand, the changes in numbers of species in a community of coniferous forest near the smelter in Gusum in Sweden (Tyler 1984) were similar to ones observed in present study.

It is interesting, that in zone of high dustfall where many vascular plant species are eliminated, some of them not only remain, but expand, occupying place left by retreating ones. In this study *Festuca ovina* and *Deschampsia flexuosa* turned out to be such expansive species, bearing extremely high air and soil pollution. Also in vicinity of other smelters, increasing covering of area with *Deschampsia flexuosa*, along with increasing content of heavy metals in raw humus was observed (Folkeson and Kvillner 1983). It is possible, that this plant possesses specific populations tolerant to toxic concentrations of heavy metals. Such populations have been reported in case of *Festuca ovina* (Antonovics et al. 1971). According to Bradshaw (1976) they are frequent

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among many species of plants, and in relation to various pollutants. Perhaps *Arabis arenosa*, *Thymus serpyllum* and *Silene inflata* had resistant population in the area of this study.

Destruction of forest upon the effect of industry has far reaching consequences. It concerns not only economic aspect, analized in detail by foresters, but also other than production functions of a forest. Climatic coufitions become worsened. Water regime is changing, and water retention decreases. The forest fruits disappear and those that remain are harmful for man because of increased heavy metal content. This is even more true in case of medical herbs. Entire plant association disappears together with accompanying fauna, and temporary increase in diversity of species does not compensate losses resulting from disappearance of species connected with natural communities. For example *Arctostaphylos uva-ursi*, a species connected with pine forests and rare in Southern Poland have been previously reported from the area of this study. It is suspected that it has disappeared from vicinity of Bukowno, since it was not found during present investigations. Also *Microstylis monophyllos* from the family *Orchidaceae*, a rare species in Poland, occurs in pine forests of Bukowno. Further destruction of forests, due to expension of the smelter, will result in disappearance of this species.

The changes taking place lead to formation of communities of simple structure, smaller productivity and biomass, instead of forests. Site conditions in Bukowno are such that fresh coniferous forests will be replaced with poor, loose grasslands on sand from the class *Sedo-Scleranthetea*. Along with worsening of plant living conditions the canopy density of these grassland decreases, finally exposing bare sands. This stimulates soil erosion. Perhaps populations of grasses resistant to high concentration of heavy metals in soil, especially *Deschampsia flexuosa* and *Festuca ovina*, may be of some importance in counteracting erosion. These species may be used in sodding of open soil.

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STRESZCZENIE

I. Wstęp i cel pracy

W pracy niniejszej podjęto próbę przedstawienia niektórych aspektów niszczącego wpływu Kombinatu Górniczo-Hutniczego „Bolesław" w Bukownie koło Olkusza na roślinność świeżego boru sosnowego *Vaccinio myrtilli-Pinetum*. Zanalizowane w terenie płaty przedstawiały różne stadia degradacji tego zespołu. W zasięgu oddziaływania Kombinatu wykonano już cały szereg prac, dokumentujących destrukcyjny wpływ tego obiektu na środowisko abiotyczne: gleby (Wąchalewski i in. 1975, 1978), wody (Rybicki 1968, Pasternak 1973, 1974), powietrze (Dorling msc.), oraz świat roślin (Kaźmierczakowa, Rams 1974, Kaźmierczakowa 1975, Świeboda 1977, 1978, 1980, Wąchalewski i in. 1978) i zwierząt (Makomaska msc., Sawicka-Kapusta 1978, Wąchalewski i in. 1978). Głównym czynnikiem, działającym destrukcyjnie jest tu emisja pyłowa huty, zawierająca toksyczne w wyższych stężeniach metale ciężkie — głównie cynk, ołów i kadm. Niemałe znaczenie ma również emisja gazów, szczególnie dwutlenku siarki, oraz przesuszenie siedlisk wywołane sczerpywaniem wód kopalnianych.

Z całego szeregu skutków oddziaływania Kombinatu na strukturę i funkcję ekosystemu leśnego wybrano dwa zagadnienia: zmiany składu chemicznego roślin runa polegające na wzroście zawartości metali ciężkich znajdujących się w emitowanych pyłach, oraz jakościowe i ilościowe przekształcenia składu florystycznego zespołu boru świeżego. Stopień akumulacji metali ciężkich w roślinach posłużył przy tym jako wskaźnik wpływu emisji. Porównano stopień skażenia roślin w lesie i w zbiorowisku nieleśnym o podobnym typie siedliska. Analiza roślin z założonych w terenie poletek z nawiezioną glebą pozwoliła na określenie szybkości przebiegu procesu skażenia roślin i gleby.

II. Szczegółowa lokalizacja i zakres badań

Wokół kombinatu wybrano do badań 12 powierzchni, położonych w odległości 1,25 do 8,5 km od źródła emisji, bezpośrednio w sąsiedztwie działających tu w latach 1969—1971 punktów pomiarowych opadu pyłu. Każda z powierzchni obejmowała płat boru świeżego oraz nieużytek piaszczysty. Dane porównawcze co do zawartości metali ciężkich w roślinach uzyskano z dwóch powierzchni kontrolnych, pierwszej oddalonej o 20 km, drugiej — o około 60 km w kierunku północno-wschodnim. Dodatkowo w terenie badań założono sześć poletek z nawiezioną czystą glebą, o wymiarach 1 × 3 m i głębokości 30 cm. Poletko kontrolne znajdowało się w obrębie pierwszej powierzchni kontrolnej (ryc. 1).

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Zanalizowano zawartość ołowiu i cynku w nadziemnych i podziemnych częściach następujących gatunków roślin: z lasu — *Deschampsia flexuosa*, *Vaccinium myrtillus* i *Vaccinium vitis-idaea*; z lasu i nieużytku — *Arabis arenosa*, *Thymus serpyllum* i *Viola tricolor*. Odrębnie zanalizowano owoce *Vaccinium vitis-idaea*. Równocześnie określono zawartość obu metali — ogólną i w formie rozpuszczalnej w EDTA — w glebie pochodzącej ze strefy korzeniowej badanych gatunków roślin.

Na poletkach z nawiezioną glebą wysadzono siewki *Thymus serpyllum*. Zawartość Pb i Cd w nadziemnych i podziemnych częściach roślin oraz w glebie (Pb-EDTA i Cd-EDTA) z głębokości 0—3 cm i ze strefy korzeniowej roślin zanalizowano po dwu i pół rocznej ekspozycji (po trzech sezonach wegetacyjnych).

Na każdej powierzchni leśnej wykonano dwa lub trzy zdjęcia fitosocjologiczne metodą Braun-Blanqueta. Jako materiał porównawczy dla stwierdzenia zmian zespołu boru świeżego wykorzystano prace Michalika (1981) i Medweckiej-Kornaś (1952).

Badania terenowe prowadzono w latach 1970—1974.

III. Charakterystyka wybranych elementów środowiska w terenie badań

Gleby. Teren badań obejmował obszar pokryty piaskami pochodzenia lodowcowego. Zalegają one zwykle grubą, dochodzącą do kilkudziesięciu metrów miąższości warstwą na wapieniach muszlowych i dolomitach kruszconośnych. Te ostatnie miejscami wychodzą na powierzchnię. Najpospolitszym typem gleb są tu gleby bielicowe słabo gliniaste. Ten typ gleb reprezentowany był na wszystkich powierzchniach badań.

Stosunki wodne. Wody wgłębne zalegają na głębokości kilkunastu, a nawet kilkudziesięciu metrów. Oszuszanie terenu nasila się w miarę rozbudowy systemu kopalń. Lej depresyjny obejmuje powierzchnię kilkunastu kilometrów kwadratowych (Rybicki 1968).

Klimat. Obszar badań należy do krainy klimatycznej Śląsko-Krakowskiej, zaliczanej do klimatów Wyżyn Środkowych. Wykazuje on pewne rysy kontynentalne. Średnia roczna suma opadów wynosi 726 mm, średnia temperatura roczna — 7,1°C. Najcieplejszym miesiącem jest lipiec (17,6°C), najchłodniejszym — luty (—3,0°C). W terenie badań przewyższają wiatry zachodnie i one też wykazują największą prędkość (por. róża wiatrów na ryc. 1).

Zanieczyszczenie powietrza. Głównym źródłem zanieczyszczenia powietrza jest tu kombinat „Bolesław". Roczna emisja pyłów i gazów w okresie badań wynosiła 12 tys. t (tab. I). W najbliższym sąsiedztwie huty opad pyłu dochodził do 250 t/km² rocznie. Rozchodzenie się zanieczyszczeń zależało głównie od warunków anemologicznych (por. ryc. 1). Miejscami ilość opadających pyłów ulegała podwyższeniu wskutek istnienia lokalnych źródeł emisji (Olkusz, Bukowno). Ogólne tło opadu pyłu na tym obszarze wynosiło około 90 t /km²/ rok. Wielkość taką notowano na pierwszej powierzchni kontrolnej oraz na rozległych obszarach GOP leżących poza zasięgiem lokalnych źródeł emisji (Skawina, Wąchalewski 1965). Z opadających pyłów 47% nie rozpuszcza się w wodzie, pozostała część to pyły rozpuszczalne. Udział poszczególnych pierwiastków w opadających pyłach obrazuje tabela II. Około 40% Pb i 70% Cd w pyłach znajduje się w formie związków rozpuszczalnych w wodzie (Dorling msc.).

Zanieczyszczenie gleb. Ubogie i słabo zbuforowane gleby piaszczyste stanosią typ gleb najbardziej podatny na zmiany i łatwo ulegający trwałym niekorzystnym przekształceniom. W terenie badań obserwuje się wyraźną alkalizację gleb oraz zahamowanie procesów humifikacji i mineralizacji materii organicznej. Przyczyną tych zmian są głównie pyły przemysłowe, a zwłaszcza pierwiastki toksyczne w wyższych stężeniach, jak cynk, ołów i kadm.

IV. Metody badań

Analizy zawartości metali ciężkich w roślinach wykonywano w próbach mieszanych, złożonych z kilkunastu do kilkudziesięciu okazów roślin, lub ich fragmentów (w wypadku polikormonów). Rośliny myto w wodzie bieżącej i płukano wodą destylowaną. Oznaczenia wykonano metodą diti-

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zonową w przesączu po spaleniu prób na sucho w temperaturze 500°C. Ogólną i przyswajalną zawartość metali w glebie oraz w roślinach z poletek doświadczalnych oznaczono spektrofotometrem Varian Techtron Model 1000. Za przyswajalne dla roślin uznano formy metali rozpuszczalne w 0,05 M roztworze soli dwusodowej EDTA.

V. Wyniki

1. Akumulacja ołowiu i cynku w roślinach i jej zależność od warunków środowiska

W roślinach zebranych w sąsiedztwie huty stwierdzono bardzo wysoką zawartość Pb i Zn (tab. III). W porównaniu z wartościami uzyskanymi na II powierzchni kontrolnej, średnia zawartość Pb w roślinach wokół huty była wyższa — w zależności od gatunku i części rośliny oraz typu siedliska — od 8 do około 30 razy, a maksymalna — od 12 do 70 razy. Analogiczne różnice w zawartości cynku wynosiły: średnio — od 2 do 30 razy, maksymalnie — od 3 do 70 razy. Zawartość analizowanych metali ciężkich w roślinach na I powierzchni kontrolnej, leżącej w obrębie Śląsko-Krakowskiego Okręgu Przemysłowego, choć z dala od lokalnych źródeł emisji, były od 2 do 10 razy wyższe, niż na II powierzchni kontrolnej w terenie rolniczym (tab. III).

Z 36 przebadanych przypadków związku między wielkością opadu pyłu a zawartością w roślinach Pb i Zn, w 26 stwierdzono istotną statystycznie zależność o charakterze dodatniej korelacji prostoliniowej (tab. IV). Zależność ta była silniejsza dla części nadziemnych roślin, niż dla części podziemnych. Wielkość akumulacji zależała od gatunku rośliny, jej części oraz typu środowiska (ryc. 2—6). Pod względem wielkości kumulacji metali ciężkich przebadane gatunki roślin układały się następująco: *Arabis arenosa* > *Viola tricolor* > *Thymus serpyllum* > *Vaccinium vitis-idaea* > *Deschampsia flexuosa* > *Vaccinium myrtillus*. W obrębie rośliny wyższe stężenia Pb notowano zwykle w częściach podziemnych niż w nadziemnych, najniższe w owocach (ryc. 7, 8). Podobny był rozkład stężenia cynku, choć różnice były mniejsze, a w niektórych wypadkach, np. u *Arabis arenosa*, rozkład stężeń był odwrotny (ryc. 9).

Rośliny tego samego gatunku zebrane w lesie posiadały w swoich tkankach wyższe stężenia metali ciężkich, niż zebrane na nieużytkach. Było to związane z nieco niższym odczynem gleb leśnych w porównaniu z glebami nieużytków (ryc. 10) oraz większą zawartością ołowiu i cynku w glebach leśnych (tab. V). Dane w tabeli V wskazują, że nagromadzenie metali ciężkich w glebie zależało w dużym stopniu od wielkości opadu pyłu i zawartości materii organicznej. Analiza statystyczna wykazała, że w głębszych warstwach gleby leśnej, w strefie korzenienia się *Vaccinium vitis-idaea*, zawartość Pb i Zn była w około 90% zdeterminowana przez te czynniki. W strefie korzenienia się *Arabis arenosa* zależność ta była słabsza (około 40% determinacji), a na nieużytkach piaszczystych decydującego znaczenia nabierały inne czynniki (tab. VI). Na obu typach siedlisk istniała wysoka istotna korelacja między ogólną zawartością w glebie każdego z badanych metali, a ich zawartością w formie rozpuszczalnej w EDTA (tab. VII).

Zależność między zawartością przyswajalnych form ołowiu i cynku w glebie a ich stężeniem w roślinach tylko w połowie z 12 zanalizowanych wypadków miała charakter statystycznie istotnej korelacji. Zależność ta była silniejsza w stosunku do podziemnych części roślin, a słabsza w odniesieniu do części nadziemnych. Niekiedy stwierdzano w tkankach roślin wyższe stężenia metali, niż wynosiła zawartość ich form przyswajalnych w glebie (ryc. 11 i 12).

2. Akumulacja ołowiu i kadmu w roślinach i glebie z poletek doświadczalnych

Gleba nawieziona na poletka doświadczalne zawierała początkowo 16,5 ppm Pb-EDTA i 1,5 ppm Cd-EDTA (tab. VIII). Po dwu i półrocznej ekspozycji stwierdzono znaczny wzrost zawartości obu metali, dochodzącej w warstwie powierzchniowej do 119,2 ppm przyswajalnego ołowiu i 5,95 ppm

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przyswajalnego kadmu. W warstwie głębszej, w glebie ze strefy korzeniowej *Thymus serpyllum* maksymalne wartości wyniosły 85,0 ppm Pb-EDTA i 3,55 ppm Cd-EDTA. Równocześnie wzrósł odczyn gleby (tab. IX). Stężenie metali ciężkich w roślinach z poletek zwiększyło się maksymalnie do 304,8 ppm Pb w częściach nadziemnych i 227,9 ppm Pb w częściach podziemnych, kadmu — odpowiednio do 37,7 ppm i 34,9 ppm. Na poletku kontrolnym stężenie ołowiu było sześciokrotnie, a kadmu ponad dziesięciokrotnie niższe (ryc. 13). Rozmieszczenie metali w obrębie roślin zebranych z poletek było odwrotne niż w roślinach pochodzących z gleb od dawna zanieczyszczonych, a mianowicie wyższe stężenia notowano w nadziemnych częściach roślin (tab. X).

3. Zmiany składu florystycznego boru świeżego *Vaccinio myrtilli-Pinetum* w zasięgu oddziaływania huty

Stężenie metali ciężkich w roślinach runa potraktowano jako wskaźnik presji kombinatu „Bolesław" na bory sosnowe. Zdjęcia fitosocjologiczne uszeregowane zgodnie z malejącą zawartością Zn i Pb w roślinach runa dały się podzielić na trzy grupy. Grupa pierwsza obejmowała zdjęcia 1—8 w tabeli XI. Degradacja drzewostanu odpowiadała tu klasie III (Kamieniecki 1972). Średnia liczba gatunków w zdjęciu wynosiła 24, jednorodność zdjęć była stosunkowo wysoka (ryc. 14). Odczyn gleby osiągnął w warstwie powierzchniowej niemal 6,5 pH_{H_2O}. Zwarcie koron drzew wynosiło średnio zaledwie 42%. Runo tworzyło układ mozaikowy z płatami odkrytej gleby, zajmując średnio 80% powierzchni. Mchy rosły bardzo skąpo (ryc. 16 I). Biorąc pod uwagę całe zbiorowisko, gatunki charakterystyczne dla nieleśnych klas zbiorowisk przeważały nad — rosnącymi tu w liczbie sześciu — gatunkami charakterystycznymi dla klasy *Vaccinio-Piceetea* tak pod względem wartości systematycznej, jak i ilościowości grupowej. Wśród roślin nieleśnych dominowały gatunki charakterystyczne dla klasy *Sedo-Scleranthetea*. Dość znaczny był także, zwłaszcza pod względem liczby, udział gatunków z klasy *Molinio-Arrhenatheretea* i *Nardo-Callunetea* (ryc. 16).

Zdjęcia 9—25 w tabeli XI reprezentują płaty przejściowe między III a II klasą degradacji drzewostanu. Średnio w jednym zdjęciu notowano tu najwyższą liczbę gatunków, a mianowicie 34, przy najniższej jednorodności zdjęć (ryc. 14) i dużym udziale gatunków sporadycznych (ryc. 15). Zwarcie koron drzew wzrosło tu do 65%, runo posiadało nadal charakter mozaikowy, zajmując średnio 83% powierzchni. Mchy rosły skąpo. Wartość odczynu gleby nieznacznie się obniżyła (ryc. 16 IV). Liczba gatunków z klasy *Vaccinio-Piceetea* zwiększyła się do 11. Ilościowość grupowa gatunków z wyróżnionych klas zbiorowisk zmieniła się nieznacznie, wzrosła natomiast wartość systematyczna gatunków charakterystycznych dla borów szpilkowych, przy równoczesnym ograniczeniu gatunków muraw piaskowych (ryc. 16).

Zdjęcia 26—34 reprezentują stosunkowo najlepiej zachowane płaty boru świeżego spośród przebadanych. Pod względem stopnia degradacji drzewostanu zaliczyć je należy do klasy II, co wiąże się z dużą wrażliwością sosny na zanieczyszczenia przemysłowe. Odczyn gleby był tu nieco bardziej kwaśny, niż w płatach poprzednio opisanych i wynosił w warstwie powierzchniowej średnio 5,9 pH_{H_2O}. Na jedno zdjęcie przypadało średnio 30 gatunków. Jednorodność zdjęć była wyższa, niż w grupie poprzedniej (ryc. 14). Średnie zwarcie koron drzew zwiększyło się do 77%, roślin zielnych — nie zmieniło się w stosunku do poprzedniej grupy płatów, mchów natomiast wzrosło do około 40% (ryc. 16 I). Zwiększyła się do trzynastu liczba gatunków charakterystycznych dla klasy *Vaccinio-Piceetea* a także ich ilościowość grupowa, choć udział procentowy nieco się zmniejszył. Dalszemu wyraźnemu ograniczeniu uległy rośliny muraw piaskowych (ryc. 16 II i III).

VI. Dyskusja

W pracy zanalizowano cały zebrany materiał, wszystkie próby roślin i gleby oraz wykonane zdjęcia fitosocjologiczne. Ideą pracy było bowiem sprawdzenie, w jakim stopniu oczekiwane zależności między presją kombinatu a jakościowymi i ilościowymi cechami roślin i wybranego zbiorowiska

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dają się wykazać w konkretnie istniejących w przyrodzie warunkach, dość odległych od idealnego układu (pewna niejednolitość siedlisk, dodatkowe źródła emisji itp.).

Wyraźniejsze zależności otrzymano w stosunku do prób roślin i gleby z płatów zespołu *Vaccinio myrtilli-Pinetum* niż z piaszczystych nieużytków, gdyż zespół roślinny, nawet w różnym stopniu zdegradowany, jest dobrym wskaźnikiem warunków siedliskowych.

Stwierdzone w okolicach kombinatu „Bolesław" stężenia metali ciężkich w tkankach roślin i w glebie wykazywały wielokrotne przekroczenia w stosunku do wartości uważanych za normalne, i zbliżały się do wartości podawanych przez innych autorów z bezpośredniego sąsiedztwa dużych obiektów przemysłowych (Kabata-Pendias, Pendias 1979, Peterson 1979, Jastrow, Koeppe 1980 i in.). Zawartość metali ciężkich w roślinach i glebie zależała w sposób istotny od wielkości opadu pyłu i typu siedliska, co wykazano mimo istnienia na obszarze badań wysokiego ogólnego tła opadu pyłu i dodatkowych źródeł emisji o składzie różnym od emisji kombinatu. W zależności od głównego źródła metali ciężkich, jakim dla roślin może być zawartość ich w powietrzu lub w glebie, rozmieszczenie ich w roślinie było różne, jak to wykazano dzięki poletkom doświadczalnym. Istnienie różnic w stężeniu metali ciężkich w różnych częściach rośliny wskazuje na obecność fizjologicznych barier, regulujących przynajmniej w pewnym stopniu transport tych pierwiastków w roślinie (Motto i in. 1970, Jones, Clement i Hopper 1973, Malone i in. 1974).

Las nie stanowi dla roślin zielnych żadnej ochrony przed zanieczyszczeniami pochodzącymi z powietrza. Przeciwnie, przy tym samym ogólnym opadzie pyłu, w sąsiedztwie drzew opad się zwiększa (Hajduk 1974). Ponadto gleby leśne bogate w związki humusowe kumulują większe ilości metali ciężkich niż inne typy gleb. Według Stevensona (1976) substancje humusowe stanowią ostateczny zbiornik metali ciężkich w różnych typach gleb i osadów. Większemu pobieraniu tych pierwiastków przez rośliny w lesie w stosunku do terenu bezdrzewnego sprzyja także nieco niższy odczyn tych gleb w porównaniu z glebami nieużytków, a także bardziej wilgotny mikroklimat.

Poletka doświadczalne założone wokół kombinatu pozwoliły wykazać bardzo dużą szybkość akumulacji w trwałych roślinach metali ciężkich znajdujących się w emisji. Dwu i półroczna ekspozycja doprowadziła do skażenia roślin w stopniu niewiele ustępującym wieloletniej emisji. Zwraca także uwagę duża rozległość procesu zanieczyszczenia środowiska metalami ciężkimi. Analizy z poletek kontrolnych wskazują, że skażeniu ulegają nie tylko okręgi przemysłowe, ale również tereny rolnicze.

Jako wskaźnik stopnia degradacji zespołu *Vaccinio myrtilli-Pinetum* przyjęto za Falińskim (1966) i Olaczkiem (1972) udział gatunków z obcych danemu zbiorowisku jednostek fitosocjologicznych. Wyróżnione wokół kombinatu trzy fazy degradacji zespołu porównano ze stanem zbiorowiska opisanym przez Michalika (1981) z bezpośredniego sąsiedztwa terenu badań, oraz ze zdjęciami wykonanymi w tym zespole przed Medwecką-Kornaś (1952) na Jurze Krakowskiej w latach 1948—49. Na rycinie 16 widać wyraźnie wyklinowywanie się gatunków obcych dla zespołu boru świeżego w miarę poprawy stanu zbiorowiska. Wraz z nasilającą się degradacją wzrasta udział roślin obcych dla tego zespołu, głównie gatunków z klasy *Sedo-Scleranthetea*. Warto zaznaczyć, że niektóre zespoły z rzędu *Festuco-Sedetalia*, należące do wymienionej klasy, wchodzą w skład dynamicznego kręgu zbiorowisk borów sosnowych i mogą tworzyć końcowe fazy procesu ich degradacji (Matuszkiewicz 1981).

Dobrym wskaźnikiem stopnia degradacji zbiorowiska leśnego okazały się mchy — tak pod względem ilościowym, jak i liczby i składu gatunkowego. Istniały duże podobieństwa między reakcją mchów wokół kombinatu „Bolesław" a zmianami we florze mchów w otoczeniu huty miedzi i cynku w Gusum w południowej Szwecji (Folkeson, Kvillner 1983). Podobne do przedstawionych powyżej zmiany składu gatunkowego zespołu *Vaccinio myrtilli-Pinetum* pod wpływem emisji przemysłowych zaobserwował Lux (1964), z tym że badane przez niego zbiorowisko nie osiągnęło tak skrajnego stopnia degradacji, jak to miało miejsce wokół kombinatu „Bolesław".

W strefie wysokiej i silnie toksycznej imisji, gdzie następuje wyeliminowanie wielu gatunków roślin naczyniowych, niektóre z nich nie tylko pozostają, ale nawet rozprzestrzeniają się. Można przypuszczać, że w obrębie tych gatunków wyselekcjonowały się populacje tolerancyjne w stosunku do toksycznych składników emisji. Do takich gatunków należały *Deschampsia flexuosa*, *Festuca*

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ovina, *Arabis arenosa*, *Thymus serpyllum* i *Silene nutans*. Dla wielu z nich opisano populacje odporne, pojawiające się w terenach o wysokim stopniu skażenia (Antonovics i in. 1971, Bradshaw 1976, Folkeson, Kvillner 1983).

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